UNIT: 1 INTRODUCTION

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

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

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

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

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

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

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

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

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

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

Geomorphology: The description and interpretation of land forms.

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

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

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

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

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

SCOPE OF GEOLOGY: In Civil Engineering

- Geology provides necessary information about the construction materials at the site used in the construction of buildings, dams, tunnels, tanks, reservoirs, highways and bridges.
- Geological information is most important in planning stage, design phase and construction phase of an engineering project.
- Geology is useful to know the method of mining of rock and mineral deposits on earth's surface and subsurface.
- Geology is useful for supply, storage and filling up of reservoirs with water.

IMPORTANCE OF GEOLOGY FROM CIVIL ENGINEERING POINT OF VIEW

- Before constructing roads, bridges, tunnels, tanks, reservoirs and buildings, selection of site is important from the point of stability of foundation.
- Geology provides a *systematic knowledge of construction materials and* their properties.
- The knowledge about the nature of the rocks in tunneling and construction of roads.
- The *foundation problems* of dams, bridges and buildings are directly related with geology of the area where they are to be built.

- The *knowledge of ground water* is necessary in connection with excavation works, water supply, irrigation and many other purposes.

- The knowledge of *Erosion, Transportation and Deposition* (ETD) by surface water helps in soil conservation, river control.

- *Geological maps* and sections help considerably in *planning* many engineering projects.

- If the geological features like faults, joints, beds, folds are found, they have to be suitably treated. Hence, the *stability of the rock structures is* important.

- Pre-geological survey of the area concerned reduces the *cost* of planning work.

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

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

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

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

The outermost sphere is Atmosphere which consists of several gases and vapours and envelopes the earth. Atmosphere is essentially a mixture of N_2 and O2 with smaller quantities of vapour, CO2 etc... Geologically atmosphere is important as the medium of climate and weather. Hydrosphere includes the natural waters of the earth ie., oceans, seas, lakes, rivers, streams and underground water. Lithosphere is the outer part of the earth's crust consisting of rocks and minerals.

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

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

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

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

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

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

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

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

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

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

Geological works of Rivers

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

VALLEY DEVELOPMENT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examples for metamorphic rocks are:

Quartzite	Hornfels	Marble
Amphibolite	Eclogite	Schist
Gneiss	Khondalite	Slate
Phyllite		

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

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

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

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

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

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

Importance of geological structures in Civil engineering operations:

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

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

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

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

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

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

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

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

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

3. Tigra Dam (Madhya Pradesh, India, 1917): This was a masonry gravity dam of 24 m height, constructed for the purpose of water supply. A depth of 0.85 m of water overtopped the dam over a length of 400 m. This was equivalent to an overflow of 850 m3s-1(estimated).

Two major blocks were bodily pushed away. The failure was due to ***sliding.*** The dam was reconstructed in 1929.

List of major dam failures

Dam/incident	Year	Location	Details
Austin Dam	1911	Pennsylvania, U S	Poor design, use of dynamite to remedy structural problems.
St. Francis Dam	1928	Valencia, California, Los Angeles , U S	Geological instability of canyon wall that could not have been detected with available technology of the time, that assessed developing cracks .
Malpasset	1959	Côte d'Azur, France	Geological fault possibly enhanced by explosives work during construction; initial geo-study was not thorough.
Baldwin Hills Reservoir	1963	Los Angeles, California, U S	Subsidence caused by over-exploitation of local oil field
Vajont Dam	1963	Italy	Filling the reservoir caused geological failure in valley wall, leading to 110 km/h landslide into the lake; Valley had been incorrectly assessed stable.
Buffalo Creek Flood	1972	West Virginia, U S	Unstable loose constructed dam created by local coal mining company, collapsed in heavy rain
Teton Dam	1976	Idaho, U S	Water leakage leading to dam failure.
Laurel Run Dam	1977	Pennsylvania, U S	Heavy rainfall and flooding that over-topped the dam.
Machchu-2 Dam	1979	Gujarat, India	Heavy rain and flooding beyond spillway capacity.
Peruća Dam detonation	1993	Croatia	detonation of pre-positioned explosives
Saguenay Flood	1996	Quebec, Canada	constant rain. Post-flood enquiries discovered that the network of dikes involvement
Ringdijk Groot-Mijdrecht	2003	Wilnis, Netherlands	Peat dam became lighter than water during droughts and floated away
Hope Mills Dam	2003	North Carolina, United States	Heavy rains caused earthen dam and bank to wash away
Big Bay Dam	2004	Mississippi, U S	A small hole in the dam, grew bigger and led to failure.
Shakidor Dam	2005	Pakistan	extreme rain
Taum Sauk reservoir	2005	Lesterville, Missouri, U S	dam continued to fill. Minor leakages caused for failure
Campos Novos Dam	2006	Campos Novos, Brazil	Tunnel collapse
Kyzyl-Agash Dam	2010	Kazakhstan	Heavy rain and snowmelt
Hope Mills Dam	2010	North Carolina, U S	Sinkhole caused dam failure
Delhi Dam	2010	Iowa, US	Heavy rain, flooding.
Ajka alumina plant accident	2010	Hungary	Failure of concrete impound wall

Fujinuma Dam	2011	Japan	Failure due to 2011 Tōhoku earthquake.

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

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

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

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

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

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

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

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

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

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

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

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

$$\underset{\text{(K – Feldspars)}}{K_2Al_2O_3\,6\,SiO_2} + \underset{\text{(Hydration)}}{H_2O + CO_2} \longrightarrow K_2CO_3 + \underset{\text{(Kaoline)}}{Al_2O_3\,2\,SiO_2\,2H_2O} + \underset{\text{(Silica)}}{4\,SiO_2}$$

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

Oxidation: The decomposition of minerals in a rock during chemical weathering is brought about by O_2 in water. For eg pyroxene changes into limonite because of oxidation through the following reaction.

$$\underset{\text{(Pyroxene)}}{4FeSiO_3} + O_2 + 2H_2O \longrightarrow \underset{\text{(Limonite)}}{4\,FeO\,(OH)} + \underset{\text{(Silica)}}{4\,SiO_2}$$

Pyrite (FeS2) converts into Haematite (Fe2O3) during oxidation process

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

$$\underset{\text{Orthoclase feldspars}}{K\,AlSi_3\,O_8} + \underset{\text{ion}}{H^+} \longrightarrow \underset{\text{Silicic acid}}{H\,AlSi_3O_8} + \underset{\text{ion}}{K^+}$$

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

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

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

Weathering effect over the properties of rocks:

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

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

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

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

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

Rainfall contributes to the growth of organisms (bacteria) which produces CO_2.

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

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

IMPORTANCE OF WEATHERING

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

Advantages of weathering from civil engineering point of view:

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

Disadvantages of weathering from civil engineering point of view:

- Weathering is not a welcome process, because it reduces the strength, durability and good appearance of rocks.
- Therefore, the weathered rocks are unfit to be at the site of foundation in case of civil structures like dams and bridges.
- Since weathered rocks are characterized by loose characters ie strength, durability etc, they become unfit for the formation of road metal or as a building stone.
- Weathered rocks are being weak, therefore unsuitable for tunneling.
- Occurrence of weathered zone in the upstream side creates silting problem in case of reservoirs as the accumulation of rapid silt reduces the reservoir capacity.
- Loose boulders due to weathering along steep slopes may turn out landslides which is civil engineering hazard.

UNIT: II - MINERALOGY

Mineral: The study of the characters of minerals (eg: quartz, pyroxene, amphibole, mica, chlorite, garnet) is known as Mineralogy. A mineral is a naturally occurring homogeneous substance, inorganically formed with a definite chemical composition, with a certain physical properties and crystalline structures. The stability of minerals depends on temperature, pressure and chemical composition of the environment. At present more than 3000 mineral species have been established.

The earth's crust is mainly composed of feldspars and quartz and accounts 55% and 10% respectively. Pyroxenes, amphiboles, chlorites, micas, clay carbonates are widely spread too. Following a few rare minerals is also common:

Explanation:

Homogeneous: all parts of the minerals should possess the same physical and chemical characters.

Crystalline: possess atomic structure in a mineral.

Crystal: A crystal may be defined as a natural solid body bounded by smooth and plain surfaces, arranged geometrically. Crystals develop under favourable conditions depending on: (1) slow cooling (2) surroundings to facilitate the crystal growth in different directions. (3) Non-interference by the adjacent growing minerals during solidification.

Exceptions for Definition of Mineral:

1. Precious gemstones like diamonds, rubies, sapphires and emeralds are *synthetically produced* under controlled laboratory conditions.

2. Coal, amber, petroleum, etc., are typical *organic substances* which can be considered as minerals.

3. Amethyst, smoky quartz, citrine, cat's eye, aventurine quartz are some varieties of quartz. Colour or appearance peculiarity in them is because they possess some impurities or inclusions or *in homogeneities.*

4. Asphalt (a variety of bitumen, semi-solid in nature, and black in color), mercury and natural gas are semisolids, liquids or gases. Though these are called minerals, they are *not solid substances.*

5. A good number of minerals are now found to be members of isomorphic groups. Isomorphic minerals *do not have a definite chemical composition,* but have a definite range of composition.

Minerals are broadly grouped into

(a) Rock forming minerals (constitute a rock) and
(b) Ore–forming minerals (composition of an ore which is economically imp).

The term ore mineral embraces minerals from which valuable metallic elements can be extracted. Eg; Cu, Ag, Fe, Al.

Minerals are extremely important economically, aesthetically, industrially and scientifically.

Economically, utilization of minerals is necessary to maintain anything for standard of living. Gold, silver, copper, iron, aluminum etc are economically important minerals for human beings.

Aesthetically, minerals of diamond, ruby, sapphire, and emerald shine as gems and enrich our lives. Gems in jewellery, crown jewel collections attract the attention of millions of people. All in all, approximately 10% of all mineral species are used at present for **industrial** purposes.

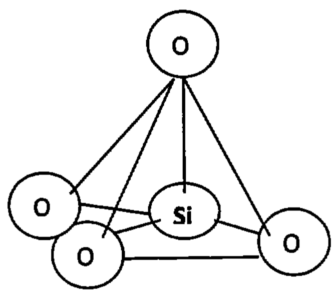
Scientifically, minerals comprise the data bank from which we can learn about our physical earth and its constituent materials.

All the minerals are grouped into 8 classes:

1. Native elements (Eg: Au, Ag, Cu, Arsenic, Bismuth, Platinum, Diamond)
2. Sulphides (Eg: Galena, Pyrite, Cinnabar, Stibnite, Pyrrhotite)
3. Oxides (Magnetite, Haematite, Rutile) and hydroxides (Eg: serpentine; amphiboles)
4. Halides (Eg: Fluorite, Halite)
5. Carbonates (Eg: calcite, Magnesite), nitrates and borates
6. Sulphates (Eg: Barytes, Gypsum), chromates (Eg: Uvarovite)
7. Phosphates (Eg: Apatite, Monazite)
8. Silicates (Eg: Quartz, feldspars, Muscovite, Biotite, Tourmaline, Zerolite, Topaz).

Since silicates are the most common rock forming minerals, it is desirable to know some relevant aspects about these.

In all silicate structures, the silicon atoms are in fourfold coordination with oxygen. The bonds between silicon and oxygen are so strong that the 4 oxygen's are always at the corners of a tetrahedron of nearly constant dimensions.



STRUCTURE OF SILICATES / CLASSIFICATION OF SILICATES

Silicate classification for most silicate minerals is based on the types of linkages as follows:

1. NESO SILICATES
2. SORO SILICATES
3. INO SILICATES
4. CYCLO SILICATES
5. PHYLLO SILICATES
6. TECTO SILICATES

1. NESOSILICATES: (independent tetrahedral groups): in this group SiO_4 tetrahedra occur as independent units in mineral structure.

Eg: **Olivine family; Aluminum silicate family** (kyanite, sillimanite; Andalusite) **Garnet family**.

OLIVINE FAMILY:

OLIVINES are nesosilicates in atomic structure with the general formula R_2 (SiO4) in which R = Mg or Fe. Olivine family consists of Forsterite (Mg2SiO4), Fayalite (Fe_2 SiO_4) Olivine (Mg Fe)$_2$ SiO_4.Olivine is one of the first minerals to form alongwith calcic plagioclase feldspars during the solidification of magma. As magma cools down, olivine reacts with silica content of parent magma and changes over to pyroxene. Alteration: olivines are highly susceptible to decomposition. Hydrothermal alteration of olivines produces serpentine.

$$\underset{\text{Forsterite}}{3\,Mg_2\,SiO_2} + H_2O + SiO_2 \longrightarrow \underset{\text{serpentine}}{2\,Mg_3\,Si_2O_5\,(OH)_4}$$

Occurrence: Occurs in Ultrabasic igneous rocks such as Dunite, Peridotite, and Picrite. Also occurs as accessory mineral in Basalts, Dolerites, and Gabbros.
Uses: Due to its high melting point, olivine is used in the manufacture of refractory bricks.

ALUMINUM SILICATES

In nature, totally, three minerals with different physical properties with same composition occurs as $Al_2\,SiO_5$, which are called as aluminum silicates.

GARNET FAMILY:

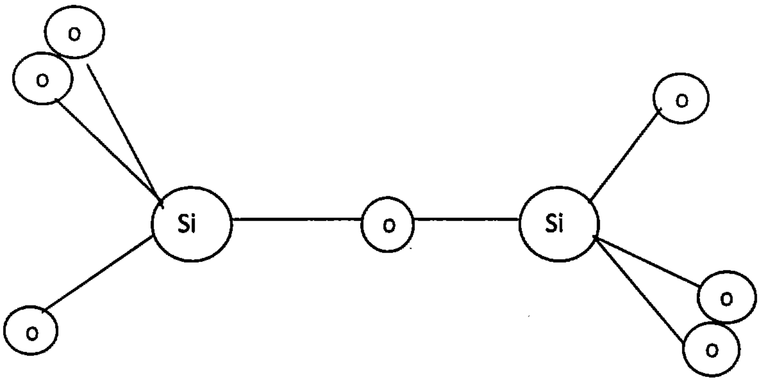
This family is also belonging to nesosilicates and consists of the following minerals:

Grossular	$Ca_3\,Al_2\,(SiO_4)_3$
Almandine	$Fe_3\,Al_2\,(SiO_4)_3$
Pyrope	$Mg_3\,Al_2\,(SiO_4)_3$
Spessartite	$Mn_3\,Al_2\,(SiO_4)_3$
Andradite	$Ca_3\,Fe_2\,(SiO_4)_3$
Uvarovite	$Ca_3\,Cr_2\,(SiO_4)_3$

Under microscope, garnet can be seen rounded crystals, traversed by branching cracks and having no cleavage.
Occurrence: Gneisses, Kyanite Schists; Syenites etc
Uses: used as abrasive in the polishing of wood and as a gemstone.

2. SOROSILICATES: (Double tetrahedral structures): in this group of minerals, SiO_4 tetrahedra occur in pairs in which one oxygen is shared between the two silicon atoms. The epidotes are all similar in their atomic structure, a mixed type containing both SiO_4 and Si_2O_7 groups forms a different types of minerals eg: Idocrase.

(Si : O : : 2 : 7) Two silicon – oxygen tetrahedron



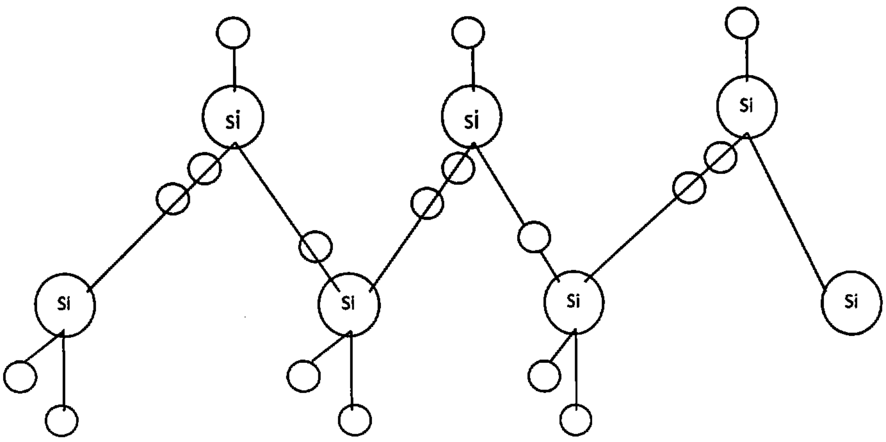
Epidote family consists of Zoisite.. $Ca_2 Al_3 (SiO4)_3$ OH
Epidote.. Ca_2 (Al, Fe)$_3$ $(SiO4)_3$ OH
Allanite.. (Ca, Fe)$_2$ (Al,Fe,Ce)$_3$ $(SiO4)_3$ OH

Melilite .... $Ca_2 Mg\ Si_2O_7$
Hemimorphite $Zn_4Si_2O_7 (OH)_2 H_2O$

3. INOSILICATES: Two varieties of inosilicates (single chain & double chain structures) occur in nature.

SINGLE CHAIN SILICATES Si : O : : 1 : 3

In this group of minerals, SiO_4 tetrahedra occur as chains resulting in more growth of minerals along one direction. The chains consist of a large number of linked SiO4 tetrahedrons, each sharing two oxygen's. **Eg: pyroxenes**



The pyroxenes are a group of minerals which possess the Si_2O_6 chain structure.

AUGITE :

It is a silicate of calcium, magnesium, iron and aluminum with a composition of (Ca Mg Fe Al)$_2$ (Al) Si_2 O_6. It forms as a crystal, lamellar and sometimes fibrous. Augite occurs in Black and greenish black in color.

Amphiboles	Composition	Occurs in
Anthophyllite	(Mg,Fe^{+2})$_7$ (Si_8O_{22}) $(OH)_2$	Anthophyllite schists, gneisses
Cummingtonite	(Mg,Fe)$_7$ (Si_8O_{22}) $(OH)_2$	In metamorphic rocks
Grunerite	(Fe, Mg)$_7$ (Si_8O_{22}) $(OH)_2$	
Tremolite	$Ca_2 Mg_5$ $Si_8 O_{22}$ $(OH)_2$	In Serpentinites, greenstones, Actinolite schists
Actinolite	Ca_2 (Mg,Fe)$_5$ $Si_8 O_{22}$ $(OH)_2$	
Hornblende	(Ca Na Mg Fe Al)$_{7\text{-}8}$ $Si_8 O_{22}$ $(OH)_2$	Granites; Syenites; diorites, Hbl gneisses; hbl schists, amphibolites
Glaucophane	Na_2 (Mg Fe)$_3$ (Al Fe^{+3}) Si_8 O_{22} $(OH)_2$	Soda rich ig rocks ie glaucophane schists
Riebeckite	(Na_2 Fe^{+2}) (Fe^{+2})$_3$ (Fe^{+3})$_2$ Si_8 O_{22} $(OH)_2$	Nepheline schists, pegmatites.

HORNBLENDE:

It is a silicate of aluminium, calcium, magnesium and iron with sodium represented by the formula (Ca Na Mg Fe Al)$_{7\text{-}8}$ $Si_8 O_{22}$ $(OH)_2$. Hornblende occurs as crystals, prismatic in habit.

ASBESTOS:

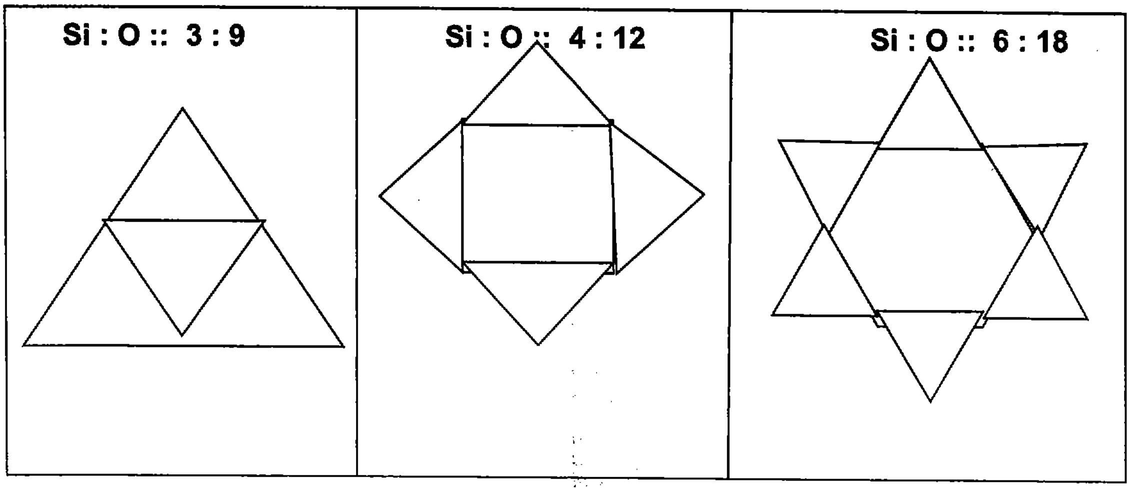
The term "asbestos" is a commercial name which indicates fibrous varieties of several minerals differing widely in composition. The fibres are flexible and easily separated by the fingers. The color of asbestos varies from white to greenish and brownish.

4. CYCLO SILICATES (Ring structures): When each SiO_4 tetrahedron shares two of its oxygens with neighbouring tetrahedra, they may be linked into rings. (Closed rings of tetrahedral each sharing two oxygens) - These are also called ring silicates. In this group of minerals, 3 or 4 or 6 tetrahedra occur in ring form.

Eg for 3 tetrahedra : Bentonite (Ba Ti Si_3 O_9)

Eg for 4 tetrahedra : Axinite Ca_2 (Fe,Mn) Al_2 (BO_3) (Si_4O_{12}) (OH)

Eg for 6 tetrahedra : Beryl (Be_3 Al_2 Si_6 O_{18})



Occurrence: these minerals occur as accessory in Granites, Syenites, Pegmatites,Mica –

Uses: some of the minerals are used as gemstone. The main producers are Brazil, Russia, Madagascar, and United States.

5. PHYLLOSILICATES (SHEET STRUCTURES): These are also called sheet silicates. They possess the SiO4 sheet structure resulting in more growth along two directions of a mineral. Eg: Mica family, Chlorite family, Talc, Serpentine, Kaolinite **(Si : O : : 2 : 5) or (Si : O : : 4 : 10)**

Mica Family:

MICA is the family name of some silicate minerals. These are silicates of aluminum, potassium together with magnesium. Some varieties contain sodium, lithium or titanium.The hydroxyl radical is always present and is commonly replaced partially by Fluorine. Hence, all mica minerals possess ($Al\ Si_3$) O_{10} $(OH,F)_2$ as a common radical. Micas may be divided into: 1) Muscovite group & 2) Biotite group.

Muscovite group	Composition	Usual name
Muscovite	$K\ Al_2\ (Al\ Si_3)\ O_{10}\ (OHF)_2$	Potassium mica
Paragonite	$Na\ Al_2\ (Al\ Si_3)\ O_{10}\ (OHF)_2$	Sodium mica
Lepidolite	$K\ (Al\ Li)_3\ (Al\ Si_3)\ O_{10}\ (OHF)_2$	Lithium-pot mica

Biotite group	Composition	
Biotite	$K\ (Mg,Fe)_3\ (Al\ Si_3)\ O_{10}\ (OHF)_2$	Iron-mag mica / black mica
Phlogophite	$K\ (Mg)_3\ (Al\ Si_3)\ O_{10}\ (OHF)_2$	Magnesium mica
Zinnwaldite	$K\ (Li\ Fe\ Al)\ (Al\ Si_3)O_{10}\ (OHF)_2$	Lithium mica
Glauconite	$K\ (Fe\ Al)_2\ (Si\ Al)_4\ O_{10}\ (OH)_2$	
Margarite	$Ca\ Al_2\ (Si_2\ Al_2)\ O_{10}\ (OH)_2$	

Atomic structure: all micas are phyllosilicates ie in their atomic structure SiO4 tetrahedra are arranged in sheet pattern (growth in two dimensions).

Varieties: when thin mica layers are punched by a steel rod, a small six-rayed figure known as a "percussion" figure appears.

Illite: is clay mica found in sedimentary rocks.

Mineral	Occurrence
Muscovite	Found as accessory mineral in acid ig rocks such as Granites and Pegmatites. In metamorphic rocks of Gneisses & mica-schists.
Biotite	Igneous rocks such as Granites, Diorites; Gabbros. Also in Biotite gneisses; biotite schists; biotite hornfels.
Phlogophite	Found in crystalline limestones and peridotites.
Lepidolite	In Pegmatites.

Uses: Muscovite used to be to cover lanthorns in electrical industry as an insulating material. In the manufacture of rubber tyres; powdered mica is used to give the frost effect on Christmas cards.

Lepidolite is mined as an ore of lithium & used in lithium batteries. Phlogophite mica is superior to muscovite mica

Chlorite Family:

Generally chlorite is considered as hydrous silicates of aluminum, iron and magnesium. Chlorite is a green coloured mineral. Chlorite resembles to some extent biotite (mica) in physical properties but has no alkalies..

Composition: the formula for chlorite is $(Mg\ Fe)_5\ (Al\ Si_3)\ O_{10}\ (OH)_8$.

Atomic structure: This is a phyllosilicate with silicon oxygen ratio of 4: 10. Chlorite is formed as a product of alteration of mafic minerals such as biotite or hornblende.

Occurrence: chlorite occurs in chlorite schists and phyllite. It also occurs as amygdale.

Varieties: Clinochlore; penninite; ripidolite.

Talc:

Talc is a hydrous magnesium silicate. Its chemical composition is $Mg_3\ (SiO_3)_4\ H_2O$ containing 63.5% of SiO_2 ; 31.7% of MgO and 4.7% of H_2O .

Properties: having a good lustre and high lubricating power, particularly for oil and grease absorption, high fusibility very low shrinkage value. It has a low electrical and thermal conductivity and a good resistance to heat shock.

Atomic structure: Talc is a phyllosilicate with a Si: O ratio of 4: 10. It is a metamorphic mineral and formed due to alteration of magnesium - bearing rocks like peridotites; dolomites; gabbros.

Varieties: **Steatite** or **soapstone** is a massive variety of Talc, mostly white or grey or pale green in color. **Potstone** is an impure massive talc, green in color or brownish black in color. **French chalk** is a steatite used by tailors for marking on clothes.

TALC DEPOSITS: Bihar; UP; AP ; Tamil Nadu; Rajasthan M.P; Maharashtra; Karnataka are producing talc / steatite deposits.

Uses: as a filler for paints, paper, rubber , cosmetics, and textiles ; removing grease from clothes; in leather making; talcum powder ; in switch boards, in lab table tops. 50% used in paper industry; 15% pesticide industry; 3% talcum powder industry and remaining in textile, ceramics; rubber industry etc..

6. TECTO SILICATES (Frame work structures): In this group, SiO4 tetrahedra occur in a three dimensional framework, resulting equidimensional growth of a mineral. **(Si : O : : 1 : 2) or** every SiO4 tetrahedron shares all of its corners with other tetrahedron giving a three dimensional network . In this framework structures, Si is generally replaced by Aluminum thus making them aluminum silicates.

Minerals which this structure include: eg: quartz, other forms of silica (Flint ; Jasper; Chalcedony etc..); Feldspars family, zeolite family, feldspathoids family; Scapolite family.

FELDSPARS FAMILY:

It refers to a group of different minerals which possess similar chemical composition, atomic structure; physical and optical properties. These are aluminous silicates of K. Na; Ca or Ba and may be considered as isomorphous compounds.

Feldspars are sub-divided into: PLAGIOCLASE FELDSPARS and ALKALI FELDSPARS

The Plagioclase feldspars may be defined as

Feldspar group	Range	composition	Occurrence
Albite		Ab 100 - An 0	Granites; Syenites;
Oligoclase		Ab 90 – An 10	Diorites; Rhyolites;
Andesite	$Na\,Al\,Si_3\,O_8$	Ab 70 - An 30	Trachytes; Gabbros;
Labradorite	to	Ab 50 - An 50	Sandstones; Schists
Bytownite	$Ca\,Al_2\,Si_2\,O_8$	Ab 30 – An 70	& Gneisses;
Anorthite		Ab 10 - An 90	

Uses: Feldspars are used in the manufacture of Porcelain; Pottery; glazes on earthware; Sanitary ware; in the manufacture of glass and ceramic industries.

FORMS OF SILICA (QUARTZ; FLINT; JASPER)

The forms of silica, including the hydrated forms can be grouped as:

Silica occurs in nature as crystalline (eg: Quartz;Tridymite;Cristobalite) ,as cryptocrystalline (eg: chalcedony; Flint; Chert; Jasper; Agate) ,as Hydrous / amorphous forms (eg: opal)

QUARTZ:

Next to feldspars and mafic minerals, quartz is the most common rock forming mineral. It is SiO_2 in composition and may be treated as an oxide or as a silicate. Structurally, it is a tectosilicate ie; in its atomic structure, the SiO_4 tetrahedra are arranged in a three dimensional network pattern.

Quartz, Tridymite and Crystabalite are important crystalline forms of silica with SiO2 composition but possess different physical properties and hence these are called POLYMORPHS.

Varieties of Quartz:
Rock crystal: Transparent form of quartz and purest.
Amethyst: Purple / violet colored; transparent form of quartz
Rose quartz: Pale pink / rose colored variety of quartz
Smoky quartz: smoky yellow / brown color of quartz
Milky quartz: milky white in color due to a large no. of mica cavities
Ferruginous quartz: contains iron oxides which impart reddish color

Uses: employed in jewellery (eg: amethyst); Making spectacle glasses; Sand papers; toothpaste; Pottery; silica bricks. Depend on its piezo – electric properties, a certain type of quartz is used to control the frequency of radio-circuits.

FLINT:

It is a compact cryptocrystalline silica of a black color or various shades of grey occur as irregular nodules. Flint breaks with a well marked conchoidal fracture and affords sharp cutting edges. Flint was extensively used by prehistoric man for the fabrication of weapons, chisels.. Flint generates sparks when struck with steel. Flint is used in tube mills; pottery industry; for road making and building properties. Flint nodules occur in limestone formations in North Wales.

JASPER:

it is an opaque form of silica, usually of red, brown yellow color and rarely green. Egyptian or Ribbon Jasper are beautifully banded with different shades of brown. Porcelain Jasper is merely clay altered by contact with a hot igneous rocks.

CALCIUM MINERALS:

Calcium doesn't occur in the free state but its compounds are extremely abundant. Calcium occurs in limestone as $CaCO_3$. Calcium also enters into the composition of many rock forming silicates such as :

Anorthite (feldspar group) .....$Ca\ Al_2\ Si_2\ O_8$ and in Pyroxenes; amphiboles; garnets; scapolites; epidotes; zeolites and wollastonites.

Calcite is a non-silicate mineral and of great economic value. The following are the important non-silicate calcium minerals:

Mineral	composition	Class
Calcite	$Ca\ CO_3$	Carbonates
Aragonite	$Ca\ CO_3$	
Siderite	$Fe\ CO_3$	
Dolomite	$Ca\ Mg\ (CO_3)_2$	
Anhydrite	$Ca\ SO_4$	Sulphates
Gypsum	$Ca\ SO_4\ 2\ H_2O$	
Glauberite	$Na_2\ Ca\ (SO_4)_2$	
Apatite	$Ca_5\ (F, Cl)\ (PO_4)_3$	Phosphates
Fluorspar	$Ca\ F_2$	Fluorides
Ulexite	$Na\ Ca\ B_5\ O_9\ 8\ H_2O$	Borates
Colemanite	$Ca_2\ B_6\ O_{11}\ 5\ H_2O$	

DIFFERENT METHODS OF STUDY OF MINERALS

According to the mineral definition, every mineral has *its own chemical composition and atomic structure* and it *is unique for every mineral.* This fact facilitates the study of mineral in different ways. Common methods of study and identification of minerals based on their

(i) Physical properties

(ii) Chemical properties

(iii) Optical properties and

(iv) X-ray analysis.

(i) *Study of Physical properties*: Physical properties like **Color, Form, lustre, Hardness** (resistance to scratching), **Density** (Specific Gravity), cleavage etc., can be studied with simple observations. These properties are dependent on chemical composition and atomic structure i.e.,if the atomic structure and chemical composition remains the same, the resulting properties should also be similar. This principle is the basis for the study of minerals.

For example, any **galena** mineral irrespective of its place of occurrence, size, shape, association ,consistently exhibits lead grey colour, metallic shine, opaque character, high Sp gr (density = 7.4 – 7.6), tendency to break easily along three different directions and is scratched easily by knife. This set of physical properties is never exhibited by any other mineral .Therefore, if such properties are observed an unknown mineral it must be only galena.

(ii) *Study of Chemical composition*: According to the definition, every mineral which is expected to have its own individual chemical composition, which is not to be found in any other mineral. Therefore, by chemical analysis if composition is known it should be possible to identify the mineral.

For example, if the composition of an unknown mineral is found to be **lead sulphide (PbS),** then that must be only **galena** because galena always has the composition lead sulphide and no other mineral has this composition.

(iii) *Study of optical properties*: In this method of study, the minerals are made very fine (0.03 mm) and fixed over glass slide by means canadabalsam such skillfully prepared slides are called thin sections. **They are studied under petrological microscope.** Different optical properties such as interference colours, their order, interference figures, optic sign, twinning, alteration etc., are studied under crossed nicols with help of some other accessories, if necessary. The optical properties of every mineral are also distinctive and hence helpful in the identification of minerals. For example, quartz is characterized by: **anhedral shape, clourless, no cleavage, transparent, low relief, non-pleochroic, grey or yellow, interference colours of first order, positive uniaxial interference figure, positive elongation, no alteration etc,.**

(iv) *Study of X-ray analysis*: When a beam of x-rays falls on a crystal, it is diffracted by the layers of the atoms within the crystal. In making an x-ray analysis of atomic structure of the crystal, the diffracted x-rays are allowed to fall on the on photographic plate and resulting photograph shows a series of spots or lines which form more or less symmetrical pattern. From measurements made on the photograph, the arrangement of the atoms in the crystal can be deduced and also the distances between them. The results of x-ray analysis of minerals reveal their atomic structure, which is distinctive, for each mineral. This enables the accurate identification of minerals.

STUDY OF PHYSICAL PROPERTIES OF MINERALS

FORM: The form of mineral is defined as its shape. The external shape of mineral reflects the internal arrangement of atoms. When a mineral occurs as a well developed crystal, it is called **crystallized**. If the growth of the crystals is hampered due to interference of other crystal grains then the resulting form is called **crystalline**. When just traces of crystalline structures are present, it is called **cryptocrystalline**. Some of important forms are listed below.

S.No	Name of the form	Description	Mineral Examples
1.	Lamellar Form	Mineral appears as **thin separable layers**	Muscovite, Biotite
2.	Tabular Form	Minerals appears as **slabs of uniform thickness**	Feldspars, Gypsum
3.	Fibrous Form	Mineral appears as **fine threads**	Asbestos
4.	Pisolitic Form	Mineral appears as sphericals	Bauxite
5.	Rhombic Form	Rhombic shape	Calcite, garnet
6.	Bladed Form	Minerals appear as independent blade or lath-shaped grains	Kyanite
7.	Granular Form	innumerable equidimensional grains of coarse/medium/fine size	Chromite, graphite, Magnetite
8.	Reni Form	Kidney-shaped	Hematite
9.	Prismatic Form	Elongated crystals	Olivine, Augite
10.	Spongy Form	Porous	Pyrolusite, Bauxite
11.	Cubic Form	Geometrical Shapes	Garnet, Pyrite, Galena
12.	Massive Form	No definite shape	Graphite, Olivine, Quartz, haematite, Magnesite, Jasper, Pyrolusite
13.	Nodular Form	Irregularly shaped compact bodies with curved surfaces	Flint

COLOR: Minerals show great variety of colors and can be identified by their color. Color wise the minerals are of two types (i) Dark colored minerals and (ii) Light colored minerals. Mineral colors are generally related to the spatial arrangement of the constituent atoms or the impurities present in the minerals or all of these.

For example: (i) the color related to atomic structure. Diamond is colorless and transparent where as Graphite is black and opaque even though both contain carbon. (ii) The color related to impurities: Generally pure quartz colorless and transparent. But commonly due to impurities it shows colors such as pink, purple etc.

Mineral	Color	Mineral	Color
Calcite	Colorless / white / red / grey / yellow		
Feldspar	White / grey / red / green / dirty white		
Quartz	Colorless / white / green / violet / grey / yellow / pink		
Hornblende	Dark green	**Augite**	Greenish black
Ruby	Red	**biotite**	Black, greenish black
Pyrite	Brass yellow	Chalcopyrite	Golden yellow
Emerald	Green	**Chlorite**	Grassy green
Graphite	Shining black	Coal	Black

Barytes	White / pale grey	gypsum	Colorless / white
Galena	Dark lead grey	**Haematite**	Dark steel grey
Microcline	White/pink/green	**kyanite**	Blue
Chromite	Black	**magnetite**	Black
Sapphire	Blue	**Muscovite**	Silver white
Malachite	Dark green	**Olivine**	Olivine green
Orthoclase	White / red	**plagioclase**	Grey / white
Garnet	Red	**talc**	White/yellow
Opal	Milky white	Tourmaline	Jet black

STREAK: The streak of mineral is color of its powder. Many minerals exhibit a different color in the powder form compared to form of mass. The powder of the mineral is obtained either by scratching the mineral with a pen knife or rubbing it across piece of unglazed porcelain plate called streak plate. **Most transparent minerals show a white streak. colored minerals show a dark color streak of the mineral.** Sometimes the streak is altogether different in color from the color of the mineral.

S.No	*Streak*	*Minerals*
1	Dark brown, black	Pyrite, magnetite, chromite, Pyrolusite, biotite, graphite.
2	Bluish black	Pyrolusite.,
3	Cherry red	Haematite
4	Dark grey	Galena
5	White	Calcite, jasper, olivine, muscovite, asbestos, Kyanite, garnet, talc, calcite, Magnesite,
6	Colorless	Quartz
7	White to grey	Augite, biotite,
8	Grey to greenish grey	Hornblende,
9	Silver white	Muscovite
10	Greenish black	Biotite, pyrite,
11	Red or reddish brown	Haematite,

LUSTRE: Lustre is the nature of shining on the surface of the mineral under reflected light. It varies considerably depending upon the amount and type of light reflected.

Based on the type of shining, lustres are grouped as metallic and non-metallic. Metallic lustre is the type of shining that appears on the surface of the metal. Non-metallic lustres are named considering the type of shining that appears in some common materials. Some important non-metallic lustre that are observed mainly in rock-forming minerals are:

S.No	**Non-metallic Lustre**	**Description**	**Minerals**
1.	Vitreous lustre	Shining like a glass	Quartz,Calcite, Feldspar
2.	Subvitreous lustre	Subvitreous lustre is similar to vitreous luster but with less shining	Pyroxenes (augite)
3.	Pearly lustre	Shining like pearl	Talc, Muscovite(mica)
4.	Silky lustre	Shining like silk	Asbestos
5.	Resinous lustre	Shining like resin	Opal, Agate
6.	Greasy lustre	Shining like grease	Graphite, Serpentine

7.	Adamantine lustre	Shining like diamond	Garnet, Diamond
8.	Earthy or Dull lustre	No shining like earth or chalk	Magnesite, Bauxite

CLEAVAGE: The definite direction or plane along which a mineral tends to break easily is called the cleavage of that mineral. Crystallized and crystalline minerals can have cleavage. **Amorphous minerals do not show cleavage.** Cleavage, if present , occurs as innumerable planes along which mineral is equally weak. Hence all such parallel planes of weakness are referred to as a **set.**

Depending upon their atomic structure, crystalline minerals will have 1 set of cleavage (or) 2 sets (or) 3 sets (or) 4 sets (or) 6 sets of cleavages (or) no cleavage.

Since atomic structure of a mineral is definite, the cleavage character of the mineral will also be definite. Depending upon the degree of perfection, cleavage may be described as perfect or eminent or excellent (mica) , good (calcite) , imperfect or poor or indistinct (apatite).

S.No	Cleavage	Sets	Minerals
1	None	-	Quartz, Flint, Jasper, Olivine, garnet, haematite,
2	Indistinct	-	Pyrolusite, Graphite, apatite
3	Present	1	mica, chlorite, talc, Asbestos
4	Perfect	3	Calcite, Magnesite, galena
5	Perfect	2	Feldspars, hornblende, Kyanite, augite

FRACTURE: Fracture is the nature of randomly broken surface of mineral. Based on the nature of a broken surface, fractures are described as even fracture, uneven fracture, hackly fracture, and conchoidal fracture.

S.No	Name of fracture	Description	Minerals example
1.	Even Fracture	If the **broken surface of a mineral is plain and smooth**, it is called even fracture	Magnesite, Chalk
2.	Uneven Fracture	If the **broken surface is rough and irregular**	Augite, hornblende, mica, chlorite, talc, pyrite, haematite, magnetite, Pyrolusite, graphite, bauxite.
3.	Hackly Fracture	If the broken surface is very irregular like **the end of a broken stick**	Asbestos, Kyanite, chlorite,
4	Conchoidal Fracture	If the **broken surface is smooth and curved**	Agate, Flint, Jasper, galena, bauxite.
5	Even to uneven		Olivine, Magnesite
6	Conchoidal to sub-conchoidal		Garnet,

***Hardness*:** Hardness may be defined as the **resistance offered by the mineral to abrasion or scratching.**

For example, if mineral specimen is muscovite (mica), when it is tested on the mohs' scale of hardness, it should not scratched by gypsum but by calcite. The composition of the mineral appears to have less influence over hardness. For example, graphite and diamond which possess the same composition, but different atomic structures, represent nearly two extremes of the hardness in the mineral kingdom i.e. graphite is extremely soft and diamond is extremely hard.

Mohs' Scale of Hardness: In 1882 an Australian mineralogist, Mohs proposed a relative scale for hardness of minerals. The standard set of ten reference minerals used to determine the hardness of any unknown mineral is called Mohs' scale of hardness. The actual minerals of the set and their hardness are as follows:

Talc = 1; Gypsum = 2; Calcite = 3; Fluorite = 4; Apatite = 5;	Feldspar = 6; Quartz = 7; Topaz = 8; Corundum = 9; Diamond = 10;

Thus Talc is the least hard mineral and Diamond is the hardest mineral. The relative hardness of an unknown mineral is determined by scratching it with the Mohs' scale of hardness starting with Talc and followed by minerals of increasing hardness. Common minerals like finger nail (H = 2.5), a copper coin (H=3.5), a broken glass piece (H=5.5) and pen knife (H=6.5) may be used to fix the lower limit.

SPECIFIC GRAVITY *(density):* Specific gravity of mineral depends on their chemical composition and atomic structure. **The specific gravity of a mineral is the weight of it to the weight of an equal volume of water**. In the laboratory, specific gravity of minerals is determined using either Walker's steel yard or Jolly's spring balance. In determining specific gravity care should be taken to select only fresh (ie unweathered) minerals free from inclusions, impurities etc,.

For routine identification of minerals based on physical properties, **determination of actual specific gravity is tedious and unnecessary** because most of the rock-forming minerals have specific gravity range of 2.5 to 3.5; while common ore minerals like magnetite, hematite, ilmenite, galena, pyrite, Pyrolusite and Psilomelane, have specific gravity over 3.5. Only few minerals have a specific gravity less than 2.5. Thus based on this range of specific gravity of minerals, the density character of minerals may be described as **high, medium or low.**

The medium density refers to the common rock-forming minerals and higher density refers to the common ore minerals.

	Sp. Gravity	Minerals
Low Density	< 2.5	Talc, graphite
Medium Density	2.5 to 3.5	Feldspars,quartz,flint, jasper, olivine, augite, hornblende, mica, chlorite, asbestos, calcite, Magnesite, bauxite
High Density	> 3.5	Kyanite, garnet, pyrite, haematite, magnetite, chromite, galena, Pyrolusite,

TRANSPARENCY –TRANSLUCENCY:

A mineral is transparent when the outlines of objects seen through it appear sharp and distinct. Eg: quartz -transparent, Selenite-transparent, Fluorite; Topaz - sub-transparent.
A mineral which, though capable of transmitting light, cannot be seen through is translucent. When no light is transmitted the mineral is opaque.

TASTE: When the minerals are soluble in water, generally possess a characteristic taste which may be designated as follows:

Taste	Result
Saline	The taste of common salt, eg: halite
Alkaline	That of potash & soda
Acidic / sour	The sour taste of H_2SO_4
Cool	The taste of potassium chlorite
Sweetish astringent	That of alum
Bitter	That of Epsom salt

ODOUR: Some minerals have characteristic odours when struck, rubbed, breathed, heated etc… terms used are::

Odour	Result on smell
Alliaceous	Garlic odour when arsenic compounds are heated . eg: arsenopyrite, orpiment, realgar
Horse-radish odour	The odour of decaying horse radish when selenium compounds are heated
Sulphurous	The odour of burning sulphur when sulphides heated
Foetid	The odour of rotten eggs given by heating
Clayey	The odour of clay. Eg: kaolin

STUDY OF COMMON ECONOMIC MINERALS

BAUXITE: is an amorphous mineral which consists of the metallic element of aluminum. Bauxite is formed under tropical weathering from different rocks. Such weathering results in leaching of all soluble matter and leaving behind enriched residues of oxides and hydroxides of aluminum , ferrous, ferric , manganese, titanium and silica. Aluminum is not found in a free state, but it is the most abundant metal in earth's crust.

Chemical composition: Bauxite, a mixture of aluminum hydroxides such as diaspore (H Al O_2), boehmite (AlO (OH)) and gibbsite (Al ($OH)_3$) together with impurities of iron oxide, phosphorus compounds and titania. The following is the range of oxide percentage of bauxite:

Al_2O_3	55 – 65%
Fe_2O_3	2 - 20%
SiO_2	2 - 10 %
TiO_2	1 – 3%
H_2O	10 – 30%

Occurrence: Bauxite results from the decay and weathering of aluminum – bearing rocks.

Uses: For the manufacture of aluminum. Aluminum is used as abrasives; as refractory bricks.; in making cables ; household vessels, wrapping aluminum foil, cans, etc.. Owing to its low specific gravity 2.58, it is of great value in the manufacture of many articles

PYRITE :

Though there are no native sulphur deposits in India, Pyrite serve the purpose of producing sulphur by eliminating sulphur from iron pyrites (FeS_2), which contains 53 % of sulphur and 47% Fe. It has a brass yellow color. Pyrrhotite, which also contains iron and sulphur, has a formula of $Fe_{11}S_{12}$. **Pyrite occurs** as massive or lumps or as fines.

Chemical composition: $Fe S_2$.

Occurrence: The principal sources of pyrites and pyrrhotite in India are the sedimentary pyrite deposits of Bihar and Rajasthan. Karnataka, also producing pyrite deposits and the deposits are restricted to ultra basic igneous rocks.

Uses: The main use of pyrite is to manufacture sulphuric acid, in the manufacture of phosphatic fertilizers.. Motion picture films consume a good amount sulphuric acid.

GRAPHITE:

Graphite is one of the principal allotropic modifications of carbon, the other two are coal and diamond. Carbon is known in three different conditions where transparent and crystallized as diamond, Scaly and crystalline as Graphite and Amorphous as charcoal, coal. These different forms, though chemically identical, vary in hardness, specific gravity and other physical properties.

Native carbon occurs as two important minerals viz., diamond and graphite while amorphous carbon is coal. Again, carbon forms with oxygen and hydrogen many series of compounds known as the Hydrocarbons.The sp gravity of graphite is 2.1 and hardness varies between 1 and 2. It is absolutely opaque in character and resistant to heat and a very good conductor of heat and electricity.

Chemical composition: It is a pure carbon and sometimes contaminated with a small amount of silica, iron-oxides , clay etc.

Occurrence: Graphite is the stable form of carbon at a high temperature. The majority of graphite deposits are formed by the metamorphism of carbonaceous matters particularly anthracite coal . Graphite occurs in Bihar, Orissa, Tamil Nadu, Kerala, Rajasthan; WB;

Uses: Low grade graphite is used in the paint and varnish industries whereas the high grade variety is used in batteries, lubricants, and brushes. Graphite's are used for the manufacture of crucibles for melting of metals. It is required for lead pencil manufacturing industry. Graphite is also used for dry lubrication where oil or grease is harmful.

MAGNESITE :

Magnesite, which is a carbonate of magnesium ($MgCO_3$), contains about 47% of MgO and 53% of CO_2.Magnesite is considered as an ore for the extraction of metallic magnesium. When Magnesite is Calcined at a temperature of 1500° C, the magnesia is converted to a crystalline form known as Periclase which has a spgravity of 3.68.

Chemical composition: It is a magnesium carbonate ($Mg CO_3$). Magnesite is commonly massive and fibrous, sometimes very compact.

Occurrence: Economically important deposits of Magnesite occur as irregular veins in serpentinite rocks and it is found as alteration of serpentinite rocks. In India Magnesite occurs extensively in Salem district of Tamil Nadu where the Magnesite deposits were formed in the ultra basic rocks of chalk hills. In addition, Magnesite occurs in Karnataka as a decomposition product of ultra basic rocks.

Uses: Magnesite required as fertilizer. It is also used as filler in paint and glass industries. Calcined magnesia is useful in manufacturing paper pulp from wood and bamboo. Magnesia powder is used in furnace - linings and crucibles; also employed in the manufacture of special cements and sugar industries.

UNIT: 3 PETROLOGY

The study of rocks in all their aspects including their mineralogies, structures / textures (systematic description of rocks in hand specimen and thin sections); their origin and their relationships to other rocks. A Rock is a mineral aggregate consist of one mineral or many.

Role of Magma: If the molten material is below the Earth's surface, it is called magma or else it comes out about the surface , it is known as lava.

Magma is a complex mixture of liquid, solid, and gas. The main elements in magma are oxygen (O), silicon (Si), aluminum (Al), calcium (Ca), sodium (Na), potassium (K), iron (Fe), and magnesium (Mg). However, two major molecules found in magma that controls the properties of the magma. These two molecules are silica (SiO_2) and water (H_2O). Silica comprises as much as 75 percent of the magma.

When rock melts deep underground, the magma rises through the earth's crust because the molten rock is less dense than solid rock. In many cases, the magma is unable to reach the surface, and it will cool in place many miles under the ground. This underground cooling produces the largest crystal sizes, because it cools more slowly. Sometimes the magma extrudes onto the surface, either on land or underwater.

The heat generated by processes such as radioactive mineral disintegration. Magma doesn't occur every where below the earth because when temperature increases with depth, pressure also increases with depth due to overburden.

Magma is always associated with huge quantities of various volatiles, whereas these volatiles are absent in case of lava since these volatiles escape into the atmosphere in case of lava. volatiles consists of dominantly water vapour, CO_2.

The rise in temperature tends to increase the volume of the material whereas the rise in pressure tends to decrease the volume of the material. Hence, the effects of these two mutually are different.

Depending upon local conditions where the pressure effect is more than the effect of temperature, MAGMA is formed.
Rocks: The solid Earth (the mantle and crust) is made of rock. There are three types of rocks those that form from molten material or magma (**igneous** rocks), those that are deposited from air or water (**sedimentary** rocks), and those that have formed by altering another rock (**metamorphic** rocks). The chemical composition of a rock is expressed in terms of oxides for eg: SiO_2; Al_2O_3; Fe_2O_3; FeO; MgO; CaO; TiO_2 etc

Forms of igneous rocks

Igneous rocks are formed out of very hot lava or magma. The extruded lava on solidification over the earth surface gives rise to extrusive igneous rocks. The magma on solidification below the earth surface gives rise to intrusive igneous rocks.

Dykes and sills

Igneous rocks are formed out of hot magma or lava. The lava on solidification over the earth's surface gives rise to Extrusive igneous rocks while the magma on solidification below the earth's surface gives rise to intrusive igneous rocks.

Igneous intrusions occur in different sizes and forms depending on the conditions during the formation of intrusion. eg: Dykes and Sills are the common forms.

If the intrusion is parallel to the layering in the host rock, it is called as a sill whereas the intrusion cutting across the trend of the host rock, it is called as a Dyke.

Dykes are the common form of igneous rocks and are vertical or inclined intrusive igneous bodies. Dykes occur cutting across the bedding planes of the country rocks in which they are found. Due to forceful pressure, magma intrudes through the fractures, cracks, joints, shear zones, weak planes and subsequent solidification of this gives rise to dykes.

The dimensions of dykes vary widely. They may be long (50-60 kms) and thick (upto 30 mts). eg: dyke of midland of Scotland or t hey may be short upto to a few mts and thin a few cms.

Though different rocks may appear as dykes, dolerite dykes are the most common. Dykes are important from Civil Engg point of view for the following reasons:

1. They are undesirable at the sites of foundations of dams as their sides (contacts) turn out to be weak planes.
2. They act as barriers and interrupt the ground water movement in a region.
3. They may give rise to springs.
4. Since, the dykes are hard, durable (resisting to weathering), black in color, fine grained, they are used in making of statues, sculptures etc.

Sills are similar to dykes but are formed due to penetration of magma into bedding planes of country rocks. The spreading capacity depends on the viscosity of magma, its temperature and the weight of the overlying rocks. Sills which spread over large areas are generally thin with uniform thickness.

- Eg: 1 The great whin soil of England spreads over 3900 sq.kms
- Eg: 2 Karroo sills (dolerite composition) spreads over 510000 sq kms in South Africa.

Sills act sometimes as mineralizing bodies. eg: Barytes, Asbestos deposits of cuddapah. Sills occur as horizontal and inclined bodies.

Lava flows may resemble sills closely because both are relatively thin, horizontal sheet like igneous bodies spreading over large areas. But they can be distinguished from one another as follows:

- Lava flows show an irregular lower surface whereas sills have more or less flat on both sides.
- Lava flows shows vesicular character on the upper surface, whereas sills present no such characters.
- Lava flows undergo quite cooling producing fine grained rocks whereas sills cool slowly causing coarse to medium grained rocks.
- Sills give out tongues (minor intrusions) into the overlying rock masses, whereas lava flows do not.

Other intrusives:

Laccoliths: If the intrusion takes place forcibly in stratified rock, resulting a mushroom shaped intrusive in the host rock, it is termed as Laccoliths.

Phaccolith: In the folded rocks, if the intrusion takes place at a later stage, it occupies the openings at the crest (in case of anticlines) and trough (in case of synclines) of folds, the resulting form of intrusive is denoted as Phaccolith.

Bysmalith: when the magma happens to be highly viscous the lateral spread along the bedding plane will be very less and intruding magma acquires a somewhat cylindrically shaped body. It is called bysmalith.

Lopolith: Large igneous intrusions of several kilometers in extent having a form which is the top in nearly flat and the bottom is convex downwards is known as Lopolith.

Batholiths: The term is applied to any large intrusive mass of igneous rock (eg granite). Batholiths, occupy a large area of out crop extending to greater depths with the presence of Roof Pendants and Xenoliths.

Batholiths occur usually in mountain regions and are parallel to the folded regions. Compositionally, batholiths are either granites or granodiorites. Eg: British Colombia batholiths of 1250 miles extension and a width of 50 miles. The **roof pendants; Stocks; Bosses** offering evidence.

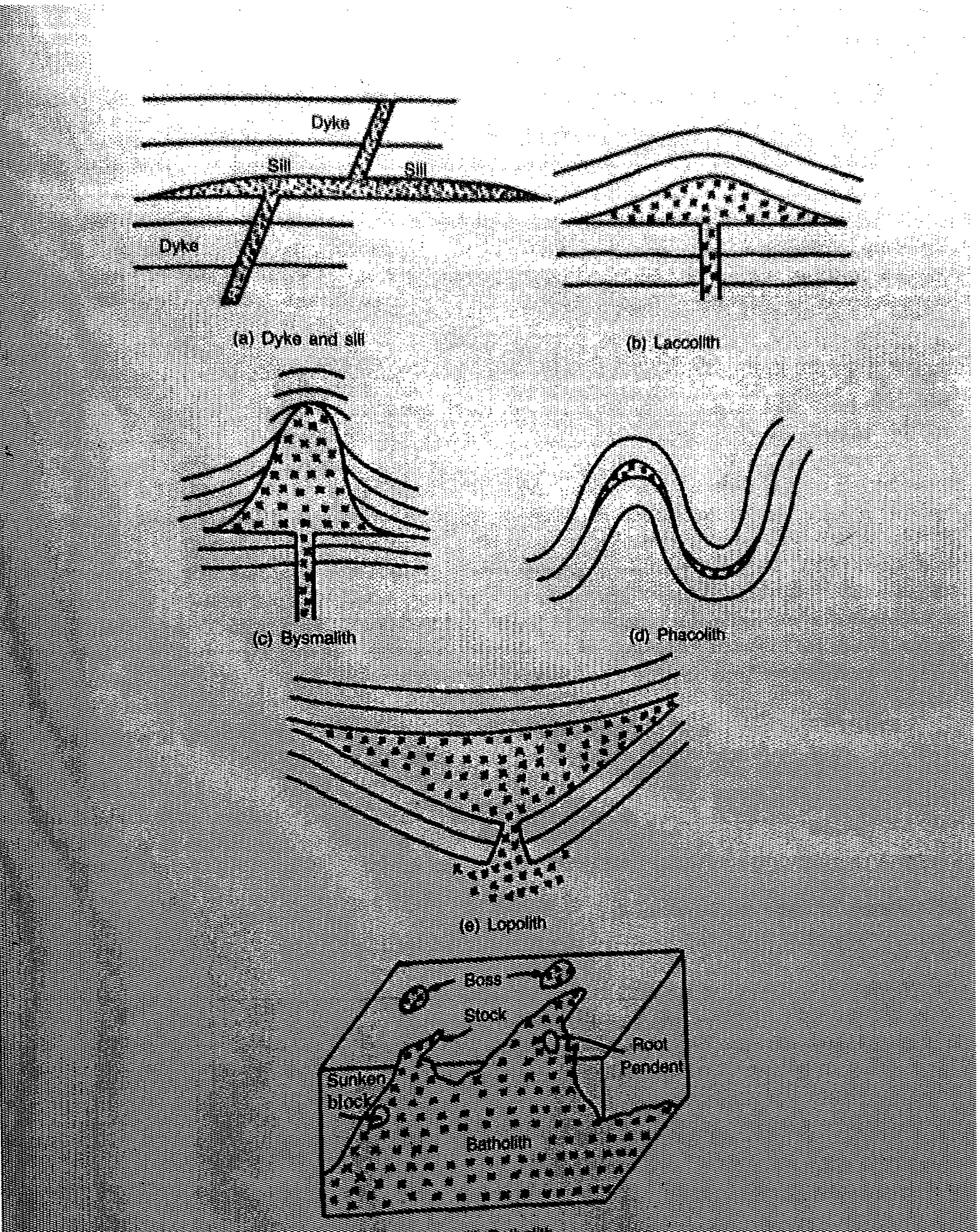


Fig. 6.1 Forms of intrusive igneous rocks

CLASSIFICATION OF IGNEOUS ROCKS: Igneous rocks are the first formed rocks in the earth's crust and hence these are called PRIMARY ROCKS, even though igneous rocks have formed subsequently also.

Igneous rocks are the most abundant rocks in the earth crust and are formed at a very high temperature directly as a result of solidification of magma since magma is the parent material of igneous rocks. The temperature increases proportionately with the depth --- this is one of the reasons for the formation of igneous rocks.

Igneous rocks are usually massive, unstratified, unfossiliferous and often occur as intrusive cutting across other rocks (country rocks or host rocks). The igneous rocks are classified based on silica%, silica saturation and depth of formation

1. CLASSIFICATION BASED ON SILICA % :

Nature	Silica %	Rock examples
Acidic	➢ 65	Granite, Pegmatites; (coarse) ; Rhyolite (fine)
Intermediate	55 – 65	Syenite (coarse) ; Trachyte (fine)
Basic	45 – 55	Gabbro (coarse); Basalt (fine)
Ultrabasic	< 45	Picrite, Peridotite , Dunite (coarse)

Acidic igneous rocks:

- Composed of quartz, alkali feldspars, mica minerals and compositionally rich in Si, Al, Na, K etc but are poor in Ca, Mg, Fe
- Leucocratic due to the presence of light coloured minerals.
- Relatively lighter rocks and have a slightly higher specific gravity of 2.6

Intermediate igneous rocks:

- Lacking of quartz or a little quartz present but dominantly composed of alkali feldspars and compositionally rich Na, K.
- Mesocratic in colour due to the presence of dark colored minerals.

Basic igneous rocks:

- Dominantly composed of ferro-magnesium minerals(mafic minerals) such as hypersthenes, feldspars (plagioclase), pyroxene (Augite), amphiboles (hornblende) , biotite and compositionally rich in Ca, Mg, Fe.
- Melanocratic in color
- Quartz or olivine is generally absent or occur in small quantities.
- Due to the presence of mafic minerals, these rocks to have a slightly higher specific gravity of 3.1

Ultra basic igneous rocks:

- Composed of mafic minerals and quartz is almost absent and compositionally rich in Mg, Ca.
- Melanocratic in color.
- Higher density of about 3.6

2. **CLASSIFICATION BASED ON SILICA SATURATION:**

Depending on the silica content in parent magma; the mineral associations are categorized as:

Oversaturated igneous rocks: when the parent magma is **rich in silica,** saturated minerals like feldspars and the surplus quantity of silica crystallizes as quartz.

Unsaturated minerals like olivine, nepheline, leucite never occur in over saturated rocks. Eg: granites, granodiorites, dacite, rhyolites .

Saturated igneous rocks: when the parent magma has **enough silica** for the formation of minerals, the resulting rocks possess neither quartz nor any unsaturated mineral. Presence of saturated minerals (feldspars) are seen in Syenite, Diorite, Anorthosite, Gabbro.

Unsaturated igneous rocks : when the parent magma has **silica less than what is required for the formation of saturated minerals.** Quartz is possible to the extent, and feldspars, olivine, nepheline, leucite are present usually.

This group represents Dunites, Peridotites, Phonolite

Oversaturated rocks are equivalent to acidic igneous rocks. Saturated rocks are equivalent to intermediate igneous rocks. Under saturated rocks are roughly equivalent to basic / Ultrabasic rocks.

3. **CLASSIFICATION BASED ON DEPTH OF FORMATION:**

In terms of modes of occurrence ie depth of formation, igneous rocks can be either intrusive (plutonic), extrusive (volcanic) or hypabyssal.

PLUTONIC ROCKS:

The igneous rocks which have **formed under high temp & pressure at greater depths in the presence of volatiles** in the earth's crust are called plutonic rocks. Greater pressure ensure total crystallization of minerals formed and the hot surroundings slow down the process of solidification. The net result of all these processes is the development of coarse grained texture. Eg: Granite

SLOW COOLING & SLOW CRYSTALLIZATION OF MAGMA eg; Granite

VOLCANIC ROCKS:

The igneous rocks which have formed **under low temp & pressure at shallow depths in the absence of volatiles** in the earth' crust are called volcanic rocks. Rapid cooling and quick crystallization of lava makes faster the process of solidification due to heat difference. The net result of all these processes is the development of fine grained texture. Eg: basalt

HYPABYSSAL ROCKS:

The igneous rocks which have formed **under moderate temp & pressure at shallow depths** are called hypabyssal rocks. Medium rate of cooling causes for the formation of medium grained rocks. Eg: dolerite

Brief description of IGNEOUS ROCKS

Andesite	An igneous volcanic rock predominantly consists of plagioclase feldspars with or without silica. The Ferro-magnesium minerals (biotite, hbl, augite, enstatite, hypersthene) may be present .
Anorthosite	an igneous plutonic rock composed predominantly of plagioclase
Aplite	a very fine grained intrusive igneous rock
Basalt	a volcanic rock of mafic composition
Basalt Hawaiite	a class of basalts formed from Ocean Island (hot spot) magmatism
Basalt Boninite	a high-magnesian basalt dominated by pyroxene
Charnockite	a rare type of granite containing pyroxene
Dacite	a felsic to intermediate volcanic rock with high iron content
Diabase or dolerite	intrusive mafic rock forming dykes or sills
Diorite	a coarse grained intermediate plutonic rock composed of plagioclase, pyroxene and/or amphibole
Dunite	An ultramafic rock composed of olivine
Essexite	a mafic plutonic rock (a gabbro)
Gabbro	a plutonic rock composed of pyroxene and plagioclase
Granite	A plutonic rock composed of orthoclase, plagioclase and quartz
Granodiorite	a granitic plutonic rock with plagioclase > orthoclase
Nepheline syenite	a plutonic rock with nepheline replacing orthoclase
Pegmatite	an igneous rock occurs as veins or dykes and found as granite pegmatite or syenite pegmatite consists of alkali feldspars, and quartz with tourmaline, topaz, beryl, fluorspar, apatite and Spodumene as accessories.
Peridotite	a plutonic composed of >90% olivine
Phonolite	a volcanic rock essentially similar to nepheline syenite
Picrite	an olivine-bearing basalt
Pumice	a fine grained, extremely vesicular volcanic rock
Pyroxenite	a coarse grained plutonic rock composed of >90% pyroxene
Rhyolite	a felsic volcanic rock
Syenite	a plutonic rock dominated by orthoclase feldspar; a type of granitoid

STRUCTURES & TEXTURES OF IGNEOUS ROCKS

Structures and textures are physical features associated with the rocks. These occur along with the formation of rocks and are important in view of civil engineering point because

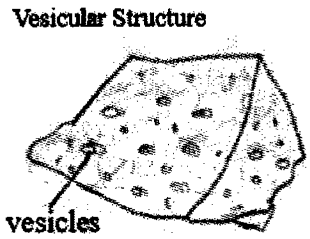
- They contribute to the strength of rocks.
- They contribute to the weakness of rocks
- They reveal mode of origin of rocks.

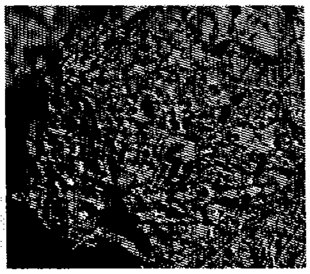
NOTE: The structures such as folds and faults are exempted though they are also structures since these develop after the formation of rocks due to tectonic forces.

The term structure refers to **certain large scale features**

1. Vesicular structure:
2. Amygdaloidal structure
3. Columnar structure
4. Sheet structure
5. Flow structure

VESICULAR STRUCTURE: This structure is due to porous in nature commonly observed in volcanic rocks. Most of the lava contains volatiles (gasses like CO_2, water vapour) which escapes into the atmosphere by creating various sizes and shapes of cavities near the surface

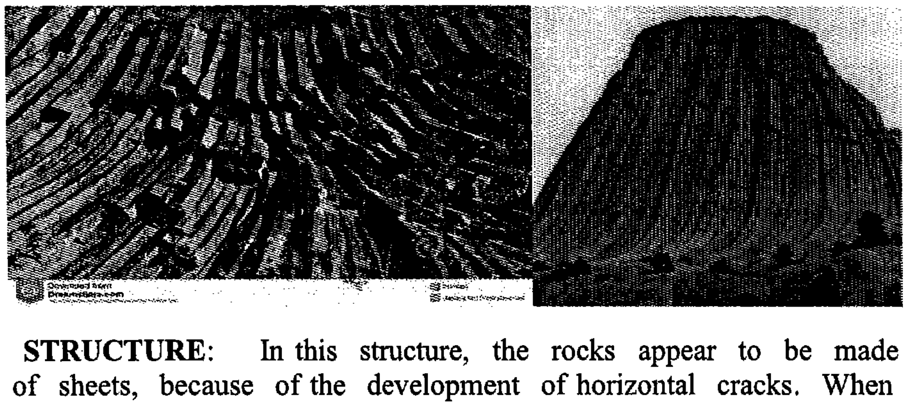




Eg: PUMICE, a light rock with porosity even that floats on water.

AMYGDALOIDAL STRUCTURE: when secondary minerals such as calcite, zeolites, hydrated forms of silica (chalcedony, agate, amethyst, opal) are filled in vesicles, in such a case it is said Amygdaloidal structure. Eg: Deccan traps of India.(ie basalts).

COLUMNAR STRUCTURE: with uniform cooling and contraction causes a regular or hexagonal form, which may be interested by cross- joints. Eg: Columnar basalts, around 40 mts high are seen at Andheri, Bombay.



SHEET STRUCTURE: In this structure, the rocks appear to be made up of a number of sheets, because of the development of horizontal cracks. When erosion takes place, the overlying strata gradually disappear and ultimately the plutonic rocks exposed to the surface resulting the development of joints / cracks parallel to the surface. Thus, the horizontal joint planes are sometimes so closely spaced as to produce a sheet structure. Eg: granite.

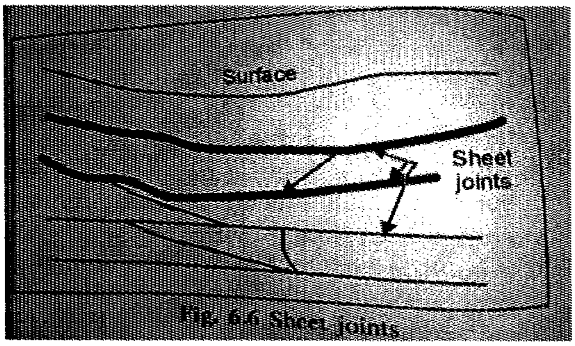


Fig. 6.6 Sheet joints

FLOW STRUCTURE: After eruption of the lava flows, some of the bands or lines are drawn over the surface of lava to the direction of lava flow. Eg: Rhyolite.

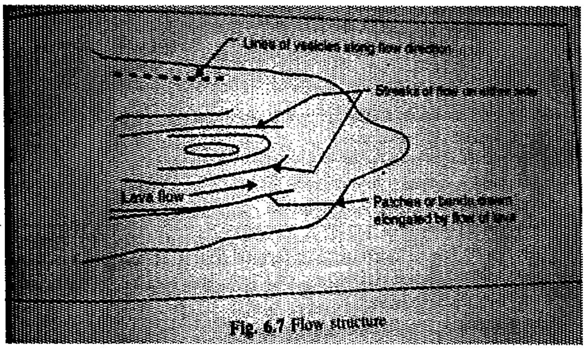


Fig. 6.7 Flow structure

Common textures of igneous rocks :-

Mutual relations of mineral constituents and glassy matter in a rock. Depending on the nature of cooling, the TEXTURES in igneous rocks are categorized into:

1. **Degree of crystallinity** - Rocks composed entirely of crystals are called holocrystalline; those composed entirely of glass are holohyalline; rocks that contain both crystals and glass are hypocrystalline / hemicrystalline .

2. **Grain size** - Overall, there is a distinction between the grain size of rocks that have crystallized at depth are medium to coarse grained (eg: gabbros) and those that crystallized at shallow depth are finer grained (eg: basalts).

3. **Based on growth of crystals / Rock fabric** - Fabric is the shape and mutual relationships among rock constituents:
   1. Euhedral, refer to grains that are bounded by crystal faces
   2. Subhedral grains that are bounded partly by some crystal faces
   3. Anhedral, when crystal faces are absent, it is called anhedral

Hypidiomorphic / granular **texture** - the most common granular texture in which a mixture of euhedral, subhedral, and anhedral grains are present.

Examples of some common textures of igneous rocks:

Equigranular structure:- when magma crystallizes under similar conditions, equigranular textures develops. In this, the minerals present are approximately of the same size. Depeding on the grain size, the texture may be described either as phaneric or asphanitic. Eg: Dolerite

Intergranular texture: This is also to be observed under the microscope in rocks like basalts. In this rectangular feldspar grains form a network, and polygonal spaces left in between are filled with matic materials like augite, divine etc. Eg: Augite, Olivine.

Ophitic texture - It is one where random plagioclase laths are enclosed by pyroxene or olivine. If plagioclase is larger and encloses the ferromagnesian minerals, then the texture is subophitic . Eg: Basalt, Dolerites.

Porphyritic texture: Large crystals that are surrounded by finer-grained matrix are referred to as phenocrysts. If the matrix or groundmass is glassy, then the rock has a **vitrophyric** texture. Eg: Granite, Diorite, Dolerite.

Graphic texture: This is an intergrowth texture formed due to eutectic crystallization in which two minerals are formed. The intergrowth of these two minerals results in peculiar graphic texture in which quartz is embedded in feldspars as prismatic or wedge shaped grains. Eg; Pyroxene.

Interlocking texture: The different minerals are closely interlinked or mutually locked with one another. It develops when a melt solidifies. In igneous rocks which are formed out of magma possess this texture and hence it is diagnostic of them. This textute is observed only under the microscope. Eg: Pegmatites and granites.

Glassy Texture: The rock displays with sharp edges like broken glass is known as Glassy Texture. No individual crystals can be seen. Eg: **obsidian**.

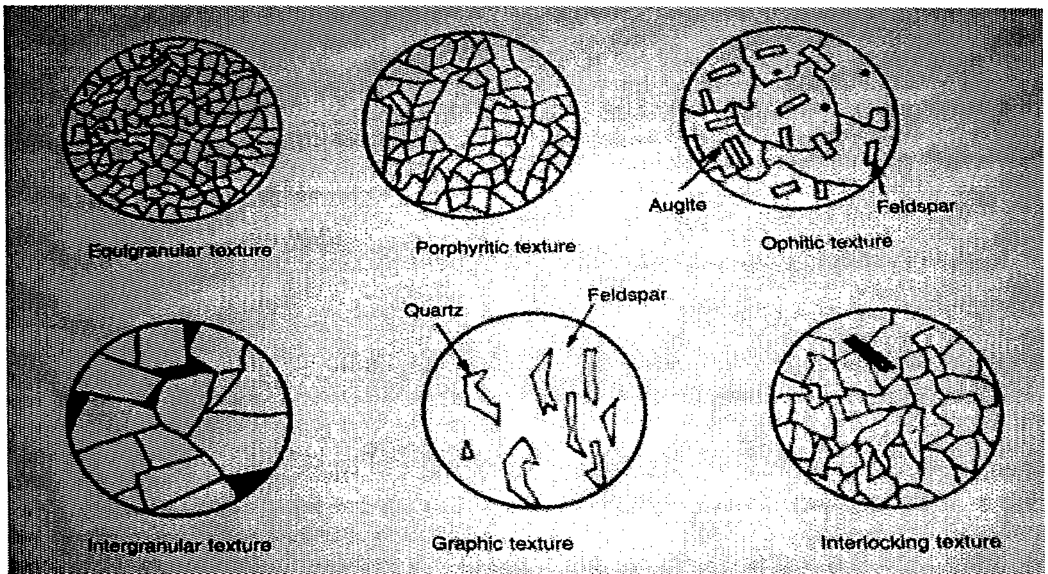


Fig. 6.10 Some common textures of igneous rocks

Phaneric texture: if minerals in the rock are big enough to seen by the naked eye, the texture is said to be Phaneric. Eg: granite.
Aphanitic texture: if minerals are too fine to be seen the texture is said to be aphanitic. Eg: basalts.

MEGA SCOPIC DESCRIPTION OF COMMON IGNEOUS ROCK TYPES:

GRANITE is a plutonic igneous rock, compact, massive and hard rock. Granites are unstratified but characterized by joints. It is a holocrystalline (completely crystalline) and leucocratic (light coloured) rock .

Minerals present in granite:
Granite is composed of primary minerals. Among these feldspars and quartz occur as essential minerals.

Structure: Granite is a compact, dense, massive, and hard rock. Granites have two sets of microfractures called rift and grain. Rock breaks more easily along the rift than the grain. Granites are unstratified.

Composition: Granite consists of quartz (> 20 – 30 %), Feldspars (60%) include alkali feldspars (orthoclase, microcline) and plagioclase feldspars (oligoclase), micas as essential minerals and accessory minerals are mafic minerals such as hornblende, biotite / muscovite , pyroxenes of hypersthenes; augite ; diopside ; magnetite / haematite, rutile, zircon, apatite, garnet..

Texture: Granites exhibit phaneric texture (coarse grained), or graphic texture (similar to Arabic writing). Granites are usually equigranular but some times show inequigranular texture in case of Porphyritic texture (feldspars occur as phenocrysts).

Relation with other rocks: Granite is closely related to granodiorite and diorite. As all these contain similar minerals but in different propotions.

Hand specimen: Granite is grayish or pinkish in color. Feldspar appears with white or brownish – red color. Quartz looks colorless. Biotite is jet black and is found as small shining flakes. Hornblende is dark greenish black.

Mode of occurance: granite rocks occur in the form of very large igneous bodies such as batholiths, stocks.

Varieties: When quartz decreases and increase in mafic minerals, granite passes over to GRANODIORITE and then DIORITE.

When both the alkali feldspars and plagioclase feldspars are equal in quantity, the granite rock is called as ADAMELLITE.

If hypersthene is more in granite then it is known as CHARNOCKITE.
If feldspars and quartz are very large in size and exhibit interlocking texture, then it is called as PEGMATITE. Occurrence of large sized beryl, tourmaline crystals is another diagnostic feature of pegmatite.

Types of granite

1. Granite as normally referred to, is an equigranular coarse grained leucocratic rock with a few accessory minerals.
2. Granite porphyry is similar to granite minerologically but has a porphyritic texture.
3. Graphic granite is devoid of accessory minerals and has a graphic texture which is very peculiar.
4. Based on the colour of feldspar, i.e., whether pink or white, the granites are named as pink granite or grey granite.

Physical properties:

1. Granite is massive, unstratified and dense.
2. Granite has an interlocking texture, which keeps minerals firmly held, and this cohesion contributes greatly to the strength of the rock.
3. Granite is either equigranular or has a porphyritic texture. These factors enable granite, on polishing, to make or a mosaic appearance or a mottled appearance respectively.
4. Granite is very rich in silica; therefore it is very much resistant to decay, i.e., weathering.
5. Being the most abundant plutonic rock, it is found in plenty and is easily available in many places.
6. Granites offer reasonable fire and frost resistance, because minerals are not many and these rocks are free from fractures.

Uses:

By virtue of so many desirable qualities granite becomes desirable as foundation rock, building stone, road metal, railway ballast or for flooring. In the past it was widely used as pillars, beams, slabs,etc., in many buildings temples, forts etc. But for roofing purposes it is used less.

PEGMATITE

It is a holocrystalline (completely crystalline) and coarse grained igneous rock .

Composition: Pegmatite resemble granites in mineralogy and hence it is described as Granite Pegmatite. When pegmatites are rich in alkali feldspars, it is called as **Syenite** pegmatites. Occurrence of large sized beryl, tourmaline crystals is another diagnostic feature of pegmatite.

Granite pegmatite consists of alkali feldspars and quartz and rich in biotite/ muscovite of micas. In addition, rare minerals of cassiterite (tin - Sb); mispickel (arsenic–Ar); niobium, tantalum etc are also present and hence pegmatites are economically very important.

Syenite pegmatites contain rare earth elements like zirconium, cerium, lanthanum, uranium and thorium.

In Andhra Pradesh, muscovite deposits in commercial quantities occur in pegmatites of Nellore district. This mica is generally light green in color.

Texture: Pegmatite exhibit an interlocking texture.

Hand specimen: Pegmatite is generally coarse grained consist of larger sized minerals of feldspars and quartz. Feldspars are often light coloured and may appear as red, white or green . Muscovite and biotite are easily identified by their color and cleavage. Hornblende looks dark greenish black and tourmaline is jet black, and prismatic.

Physical properties:

Like granites these rocks also have similar mineral content and interlocking texture. But from the civil engineering point of view these rocks are not useful because the extremely large minerals considerably influence the physical properties locally and hence the rock mass cannot behave uniformly throughout.

Uses:

It is unsuitable to be used as a building stone and also undesirable at the site of foundation of major constructions.

ENGINEERING POINT OF VIEW: Since pegmatite minerals are large in size and the rock mass cannot behave uniform throughout. Further, the presence of mica which has excellent cleavages obviously makes the rock weak. So it is unsuitable to be used as a building stone and also undesirable at the site of foundation of major constructions. However, pegmatites are economically very important due to the presence of rare and valuable minerals.

DOLERITE

Dolerite is a dark, fine grained black or dark greenish black igneous rock. It is intermediate in composition and melanocratic (dark coloured) rock . . Mineralogically and chemically, dolerite is similar to Gabbro and basalt.

Composition: Dolerite consists of Plagioclase Feldspars and pyroxene (augite). Iron oxides, hypersthene and biotite occur as common accessory minerals. Olivine is some times found if the parent magma was deficit of silica.

Minerals present in Dolerite:

Dolerite is a rock, normally composed of labradorite type of plagioclase feldspar and augite type of pyroxene as essential minerals. Iron oxides, hypersthene and biotite occur as common accessory minerals. In general, accessory minerals occur in very small quantities. Since the rock is intermediate, this minerals are generally saturated.

Mode of occurance:

Very often, dolerite occurs in nature as an intrusive rock, i.e., as dykes in granites. These dark coloured rocks are prominently noticed in the field by virtue of colour contrast with surrounding granites which are light coloured.

Texture: Dolerite is a very dense, massive and compact rock. It is neither porous nor permeable. The texture in dolerites is generally equigranular. Interlocking texture is also common in dolerite. Under the microscope dolerite exhibit Ophitic or subophitic texture.

Hand specimen: Dolerite is a fine grained rock with greenish black or black coloured. Presence of pyroxene (augite) contributes the black color of a rock. Feldspars can be observed by means of their cleavage surfaces and biotite if present appears as small, jet black..

Types of Dolerite:

1. Slightly unsaturated and olivine- bearing type is called **olivine dolerite**.
2. Slightly oversaturated and quartz bearing type is called **quartz dolerite**.
3. Normal dolerite having porphyritic texture is called **dolerite porphyry**.
4. Fine grained and volcanic equivalent of dolerite is called **basalt**.

Varieties: When all the minerals of dolerite are totally altered for eg: plagioclase into zoisite or epidote and augite into chlorite / hornblende and olivine into serpentine then the rock is **called DIABASE**.

Plutonic equivalent of dolerite is called Gabbro.

Volcanic equivalent of dolerite is called Basalt.

Glassy equivalent of dolerite is called trachylyte.

Physical properties:

Dolerite has all the merits and virtues possessed by granite except its colour. Ofcourse, pure black colour has great demand. Since dolerites are more finegrained, they are stronger and more competent than granites. The greater toughness and lack of weak planes does not make them easily workable. Except pure black coloured and very fine grained types, the normally found dark greenish coloured dolerites with medium grain texture and dolerite porphyries are not used very much. For these reasons dolerites are not common as building stones.

Uses:

These are suitable as railway ballast, concrete or bitumen aggregate, etc. As road metal, though they do not have good cementing value like limestones, they can be used if locally available. At foundation sites of dam like structures, occurance of dolerite dykes is considered undesirable as they become a cause for heterogeneity and weak planes.

SPECIAL FEATURES: The compact nature and rich in mafic minerals make the rock emit metallic sound when hit with a hammer. Dolerite occurs in nature as an intrusive rock ie as dyke.

ENGINEERING POINT OF VIEW: Dolerites are not common as building stones. They are suitable as road metal, railway ballast, bitumen aggregate, concrete purposes. At foundation sites of dam like structures, the presence of dolerite is considered undesirable as they become a cause for weak planes.

BASALT:

BASALT is a black volcanic, massive, fine grained, melanocratic rock. .

COMPOSITION: Basalt consist of plagioclase feldspars (labradorite), Pyroxenes (Augite) and iron oxides (magnetite or ilmenite). Biotite, hornblende and hypersthenes are the other accessory minerals. Pyrite may also seen sometimes. Either quartz or olivine may appear in small amounts depending on the silica content of parent lava.

Minerals:
Basalt is a simple mixture of labradorite, augite and iron oxides. It is similar to dolerite in mineral content. Biotite, hornblende and hypersthene are the other rare accessory minerals.

Structures & Textures: Vesicular and amygdaloidal structures are common in basalts. However, Columnar and flow structures are also observed in some cases. Basalts exhibit aphanitic texture in hand specimens. (ie the minerals are too fine).

Types:

1. Basalt refers to a massive, very fine grained melanocratic rock without vesicles or amygdales or quartz or olivine.
2. Vesicular basalt is a basalt with vesicles or empty cavities. Scoria and pumice are more porous, spongy or foamy varieties, respectively.
3. Amygdaloidal basalt is vesicular basalt with cavities filled up by secondary minerals.
4. Dolerite is the hypabysal equivalent of basalt.
5. Gabbro is plutonic equivalent of basalt.

Appearance in Hand specimens: Basalt is typically black or greenish grey or greenish black. Non-vesicular, massive in nature. Exhibit a typical aphanitic texture ie extremely fine grained with or without vesicles. Basalts are always unstratified, unfossiliferous and do not react with acids.

VESICULAR BASALT: it is characterized by the presence of empty cavities or vesicles.

AMYGDALOIDAL BASALTS is a vesicular basalt with cavities filled up by secondary minerals of silica (quartz, amethyst, opal, agate); zeolites, calcite. Among these, silica minerals may be used as semi-precious gemstones.

SEDIMENTARY ROCKS

Sedimentary Rocks are those formed due to weathering (which is a natural process of disintegration and decomposition) and / or erosion of the pre-existing rocks. Also formed due to chemical precipitation or due to accumulation of organic remains such as plants and animal hard parts. Since, the sediments represent secondary , these rocks are also called as "**Secondary rocks**". By volume, the secondary rocks constitute about 5% of the lithosphere.

SIZES OF SEDIMENTS

GRADE	GRAIN SIZE	GRADE	GRAIN SIZE
Boulders	➢ 200 mm	Coarse sand	1 – 2 mm
Cobbles	50 – 200 mm	Fine sand	0.1 – 0.25 mm
Pebbles	10 – 50 mm	Silt	0.01 - 0.1 mm
Gravel	2 – 10 mm	Clay	< 0.01 mm

Among different sedimentary rocks; SHALE is the most abundant; SANDSTONE and LIMESTONE are next in order. These three rocks represent approximately 4%; 0.70%; 0.25% respectively of the earth's crust. The other sedimentary deposits which include Laterites; Conglomerates; Breccias, Coal seams though insignificant in quantity (0.05%)

TRANSPORTATION OF SEDIMENTS: The sediments are transported by natural agencies by wind action or running water action (most common agency for transportation) or Glacial action.

During the process of transportation, the disintegrated constituents undergo initial differentiation (change in the shape, volume, size etc) thus loosing their original characters.

The soluble constituents during transportation are carried away to long distances and are ultimately deposited as CHEMICAL PRECIPITATES or ORGANIC DEPOSITS. The soluble materials are generally chlorides, sulphates and carbonates.

The insoluble constituents during transportation are carried to considerable distances, ultimately giving rise to ARGILLACEOUS DEPOSITS. Insoluble residues are generally aluminium silicates.

Finally, the constituents that are resistant to weathering (unaltered) are transported to lesser distances to be accumulated as ARENACEOUS DEPOSITS. The resistant material is mainly silica.

Sedimentary structures: Several primary structures are evidenced in sedimentary rocks. These structures offer significant evidences of depositional conditions (environments). These are:

Stratification indicates the time period involved in their deposition (Rocks which display layering or bedding) Eg; shales

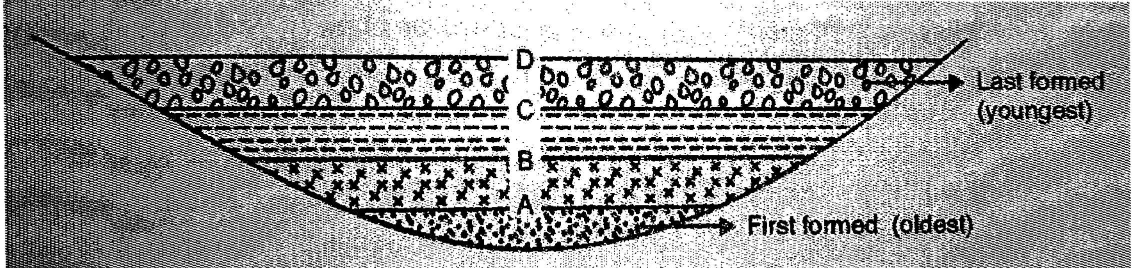


Fig. 7.2 Order of superposition

Cross-bedding indicates shallow water deposits. Eg: sandstone (A series of inclined bedding planes having some relationship to the direction of current flow.

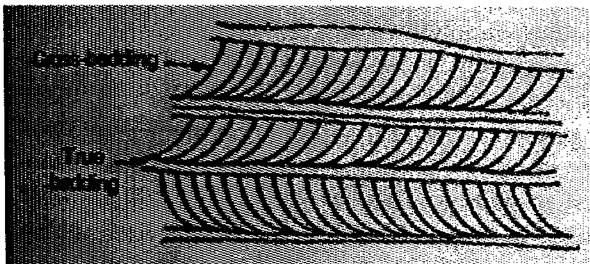


Fig. 7.3 Cross-bedding

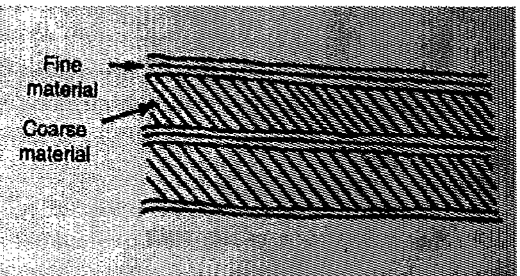


Fig. 7.4 Torrential bedding

Graded bedding indicates deeper water deposits. Eg: Greywacks (Coarser material at base and the finest material at the top due to involvement of a river or stream flow is called as graded bedding).

Ripple marks : indicate the shallow water deposition. In stangnant and shallow water bodies the waves on the surface of water produce sympathetic impressions in the form of minar undulations on the loose and soft sediments which lie at the bottom.these are known as ripple marks.

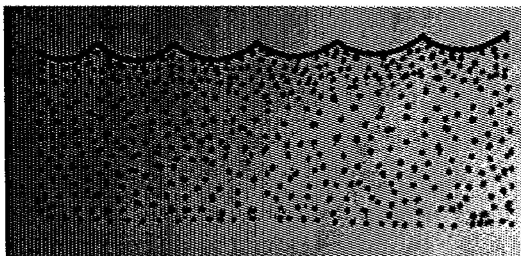


Fig. 7.5(a) Wave ripple marks

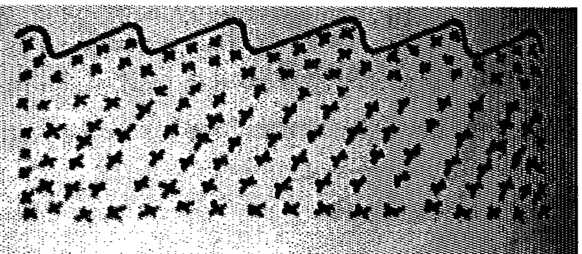


Fig. 7.5(b) Current ripple marks

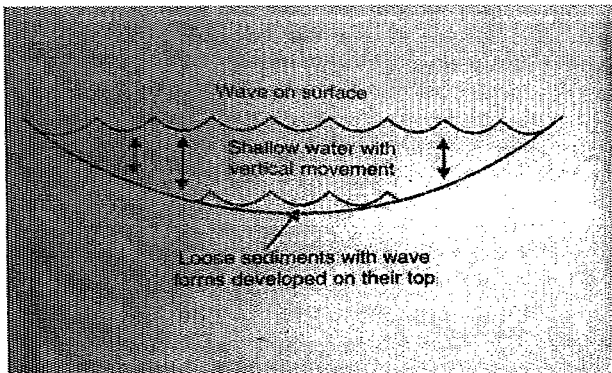


Fig. 7.5(c) Formation of ripple marks

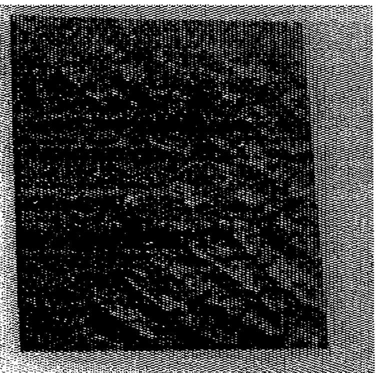


Fig. 7.5(d) Ripple marks

Sun cracks or mud cracks:

Water of a sea or lake depending on different conditions like season effect covers the gently sloping sides on and off.when such a wet surface is not covered it dries up and developes vertical polygonal cracks which are wedge shaped down wards .the surface is covered by water ,loose sediments may be deposited on it,fill up the underlying cracks.due to this the feature of mud cracks retain in these rocks.

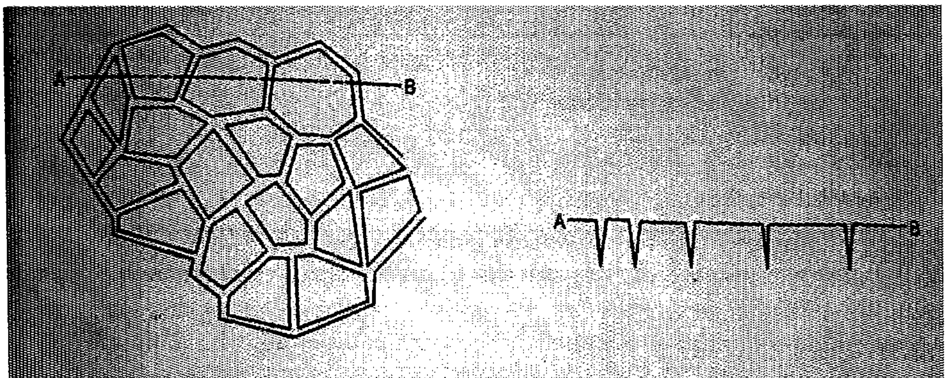


Fig. 7.6(a) Polygonal mud cracks (plan) and (b) wedge-shaped vertical mud cracks (section)

Rain prints or rain marks:

a rain mark is a slight shallow depression encircled by alow ridge which is raised by the impact of the rain drop.

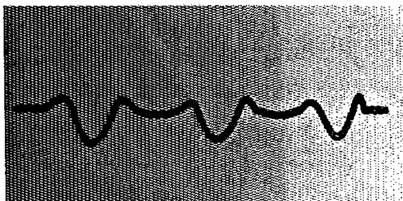


Fig. 7.7(a) Rain prints with raised ridges

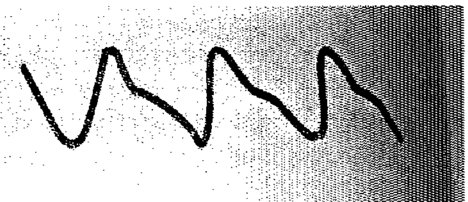


Fig. 7.7(b) Shape of rain prints when rain drops fall obliquely

Tracks and tails:

Tracks and tails are the markings indicating the paths of some animals over a soft sediment which is able to take and retain the impression.

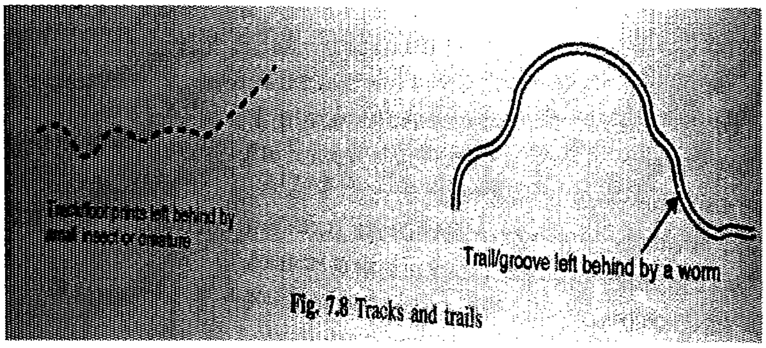


Fig. 7.8 Tracks and trails

CONGLOMERATES:

It is a Rudaceous sedimentary rock which is made up of round or sub-rounded pebbles and gravel. Occasionally, cobbles and boulders also are encountered in some conglomerates. Mineralogically, pebbles are usually jasper, flint, quartz. The cementing material may be siliceous, ferruginous, calcareous...

The rounded nature of pebbles indicates that the source of rocks from which pebbles of the conglomerate have been derived far away from the place of occurrence of the conglomerate.

Properties:

1. The compositional hetrogineity of pebbles and cementing material results in differences in their physical characters- this contributes to the weakness of rocks.
2. The incomplete cementation contributes to the usual porosity and permeability associated with conglomerates- this makes them good acquifers but incompetent rocks.
3. The rounded shape of pebbles of conglomerates does not allow firm grip for cementing material.

Uses: The conglomerates may be used as building stones. Very important aspect is that the conglomerates of upper vindhyans are famous as diamondiferous.

CIVIL ENGINEERING POINT OF VIEW:

Conglomerates are undesirable at the site of foundation of major civil engineering structures. St Francis dam in USA had rested on schists and conglomerates. Heavy seepage along the conglomerates resulted in failure by sliding.

Since conglomerates are unimportant they do not merit any serious consideration. However, conglomerates can be used as building stones.

ARENACEOUS rocks may be accumulated by wind action or deposited by water action include Sandstone ; Arkose; Greywacke etc...

Sandstones are abundant among sedimentary rocks but are next to shales. Sandstones are made up of sand and described as Arenaceous rocks. Sandstones are stratified and sometimes fossiliferous too. Compositionally, sandstones consist of sand grains (90% quartz) with accessory minerals of such as mica, ilmenite, magnetite, garnet, zircon, rutile, feldspars cover the rest.

Based on grain size:

a) Coarse grained (size of sand grains 1 to 2 mm).
b) Medium grained(size of sand grains is about 0.5mm).
c) Fine grained (size of sand grains is <0.5 mm).

In a hand specimen of sandstone, the size of sand grains may be coarse, medium or fine grained and other grains appear in different colors due to the presence of cementing material:

Grains	Appears as
Quartz	Colorless, fresh with vitreous lustre
Mica flakes	White colour with perfect cleavage
Ilmenite / magnetite	Jet black
Garnet	Red with shining
Zircon; rutile	White color with shining
Feldspars	Pale colours of brown, red, white, grey with a dull lustre
Pyroxenes & amphiboles	Pale colors

Sandstones are generally porous and permeable and considered one of the best aquifers. By virtue of their porosity and permeability, they are not only capable of holding a good quantity of groundwater but also yield the same when tapped.

Varieties in sandstones:

Arenite	A consolidated lithified sand with < 10% of matrix
Arkose	Formed by mechanical disintegration of granitic rocks and is considerably rich in feldspars and sand grains and unsorted.
Flagstone	A thinly bedded sandstone.
Greywacke	A dark, tough, rich in clay & contains less of quartz and unsorted
Grit	A sandstone composed of coarse angular grains.

Siliceous sand stone	Cementing material is also silica (porosity is less)
Ferruginous sandstone	Cementing material is a mixture of oxides & hydroxides of Fe
Calcareous sandstone	Cementing material is calcium carbonate
Argillaceous sandstone	Cementing material s clay

CIVIL ENGINEERING POINT OF VIEW: When sandstone is more porous, more permeable (not massive), so its inherent load bearing capacity is LESS. When sandstone is more porous and less permeable, so its inherent load bearing capacity is INTERMEDIATE.

Siliceous sandstones are the best rock for all civil engineering purposes such as site of foundation ; to be used as building stones; to be used for railways and for tunneling etc….

Ferruginous sandstones come next in order of preference for civil structures.

Calcareous sandstones initially be strong but may not be durable since carbonates react with water and leaches out easily.

Argillaceous sandstones are not desirable for civil structures due to the presence of clayey minerals.

Argillaceous rocks include the rock fragments/sediments with >50% of silt or clay. Eg:Siltstone, Mudstone, Clay stone, Shales, Bauxite (laterite), Terra Rossa.

Terra Rossa is reddish clayey soil covering limestones in dry regions. It is formed when limestones are dissolved, the insoluble clay content and other mineral matter is left behind as Residue (Terra Rossa) while calcium carbonate content is carried away in solution form.

SHALES :

Shales are more abundant than all other sedimentary rocks put together. These rocks are formed out of mechanically transported and deposited sediments. Shales are made up of solid particles of extremely fine grained silt and clay.

Stratification of lamination is best seen in shales because the individual layers are very thin. Shales often contain fossils of flora and fauna. Compositionally, shales are Hydrous aluminium silicates which the products of weathering of feldspars and other silicate minerals.

Field samples show different colours such as white, red, yellow, grey, brown and black. Shales are compact and extremely fine grained. Cross –bedding; ripple marks, mud cracks and fossil content are observed in some specimens of shales.

Mineralogically, shales are mainly made up of montmorillonite, kaolinite; Illite; halloysite; pyrophillite minerals.

Varieties in shales:

Siliceous shale	With considerable amount of silica
Calcareous shale	With increasing calcium carbonate content
Bituminous shale	With organic matter
Carbonaceous shale	Black color with rich in vegetal / organic matter
Mud stone	Similar to shale
Oil shales	Carbonaceous shales which yield oil on destructive distillation.

Shales are highly porous (due to the presence of various clays with porosity 50 – 60% ; impermeable rocks (do not yield water due to surface tension phenomenon) called as AQUICLUDES means shales contain water but do not yield groundwater when tapped.

CIVIL ENGINEERING POINT OF VIEW:

Shales are soft, fine; thin layered and unable to resist overburden. Therefore, these are unsuitable at the site of foundation of civil structures such as dams, tunnels etc.. Since shales are incompetent rocks, they may undergo subsidence.

CHEMICAL DEPOSITS are limestones; Dolomites, Flint, Chert, salt beds, iron-bearing rocks (iron ore). Limestone consists of over 95% calcite whereas dolomite consists of 90% of dolomite and 10% calcite and belonging to **Carbonate rocks**. Quartz, Chalcedony, Opal are three varieties of CHERT formed as chemical precipitate and is known as **Siliceous rocks.**

Uses:

1. On disintegration, they produce soils which are indispensable for agriculture.
2. They form one of the chief raw materials for cement manufacture.
3. They are invaluable as cap rocks in the occurance of oil and gas deposits.
4. Shales are known for their fissility. For this reasons, shales are unsuitable as construction material.

LIMESTONES:

In hand specimens, limestones show different colours of white, gray, buff, cream, pink, yellow and black. In nature, limestones occur both as porous and massive types. On the other hand, shell limestones care common and may be porous.

Types of Limestones:

Chalk: A soft, white fine grained calcareous deposit with dull lustre. It is also consists of fossils viz., foraminifera.

Stalactites result from the process when surface water with dissolved calcium carbonate pass through minute fractures and grows downwards from the roof of a cave.

If the rate of percolation of solution is excess than required evaporation, the solution falls on floor and form as a cone like deposit which grows upwards from the floor is called as **Stalagmites.**

If growth continues stalactites and stalagmites may come together after some time producing a pillar like structure, called a **DRIP STONE**.

Travertine: this is the evaporate formed at the site of hot springs through which calcareous water comes out.

Kankar: this is the nodular or concretionary form of calcium carbonate formed by the evaporation of sub soil water rich in calcium carbonate, just near the surface.

Fossiliferous or Shell limestone: These are formed organically with hard parts of marine organisms of coral reefs or gasteropods or lamellibranchs or brachiopods etc...

Siliceous limestone: with silica as impurity.

CIVIL ENGINEERING POINT OF VIEW: Massive and compact limestones are reasonably competent to support civil structures. But, these are undesirable for foundation if pores or cavities are present. They are suitable as road metal, railway ballast and as construction material.

ORGANIC DEPOSITS are formed out of active involvement of plants and other organisms. Eg: Phosphoritic deposits (guano deposits) / Rock Phosphates

Guano deposits are formed from fish eating sea birds which live in some isolated islands where there is no rain fall. West coast of America; South Africa; Australia have vast deposits of Guano.

Uses:

Limestones are mostly used in industries like cement and steel.

METAMORPHIC ROCKS

Igneous and sedimentary rocks which are formed under a certain physico-chemical environment, (they were in equilibrium) in terms of temperature, pressure and chemically active fluids. Subsequent to their formation if any of these factors changes, the existing equilibrium gets disturb in the constituent minerals of parent rocks by metamorphism. As a result of Metamorphism

1. Granite changes to Granitic Gneiss
2. Peridotite (Ultrabasic) changes to Serpentine / Talc Schist.
3. Gabbro / Dunite changes to Hornblende Schist.
4. Sandstone changes to Quartzite.
5. Limestone changes into Marble.
6. Shale changes into Slate

The process of metamorphism occuring in rocks due to the effect of high temperature, pressure and chemically active fluids and are known as metamorphic agents. These three act together to cause metamorphism and sometimes any one or two of them dominate and play an active role.

Temperature: Metamorphic changes mainly take place in the temperature range of 350°C to 850°C.

Pressure: Uniform pressure (vertically downwards) increases with depth and effect on liquids and solids at greater depths whereas the **direct pressure (stress)** due to tectonic forces acts in any direction i.e., upwards, downwards and side wards and effect only on solids.

Chemically inactive fluids: The most common liquid is water. Also the magma or hot hydrothermal solutions (containing various chemicals) may react directly with those rocks when they come in contact.

Types of Metamorphism:

1. **Thermal Metamorphism (Heat predominant):** All kinds of metamorphism in which heat plays a predominant role are given the common name thermal metamorphism.

   Types of thermal metamorphism :

   a) Pyro metamorphism
   b) Optalic metamorphism
   c) Contact metamorphism
   d) Pneumatolytic metamorphism

2. **Dynamic/Cataclastic Metamorphism:** When direct pressure is predominant and acts, rocks are forced to move past resisting in their crushing and granulation.
3. **Geo-Thermal Metamorphism:** Uniform pressure is predominant alongwith heat brings changes in oceanic salt deposits but not changes in silicate rocks.
4. **Metasomatic Metamorphism (chemically active fluids predominant):** This Metamorphism alters the composition of the rock significantly. Hydrothermal solutions are hot (upto 400°C) and cause for providing new minerals such as Pb, Zn, Mn etc. Tourmaline, topaz and fluorspars are produced when the volatiles involved .

   Eg: When Granite is attacked by watervapour, Boron, fluorine will suffer mineralogical changes where by feldspars replaced by tourmaline, the resultant rock may be Tourmaline Granite.
5. **Dynamothermal Metamorphism: (Direct pressure and Heat pressure):** When an argillaceous rock (shale) undergo Dynamo Thermal Metamorphism different minerals are produced. Eg. Gneisses and schists.

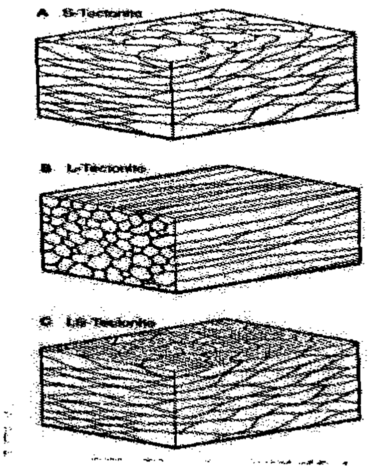
   Chlorite → Biotite → Garnet Staurolite → Kyanite → Sillimanite →

- The presence of chlorite and biotite in a metamorphic rock indicates that it had been formed under low grade Metamorphism.
- Presence of Garnet and Staurotite indicates medium grade of Metamorphism.
- Occurrence of Kyanite and Sillimanite indicates high grade of Metamorphism.

Mineral Composition: Following are the common minerals found in metamorphic rocks: Cordite, Staurotite, Andaulusite; Sillimanite, Kyanite, idocrase formed during Metamorphism. Garnet, Chlorite, Talc, Epidote, Quartz, Feldspars, Pyroxenes, Calcite, Mica, Hornblende also occur in different ways due to Metamorphism.

Metamorphic Textures:

1. Foliation: When Chlorite, Mica, Talc etc orient themselves parallel to one another is called as foliation ie the arrangement of in-equidimensional minerals.



Tectonites: Rocks that are pervaded by foliation and or lineation- flowed in solid state

Schistosity (foliation) only due to flattening- no lineation.

L: Lineation only, due to unidirectional stretching or constriction.

LS: Foliation and Lineation, related to non coaxial strain- shearing.

2. Lineation: when Hornblende, Tourmaline, Actinolite, Tremotie orient themselves parallel to one another is called Lineation ie the arrangement of equidimensional minerals.

3. Xenoblastic Texture: The constituent minerals of the rock have no well developed crystal faces.

4. Idioblastic Texture: The constituent minarals have well developed crystals.

Textures of Metamorphic rocks also depends on the shape of minerals, on their mode of growth and mutual arrangement. Some of the textures are seen under microscope.

1. **Porphyroblastic :** large crystals embedded in fine grained ground mass.
2. **Granoblastic:** the mineral granules are equidimensional.
3. **Ophitoblastic:** small crystals embedded in phenocryst

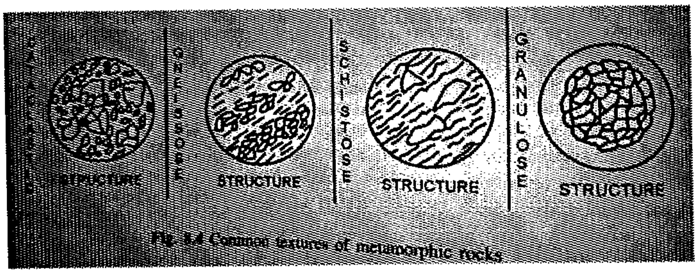
Structures:

1. **Gneissose Structure:** Both equidimensional (qtz, feldspars, pyroxenes, calcite) and other platy and prismatic minerals occur in considerable proportions and they appear in alternating bands. Eg: Granitic Gneiss.

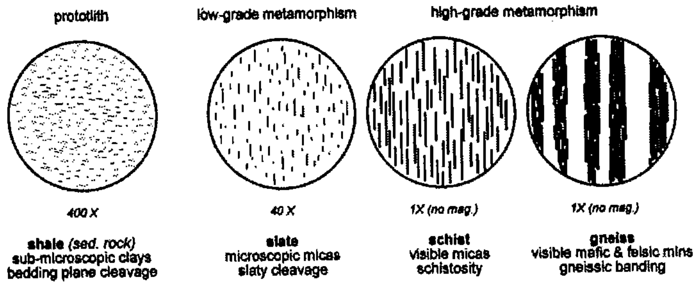
2. **Schistose Structure:** If a rock consists of only prismatic or platy minerals without any segregation is called a Schistose structure. (equidimensional minerals will be negligible) Eg: Mica schist, Chlorite schist, Hbl schist, Kyanite schist.

3. **Grannulose Structure:** Only equidimensional minerals present in the Metamorphic rocks. Prismatic or platy minerals will be either negligible or absent.
   Eg: Marble, Quatzite.

4. **Cataclastic structure:** It is produced under the influence of directed pressure (shearing stres) upon hard and brittle materials in the upper zones of the earth crust.
   Eg: Hornfels



Common textures of metamorphic rocks



DESCRIPTIVE STUDY OF COMMON METAMORPHIC ROCKS: The most commonly occurring metamorphic rocks in nature are Gneiss, Schist, Quartzite, Marble, Slate and Khondalite.

GNEISS:

A name is generally given to any metamorphic rock when shows a gneissose structure. A few details of its physical description are as follows:

Diagnostic character: Foliation present.
Color: grey and pink but generally pale coloured
Grain size: medium to coarse grained
Texture and Structure: Generally equigranular but sometimes porphyroblastic.
Minerals present: Feldspars and quartz usually make up the bulk of a gneiss. In addition, garnet, rarely pyroxenes occur in such bands.. If hornblende and biotite are present, then the rock appear as dark or black coloured bands. The other minerals which may also occasionally occur in gneisses are chlorite, sillimanite, kyanite, staurolite, talc, serpentine etc..

Types: Based on texture, mineral content etc different varieties of gneisses are named.

Orthogneiss: This is a gneiss derived from igneous rock

Paragneiss: This is a gneiss derived from sedimentary rock

Granite gneiss: if a gneiss, which has minerals similar to that of granite.

Augen gneiss: This is a gneiss in which quartz and feldspars appear as thick elongated lens shaped (resemble to eye).

Origin: Gneisses are usually formed out of Dynamothermal metamorphism of granites, Syenites, Sandstones.

Properties and uses of civil engineering importance: Due to non-porous and impermeable, it has a good strength. The foliation to some extent, improves the workability of gneiss. It may be used as building stone in addition to road metal, as railway ballast, as load bearing beams. In case of tunneling, the presence gneiss doesn't require any lining.

SCHIST:

Like a gneiss, schist is also a very common metamorphic rock due to schistose structure. A few details of its physical description are as follows:

Diagnostic character: schistose structure is present.

Color: silvery white (mica-schist), jet black (biotite schist), dark gree (chlorite schist)

Grain size: fine to medium and sometimes even coarse grained

Texture and Structure: Lineation or foliation texture occurs depending on when prismatic or platy minerals occur predominantly..

Minerals present: Actinolite, tremolite, hornblende, sillimanite, tourmaline make up the bulk of a schist. In addition, chlorite, muscovite, biotite, talc, kyanite etc are the common platy minerals occuring in schists.. garnet, quartz, staurolite, cordierite also occur as other minerals ..

***Types*: Depending on the grade of metamorphism, schists are named as Low Grade Schists** (Mica schist: Chlorite schist: Talc Schist; Hornblende Schist; Mica–Garnet Schist; Mica–Quartz Schist) and **High grade schist** (Sillimanite schist; Eclogite Schist; Staurolite Schist).

Origin: Schists are usually formed due to Dynamothermal metamorphism of different kinds of igneous and sedimentary rocks and the nature of combination of metamorphic agents.

For eg:Mica schist is formed out of shale

Mica – quartz schist is formed out of feldspathic sandstone
Talc schists are formed out of magnesia rich Ultrabasic igneous rocks like peridotite.
Hornblende Schists are formed from basic igneous rocks under high stress and high temperature..
Chlorite schist is formed under high stress and low temperature.
Eclogite Schist consists of pyroxenes, garnet and quartz formed under low stress and moderate temperature.

Properties and uses of civil engineering importance: Schists are considered weak, incompetent and undesirable rocks. The minerals of schists such as talc, chlorite, biotite, muscovite and serpentine are relatively very soft and are not strong and durable. Presence of cleavage in the minerals cause weakness of rocks. Schists are unsuitable for foundations, as building stone, as aggregate for concrete making, as road metal and as railway ballast. Schists are also unsuitable in case of tunneling.

One of the main factors for the failure of St. Francis dam was that it was constructed over Schists.

Comparison of Gneiss and Schist.

S No	Kind of difference	Gneiss	Schist
1	Appearance	Alternating colour bands occur	Alternating colour bands do not occur
2	Minerals present	More than one mineral	Usually one mineral after which the schist is named eg: talc – schist
3	Color	Pale grey or pink	White, black, green
4	Parent rock	Granite in more cases	Igneous and sedimentary rocks
5	Proportion of platy or prismatic minerals	Relatively less	Make up bulk of the rock
6	Strength	Reasonably strong	Weak and incompetent
7	Suitability for civil engineering works	Suitable	Unsuitable.

QUARTZITE:

Color: white or pale color. Red, brown, grey, green colours also may be seen.

Grain size: fine to coarse grained

Texture and Structure: Granulose structure is common. No alternating color bands. No foliation occurs.

Minerals present: quartz usually make up the bulk of a quartzite. The other minerals which may also occasionally occur in quartzites are mica, garnet, feldspar, pyroxenes; chlorite, kyanite, epidote, magnetite etc..

Types: Based on mineral content different varieties of quartzites are named as Micaceous quartzite and Quartzite Schist.

Important feature of quartzites: Lord Venkateshwara temple is located on nagari quartzites at Tirupathi – Tirumala hills as thick beds for many kilometers.

Natural bridge is seen in the same quartzites which is a unique feature.

Origin: Quartzites are formed due to dynamic or thermal or Dynamothermal metamorphism of sandstones. They occur as usually as bedded formations.

Properties and uses of civil engineering importance:

It is a silica–rich and makes highly durable and resist to weathering. The predominance of quartz makes the rock very hard. Due to less porosity and permeability, the rock is made more competent. It may be used as building stone in addition to road metal, as railway ballast, as load bearing beams. In case of tunneling, the quartzites doesn't require any lining.

MARBLE:

It is a calcareous metamorphic rock and not hard or strong or durable. Its value is due to its pleasant color, good appearance, easy workability and the ability to take an excellent polish.

Color: Milky white. However, pleasant shades of green, yellow, brown, ;blue or grey colours also seen.

Acid test: Marbles react vigorously even with cold and dilute acids.

Grain size: Fine to medium or even coarse grained and the rock is equigranular.

Texture and Structure: Granulose structure is common. . No foliation occurs.

Minerals present: calcite usually make up the bulk of Marble. The other minerals which may also occasionally occur in marbles are serpentine, olivine, garnet, graphite, mica, talc, tremolite, pyrite. mica, garnet, feldspar, pyroxenes; chlorite, kyanite, epidote, magnetite etc..

***Types*: Based on their colors, different varieties of marbles are named as white marble; pink marble; green marble.**

Important feature of marble: The famous Taj Mahal of Agra constructed out of marble, is regarded as one of the Seven Wonders of the World.

Origin: Marbles are formed due to thermal metamorphism of limestones.

Properties and uses of civil engineering importance: Physically, the mineral calcite is not only soft but also has three sets of well developed cleavages. This inherent weakness makes the rock split or break easily under loads. Marbles provide aesthetic beauty and a pleasing appearance to the constructions and specially chosen for face works, wall panels; flooring, statue making etc. Marbles are not used as road metal, aggregate for concrete due to soft and weak characters.

SLATE:

It is a fine grained metamorphic rock. By virtue of its cleavage character, it splits into very thin sheets of considerable size.

Diagnostic character: Extreme fine grain size, absence of reaction with acid, slaty cleavage and shining on surfaces are diagnostic characters of slate. .

Color: black or grey coloured

Grain size: fine grained

Texture and Structure: Foliation is clearly visible

Minerals present: Slates are made up of mica (sericite) and quartz. Other minerals which may also occur are biotite, muscovite, talc, chlorite, feldspars, calcite, pyrite, magnetite..

Types: Based on colors different varieties of slates are named as Black slate, grey slate etc. Phyllite is similar to slate in appearance and represents slate itself which is further metamorphosed. When Calcium is present, slate is described as calcareous slate.

Origin: Generally,it is formed due to Dynamic or regional metamorphism of shales.

Properties and uses of civil engineering importance: Since, slates are soft and incompetent, they cannot withstand great loads. So they are not suitable as site rocks for foundation purposes. Due to cleavage character and softness, they split easily and hence may be used as building stone.