SYNERGY POLYTECHNIC BHUBANESWAR

(DEPARTMENT OF MINING ENGINEERING)

LECTURE NOTES ON

MINE GEOLOGY-I

(3RD SEMESTER)

Prepare By: -
Pratyasha Kumar Sethy
(Lect. MNE)

1.Define Weathering

Weathering is the activity of weather and climatic components on earth materials. Wind, water, temperature change, and other elements break down rocks, and running water transports weathering rock particles and deposits them over plains. Weathering is also described as the mechanical disintegration and chemical degradation of rocks caused by the operations of numerous weather and climatic variables. Weathering is an in-situ or on-site process since there is little or no material movement.

Types of Weathering

Weathering may be classified into 3 types: physical weathering, chemical weathering, and mechanical weathering.

A. Physical weathering

Physical weathering is the separation of a rock's physical structure. For example, in a chilly environment, water that collects and freezes in rock holes will cause those holes to enlarge, shatter, and divide the rock.

b. Chemical Weathering

Chemical weathering causes changes in the chemical structure of the rock. As a result, the rock becomes softer or more easily broken. For example, iron in a rock may react with air to generate decomposable rust, while acids in water may remove calcium from limestone and marble.

c. Mechanical Weathering

Mechanical force can also break rocks. Mechanical weathering refers to the process of fragmentation. Rocks begin to compress and expand as a result of the regular temperature changes. These activities disintegrated rocks.

PROCESS OF WEATHERING: -

1.Physical weathering process:- This process refers to the mechanical disintegration of rocks in ich their mineralogical composition is not changed. This is brought about chiefly by temperature changes. The following are some of the important processes of physical weathering.

(a) Exfoliation: - In this case thin sheets of rocks split off owing to differential expansion and contraction during heating and cooling over the diurnal temperature range.
(b) Crystal growth: - The soluble constituents of the rocks or minerals, enter the rocks through fractures and joints, along with water. With the evaporation of water the solution is precipitated to form crystals or crystalline aggregates and as they grow, they exert large expansive stresses, which help in breaking up some rocks.
(c) Freezing of water: - By freezing the pressure exerted on the walls becomes more and more intense. Which results in widening the existing fracture and new fractures form. This is the dominant mode of weathering in climates where there is repeated freezing and thawing.
(d) Differential expansion: - Rock-forming minerals expand when heated but contract when cooled. Where rock surfaces are exposed daily to intense heating by direct solar rays, alternating with intense cooling by long wave radiation at might, the resulting expansion and contraction of mineral-grains tends to break them apart

2.Chemical processes of weathering. Three processes are notably responsible for chemical weathering.

(a) Oxidation: - The presence of dissolved oxygen in water in contact with mineral surfaces leads to oxidation, which is the chemical union of oxygen atoms with atoms of other metallic elements. Oxygen has a particular affinity for iron compounds and these are among the most commonly oxidized materials.
(b) Hydration: - The chemical union of water with a mineral is called hydration. The process of hydration is particularly effective on some aluminum bearing minerals, such as feldspar.
(c) Carbonation: - Carbonic acid is the most common solvent acting on the crust. The effect of this process is well noticed in the lime stones or chalk areas in the humid regions of the world.

3.Biological weathering. This process of weathering is mainly related to the activities of various organisms. Organisms, mainly plants and bacteria, take part in the transformation of rocks at the surface in the following ways.

(a) Bio-physical processes: - Plants-roots, growing between joint blocks along minute fractures between mineral grains, exert an expansive force tending to widen those opening and sometimes create new fractures.

(b) Bio-chemical processes: - Sometimes certain groups of bacteria, algae and mosses break rock-forming silicates down directly, removing from them elements like silicon, potassium, phosphorous, calcium, magnesium, that they need as nutrients. This transformation occasionally occurs on a large scale is decisive in the alteration of parent rocks and facilitate rock weathering.

2.Definition of erosion

Erosion is the geological process in which earthen materials are worn away and transported by natural forces such as wind or water. A similar process, weathering, breaks down or dissolves rock, but does not involve movement.

3.Difference between Weathering & Erosion

Weathering	Erosion
Weathering is the decomposition of rocks, soil, and minerals as a result of direct contact with the environment.	Erosion is the displacement of solids caused by wind, water, and ice.
The weathered materials are not displaced.	The eroded materials are displaced.
Weathering is produced by elements such as air pressure.	Wind, water, ice, and human activity all contribute to erosion.
It is classified into three types: physical, chemical, and biological weathering	It is different types of such as water, wind, ice, thermal, and gravity erosion.

4.1What are the erosional and depositional landforms due to Wind?

Erosion is the wearing away of the landscape by different agents like water, wind and ice. The eroded material is carried away or transported by water, wind, etc. and eventually deposited. Landforms created because of erosion are called erosional landforms and landforms created because of deposition are called depositional landforms.

1.Erosional landforms: Valleys, potholes, entrenched Meanders and river Terraces.

2.Depositional landforms: Alluvial Fans, deltas, meanders and braided channels.

4.2. Erosional Landforms due to Wind

1. Pediplains

When the high relief structures in deserts are reduced to low featureless plains by the activities of wind, they are called as Pediplains.

2. Deflation Hollows

Deflation is the removal of loose particles from the ground by the action of wind.

When deflation causes a shallow depression by persistent movements of wind, they are called as deflation hollows.

3. Mushroom Tables

*Ventifacts are rocks that have been abraded, pitted, etched, grooved, or polished by wind-driven sand or ice crystals.

***These geomorphic features are most typically found in arid environments where there is little vegetation to interfere with aeolian particle transport, where there are frequently strong winds, and where there is a steady but not overwhelming supply of sand.

*Mushroom Tables / Mushroom rocks are Ventifacts in the shape of a mushroom.

4.3) Depositional Landforms of Wind

1. Sand dunes

Dry hot deserts are good places for sand dune formation.

According to the shape of a sand dune, there are varieties of sand dune forms like Barchans, Seifs etc.

The crescent-shaped dunes are called as Barchans and they are the most common one.

Seif is similar to Barchans but has only one wing or point.

2. Loess

In several large areas of the world, the surface is covered by deposits of wind-transported silt that has settled out from dust storms over many thousands of years. These depositions are called as Loess.

5.What are the erosional and depositional landforms due to River?

1. Landforms created by the river and depend on the channel gradient, velocity, and volume of water. The landforms formed due to the action of rivers are called Fluvial landforms.
2. They are divided into two major groups, i.e., depositional and erosional.
3. Depositional landforms are leeves, deltas, and plains, while erosional ones are waterfalls, potholes, and V-shaped Valleys. A river goes through three stages: youthful, mature, and old.
4. The course of a river includes the upper stage, the middle stage, and the lower stage, and a kind of work dominates each stage of the River.
5. Landforms such as rapids, waterfalls, and gorges are generally formed in the upper course of a river due to high energy flows and steep gradients.
6. In the middle course, gentler gradients can lead to the formation of pools, riffles, natural levees, oxbow lakes, and floodplains in geographical locations as well as various other natural sources. Two landforms in the lower course of a river are the Delta and the estuary.

5.1Processes of Landform Formation by Rivers

Processes involved in landform formation by rivers are:

1.Corrosion / Abrasion: It is the mechanical grinding of the traction load of a river against the river's banks and bed. This process results in the hurling of the rock fragments against the sides of the river and their rolling against the bottom of the river. Corrosion takes place in two manners:

a. Lateral corrasion: This results in sideways erosion and the widening of the V-shaped valley.

b. Vertical corrasion: it is associated with the downward action of the river leading to the deepening of the river channel.

2.Corrosion / Solution: this process involves the chemical action of the water on the soluble components of the rocks. It is most significant in carbonate rocks due to its easy solubility.

3.Hydraulic action: It is associated with the mechanical loosening of the rocks due to the action of the river, which leads to the sweeping away of the rock materials. The continuous action of the river water on the rocks leads to the disintegration of the rock.

4. Attrition: It is the wear and tear of transported materials while they roll and collide among themselves. The coarser boulders are broken down into smaller stones and then smoothened to form pebbles.

6.Defination Iceberg & Glacier

Icebergs and glaciers are both enormous masses of snow, built up over the years through natural processes. However, they are both different from each other in form and structure, as well process of formation.

a) Glacier-Glaciers are formed by continual deposition of snow at a place where it does not melt.

b) Iceberg- When a chunk of this glacier breaks off and floats in the water, it is known as an iceberg.

6.1) Formation and Movement of Glaciers

Glaciers are solid ice that move extremely slowly along the land surface (Figure below). Glacial ice erodes and shapes the underlying rocks. Glaciers also deposit sediments in characteristic landforms. The two types of glaciers are:

1.Continental glaciers are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amount of snow and ice accumulate.

2.Alpine or valley glaciers flow downhill through mountains along existing valleys.

6.2) How are glaciers and icebergs formed?

Glaciers are formed with incessant deposition of snow, which transforms into ice, over time. As time passes, the ice crystallizes into sugar-like granules and compresses the air pockets that are present. With time, the crystals become larger in size and the air pockets become of negligible size. This process consumes almost a hundred years.

6.3) Difference between Glacier & Iceberg

	GLACIER	ICEBERG
Formation	Incessant deposition of snow and other frozen precipitation. Glaciers grow partly by spreading due to their weight.	Broken off of a glacier. When a chunk of glacier breaks off it is called calving
Size	Larger	Smaller
Location	Mountains, valleys and polar regions	Fresh or sea water beds
Exposoure	Entirely above water level	10% above water level
Introduction	A glacier is a large persistent body of ice that forms where the accumulation of snow exceeds its ablation (melting and sublimation) over many years, often centuries.	Ice bergs are formed from breaking off glaciers.
Terminology	When a chunk of glacier breaks off it is called calving	A fresh iceberg is also called a calf.
Composition	Pure snow and ice on a bed of "fluid ice" (the pressure of the ice above is higher than the skew strength of the ice at the bottom)	Pure ice floating on fresh or salt water. The portion of the iceberg above water is higher in sea water.

6.4) A) Erosional landforms due to Glaciers

1. Cirque or Corris

They are deep, long and wide troughs or basins with very steep concave to vertically dropping high walls at its head as well as sides.

They are simply a bowl-shaped depression formed due to the erosional activity of glaciers.

When these depressions are filled with water, they are called as Cirque lake or Corrie Lake or Tarn Lakes.

2. Hanging Valleys or U-shaped Valleys, Fjords/fiords

The Glacier doesn't create a new valley like a river does but deepens and widens a pre-existing valley by smoothening away the irregularities.

These valleys, which are formed by the glacial erosions assume the shape of letter 'U' and hence are called as U-shaped Valleys or Hanging Valleys.

A fjord is a very deep glacial trough filled with sea water and making up shorelines.

A fjord is formed when a glacier cuts a U-shaped valley by ice segregation and abrasion of the surrounding bedrock and this valley gradually gets filled with the seawater (formed in mountains nearby sea).

3. Horns and Aretes

Horns are sharp pointed and steep-sided peaks.

They are formed by headward erosion of cirque wall.

When the divide between two cirque walls gets narrow because of progressive erosions, it results in the formation of a saw-toothed ridge called Arete.

B) Depositional Landforms due to Glaciers

Glacial deposits are of two types:

(i) Glacial Till – unassorted coarse and fine debris;

(ii) Outwash – assorted roughly stratified deposits.

EROSIONAL FEATURES PRODUCED BY GLACIER: -

1. Cirques: - These are circular depressions formed by plucking and grinding on the upper parts of the mountain slopes.

2. Arete: - This name is applied to the sharp ridges produced by glacial erosion. Where two cirque-walls intersect from opposite sides, a jagged, knife-like ridge, called an arete results.
3. Horn: - Where three or more cirques grow together, a sharp-pointed peak is formed by the intersection of the arêtes. Such peaks are known as horns.
4. Col: - Where opposed cirques have intersected deeply, a pass or notch, called a col is formed.
5. Glacial-trough: - Glacier flow constantly deepens and widen its channel so that after the ice has finally disappeared there remains a deep, steep walled, 'U' shaped valley, known as glacial trough.
6. Hanging valley: - Tributary glaciers also carve 'U' shaped troughs. But they are smaller in cross-section, with floors lying high above the floor-level of the main-trough. Such valleys are called hanging valleys.
7. Fiords: - When the floor of a glacial trough open to the sea lies below sea-level, the sea-water will enter as the ice-front recedes, producing a narrow estuary, known as a fiord or fiords.
8. Tarns: - the bed-rock is not always evenly excavated under a glacier, so that floors of troughs and cirques may contain rock-basin and rock-steps. Cirques and upper parts of throughs thus are occupied by small lakes, called tarns.

DEPOSITIONAL FEATURES PRODUCED BY GLACIER :-

Depositional by a glacier takes place when the ice begins to melt and the glacier slows down and vanishes, loosing its transporting power. The unstratified, unsorted debris dropped more or less in a random fashion by glacier form deposits known as morains. Three types of morains are known, lateral, medial or median and terminal or end. These three types are differentiated on the basis of their location in the valley.

6.5) Define Moraine

1. Moraines are long ridges of deposits of glacial till.
2. When these deposits are at the end of a glacier, they are called as Terminal moraines and when they are deposited on both sides, they are called as Lateral moraines.
3. When lateral moraines of two glaciers join together, they form Medial moraines.
4. When the lateral moraines of both sides of a glacier join together, it forms a horse-shoe shape.
5. Ground moraines are deposits left behind in areas once covered by glaciers.
6.

6.6) Describe the different type of Moraine

Lateral Moraine

A lateral moraine forms along the sides of a glacier. As the glacier scrapes along, it tears off rock and soil from both sides of its path. This material is deposited as lateral moraine at the top of the glacier's edges. Lateral moraines are usually found in matching ridges on either side of the glacier. The glacier pushes material up the sides of the valley at about the same time, so lateral moraines usually have similar heights.

If a glacier melts, the lateral moraine will often remain as the high rims of a valley.

Medial Moraine

A medial moraine is found on top of and inside an existing glacier. Medial moraines are formed when two glaciers meet. Two lateral moraines from the different glaciers are pushed together. This material forms one line of rocks and dirt in the middle of the new, bigger glacier.

If a glacier melts, the medial moraine it leaves behind will be a long ridge of earth in the middle of a valley.

Supraglacial Moraine

A supraglacial moraine is material on the surface of a glacier. Lateral and medial moraines can be supraglacial moraines. Supraglacial moraines are made up of rocks and earth that have fallen on the glacier from the surrounding landscape. Dust and dirt left by wind and rain become part of supraglacial moraines. Sometimes the supraglacial moraine is so heavy, it blocks the view of the ice river underneath.

If a glacier melts, supraglacial moraine is evenly distributed across a valley.

Ground Moraine

Ground moraines often show up as rolling, strangely shaped land covered in grass or other vegetation. They don't have the sharp ridges of other moraines. A ground moraine is made of sediment that slowly builds up directly

underneath a glacier by tiny streams, or as the result of a glacier meeting hills and valleys in the natural landscape. When a glacier melts, the ground moraine underneath is exposed.
Ground moraines are the most common type of moraine and can be found on every continent.

Terminal Moraine

A terminal moraine is also sometimes called an end moraine. It forms at the very end of a glacier, telling scientists today important information about the glacier and how it moved. At a terminal moraine, all the debris that was scooped up and pushed to the front of the glacier is deposited as a large clump of rocks, soil, and sediment.

7.) Petrology & Petrography

Petrology - The branch of geology dealing with the origin, occurrence, structure, and history of rocks.

Petrography - The branch of geology dealing with the description and systematic classification of rocks, especially by microscopic examination of thin sections. Petrography is a subfield of Petrology.

7.1) Characteristics of Magma

Types of Magma

Types of magma are determined by chemical composition of the magma. Three general types are recognized, but we will look at other types later in the course:

1. ***Basaltic magma*** -- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
2. ***Andesitic magma*** -- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
3. ***Rhyolitic magma*** -- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na

Gases in Magmas

At depth in the Earth nearly all magmas contain gas dissolved in the liquid, but the gas forms a separate vapor phase when pressure is decreased as magma rises toward the surface. This is similar to carbonated beverages which are bottled at high pressure. The high pressure keeps the gas in solution in the liquid, but when pressure is decreased, like when you open the can or bottle, the gas comes out of solution and forms a separate gas phase that you see as bubbles. Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma are:

- Mostly H_2O (water vapor) with some CO_2 (carbon dioxide)
- Minor amounts of Sulfur, Chlorine, and Fluorine gases

The amount of gas in a magma is also related to the chemical composition of the magma. Rhyolitic magmas usually have higher dissolved gas contents than basaltic magmas.

Temperature of Magmas

Temperature of magmas is difficult to measure (due to the danger involved), but laboratory measurement and limited field observation indicate that the eruption temperature of various magmas is as follows:

- Basaltic magma - 1000 to 1200°C
- Andesitic magma - 800 to 1000°C

- Rhyolitic magma - 650 to 800^oC.

Viscosity of Magmas

Viscosity is the resistance to flow (opposite of fluidity). Viscosity depends on primarily on the composition of the magma, and temperature.

- Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas (viscosity increases with increasing SiO_2 concentration in the magma).
- Lower temperature magmas have higher viscosity than higher temperature magma(viscosity decreases with increasing temperature of the magma).

Thus, basaltic magmas tend to be fairly fluid (low viscosity), but their viscosity is still 10,000 to 100,0000 times more viscous than water. Rhyolitic magmas tend to have even higher viscosity, ranging between 1 million and 100 million times more viscous than water. (Note that solids, even though they appear solid have a viscosity, but it is very high, measured as trillions time the viscosity of water). Viscosity is an important property in determining the eruptive behavior of magma.

8) IGNEOUS ROCKS

Igneous rocks are formed when molten rock (magma or lava) cools and solidifies. They can be classified into four categories based on their chemistry or mineral composition: felsic, intermediate, mafic, and ultramafic.

OR

The term 'igneous' is derived from the Latin word 'ignis' means fire. Igneous rocks are formed through cooling, solidification and crystallization of molten materials i.e. magma. They are sometimes called as primary rocks these rocks were organized first of all the rocks at the time of origin of earth and especially during the formation of lithosphere. In other words, igneous rocks represent the rocks from which all other rocks directly or indirectly have been derived. That is why these rocks are also called as parent rocks. Igneous rocks are characterized as the hardest rock as resistant to weathering, fine to coarse grained texture with absence of fossils and no strata like sedimentary rocks.

8.1) Classification of Igneous Rocks

Classification on the Basis of Mode of Occurrence Igneous rocks can be divided into groups depending upon the conditions under which they solidify. One group is termed as extrusive rocks and another one is intrusive rocks. These groups of igneous rocks are discussed as follows:

8.1.1) Extrusive Rocks

Extrusive rocks are those rocks which have been ejected from a volcano or some other vent and are accumulated and solidified on the surface of the earth. These rocks may be further subdivided into two parts on the basis of the way of eruption.

8.1.2) Mode of Occurrence of Igneous Rocks

A) Explosive Type

Explosive type of volcanic eruption ejects accumulated gases and lavas which are thrown violently into the air. Volcanic materials include bombs which are big fragmented rocks; those about the size of a walnut are lapilli and very fine materials are called ash or volcanic dusts. Fine volcanic materials when deposited in aquatic condition, are called tuffs. 'Breccia' or 'agglomerates' are formed after deposition of coarse and fine materials.

B) Quiet Type

The molten materials come out through minor cracks on the earth's surface which is called lava flows. It may happen that the successive flows give rise to layers of lavas after being piled one on another. These lavas after being cooled and solidified from form basaltic igneous rocks. Such kind of flood basalts is formed by several episodes of lava flow during fissure flow of volcanic eruption that further forms lava plateaus and lava plains.

8.2) Intrusive Rocks

The rising magma solidifies below the earth's surface during a volcanic activity and remains surrounded by older, pre-existing rocks, is called intrusive rocks. They further sub-divided into two major groups on the basis of depth and place of cooling:

A) Plutonic Igneous Rocks

They are formed due to cooling of magmas at deep inside the earth where surrounding rocks totally covers the hot magma and consequently slow down the rate of cooling. Due to the situation at the greater depth, magma may require many thousands of years for complete cooling and the mineral crystals in the rocks can grow to relatively larger size that can be seen with naked eye. B)

B) Hypabyssal Igneous Rocks

When the rising magmas are come just below the surface of the earth from the interior with the cracks, pores crevices and hollow places during the volcanic eruption, the resultant cooled and solidified rocks are known as hypabyssal igneous rocks or volcanic rocks. The mineral crystals in volcanic rocks are so small as to be invisible without microscopic inspection. Black or dark grey colored and fine-grained basalt rock is the suitable rocks examples of hypabyssal igneous rocks. There are some important forms of these rocks according to the solidification depending on hollow places such as batholiths, laccoliths, phacolites, lopoliths, sills, dykes, necks etc.

8.3) On the basis of texture, igneous rocks can be divided into five parts such as:

1. Glassy Igneous Rocks

They are characterized by general absence of grains and is produced by very fast cooling of magma on surface of the earth. Obsidians, pitch stones, pumice perlite etc. are the most common example. **2. Aphanitic Igneous Rocks**

The word 'aphanitic' has been derived from a Greek word 'phaneres' meaning thereby visible. These rocks are characterized by small grains that can be visible without a microscopic vision. Basalt, felsite and the rocks of sills and dykes are the example of this category.

3. Phaneritic Igneous Rocks

These rocks contain grains that is enough large to see it without microscope. As the equal size and form of grains, the equigranularity texture represents a uniform rate of cooling and the large size of the crystals. For example, coarse grained and plutonic igneous rocks are such as granite, diorites etc.

4. Porphyritic Igneous Rocks

Porphyritic rocks contain two types of grains with different sizes. These are found two stages of cooling. In initial stage, the rate of cooling is slow resulting larger crystals but in next stage, the rate of cooling is faster than earlier those forms smaller crystals. Porphyritic texture occurs in both aphanitic and phaneritic rocks. For example, basalt, granite, felsite, diorite etc.

5. Pyroclastic Igneous Rocks

The word 'pyroclastic' has also been derived from the Greek word 'klastos' meaning thereby broken. These rocks are characterized by broken and fragmented rather than the interlocking or interconnected crystals. Such type of igneous rock constitutes bombs, lapilli, breccia, volcanic dusts, ashes, tuffs etc.

8.4) Classification of Igneous Rocks on the Basis of Chemical Composition The dominant chemical present in igneous rock is silica (SiO_2). Igneous rocks are divided into four types on the basis of silica content such as:

1. Acid Igneous rock

In these rocks, silica content ranges between 65 to 85 per cent and average density ranges between 2.75 to 2.8. Acid igneous rocks are composed of Quartz, white and pink feldspar. The most predominant example of such type of rock is granite.

2. Basic Igneous Rocks

In these rocks, silica content ranges between 45 to 60 per cent and the average density varies between 2.8 to 3.0. These rocks are heavy and dark coloured because of the dominance of iron content. The significant examples are basalt, dolerite, gabbro etc.

3. Intermediate Igneous rocks

Silica content in these rocks is less than the amount present in the acid igneous rocks but more than basic igneous rocks. The most dominant rocks of this group are diorite and andesite.

4. Ultra- Basic Igneous Rocks

These rocks contain less than 45 per cent of silica but their average density differs from 2.8 to 3.8 that mean the highest average density is found in this group of igneous rocks. Peridotite is the representative of this group of rocks.

9) What are sedimentary rocks?

Sedimentary rocks are formed from pre-existing rocks or pieces of once-living organisms. They form from deposits that accumulate on the Earth's surface. Sedimentary rocks often have distinctive layering or bedding. Many of the picturesque views of the desert southwest show mesas and arches made of layered sedimentary rock.

9.1) Common Sedimentary Rocks:

Common sedimentary rocks include sandstone, limestone, and shale. These rocks often start as sediments carried in rivers and deposited in lakes and oceans. When buried, the sediments lose water and become cemented to form rock. Tuffaceous sandstones contain volcanic ash.

9.2) Classification of Sedimentary Rocks

1. On the Basis of the Nature of Sediments

1.1. Mechanically Formed or Clastic Rocks

The rocks of the lithosphere are decomposed and broken up by mechanical agents like water, wind, glaciers etc. Fragments of many different kinds of rocks and minerals accumulate on the earth's surface in the form of soils, dust and coarser fragments with variable size and shape. These fragments are classified into five different rocks with respect to their size, shape and contents.

1A) Sandstone Sandstones are formed mostly due to deposition, cementation and consolidation of sand grains. These rocks are composed of quartz grains. On the basis of their size, they can be divided into following categories.

a. Grain Size Sand b. Very Coarse Sand

c. Medium Sand d. Fine Sand e. Very Fine

1B) Conglomerates-These rocks are also composed of coarser sand grains with pebbles and boulders of varying sizes. The term 'conglomerate' is applied to cemented fragmental rocks containing rounded fragments such as pebbles and boulders; if the fragments are angular in shape, the rock is called breccia. When the rounded fragmented materials are cemented by quartz, the resultant rocks become conglomerates.

1C) Clay Rock -Clay rocks are formed due to the deposition and cementation of sediments. These rocks are composed of fine grains with the size of 0.03 mm to 0.004 mm are called silts whereas, clays are formed when the sediments of the grain size of 0.004 mm to 0.00012 mm are cemented and consolidated. Both the rocks are impervious but they are soft. Clays are composed of almost entirely of kaolin.

1D) Shale Shales-are formed of laminae which are easily separated. These rocks are impure clays which contain a considerable proportion of minerals other than kaolinite.

1E) Loess- It is very fine-grained materials which are deposited by wind on the land. These rocks are very poorly stratified that means there is an absence of layers. The colour varies from light brown to dull yellow. A peculiar property of loess is its ability to stand vertical cliffs. Loess is generally poorly consolidated are very prone to erosion. Due to its finely divided condition and to the remarkable wealth of soluble mineral plant foods which it contains, loess soils are very fertile.

9.3) Representation of Different Mechanically Formed or Clastic Sedimentary Rocks

1. Chemically Formed Sedimentary Rocks

Chemical materials are contained by running water. When such chemical active water comes in contact with the continental rocks, soluble materials are removed from the rocks. These materials are called chemically formed sediments. For example, gypsum and salt rock.

2. Organically Formed Sedimentary Rocks

These rocks are formed due to disintegration and decomposition of sediments by bot animals and plants. These sediments after being deposited and consolidated form organic sedimentary rocks. On the basis of lime and carbon content, these rocks are divided in three groups.

A. Calcareous Rocks

These rocks are firmed by sediments which are derived from the skeletons and remains of those animals and plants containing large portion of lime. For example, Limestone and Chalk.

B. Carbonaceous Rocks

Unlike other sedimentary rocks groups, these are direct vegetation origin. These rocks are formed due to transformation of vegetation because of their burial during earth's movement and consequent weight and pressure of overlying deposits. Finally this results different grades of coals. For example, Peat, Lignite, Bituminous and Anthracit.

C. Siliceous Rocks

These rocks are formed due to dominance of silica content. Diatomaceous or infusorial earth is a loose in structure and white or grey or brown in colour in colour. Siliceous rocks are formed due to aggregation and compaction wastes derived from sponge, radiolarian organisms and diatom plants. Geyserite is the best example of these groups of rocks.

10) METAMORPHIC ROCKS

10.1) Formation of Metamorphic Rocks and Metamorphism

Earth is an active and dynamic planet. Rocks once are buried at the great depth of the earth's surface, they may be deformed and their temperature may be changed as a consequence of burial or by the intrusion of hot magmas. After such changes in the surrounding condition of rocks, the characteristics of the rocks commonly become modified with undergoing metamorphism and finally transformed into metamorphic rocks. It is sure that changes in temperature and pressures the causes of rocks in metamorphism but they are not the only ones. Changes may be occurred as a result of changes in chemical composition. In this case, changes are most commonly associated with the movement of fluids combination like carbon dioxide (CO2) and water (H2O).

Metamorphism often progresses slowly from slight changes (low grade metamorphism) to substantial change (high grade metamorphism). For example, under low grade metamorphism, sedimentary rock like shale becomes the more compact metamorphic rock slate.

10.2) Agents of Metamorphism

There are some important influential factors which help rocks to be metamorphosed. The degree of metamorphism and the role of factors differ greatly from one environment to another.

A) Heat:

High temperature is one of the obvious causes of rock metamorphism. It accelerates the chemical reaction that leads to the recrystallization of existing minerals and formation of new minerals. For example, limestone is recrystallized in the solid state but the rock is not melted however, only the mineral or textural changes take place that results into marble (CaCO3). In contrary to this, some rocks are not stable at higher temperatures because of containing so much water and break down to form new minerals, for instance, clay is transformed into mica. Pre-existing rocks experience an elevation in temperature when they are intruded by magma coming from below, is called contact or thermal metamorphism. The temperature increases with the depth of the earth's surface. So, the minerals of rock start becoming unstable which further leads to recrystallization into other minerals.

B) Pressure:

Metamorphism is not purely thermal as pressure is another important factor in the process of metamorphism. Greater pressure in rocks consolidates mineral grains and produces a more compact rock with greater density. Bounding pressure at the greater depth may cause minerals to recrystallize into new minerals displaying more compact crystalline forms. In Mountain building process the differential stress deforms rocks.

C) Chemical:

This become active when they are in contact with water. If it is hot water passing through rocks eat the greater depth of the surface then it is called hydro-thermal solutions which dissolve some materials and deposits in some other place. Such kind of solutions acts as accelerator to promote recrystallization by enhancing ion migration from one chemical to another. Chemical reaction is more advanced in hot environment where the solutions or fluid supply OH^{-2} (the hydroxyl ion) for the creation of certain key minerals like chloride and antinolite. For example, after being contact with water, asbestos forms serpentine.

10.3) Types of Metamorphic Rocks

1. Classification on the basis of place of occurrence

1.1. Contact Metamorphism

Such metamorphism happens when the mineral composition of surrounding rocks is altered due to high temperature of ascending magma. It is also known as thermal metamorphism. The best example is limestone which is altered to marble because of contact metamorphism. The area between the altered rocks and intruded magma is called aureoles.

1.2. Regional Metamorphism

When pressure is dominant to change the forms of rock in extensive area, the process is known as regional metamorphism. This process is also known as dynamic metamorphism. Apart from pressure, temperature is also active in changing the forms of rocks. Both pressure and heat change the original form of sedimentary rock leading to folding during mountain building. Consequently, rocks are crystallized and crystallized can be further recrystallized by greater pressure and heat.

10.4) Classification on the basis of foliation or structure

1. Foliated Rocks

The term foliation comes from the Latin word 'leaf' (as the parallel leaves or pages of a book) thereby characterizes as the nearby flat arrangement of minerals in a rock. Foliation may develop in both igneous and sedimentary rocks. Granite among igneous rocks can be metamorphosed in the similar foliation process to become granitic gneiss.

A. Slate:

It is composed of very fine-grained mica flakes which are too small to be visible. Under the higher temperature, some of the clay minerals become unstable and break down to form new phyllosilicates. The most important characteristic is that it has excellent rock cleavage that can be broken down into flat slabs. Slate is produced by the low-grade metamorphism of shale.

B. Schist:

Schists are platy that split into thin flakes or slabs very easily while this process is called schistosity or schistose structure. Coarse grained minerals like Muscovite and biotite are the composition of mica schist.

C. Gneiss:

This rock is composed of medium and coarse grain minerals in which there may be a limited or partial development of schistose structure that often give rise to a layered or lenticular structure. The most predominant minerals of gneiss are feldspar, quartzite, muscovite, biotite and hornblende.

2.Non-Foliated Rocks

Unlike foliated rocks, non-foliated rocks form under constant pressure but a minimum deformation takes place and the parent rocks are composed of mineral crystals like quartzite or calcite. For example, when a limestone composed of fine-grained calcite is heated by the intrusion of magma, the fine grains recrystallize to form larger interlocking crystals producing marble with large equidimensional grains which are actually randomly oriented.

A. Marble:

It is characterized by coarse grained crystalline rock which originates from limestone. It is discussed earlier that marble is made of large interlocking calcite crystal that was in the form of smaller size in limestone. Marble is useful as building stone due to its colour and relative softness.

B. Quartzite:

This rock is composed of more than 80 per cent of quartz because the parent rock is quartz sandstone. Another important characteristic of this rock is that this is very hard metamorphic rock due to the high grade of metamorphism in which quartzite grains in parent rock blend. The colour of pure quartzite is white while iron oxide may exhibit reddish or pinkish marks and grey colour is because of dark minerals.

10.5) Defination Metamorpic Rock

Metamorphic rocks are rocks that have been changed from their original igneous, sedimentary, or other metamorphic state by intense heat, pressure, or hot mineral-rich fluids. The process of changing rocks in this way is called metamorphism.

11.) Rock Cycle

The rock components of the crust are slowly but constantly being changed from one form to another and the processes involved are summarized in the rock cycle.

The rock cycle is driven by two forces:

(1) Earth's internal heat engine, which moves material around in the core and the mantle and leads to slow but significant changes within the crust.

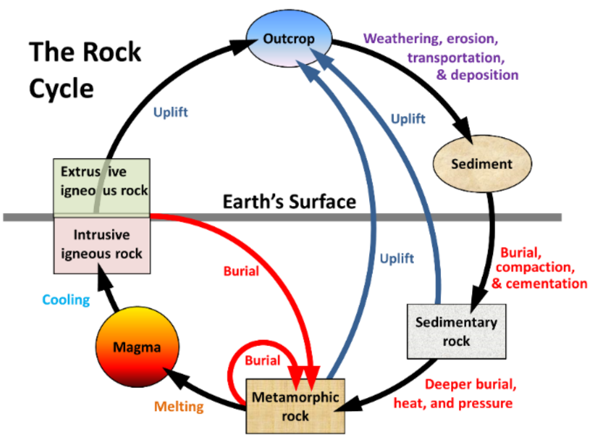
(2) the hydrological cycle, which is the movement of water, ice, and air at the surface, and is powered by the sun.

The rock cycle is still active on Earth because our core is hot enough to keep the mantle moving, our atmosphere is relatively thick, and we have liquid water. On some other planets or their satellites, such as the Moon, the rock cycle is virtually dead because the core is no longer hot enough to drive mantle convection and there is no atmosphere or liquid water.

In describing the rock cycle, we can start anywhere we like, although it's convenient to start with magma. As we'll see in more detail below, magma is rock that is hot to the point of being entirely molten. This happens at between about 800° and 1300°C, depending on the composition and the pressure, onto the surface and cool quickly (within seconds to years) — forming extrusive igneous rock

Magma can either cool slowly within the crust (over centuries to millions of years) — forming intrusive igneous rock, or erupt onto the surface and cool quickly (within seconds to years) — forming extrusive igneous rock. Intrusive igneous rock typically crystallizes at depths of hundreds of metres to tens of kilometres below the surface. To change its position in the rock cycle, intrusive igneous rock has to be uplifted and exposed by the erosion of the overlying rocks.

Through the various plate-tectonics-related processes of mountain building, all types of rocks are uplifted and exposed at the surface. Once exposed, they are weathered, both physically (by mechanical breaking of the rock) and chemically (by weathering of the minerals), and the weathering products — mostly small rock and mineral fragments — are eroded, transported, and then deposited as sediments. Transportation and deposition occur through the action of glaciers, streams, waves, wind, and other agents, and sediments are deposited in rivers, lakes, deserts, and the ocean.



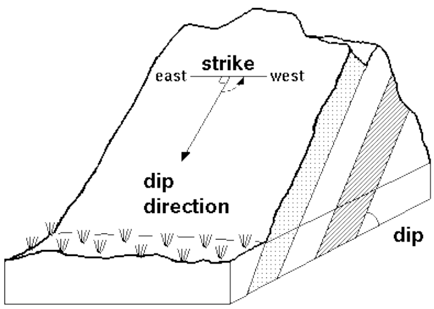
12) INTRODUCTION STRUCTURAL GEOLOGY
Structural geology is the branch of geology that deals with the recognition, representation, and genetic interpretation of rock structures. It also involves the study of the forces which give rise to these structures. The term 'Structural' is derived from Latin word 'Struere' which means 'to build'

12.1) Defination Structural Geology
Structural geology deals with the geometry, distribution and formation of structures (Fossen, 2010). Geologic structures or rock structures incorporate symmetry and geometric configuration of rocks present in the Earth's crust on all scales. Geologic structures result from the deformation caused by the tectonic forces present in Earth, i.e., they are endogenic. The term tectonics is derived from Greek word 'Tektos' meaning 'builder'. Tectonics is the study of the forces and motion that result in rock deformation and structure.

12.3) Definition of DIP?
1. It is the angle of inclination of a rock bed with the horizontal plane. The inclination of rock strata from the horizontal is specified by,
2. The amount of inclination is expressed as gradient like 1 in 5, 1 in 10 etc., more commonly in degree and minutes.
3. The direction of inclination is expressed full circle bearing like N 150° or more commonly quadrants bearings like N 15° W.

12.4) True Dip (TD):
It is the measure at right angle to the strike. The maximum amount of inclination or slope of bed along a line perpendicular to the strike is the maximum slope with respect to the horizon, it is called true dip.

12.5) Apparent Dip (AD):
The dip of the bed measured in any direction other than that of true dip is called apparent dip. The amount of apparent dip is always less than amount of true dip. If the angle is measured in any other direction than the true dip direction.



12.6) Amount of dip:
It is the angle which varies from 0o to 90o, according to the inclination of the bed. As discussed above the disposition of the beds (Figure 3) can be: • Horizontal: angle of dip=0o (no dip) • Inclined or tilted: angle of dip varying between 0o -90o • Vertical: angle of dip=90o

13) Defination of Strike
strike is the direction of a line that's formed when a planar geologic surface, like a fault or bed, intersects with a horizontal surface, like the ground. It's a representation of the orientation of a tilted feature, and is typically measured as the angle of the feature relative to true north.

13.1) Importance of Strike and Dip:
(a) Determination of the younger bed or formation:

In geological formations the older rocks deposit at the base which is superimposed by the younger rocks. Hence, in a tilted rock sequence when we move in the direction of dip then relatively beds of younger age will be encountered and vice-versa.

(b) (b) Classification of geological structures:

Dip and strike data provides useful information in the classification of rock or geologic structures.

13.2) Measuring Strike and Dip of an Inclined Bed

Let us discuss following procedure to measure the strike and dip of bed:

1. To measure the strike direction, place the compass on bedding plane in so that the bridge of the compass touches the bedding plane completely.
2. Then rotate the compass so as to ensure that the bridge becomes horizontal and one end of the bridge still touches the bedding plane. Now let the magnetic needle move freely. Let the needle come to rest and then read both ends of the azimuthal circle which represent strike.
3. In order to measure the amount of dip of the bed, draw a line on the bed perpendicular to strike and keep the bridge on the bedding plane along this line in such a way that the dial plane is vertical. The reading in clinometer gives the amount of dip.
4. In order to measure the direction of the dip, place the bridge along the line drawn on the bedding plane so that the dial face the sky. Then rotate the compass to horizontal so that the bridge and N-S line of the dial both remain parallel to the line. The crown is often marked as N. Take care the crown in the dial is towards the dip direction of the bed.
5. On rotation of clinometer to the horizontal, the N marked end of the magnetic needle gives the dip direction. You can check your reading. The true dip and strike directions are always perpendicular to each other.

13.3) Differences between True dip and Apparent dip are as follows:

1.Apparent dip is always measured in the vertical plane, whereas True dip is measured perpendicular to the strike line.

2.The angle of the True dip is between 0 to 90^{0}, whereas the Apparent dip is always less than the True dip.

3.The magnitude of the apparent dip is smaller compared to the true dip.

4.The orientation of apparent dip is overturned while bending where true dip has vertical cleavage.

On the plane surface, the true dip is always the biggest sip slope than the apparent dip.

14) Defination of Folds

1. A fold is a bend or twist in a rock that occurs when layers of rock are permanently deformed and curved. Folds can be microscopic or as large as mountains, and can appear as valleys or mountains on the surface.
2. Folds are combination of planar and linear structures. You can imagine folds in rocks are like folds in clothing. Similarly when the layers of rocks suffers gradual compression by the tectonic forces in the crust, they are pushed into folds. The layers of rocks can be crumpled or buckled into folds.

14.1) Importance of folding:

The study of folds in geological studies is important because of following reasons:

1. Folding exposes the deep seated rocks on the surface of the Earth.
2. It increases the mineral deposits because of repetition of layers due to folding in a limited area.
3. It facilitates development of site for deposition of mineral bearing solution.
4. Folds serve as good host for oil and natural gas.
5. Folding causes beautiful landscapes to develop which may enhance geotourism.

14.2) The parts of a fold :

1.Limbs: The two sides of the fold, located between the crest and troughs

2.Axial plane: An imaginary surface that divides the fold in half

3.Fold axis: The line where the axial plane intersects the folded strata
4.Hinge line: The line where the axial plane intersects the Earth's surface
5.Hinge: The point of maximum curvature in the fold
6.Crest: The highest point of the fold
7.Trough: The lowest point of the fold
8.Inflection point: The point on a limb where the concavity reverses

14.3) Parts of folds

1. **Crest and Crestal plane:** The crest of the fold is the highest point of the fold surface or the hingeof fold. The plane connecting all the crests is called crestal plane.
2. **Trough and Trough plane:**
   The trough is the lowest points of the fold. The plane connecting suchpoints may be called the trough plane.
3. **Hinge Point**:
   point of maximum curvature.(If the hinge is sharp, that point is called the hingepoint otherwise it is called a hinge zone.)
4. **Hinge line:**

The line connecting the points of maximum curvature of the bedding planes in a fold.Folds with a straight hinge line are called cylindrical folds.it may be horizontal, inclined, or vertical.it is defined by plunge/trend.

5. **Axial plane:**

is the surface connecting the successive hinges of a folded strata. also it is the plane or surface that divides the fold as symmetrically as possible. The axial plane may be vertical, horizontal, or inclined.the attitude of A.p. is defibed by strike and dip.

6. **Axis:**

fold axis is a line which lies parallel to the hinge line and marks the intersection of the axial plane with the hinge zone.

7. **Limbs or Flanks:**

A limb extends from the axial plane in one fold to axial plane in the next.
or it is that portion of curved surface between the hinge point and inflection point.
Inflection Point: point where curve changes from concave to convex.

8. **Inflection lines:**
   Lines connecting points of zero curvature.
9. **Median Surface:** Surface passing through the inflection points of a single folded layer
10. **Wavelength:** the line connecting three inflection points. Or is the distance from one anticlinal hinge to the next anticlinal hinge
11. **Amplitude:** Half the height of the structure measured from crest to trough. or the height between the crest and median surface, measured parallel to axial surface.

Enveloping Surface: imaginary plane that is tangential to the hinge zones of series of small folds.it contains all antiformal or synforma hinges.

12. **Interlimb Angle:** the minimum angle between the limbs as measured in the profile plane.

We assume that the limbs are relatively planar or we use the tangent at the inflection Point.

15.Defination of Fault

Fault can be defined as a fracture along which there is an observable amount of dislocation or displacement of the two rock blocks. Like folds, faults also occur in all sizes. The development of fault in rock takes place due to tectonic stresses such as tensional, tangential or compressional or in combination.

15.1) Importance of Faults:

- Faulting exposes the rocks from the deeper level to the Earth’s surface which provides knowledge of
- the subsurface geology.
- Faults provide the excellent channel for the movement of mineralized solution or petroleum. They
- trap petroleum from migration and loss.
- Faults may create beautiful landscapes which enhance geotourism.
- They may be the cause of origin of earthquakes.
- Fault locations are very important prospects in mining and exploration

15.2) The primary types of faults are:

1.Normal Fault:
In a normal fault, the hanging wall (the block of rock above the fault plane) moves downward relative to the footwall (the block of rock below the fault plane). Normal faults are common at divergent plate boundaries where the Earth’s crust is stretching.

2.Reverse Fault (Thrust Fault):

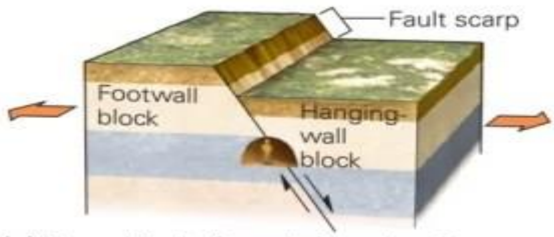
In a reverse fault, the hanging wall moves upward relative to the footwall. Reverse faults typically occur at convergent plate boundaries where tectonic plates are colliding and undergoing compression.

3.Strike-Slip Fault:

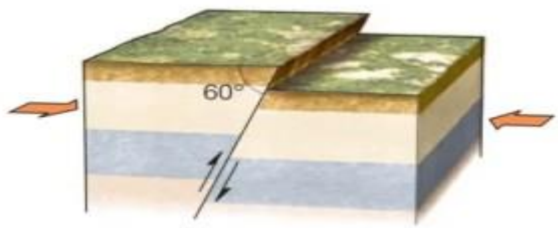
In a strike-slip fault, the movement is primarily horizontal, with minimal vertical displacement. The rocks on either side of the fault slide past each other horizontally.

4.Transform Fault:

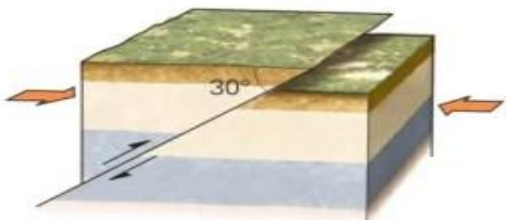
Transform faults are a type of strike-slip fault that forms the boundary between two tectonic plates. They accommodate horizontal motion between the plates. The motion is typically parallel to the fault’s strike.



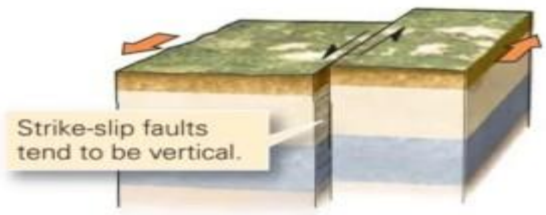
(a) Normal faults form during extension of the crust. The hanging wall moves down.



(b) Reverse faults form during shortening of the crust. The hanging wall moves up and the fault is steep.



(c) Thrust faults also form during shortening. The fault’s slope is gentle (less than 30°).



(d) On a strike-slip fault, one block slides laterally past another, so no vertical displacement takes place.

15.3) Based on Movement:

1. **Normal Fault:** In a normal fault, the hanging wall moves downward relative to the footwall. This type of fault is associated with extensional tectonic forces, typically found at divergent plate boundaries.
2. **Reverse Fault (Thrust Fault):** In a reverse fault, the hanging wall moves upward relative to the footwall. Reverse faults are associated with compressional tectonic forces and are commonly found at convergent plate boundaries.

3. **Strike-Slip Fault:** In a strike-slip fault, the movement is primarily horizontal, with minimal vertical displacement. The rocks on either side of the fault slide past each other horizontally.

15.4) Based on Geological Setting:

1. **Plate Boundary Faults:** These faults are located at the boundaries of tectonic plates and play a significant role in plate tectonics. Examples include the San Andreas Fault (a transform fault) at the boundary between the Pacific and North American plates and the Himalayan Thrust Fault at the convergent boundary of the Indian and Eurasian plates.
2. **Intraplate Faults:** Intraplate faults occur within the interior of tectonic plates, away from plate boundaries. They are less common but can still generate significant seismic activity.

15.5) Based on Displacement:

1. **High-angle Fault:** High-angle faults have a steep dip angle (close to vertical) and are common in both extensional and compressional settings.
2. **Low-angle Fault:** Low-angle faults have a shallow dip angle (close to horizontal) and are often associated with thrust faulting in compressional settings.

15.6)Based on Fault Geometry:

1. **Dip-Slip Fault:** In dip-slip faults, the movement is primarily vertical along the fault plane. Normal and reverse faults are both types of dip-slip faults.
2. **Strike-Slip Fault:** Strike-slip faults primarily involve horizontal movement along the fault plane. These faults can be further classified as right-lateral or left-lateral, depending on the direction of horizontal movement when facing the fault.
3. **Oblique-Slip Fault:** Oblique-slip faults combine both vertical (dip-slip) and horizontal (strike-slip) movements. These faults do not fit neatly into the categories of normal, reverse, or strike-slip.
4. **Listric Fault:** A listric fault has a curved fault plane that steepens with depth. This type of fault is often associated with extensional tectonics and can transition from normal faulting at the surface to a low-angle fault deeper within the Earth's crust.

16) Define unconformity

An unconformity is a plane of discontinuity that separates two rocks, which differ notably in age. The younger of these rocks are nearly always of sedimentary origin and must have been deposited on the surface of the older rock, which is a surface of erosion.

16.1) TYPES OF UNCONFORMITIES: -

The various types of unconformities may be enumerated as follows:

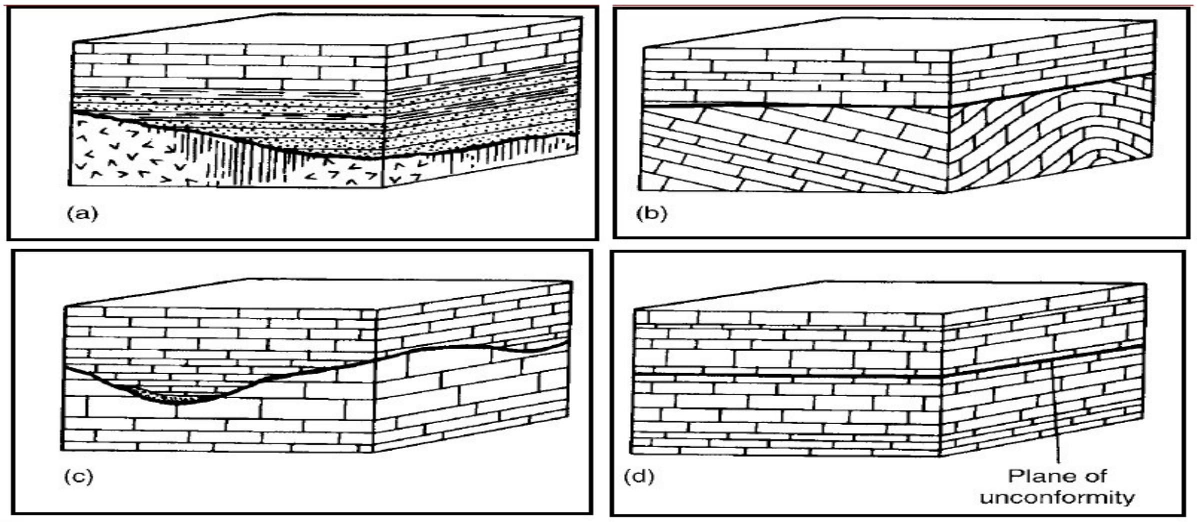
(a) Angular unconformity: - If the beds beneath the erosion surface are folded or tilted so that there is an angular discordance between the younger and older beds, the contact is called an angular unconformity.

(b) Disconformity: - It is also known as Parallel-unconformity in view of the fact that the bedding above and below the plane of discontinuity. The lower and upper series of beds dip at the same amount and in the same direction, thus this type or unconformity is formed when there is a lesser magnitude of diastrophism, or disturbance between the deposition of the two succession strata.

(c) Local-unconformity: - It is also known as a non-depositional unconformity. It is similar to disconformity, but it is local in extent and hence the name. the time involved is also short. Thus, it represents a short period of non-deposition. So, the age difference between the overlying and underlying beds is very less.

(d) Non-conformity: - It is commonly applied to structures in which the older formation made up essentially of plutonic rocks, is overlain unconformably by sedimentary rocks or lava flows. The essential concept being that prolonged erosion must have occurred to expose the intrusive before burial.

(e) Blended unconformity: - It is a surface of erosion, which may be covered by a thick residual soil that grades into the underlying bed rock. Younger sediments deposited above the surface may incorporate some of the residual-soil and a sharp contact may be lacking. Such a contact may be called as Blended unconformity.



a) Nonconformity or heteroconformity
b) Angular unconformity
c) Disconformity
d) Paraconformity

17)Defination of Joints

- Joints are defined as fractures of geological origin along which no appreciable displacement has occurred.
- Joints occurs generally in parallel or sub parallel called joint set.

17.1) Classification of Joints:

- **Tension joints**:Tension joints are those, which are formed as a result of tension forces.These joints are relatively open and have rough and irregular surfaces.
- **Shear joints**: These are joints associated with deformed rocks especially folded rocks. These joints occur as intersecting or crisscrossing sets at a high angle. These joints are referred to as conjugate joint system.
- **Mural Joints:** These joints are common in granites and related plutonic rocks and some hypabyssal rocks. These joints appear in a three dimensional network, the joint sets being mutually perpendicular to each other. The joints break the rock into separate somewhat cubical blocks.
- **Sheet Joints:**These joints also are seen in granites and other plutonic rocks. In thiscase there is one set of prominent joints parallel to the ground surfacewhose spacing generally increase with depth and a second set running at right angles.
- **Columnar Joints**:These joints are seen in basalts and some other volcanic igneous rocks.They consist of vertical and horizontal joints separating the rock bodyinto a number of vertical polygonal (quite often hexagonal prismatic columns). When the horizontal lavas cool weak planes are developed by radial contraction causing these joints.

- **Stylolitic joints:** Stylolitic joints have a characteristic saw-tooth profile and an interdigitating cone-like form in three dimensions. The interlocking

'teeth' are normal or oblique to the joint surface. Stylolitic joints are form due to deformation mechanism is called pressure solution.Stylolites are particularly common in limestone.

- **Exfoliation joints or sheet joints** are surface-parallel fracture systems in

rock, and often leading to erosion of concentric slabs.

18) Defination Crystal

A crystal is a homogeneous solid in which particles (atoms,molecules or ions) are arranged in a definite pattern due to which they have a definite geometrical shape with a plane surface.

18.1) There are 7 types of Crystal

Monoclinic System: It comprises three axes where two are at right angles to each other, and the third axis is inclined. All three axes are of different length. Based on the inner structure the monoclinic system includes Basal pinacoids and prisms with inclined end faces. Some examples include Diopside, Petalite, Kunzite, Gypsum, Hiddenite, Howlite, Vivianite and more.

Triclinic System:It is the most unsymmetrical crystal system. All three axes are inclined towards each other, and they are of the same length. Based on the three inclined angles the various forms of crystals are in the paired faces. Some standard Triclinic Systems include Labradorite, Amazonite, Kyanite, Rhodonite, Aventurine Feldspar, and Turquois

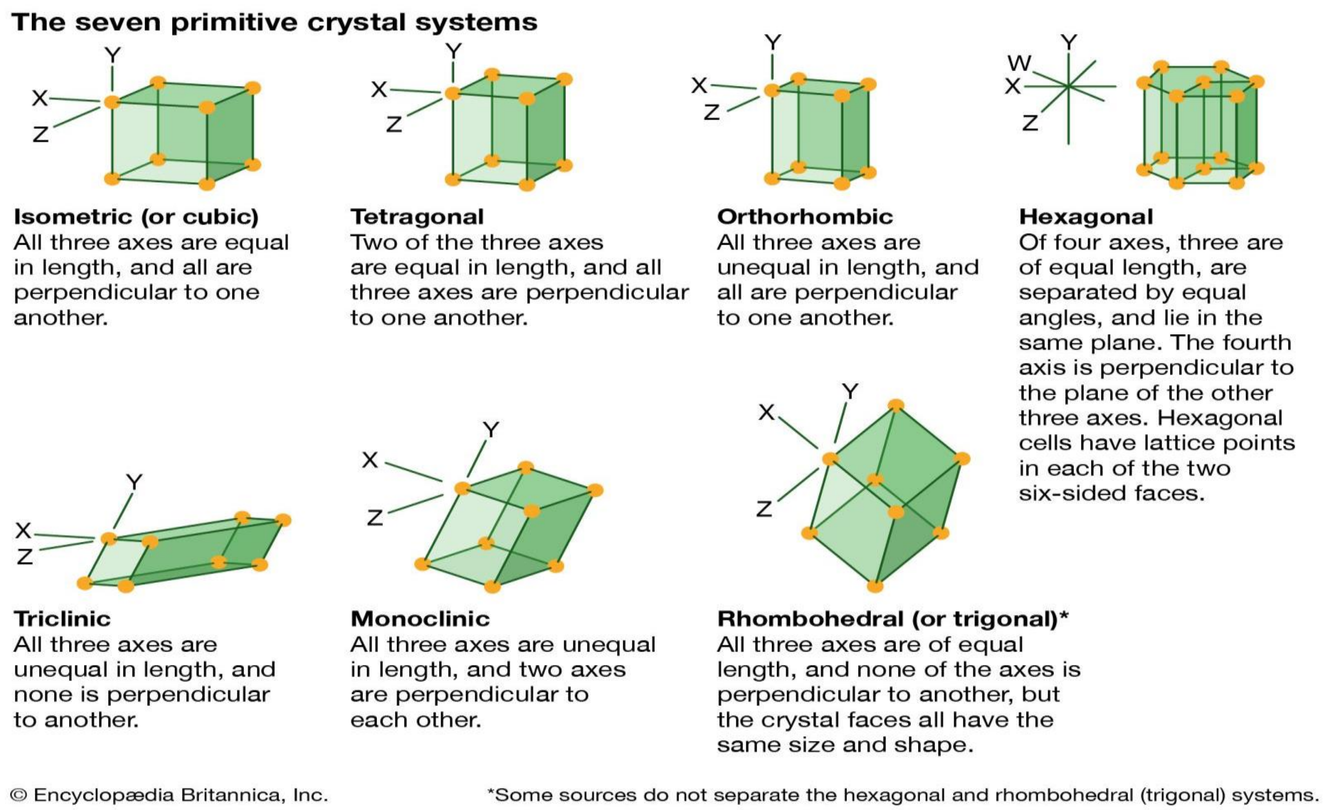
Orthorhombic System:It comprises three axes and is at right angles to each other. There are different lengths. Based on their Rhombic structure the orthorhombic system includes various crystal shapes namely pyramids, double pyramids, rhombic pyramids, and pinacoids. Some common orthorhombic crystals include Topaz, Tanzanite, Iolite, Zoisite, Danburite and more

Trigonal System: Angles and axis in a trigonal system are similar to Hexagonal Systems. At the base of a hexagonal system (ross-section of a prism), there will be six sides. In the trigonal system (base cross-section) there will be three sides. Crystal shapes in a trigonal system include three-sided pyramids, Scalenohedral and Rhombohedra. Some typical examples include Ruby, Quartz, Calcite, Agate, Jasper, Tiger's Eyes and more.

Hexagonal System: It comprises four axes. The three a1, a2 and a3 axes are all contained within a single plane (called the basal plane) and are at 120°. They intersect each other at an angle of sixty degrees. The fourth axis intersects other axes at right angles. Crystal shapes of hexagonal systems include Double Pyramids, Double-Sided Pyramids, and Four-Sided Pyramids. Example: Beryl, Cancrinite, Apatite, Sugilite, etc.

Tetragonal Systems: It consists of three axes. The main axis varies in length; it can either be short or long. The two-axis lie in the same plane and are of the same length. Based on the rectangular inner structure the shapes of crystal in tetragonal include double and eight-sided pyramids, four-sided prism, trapezohedrons, and pyrite.

Cubic System: Cubic system is the most symmetrical one out of the seven crystal system. All three angles intersect at right angles and are of equal length. Crystal shapes of a cubic system based on inner structure (square) include octahedron, cube, and Hexaciscoherdron. Example: Silver, Garnet, Gold, and Diamond.



19)MILLER INDICES

- set of three possible integers represented as (h k l)
- reciprocals of the intercepts made by the plane on the three crystallographic axes.
- designate plane in the crystal.

19.1) Procedure for finding Miller Indices

Step 1 : Determine the intercepts of the plane along the axes

Step 2 : Determine the reciprocals of these numbers.

Step 3 : Find the LCD and multiply each by this LCD

Step 4 : Write it in paranthesis in the form (h k l).

19.3) IMPORTANT FEATURES OF MILLER INDICES

1.a plane parallel to the axes has an intercept of infinity (∞)

2.a plane cuts an axis on the negative side of the origin, is represented by a bar, as $(\bar{1}\ 0\ 0)$.

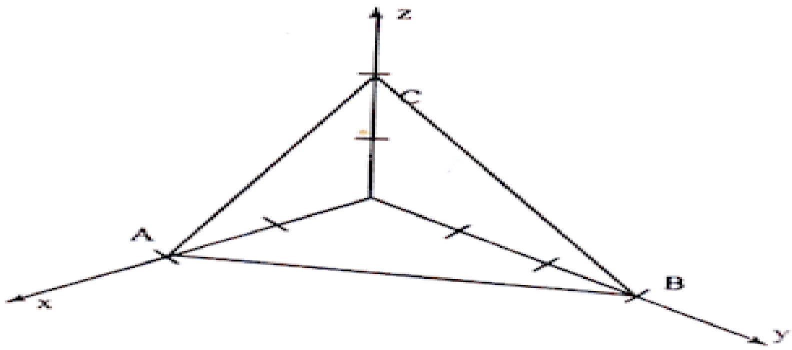
3.a plane passing through the origin have non zero intercepts

4.All equally spaced parallel planes have same Miller indices

20) ILLUSTRATION

Step 1 : intercepts - 2a,3b and 2c

Step 2 : reciprocals - 1/2, 1/3 and 1/2.



Step 3 : LCD is '6'.
Multiply each reciprocal by lcd, we get, 3,2 and 3.
Step 4 : Miller indices for the plane.ABC is (3 2 3)

ELEMENTS OF MINEROLOGY

21) Define Mineral

Mineral is a naturally occurring inorganic solid with a definite chemical composition and a crystalline structure.
The earth is composed of mineral elements, either alone or in a myriad of combinations called compounds. A mineral is composed of a single element or compound. By definition, a mineral is a naturally occurring inorganic substance with a definite chemical composition and ordered atomic structure.

21.1) Physical Properties of Mineral

The mineral can often be identified in the field using basic following properties :
1.Color 2. Streak 3. Hardness
4. Cleavage or fracture 5. Crystalline structure 6. Diaphaneity or amount of Transparency
7. Tenacity 8. Magnetism 9. Lustre 10. Odour 11. Taste and 12. Specific Gravity

21.3) Enumerate and describe the physical properties of minerals.

Minerals possess definite physical properties by virtue of which they can be distinguished from one another. The most important physical properties are as follows:

color: Some minerals possess a characteristic colour, e.g. galena, magnetic, olivine, etc; but in some others the color is variable, e.g. quartz.

Specific gravity: Most rock-forming minerals have a specific gravity between 2 and 4.

Luster: The luster may be metallic (like galena or iron pyrites), pearly (like talc) or silky.

Taste and Smell: Rock salt, alum and some other minerals can be recognized by their taste.

Streak: A few minerals, when drawn over paper or over an unglazed porcelain plate, leave a colored mark known as the streak; for example, graphite gives a black streak; hematite leaves a cherry red streak.

Crystalline: A crystal is geometrical solid bounded by smooth plain surfaces called faces and capable of increasing in size by the deposit of fresh material on the outside of these surfaces. The faces in a crystal show a definite geometrical pattern and the angles between the faces are constant; for example, quartz crystallizes in the hexagonal system, while mica or muscovite crystallizes in what is called the monoclinic system, and rock salt, in the cubic system. The crystallization may take place by : (a) deposition from solution (b) slow cooling from the molten stat, or (c) direct change from a vapour to a solid.

Cleavage: Many crystals have tendency to split along one or more direction parallel to an actual or possible crystal face. This splitting gives plane surfaces known as cleavage planes. For example, mica cleaves in one direction only; galena (lead sulphide) cleaves in three planes at right angles, forming perfect cubes.

Fracture: When a crystal breaks independently of the cleavage plane, it is said to fracture. The property is prominent in minerals with poor cleavage.

Hardness : This term gives the relative ease with which minerals can be scratched. In practice hardness is measured by reference to a set of minerals given below so arranged that the first member can be scratched by all the others, the second by all except the first, and so on.

21.4) Describe the optical properties of minerals

The optical properties of minerals refer to their behavior in the presence of light and how they interact with light when observed using various optical techniques. These properties include transparency/opacity, color, luster, refractive index (RI), pleochroism, birefringence, dispersion, extinction, and crystallography.

1. **Color**: The color of a mineral can be a useful diagnostic tool. However, it should be noted that color can vary greatly depending on impurities, and so it is not always a reliable indicator of a mineral's identity.
2. **Luster**: Luster refers to the way that a mineral reflects light. Minerals can be metallic, glassy, pearly, or dull, and each type of luster can be used to help identify a mineral.
3. **Transparency**: Some minerals are transparent, while others are opaque. Minerals that are transparent can be further categorized as either colorless, colored, or pleochroic (displaying different colors when viewed from different angles).
4. **Refractive index**: The refractive index of a mineral is a measure of how much light is bent as it passes through the mineral. This property can be used to identify a mineral by measuring the angle at which light is refracted.
5. **Birefringence**: Birefringence refers to the property of a mineral that causes light to split into two rays as it passes through the mineral. This property is particularly useful for identifying minerals in thin sections under a microscope.
6. **Dispersion**: Dispersion refers to the way that different colors of light are refracted at different angles by a mineral. This property is particularly useful for identifying gems such as diamonds.
7. **Pleochroism**: Pleochroism refers to the property of a mineral that causes it to display different colors when viewed from different angles.
8. **Fluorescence**: Some minerals exhibit fluorescence, meaning that they emit light when exposed to ultraviolet light. This property can be used to help identify minerals in certain settings.

24) What is Silicate?

Oxygen, silicon, and aluminium are the most abundant elements in the surface of the earth; more than 80% of the atoms in the solid crust are oxygen or silicon, mostly in the form of silicates.

Silicates are the minerals containing silicon and oxygen in tetrahedral SiO44- units, which are linked together in several patterns. About 95% of the earth's crust is composed of silicate minerals, aluminosilicate clays or silica.

Silicates are extremely important because the cement, ceramic and glass industries are based on their chemical composition. Metallurgical extraction processes often produce silicates as waste products or slag either because the minerals are silicate

25) Explain briefly the silicate structures.

The silicate structures, so far recognized are of the following types:

1. Neso-silicates: These are independent or isolated SiO_4 tetrahedral which are bound to each other only by ionic bonds through interstitial cations. Their structures depend chiefly on the size and charge of the interstitial cations.
2. Soro-silicates: The soro-silicates are characterized by isolated double tetrahedral groups formed by two SiO_4 tetrahedral sharing a single apical oxygen. the resulting ratio of silicon to oxygen is 2:7. they have a net charge of '-6'. As the charge is '-6', three divalent ions are needed to balance it.
3. Cyclosilicates : When each SiO_4 tetrahedron shares two of its oxygen with neighboring tetrahedral they may be linked into rings. They have a ratio of Si : O = 1:3. three possible closed cyclic configurations of this kind may exist as
   (a) Each of the three tetrahedral shares an oxygen atom.
   (b) Each of the four tetrahedral shares an oxygen atom.
   (c) Each of the four tetrahedral shares an oxygen atom.
4. Chain structures : These are also known as ino-silicates. Here SiO_4 tetrahedral are joined together to form chains of indefinite extent.
   There are two principal modifications of this structure yielding somewhat different composition :
   (a) Single chains, in which Si : O is 1 : 3 characterized by the pyroxenes and pyroxenoids.
   (b) Double chains, where alternate tetrahedral in two parallel single chains are cross linked and the Si : O ratio is 4 : 11, characterized by the amphiboles.
5. Sheet structures (Si_4O_{10}) : It is also known as phyllosilicates. It is formed when the SiO_4 tetrahedral are linked by three of their corners and extend indefinitely in a two dimensional net-work orsheet, which has a silicon and oxygen ratio of 45 : 10. this is the fundamental unit-in allmica and clay-structure.
6. Tectosilicates : It is also known as framework structure. When each of the four oxygen atoms of each tetrahedral is shared by another tetrahedron, it results in the formation of tectosilicates. Here every SiO_4 tetrahedron shares all its corners with other tetrahedral giving a three dimensional net-sork in which Si : O = 1 : 2.

25.1)Basic structure of Silicates

The X-ray crystallographic method suggests the structural principle in silicate structure.

- The electronegativity difference between oxygen and silicon (3.5-1.8 =1.7), suggests that the bonds between O and Si are 50% ionic and 50% covalent in nature.
- The radius ratio of Si^{4+}/O^{2-} = 0.29, suggests that silicon is four coordinated and it is surrounded by four oxygen atoms at the corners of a tetrahedron.
- The SiO_4^{4-} tetrahedral may exist as discrete units or may polymerize into large units by sharing corners with oxygen atoms.
- The oxygen atoms form a close-packed structure where both have an octahedral and tetrahedral void. Most metal ions are the right size to fit one type of void. Whereas Al can occupy both tetrahedral and octahedral void.

26)Defination of Mineral

Minerals can be classified in several ways, but the most common classification is based on their **chemical composition** and **crystal structure**. The classification system primarily categorizes minerals into **mineral groups** based on the dominant anion or anion group in their structure. Here's a breakdown of the major mineral groups:

1. Silicate Minerals (SiO_4)

- **Description**: Silicates are the most abundant and important group of minerals on Earth. They are composed of silicon and oxygen, often with metal cations (like aluminum, iron, magnesium, calcium, etc.) bonded to them. The basic building block is the **silicon-oxygen tetrahedron (SiO_4)**, where a silicon ion is surrounded by four oxygen atoms.
- **Sub-groups**: Based on how these tetrahedra are arranged, silicates are further classified into different sub-groups.

- **Nesosilicates (Orthosilicates)**: The silicon-oxygen tetrahedra are isolated from each other. Example: **olivine**, **garnet**.
  - **Sorosilicates**: Tetrahedra are linked in pairs. Example: **epidote**.
  - **Cyclosilicates**: Tetrahedra form rings. Example: **beryl**, **tourmaline**.
  - **Inosilicates**: Tetrahedra are linked in chains.
    - **Single-chain silicates**: Example: **pyroxenes**.
    - **Double-chain silicates**: Example: **amphiboles**.
  - **Phyllosilicates**: Tetrahedra are arranged in sheets. Example: **micas**, **clay minerals**.
  - **Tectosilicates**: Tetrahedra form a three-dimensional framework. Example: **quartz**, **feldspars**.
- **Examples**:
  - **Quartz** (SiO_2)
  - **Feldspar** (e.g., orthoclase, plagioclase)
  - **Mica** (e.g., biotite, muscovite)
  - **Olivine** (Mg_2SiO_4)

2. Oxide Minerals (O^{2-})

- **Description**: Oxide minerals are composed of oxygen bonded to metal cations. They tend to have high hardness and are often important ore minerals.
- **Examples**:
  - **Hematite** (Fe_2O_3) – an important iron ore.
  - **Magnetite** (Fe_3O_4) – an iron ore and magnetic mineral.
  - **Corundum** (Al_2O_3) – used as abrasives and gemstones (e.g., sapphire, ruby).
  - **Spinel** ($MgAl_2O_4$) – used in gemstones.

3. Sulfide Minerals (S^{2-})

- **Description**: Sulfides are minerals that contain sulfur in its most reduced form, typically bonded with metals. Sulfides are important ore minerals for many metals.
- **Examples**:
  - **Pyrite** (FeS_2) – "fool's gold," an iron sulfide.
  - **Galena** (PbS) – a lead sulfide, an important lead ore.
  - **Chalcopyrite** ($CuFeS_2$) – a copper-iron sulfide, an important copper ore.
  - **Sphalerite** (ZnS) – a zinc sulfide, the primary ore of zinc.

4. Carbonate Minerals (CO_3^{2-})

- **Description**: Carbonates are minerals that contain the carbonate ion (CO_3^{2-}) in combination with metal cations. They often form in sedimentary environments and can effervesce in the presence of acids.
- **Examples**:
  - **Calcite** ($CaCO_3$) – a major component of limestone and marble.
  - **Dolomite** ($CaMg(CO_3)_2$) – found in dolostone.
  - **Aragonite** ($CaCO_3$) – an alternative polymorph of calcite.

5. Sulfate Minerals (SO_4^{2-})

- **Description**: Sulfates are minerals that contain the sulfate ion (SO_4^{2-}) in combination with metal cations. These are often evaporite minerals, forming from the evaporation of water.
- **Examples**:
  - **Gypsum** ($CaSO_4 \cdot 2H_2O$) – used in plaster and drywall.
  - **Anhydrite** ($CaSO_4$) – similar to gypsum but lacks water molecules.
  - **Barite** ($BaSO_4$) – a heavy mineral used in drilling fluids.

6. Halide Minerals (Cl^-, F^-, Br^-, I^-)

- **Description**: Halides are minerals that contain halogen elements like chlorine, fluorine, bromine, or iodine. These minerals tend to be quite soluble in water.
- **Examples**:
  - **Halite** ($NaCl$) – common table salt.
  - **Fluorite** (CaF_2) – used as a flux in metal production.
  - **Sylvite** (KCl) – an important potassium ore.

7. Phosphate Minerals (PO_4^{3-})

- **Description**: Phosphates contain the phosphate ion (PO_4^{3-}) combined with metal cations. Phosphates are often associated with biological activity (e.g., bones, teeth) and are important for fertilizers.
- **Examples**:
    - **Apatite** ($Ca_5(PO_4)_3(F,Cl,OH)$) – the primary source of phosphorus in fertilizers.
    - **Turquoise** ($CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$) – a gemstone.

8. Native Elements

- **Description**: These are minerals that consist of a single element, without combining with other elements. They are often valuable for their rarity and metallic properties.
- **Examples**:
    - **Gold** (Au)
    - **Copper** (Cu)
    - **Diamond** (C)
    - **Graphite** (C)
    - **Sulfur** (S)

9. Hydroxide Minerals (OH^-)

- **Description**: Hydroxides are minerals that contain hydroxide ions (OH^-) in their structure. Many of these minerals form in weathering environments.
- **Examples**:
    - **Gibbsite** ($Al(OH)_3$) – a source of aluminum.
    - **Goethite** ($FeO(OH)$) – an iron oxide-hydroxide, a common weathering product.

10. Arsenate and Arsenite Minerals

- **Description**: These minerals contain arsenic combined with oxygen or sulfur. They are often found in areas with arsenic-rich mineralization.
- **Examples**:
    - **Realgar** (As_4S_4) – a bright red arsenic sulfide mineral.
    - **Scorodite** ($FeAsO_4 \cdot 2H_2O$) – an arsenate mineral.

27) Describe mineralogy and physical properties of Olivine, Quartz, Feldspar and Pyroxene group of minerals.

OLIVINE: It is a silicate of magnesium and iron found in basic igneous rocks such as dolerite, basalt and perodote. It is greenish and looks like quartz (Sp. Gr. = 3.2 to 4.3; H = 6 to 7).

Physical properties of olivine:

1. Crystal system -------------------------------- Orthorhombic
2. Colour -- Olive green
3. Streak -- Colorless
4. Luster --- Vitreous luster
5. Hardness -------------------------------------- 6.5 to 7
6. Cleavage -------------------------------------- absent
7. Sp. Gravity ------------------------------------ 3.2 to 4.3
8. Fracture -- Conchoidal
9. Twinning --------------------------------------- Rare.

QUARTZ: It is an important constituent of the granite and other acid igneous rocks, and a chief constituent of the sandstones where it occurs in the broken form (Sp. Gr. = 2.65; H = 7).

Physical properties of quartz:

1. Form: White quartz is a member of the hexagonal system. Tridymite belongs to Orthorhombic system and Cristobalite belongs to Isometric system.
2. Streak: White.
3. Luster: Vitreous to sub-vitreous.
4. Hardness: 7 (seven)
5. Cleavage: No cleavage (an important characteristic).
6. Sp. Gravity: Low, i.e., 2.65.

7. Twinning: (i) Common twins are Dauphine type, a penetration twin with the 'c' –axis as the twin axis.
(ii) Brazil type, A penetration twin with (1120) as the twin plane.

(i) Japanese law, Contact twins with (1122) as twin plane
8. Electric property: Quartz is piezo as well as pyro electric.
9. Colour : Quartz is colorless but the non-crystalline varieties are colored.

FELDSPARS: This is the most important group of the rock-forming silicates. They constitute about 2/3rd of the igneous rocks.

Physical properties of feldspars:

1. Crystal form: Orthoclase is monoclinil, Microline and other plagioclases are triclinic.
2. Color : Orthoclase is flesh red in colour. Microcline is green in colour and the colour of plagioclases ranges from white to gray.
3. Luster : Vitreous or pearly (play of colour is marked).
4. Cleavage : 2 sets – one parallel to (001) face and other to (010). The angle between the cleavages is 90° in case of orthoclase but less than 90° in other members.
5. Hardness : 6 (six)
6. Sp. Gravity : 2.5 to 3, according to calcium content.
7. Twinning : (a) (1) Carlsbad – 'c' axis is the twin axis and (010) the composition plane
   (2) Baveno : (021) is the twin plane.

   (3) Manebach : (001) is the twin plane.

   (b) Microcline :

   (1) Albite : Twin plane (001), twin axis perpendicular to this.

   (2) Pericline law : (010) composition plane, twin axis is the b-axis.

   (c) Plagioclases : They show all the above twinning types.

PYROXENE: These rocks forming silicates contain the Si_2O_6 single chain structure (inosilicates). These are anhydrous silicates of Mg and Fe and thus are predominantly found in ferro-magnesian rocks, in basic and ulrabasic rocks.

Physical properties of pyroxene:

1. Colour : Nearly black or green of various shades.
2. Lusture : Vitreous to subvitreous. Hypersthene shows a kind of metallic-pearly lusture termed Schillerisation.
3. Cleavage : 2 sets, prismatic at angles 87° and 93°.
4. Hardness : 5 to 6.
5. Sp. Gravity : Low to moderate.
6. Twinning : Contact twins in case of monoclinic members.