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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – I - GENERAL GEOLOGY-SCIA1305

SCOPE OF GEOLOGY IN CIVIL ENGINERRING

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

- Construction
- Water resources development
- Town and regional planning

GEOLOGY IN CONSTUCTION FIELD

PLANNING

Topographic maps

It's gives details of relief features and understands the relative merits and demerits of all the possible sides of proposed structure.

Hydrological maps

This map gives broad details about distribution and geometry of the surface of water channel. Geological maps. The petrological characters and structural disposition of rock types this gives an idea about the availability of materials for construction.

Design

- The geological characters that have a direct or indirect bearing upon the designed of proposed project are, The existence of hard rock beds. The mechanical properties (porosity, permeability, compressive strength, shear and traverse strength) Structural weakness (fault joints, folds, cleavage and lineation).
- The position of ground water table Seismic characters of area. Construction
- The geological knowledge is important for an engineer. The type of material for

construction is derived from natural bed rocks, soils, banks, coastal belts and seismic zones.

Geology in Water Resources Development

Exploration and water development of resources have become very important activity for scirntist, technology and engineers in all parts of world.

Geology in Town And Regional Planning

The regional town planner is responsible for adopting an integrated approach in all such Cases of allocation of land for developmental project.

BRANCHES OF GEOLOGY

- Physical Geology
- Geomorphology
- Petrology
- Mineralogy
- Economic Geology
- Mining Geology
- Paleontology
- Oceanography
- Geohydrology
- Engineering Geology
- Crystallography
- Geochemistry
- Geophysics

Physical Geology

It deals with the origin, development and ultimate fate of various surface features of the earth and also with its internal structure. The role played by internal agent (Volcanism and earthquakes) and external agent (Wind, Water and Ice) on the physical feature of the earth.

Geomorphology

This branch, although a part of physical geology, deal specifically with the study of surface feature of the earth primarily of the land surface.

Petrology

The general term for the study of rock in all their aspects are including their mineralogy, texture, structure, origins, field occurrence and their relationships to other rocks.

Mineralogy

The study of minerals is including their formation, occurrence, properties, composition and classification.

Economic Geology

Economic Geology deal with the study of those minerals, rock and fuels are occurring on and in the earth that can be exploited for the benefits of man.

Mining Geology

Mining Geology as applied to mining practice that is for the exploration and exploitation of economic minerals deposits.

Paleontology

It is deal with made of preservation of remains of plants and originals, in the form of fossil, within rock beds and theirs proper utilization in elucidating the geological history of the earth.

Oceanography

It is deal with exclusively the physical, structural, and other aspects of the extensive water bodies, the ocean, which cover about 70% of the surface area of the earth and that can be exploited for the benefit of mankind.

Geohydrology

It is an engineering science that has evolved out of interaction between hydrology and Geology. Its mainly study about the ground water and surface water bodies their occurrence and movement of through different type of rock

Engineering Geology

It is modern field of applied science that has developed due to interaction between the civil engineering practice and geology science. It is very vital role to play in the site, location, planning design, stable, various construction field and economic engineering project.

Crystallography

It is a well-established branch of mineralogy that deal with exclusively internal structure and external appearances of minerals occurring in crystallized form in the natural process.

Geochemistry

The subject of geochemistry involving geology and chemistry finds widespread application in the field of minerals investigation.

Geophysics

It is an engineering science that has evolved study of formation, Ore minerals, exploring the subsurface material through Geophysical survey and mathematical application

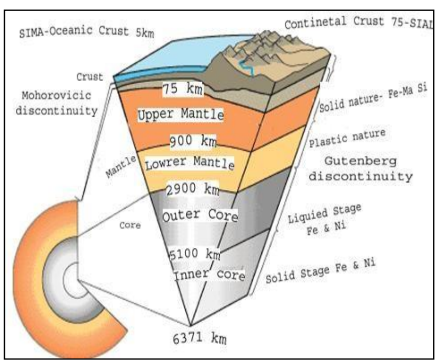


Figure No. 1.1

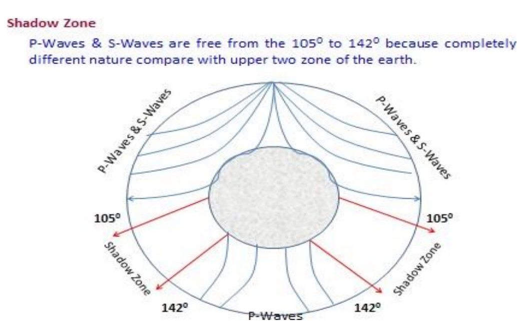


Figure No. 1.2

EARTH STRUCTURE AND COMPOSITION

Direct observation of earth is not possible due to fact that the interior became hotter. The deepest whole in the earth is only about 8km , this is quite negligible in comparison with radius of the earth The internal structures of earth is based on the existence yield at by indirect geophysical method (seismic method).The earth body comprises of several layers which are like shells resting one above the earth. The layers are distinguished by the physical and chemical properties. The interior of the earth has been obtain from the study of earthquakes waves through the earth.

There are three types of earthquake waves. They are

- P-waves/primary waves/longitudinal waves:
- The waves travel in solid, liquid and gaseous medium.
- They have short wavelength and frequency.

S-waves/secondary waves/transverse waves

These waves travel in solid medium. They have short wavelength and high frequency.

L-waves/surface waves/Rayleigh waves

These are transverse waves and confined to outer skin of crust. These waves responsible for most of the destructive course of earthquake.

The following information about the interior of the earth

The shell of the increasing density are found towards the centre of the earth is 80g/cc

Each shell is formed off different materials on the basics of seismic investigation the earth interior has been broadly divided into three major parts,

- CRUST
- MANTLE
- CORE

It inferred that

- The crust, mantle, core are separated by two sharp breaks known as major discontinuities.
- The crust is having an average thickness of about 33kms.
- The crust composed of heterogeneous materials.

- The mantle extends from below the crust to a depth of 2900kms
- The core extends from the below the mantle upto the centre of the earth is 6371kms

CRUST

- Upper most shell of the earth is crust. The thickness ranges from organic 60 to 70kms. Its thickness oceanic areas 5 to 10 km and in continental areas is 35km. it can be divided into two layers
- Upper layer (continental crust)
- Lower layer (oceanic crust)
- The Mohorovicic continuity marks the lower boundary. The boundary between SIAL and SIMA is called Conrad discontinuity,

SIAL

- Upper continental crust
- It consists of all types of rocks (Igneous, Sedimentary, Metamorphic rocks)
- This layer is rich in silica and aluminium
- The rocks are granitic and granodiotic composition
- The density of SIAL is 2.4g/cc
- The Conrad discontinuity which is located at the depth of 11km

SIMA

- Lower continental crust
- Thickness 23km extends from the Conrad discontinuity upto to Mohorovicic discontinuity
- This layer is rich in silica and magnesium
- The types of rocks are basalitic composition
- The density is 3g/cc

MANTLE

- The second part of the earth is the source region of the earth internal energy and of forces
- Responsible for ocean floor spreading and continental drift and earthquake.
- Its thickness is about 2865kms
- The mantle is denser than the overlying crustal rocks
- Depend on the velocity the mantle are classified into two

- ✓ Upper mantle
- ✓ Lower mantle

- The velocity of upper mantle is 11.32 to 11.4 km/s
- The velocity of the lower mantle is 13.4 km/s
- The lower mantle extends from 1000km to core boundary'
- The lithosphere which separated from mantle is called asthonosphere
- It is situated between 70 to 220 kms depth

CORE

- It extends upto the very centre of the earth
- S-Waves do not pass through the outer core
- No information about the inner core
- Pressure and temperature are very high
- The temperature is around 6000 and it is believed to contain nickel and iron(*NIFE*)

ATMOSPHERE

- It is the envelope of air which surrounds the earth
- Since the atmosphere is not of the density throughout and that atmosphere pressure
- decrease with height
- TOP POSITION OF ATMOSPHERE: (DRY AIR)
- Nitrogen - 78.03% by volume
- Oxygen -20.99%by volume
- Argon - 0.94%by volume
- Co2 - 0.03% by volume
- H2 - 0.01% by volume
- The above composition of the atmosphere is almost uniform upto a height of 80km from the surface

STRUCTURE OF ATMOSPHERE

- The atmosphere has been divided into several types based on change in composition. Change in temperature and degree of ionization.
- The atmosphere falls into five layers
    - ✓ Troposphere
    - ✓ Stratosphere

- ✓ Mesosphere
- ✓ Ionosphere
- ✓ Exosphere

TROPOSPHERE

- It is the lower most layer of the atmosphere
- Its height is about 12km from the surface
- It is dense of all layers
- It vital process create the climatic and weather condition of the earth surface

STRATOSPHERE

- The zone extends in form of the boundary of the troposphere
- Its height is about 55kms and temperature becomes constant upto 20kms height then it
- starts increasing
- The upper state is rich in ozone layer which serves has a shield protecting the troposphere
- and the earth surface by observing most of ultra-violet radiation
- The ozone layer is thicker important for the existence of life on the earth surface
- The water vapour content of this stratosphere is negligible

MESOSPHERE

- Above the stratosphere lies the mesosphere which is very cold region
- This layer extends upto 80kms from the surface of earth
- At a layer of about 60kms there occurs a layer called –radio waves observing layer‖

IONOSPHERE

- The ionosphere extends upto a height of 1000 to 2000 km from the earth surface
- The part of ionosphere lying between 80 to 800 km is called –Thermosphere‖
- In ionosphere almost all atoms are ionised
- This layer protects us from falling meteorites as it burns most of them

EXOSPHERE

- Above the ionosphere lies the exosphere
- It is the outermost zone of the atmosphere
- It is low density and high temperature region with minimum atomic collision
- Much about the exosphere is yet to be know

CONTINENTAL DRIFT

Continental drift is the movement of the Earth's continents relative to each other, thus appearing to "drift" across the ocean bed. The speculation that continents might have 'drifted' was first put forward by Abraham Ortelius in 1596. The concept was independently and more fully developed by Alfred Wegener in 1912, but his theory was rejected by some for lack of a mechanism (though this was supplied later by Arthur Holmes) and others because of prior theoretical commitments. The idea of continental drift has been subsumed by the theory of plate tectonics, which explains how the continents move.

Evidence of Continental Drift

Evidence for the movement of continents on tectonic plates is now extensive. Similar plant and animal fossils are found around the shores of different continents, suggesting that they were once joined. The fossils of Mesosaurus, a freshwater reptile rather like a small crocodile, found both in Brazil and South Africa, are one example; another is the discovery of fossils of the land reptile Lystrosaurus in rocks of the same age at locations in Africa, India, and Antarctica. There is also living evidence, the same animals being found on two continents. Some earthworm families (e.g. Ocnerodrilidae, Acanthodrilidae, Octochaetidae) are found in South America and Africa, for instance.

The complementary arrangement of the facing sides of South America and Africa is obvious, but is a temporary coincidence. In millions of years, slab pull and ridge-push, and other forces of tectonophysics, will further separate and rotate those two continents. It was this temporary feature which inspired Wegener to study what he defined as continental drift, although he did not live to see his hypothesis generally accepted.

Widespread distribution of Permo-Carboniferous glacial sediments in South America, Africa, Madagascar, Arabia, India, Antarctica and Australia was one of the major pieces of evidence for the theory of continental drift. The continuity of glaciers, inferred from oriented glacial striations and deposits called tillites, suggested the existence of the supercontinent of Gondwana, which became a central element of the concept of continental drift. Striations indicated glacial flow away from the equator and toward the poles, based on continents' current positions and orientations, and supported the idea that the southern continents had previously been in dramatically different locations, as well as being contiguous with each other.

Fit of the Continents

It was the amazingly good fit of the continents that first suggested the idea of continental drift. In the 1960's, it was recognized that the fit of the continents could be even further improved by fitting the continents at the edge of the continental slope the actual extent of the continental crust.

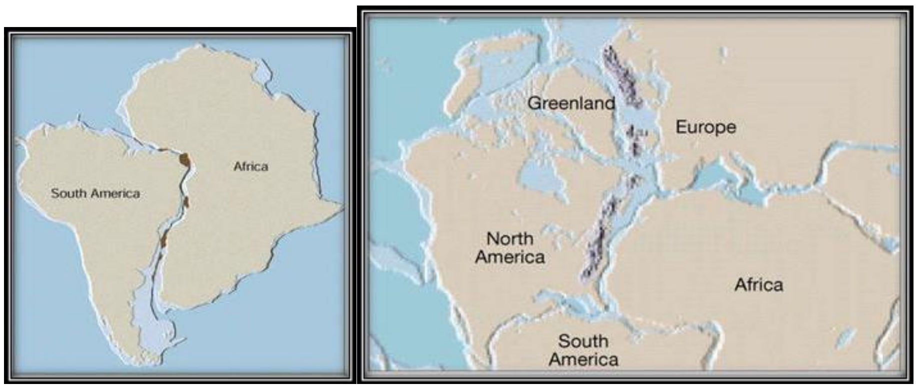


FIGURE NO. 1.3

Rock Type and Structural Similarities

When the continents are reassembled, the mountain chains from a continuous belt — having the same rock types, structures and rock ages.

WEATHERING - TYPES AND PRODUCTS

It is defined as the process of disintegration and decomposition of rocks under the influence are physical and chemical agencies of atmosphere

TYPES OF WEATHERING

- Physical weathering [temperature, wild]
- Chemical weathering [water]
- Biological weathering [vegetation and organism]

Physical weathering

Frost Action: When water is trapped in the rock like a pores, crack, fractures and cavities of rock. Repeatedly freezing and thawing over many years lead to gradual disintegration of the rock because of internal stress exerted in the process.

Thermal effect: In arid, desert and semi arid regions where summer and winter temperature differ considerably, rocks undergo physical disintegration by another phenomenon related to temperature. As we know, rocks, like many other solids, expand on heating and contract on cooling. Due to temperature variation the top layer of the rock get affected the influence of thermal effects in this phenomenon of pealing of layer from rock within in the chemical weathering is often termed as a exfoliation.

Unloading: It is decrease of pressure on the above rock surface due to removal of overlying material. Where prolonged erosional work of other agencies on the weakness rock and joints. Wetting and drying: Water penetrates into rock and reacts with their constituent minerals

Chemical weathering

Hydrolysis: Ions may be exchanged whereby some ions from water may enter into the crystal lattice of the mineral. This process of exchange ions is called hydrolysis.

Ex. $K + AL\ Si_3 O_8 + H^+$ --- $H\ AL\ Si_3O_8 + K^+$

(Orthoclase) + (Ion from water) Silicate acid like structure + (Pot, Ion)

Hydration: The ions to hold polarized side of the water molecule and from a hydrate. This process of addition of the water molecule is termed as hydration.

Ex. $Ca\ SO_4 + 2H_2O$ --- $Ca\ SO_4 2H_2O$

(Anhydrite) (water) (Gypsum)

Oxidation & Reduction: Iron is chief constituent of many minerals and rocks. The iron bearing minerals are especially prone to chemical weathering through the process of oxidation and reduction.

Oxidation: Ferrous iron (Fe^{++}) of the minerals is oxidized to ferric iron (Fe^{++}) on exposure to air rich in moisture. Ferric iron is not stable and is further oxidize to a stable ferric hydroxide.

Ex. $4Fe + 3O_2$ --- $2Fe_2O_3$, $Fe_2O_3 + H_2O$ --- $Fe_2O_3\ H_2O$

Reduction: In specific type of environment, such as where soil is rich in decaying vegetation, minerals and rocks containing iron oxide may undergo reduction of oxides to elemental iron.

Carbonation: It is the weathering of rock under the combined action of atmospheric carbon dioxide and moisture, which on combination form a mildly reacting carbonic acid. The acid formed exerts an especially corrosive action over number of silicate bearing rocks.

Ex. $Kal\ Si_3\ O_8 + 2H_2\ O + CO_2$ --- $AL_2\ Si_2O_5\ (OH)_4 + K_2\ CO_3 + 4SiO_2$

(Orthoclase) + (Carbonic acid) (Kaolinite) + (Pot. Corbonate) Silica

Solution: Some rocks contain one or more minerals that are soluble in water to some extent. Rock salt, Gypsum and calcite are few common examples. Pure water not good solvent of mineral in most cases. Lime stone is not solvable in pure water but carbonated water dissolves the rock effectively.

FACTOR AFFECTING WEATHERING

- Nature of rocks
- Climate prevailing in that area
- Physical environment
- Resistance of weathering

PRODUCTS OF WEATHERING

Regolith: Term used to express all the material eluvium and deluvium that covers a parent rock. It forms huge thickness in the suitable environment.

Eluvium: The end product that happened to lie over and above the parent rock.

Deluvium: End product that has been moved to some distance due to weathering processes.

Scree: The fragments accumulate in the mountain bottom of the region due to frost action on the slopes in the bottom deposit is called Scree deposits and the slope is called talus slope.

SOIL PROFILE

- Top layer (consists of loose particles)
- Second layer (not compacted much)
- Third layer (compact layer)
- Last layer (rocky)

Engineering Consideration of Weathering

- It is important to know about the depth and extent of weathering
- Scree
- The fragments that accumulate at the base of the heaps as commonly as scree deposits
- Talus Slope
- The fragments that remain uneven over the surface of the slope. Such slope is covered by
- the frost formed scree are often referred to as talus slope

GEOLOGICAL WORK OF RIVERS

METHODS OF RIVER EROSION

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

(a) Hydraulic Action

- ➢ It is the mechanical loosening and removal of the material from the rocks due to pressure exerted by the running water.
- ➢ The higher- the velocity, the greater is the pressure of the running water and hence greater is its capacity to bodily move out parts of the rock or grains of soil from the parent body occurring along its base or sides.

- Occurrence of planes of weakness in the rocks such as joints, fissures, cavities and cracks are especially helpful to the running water in carrying out hydraulic action.
- The river water flowing with sufficient velocity often develops force strong enough to disintegrate a loose rock, displace the fragments so created and lift them up and move forward as part of bed load.
- At places, where some of the out from the bedrock the river bed may develop potholes.

(b) Cavitations

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

(c) Abrasion

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

(d) Attrition

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

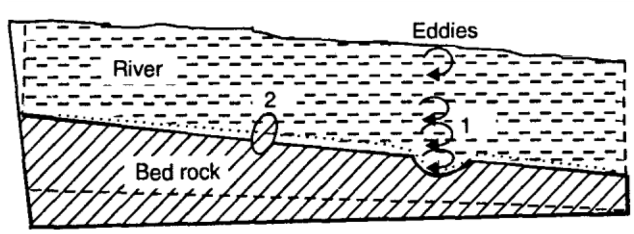
(e) Corrosion

- The slow but steady chemical (especially solvent) action of the stream water on the rocks is expressed by the term corrosion.
- The extent of corrosion depends much on the composition of rocks and also on the composition of flowing water.
- Limestones, gypsum and rock salt bodies are soluble in water to varying degrees. The stream may hardly corrode sandstones, quartzites, granites and gneisses

Features of Stream Erosion

1. Potholes

- These are variously shaped depressions of different dimensions that are developed in the riverbed by excessive localized erosion by the streams.
- The potholes are generally cylindrical or bowl shaped in outline and range from a few centimeters to many meters in diameter as well as in depth.
- The formation process for a pothole may be initiated by a simple plucking out of a protruding or outstanding rock projection at the riverbed by hydraulic action.
- This produces a small depression only at the place of plucking in the otherwise normal bedrock.
- Some of the depressions so initiated may eventually become the spots where pebbles and gravels of the stronger rocks are caught in eddies and thrown into a swirling or churning motion.



River Valleys FIGURE NO. 1.4

- A valley may be defined as a low land surrounded on sides by inclined hill slopes and mountains.

- Every major river is associated with a valley of its own. In fact, rivers are responsible for the origin, development and modification of their valleys through well- understood processes of river erosion.
- For instance, origin and deepening, lengthening and widening of river valleys are often explained as follows.

(a) Origin

- A river valley may have a modest origin when traced backwards in the geological history of the area.
- On a gently sloping land surface, rain-water gets collected along lower level and flows as small streamlets or rivulets.
- In a short time, small gullies are produced where rainwater gets naturally collected from the adjoining slopes. The gullies are, therefore, incipient valleys
- Further erosion deepens and widens an original gully that can accommodate bigger volumes of water and thus suffer greater erosion.
- In this way a small-scale gully may, with the passage of geological time, eventually grow into a large- scale feature of the same character and may be called a valley.

(b) Valley deepening

- It is achieved by cooperative action of all the processes involved in erosion: hydraulic action, abrasion and chemical action or corrosion.
- Deepening is obviously caused due to cutting down of the riverbed, which depends to a great extent on the velocity of stream and all the factors controlling the velocity.

(c) Lengthening of River Valley

- A peculiar type of is generally held responsible for lengthening of river valleys.
- In this process, the streams or rivers are more actively eroding in the higher up regions, close to their points of origin.
- Here each stream or river receives a number of tributaries having their origin in the areas away from the point of origin of the main stream.

River Capture (Piracy)

- A peculiar phenomenon of capture of drainage basin of one river by another river fast eroding its channel in headward direction has been seen at many places.
- In this case the divide between the two rivers say A and B gets eroded at a certain point to such an extent that finally part or whole of water of river B gets diverted to river A through a gap created at the divide by the river A.
- The process of river piracy is of considerable significance in the drainage basins of both the rivers in their geological work after the capture.

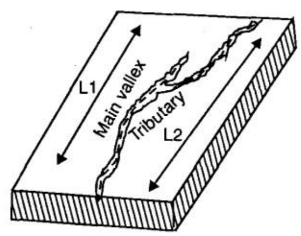


Fig 4.4 Valley Lengthening.
L_1 = Initial length;
L_2 = Length after tributary capture

FIGURE NO. 1.5

(d) Streams achieve valley widening

- The streams cut down their channels and also remove away the loose soil and rocks from the banks thereby widening the valley directly.
- This process cannot be expected to have widened their valleys to many times the width of the stream.
- As is known, once a small valley is created, the slopes of the valley are always exposed to the secondary processes such as weathering of all types, rain-wash, soil creep and landslides etc.
- The combined action of these secondary processes loosens the material from the slopes. This material is passed on to the river flowing down at the base of the valley that carries it away sooner or later.
- Thus, rivers contribute to valley widening by actively transporting whatever material is supplied to them from the valley slopes produced there through the processes of mass wasting.

Gorges and Canyons

- The process of valley deepening often gives rise to magnificent surface features known as gorges and canyons.
- Gorges are very deep and narrow valleys with very steep and high walls on either side. Their length varies considerably, from a few meters to several kilometers at a stretch.
- A canyon is a specific type of gorge where the layers cut down by a river are essentially stratified and horizontal in attitude

Valley Profile

- Rivers exhibit certain peculiarities about development of their valleys that are best understood with respect to their transverse and longitudinal profiles.

Transverse Profile

- In the mountainous and hilly tracts where a stream flows with very high velocity and where flow is often of turbulent character, the valley cross-sections at different places closely resemble to a V-shape.
- This may be attributed to down cutting of the river bed at a much faster rate compared to widening of the valley that is achieved mostly by secondary processes of mass wasting which operate comparatively at a slow rate.
- Theoretically this deepening process could continue till the base level of that river is achieved. Practically, however, most streams become sluggish much earlier due to reduction in slope channel.
- The V-shape of the river valley developed in the initial stages is subject to modification with the passage of time, especially on account of operation of valley widening processes.
- A mature river valley, therefore, may show good departure from the original V-shape. It may have a much wider base with very gentle slopes.
- Even this mature shape of the river valley may ultimately get worn-out after ages of geological work in the area to almost flat-banks in the old age of the river.

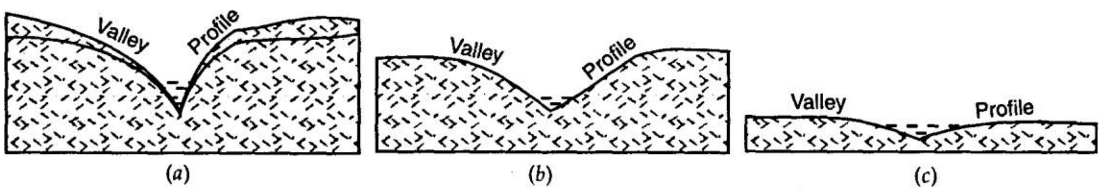


Fig. 4.7. Transverse Profile of a River Valley.
A = Mountainous tract; B = Semi Mountainous tract; C = Plain tract

FIGURE NO. 1.6

Longitudinal Profile

- It may be defined as a curve depicting the course of a stream from its head (place of origin) to its mouth (place of emptying into lake or sea).
- For a major river originating from back in the mountains and emptying into a sea, the longitudinal profile is a curve with a steep slope in the hills that gets reduced gradually to flattening lines for the plain region.
- For every stream, the main tendency is to achieve a straight longitudinal profile, as near as possible, to the base level of erosion.

(e) Escarpments

- These are erosional features produced by rivers in regions composed of alternating beds of hard and soft rocks.
- The river easily and quickly erodes the soft layers whereas the hard layers resist the erosion and stand projecting as ledges on the sides.
- These ledges are gradually undercut by continued stream erosion. A time comes when a given ledge is no longer able to support itself any further and hence falls down in the river giving rise to a steep slope in its place.
- It is this steep slope caused by falling of undercut ledge of hard rocks that is referred to as an Escarpment.

Dip Slope

- In some cases a stream may succeed in completely eroding the overlying softer rock, thereby fully exposing the underlying hard layer all along its dip (i.e. the angle of inclination of the layer with the horizontal).

- The resulting slope is the same as the dip of the layer and becomes in itself a typical erosional feature. It is called a dip slope.

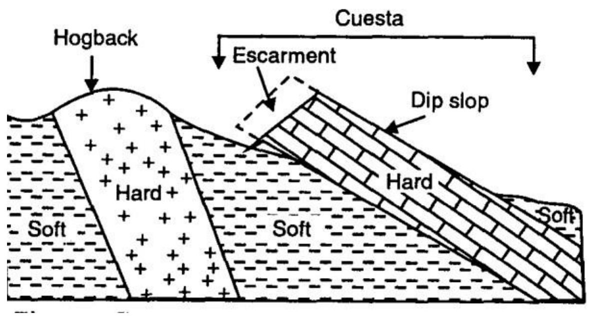
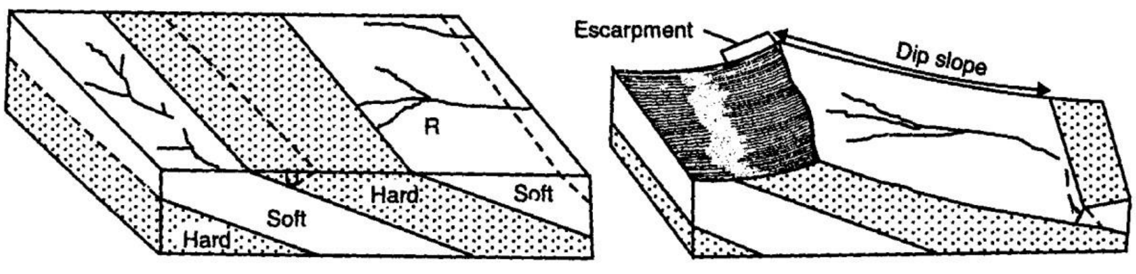


FIGURE NO. 1.7

CUESTA

- It is the term given to a combined set of escarpment and dip slope occurring adjacently in an area of escarpment topography.
- Obviously it results due to prolonged erosion of rocks forming the channel of a river and having been made of alternating hard and soft layers of rocks.



(*a*) Favourable conditions

(*b*) Escarpment and dipslope developed due to undercutting (*u*) and removal (*R*) of upper layer respectively.

FIGURE NO. 1.8

Hogback

- It is an erosional feature made by streams and is carved out from very steeply inclined rocks that have proved resistant to erosion.
- The hogback is a typically outstanding outcrop of hard rock having erosional slopes on either side.

Mesa and Butte

- These are erosional features made up essentially of horizontally layered rocks, having a cap of hard and resistant rocks that have escaped erosion.
- Large sized caps are called mesa whereas comparatively small sized and isolated patches are called butte or kopjees.
- These features (Mesa and Butte) result in areas of alternating hard and soft layers exposed to river erosion.

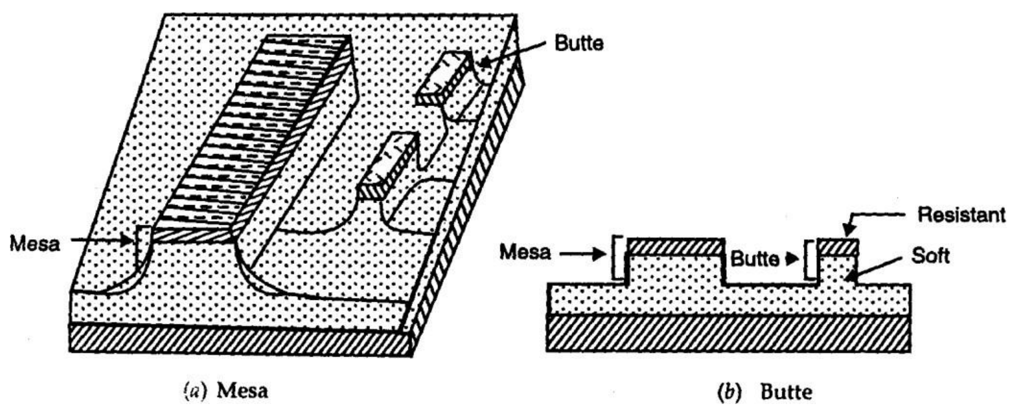


FIGURE NO. 1.9

Waterfalls

- These are defined as magnificent jumps made by stream or river water at certain specific parts of their course where there is a sudden and considerable drop in the gradient of the channel.
- In a waterfall, the stream literally falls (instead of flowing) from a considerable height before acquiring normal flow again at a lower level.
- Obviously, the velocity of water at the point of fall increases tremendously.
- Successive falls of smaller heights are sometimes referred as rapids and cascades.
- Many falls are easily attributed to unequal erosion of the channel rocks within a short distance due to the inherent nature of the rocks.
- Thus, as and where the river channel is made up of a width of rock of softer character intervening a rock of sound and strong character, the weaker rock will be eroded much faster, creating a depression just ahead of the resistant ledge.

- The water falling from the ledge gains in velocity thereby increasing the erosion of the softer bed below to still higher rates.
- Stream Terraces
- These are bench like ledges or flat surfaces that occur on the sides of many river valleys. From a distance, they may appear as succession of several steps of a big natural staircase rising up from the riverbank.
- They may be made up of hard rock or of soft rock, but the essential thing is that they look like steps.
- Some of them are clearly features of river erosion indicating that the stream has cut down its own channel not continuously but in a series of stages.

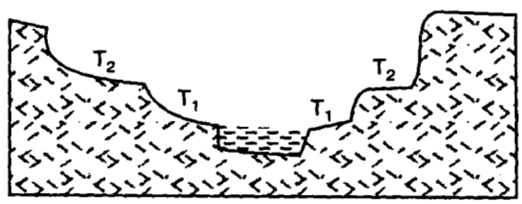


FIGURE NO. 1.10

SEDIMENT TRANSPORT BY RIVERS

Types of Load

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

The Suspended Load

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

The Bed Load

- This fraction of the river load comprises the heavier particles of sand, pebbles, gravels and cobbles and all the other type of materials, which are moved along the bed of a river in different ways.

- In this process, the current lifts up some of the load sediment or material resting on the riverbed temporarily as and when it gains some velocity (e.g. during rams) and carries the same to some distance before it again falls to a rest position.
- At the place of its fall, it (the sediment) may succeed in imparting an impact to another resting particle that may be in turn lifted up by the current for some distance.

The Dissolved Load

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

DEPOSITION BY RIVERS

The Process

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

Types of Fluvial Deposits

Following are some of the typical deposits mentioned only in outline.

Alluvial Fans and Cones.

- These are cone shaped accumulations of stream deposits that are commonly found at places where small intermittent streamlets coming down from bill slopes enter the low lands.
- Alluvial fans and cones show contrasting patterns in distribution of fragments and particles of various sizes at their apices, peripheries and in the main body.
- Further, repeated accumulations over an initial fan or cone contribute to its considerable growth upwards as well as laterally.
- Very often, the rivulet may cut out fresh channels within the existing cone or fan and deposit further load ahead of the previous deposit.
- This way the deposits grow considerably with time. Quite often some of these deposits stabilize and become locations of villages and cultivable areas.

Flood Plains

- Floodwaters are invariably heavily loaded with sediments of all types.
- When these waters overflow the river banks and spread as enormous sheets of water in the surrounding areas, their velocity soon gets checked everywhere due to inequalities of the ground, absence of a well defined channel and many other obstructions.
- As a consequence, they deposit most of the load as a thick layer of mud, so commonly seen after every major flood.
- Since such a process may get repeated after intervals, the low lying areas surrounding major rivers are actually made up of varying thickness of flood deposits.
- These are generally level or plain in nature and extensive in area; hence they are aptly called Flood Plains

Two major types of flood plains are recognized:

(a) Convex Flood Plains

- The surrounding areas are located at rather lower levels Compared with the river channel and hence give a convex shape to the deposit in a vertical cross section.

(b) The banks of the rivers are generally raised by natural levees and also have swamps in the immediate vicinity.

(c) Flat Flood Plains

- These flood plains appear mostly flat in cross section and are made up mostly of sand and silt sediments.

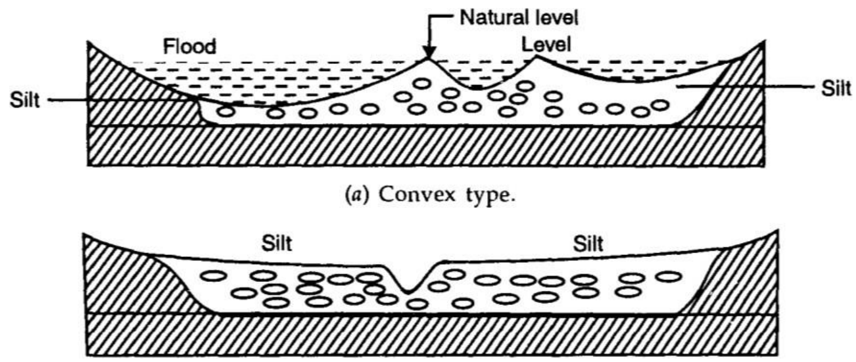


FIGURE NO. 1.11

Deltas

- Deltas are defined as alluvial deposits of roughly triangular shape that are deposited by major rivers at their mouths, i.e. where they enter a sea.
- Deltas are quite complex in their structure because of operation of a number of factors during their formation, evolution and modification with passage of time.

GEOLOGICAL WORK OF WIND

- Atmosphere is composed mainly of gases that are collectively known as air. Air in motion is called wind.
- In general it may be said that winds are born mainly due to non-uniform heating of the surface of the earth at different places causing differences in atmospheric pressure.
- The pressure difference so created makes the atmospheric gases (the air) to move from areas of high pressure to areas of low pressure in the form of winds.
- During such a movement, wind may create temporary or semi permanent changes on the land surface.
- These changes manifest themselves in the form of some surface features, their exact nature depending on wind volume, wind velocity, nature of the surface over which the wind

blows, duration of time for which it blows and so on.

- Thus, strong winds blowing over loose ground, dry soils or deserts may create many temporary new features within short span of time whereas very strong wind blowing over vast areas covered with dense vegetation may not affect the original topography at all for any length of time.
- Wind acts as agent of erosion, as a carrier for transporting particles and grains so eroded from one place and also for depositing huge quantities of such windblown material at different places.

Wind Erosion

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

(a) Deflation

- By itself, wind possesses not much erosive power over rocks or over the ground covered with vegetation.
- But when moving with sufficient velocity over dry and loose sands or bare ground over dust, it can remove or sweep away huge quantity of the loose material from the surface.
- This process of removal of particles of dust and sand by strong winds is called deflation. It is the main process of wind erosion in desert regions.
- In fact, in some deserts, deflation may cause the removal of sand from a particular location to such an extent that a big enough depression is created, sometimes with its base touching the water table at quite a depth.
- Such depressions are variously called blowouts when developed on a small scale and of shallower depth.
- Much deeper and extensive depression where the water table is intersected and it gets partially filled up with water is called an OASIS.

- Oases are the most sought after locations in deserts for more than one reason: it is only around them that some vegetation may grow and also they sustain temporary or semi permanent shelters.

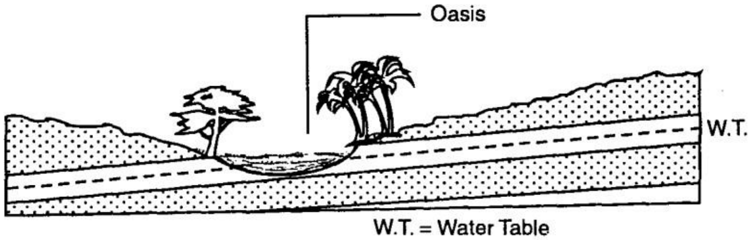


Fig. 3.5. Oasis

FIGURE NO. 1.12

- Slack is another term used for such depressions created by deflation.

  The Quattara depression of western Egypt is one of the biggest slacks. It is 300 km long and 150 km wide; its base is 130 m below sea level.

- Another feature produced due to deflation is called a Hamada.
- It is a bare rock surface in a desert from over which thin cover of sand has been blown away by strong winds.
- It is also called a desert pavement and may extend for considerable distance in a desert region.

OASIS

FIGURE NO. 1.13

SLACK

FIGURE NO. 1.14

QUATTARA in Western Egypt

FIGURE NO 1.15

(b) Wind Abrasion

- Wind becomes a powerful agent for rubbing and abrading the rock surfaces when naturally loaded with sand and dust particles.
- This load is acquired by the strong winds quite easily when blowing over sand dunes in deserts and over the dry ploughed fields.

- This type of erosion involving rubbing, grinding, abrading and polishing the rock surfaces by any natural agent (wind, water or ice) with the help of its load while passing over the rocks is termed as abrasion.
- Yardangs these are elongated, low-lying ridges forming overhangs above local depressions.
- Yardangs are formed in areas where rocks of alternate hard and soft character are laying one above another with a general gentle slope.

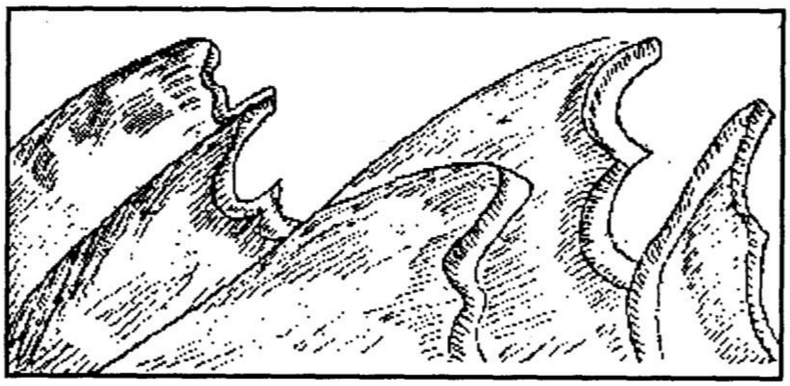


FIGURE NO 1.16

ABRASION

During dust storms the wind carries minute grains of sand in suspension.

They dash and collide against the exposed rock masses and cause erosion.

This process in which sand grains are used as tools for eroding rocks is called abrasion. This type of erosion involves the following,

Rubbing

Grinding

Abrading

Polishing

Wind abrasion is crated numerous feature of erosion on the earth surface particularly arid region. Such as a YARDANS, PEDESTAL ROCKS. VENTIFACTS and DESERT PAVEMENTS

YARDANS P
FIGURE NO 1.17

EDESTAL ROCKS
FIGURE NO 1.18

DESERT PAVEMENTS
FIGURE NO 1.19

VENTIFACTS
FIGURE NO 1.20

YARDANS

These are elongated, low-lying ridges forming overhangs above local depressions. It is trend is parallel to the direction of prevailing winds. Generally Yardans is formed group and its only occurred alternative of hard and soft rock region with dry condition. Shape of the Yardans is gentle slope one over lying by another Yardans and quickly eroded soft rock area due repeated by wind action.

VENTIFACTS

These are small sized rock fragments have one, two or three or more sides typically wind- polished surface called faces. The polishing of different sides of originally rough fragments is caused by prolonged wind erosion, face after face. After one face gets polished, partly or completely, a second face is made available for wind due to overturning of the fragment during strong gushes of wind. This process might repeat over and over again developing multifaceted fragments. These winds polished and facetted rock fragments are called ventifacts. Although two to three polished faces are quite common, ventifacts with up to eight polished faces have been observed.

DESERT PAVEMENTS

These are flat rock surface covered by rounded or sub rounded pebbles spread all over them, and are typical feature of rock deserts. Initially these rock surfaces are covered with fine particles of clay, silt and sand that have been removed by wind action. The concentration of pebbles over the surface is a particularly distinguishing features of desert pavements. These pebbles may get further polished with time and even acquire thin film of oxides of iron and manganese. This oxide film is particularly referred as desert varnish. Such coated pebbles give a characteristic brown, dark red or even black appearance to the desert pavements.

PEDESTAL ROCKS

It is another name is called Mushroom rock. Its formed due to in current of wind with loaded sand, most of the sand particles are carried along in the lower layer of wind, generally within the height 2 meters from the surface because of the density. So only the bottom of the rock quickly and easily eroded then top of the rock.

WIND TRANSPORT

Turbulent wind can easily sweep small dust particles and carry them greater distance in suspension.

However sands are transported in a series of jumps and roll along the ground such process are called saltation.

Attrition by wind

The sand grins and other particles lifted by the wind from different place are carried away to considerable distances. During this journey, the particles are not moved in straight lines for the simple reason all particle not same weight and wind velocity also varies from base to the top of the current. The grains are moved zigzag fashion, colliding with one another again and again. These repeated collusions cause lot of mutual rubbing and due to impact. It is termed attrition and is primarily responsible for reduction in size of the load particles during their transport.

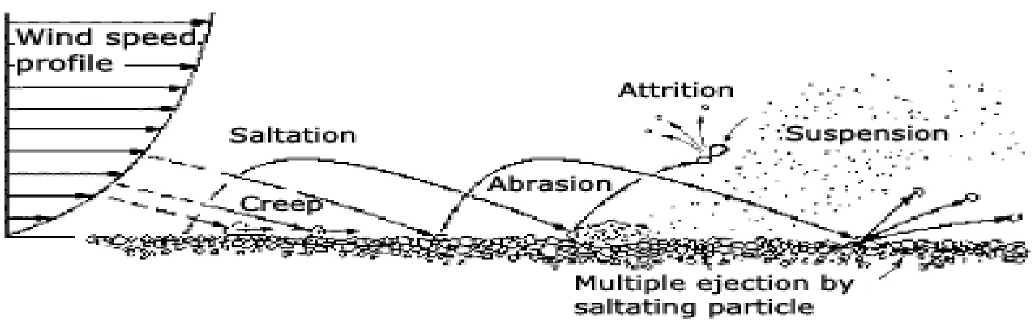
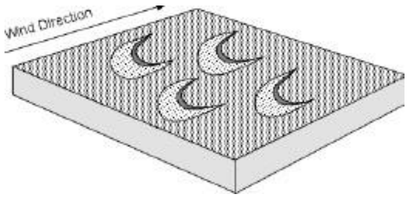


FIGURE NO 1.21

WIND DEPOSITION

Barchan Dunes - crescent-shaped dunes with the points of the crescents pointing in the downwind direction, and a curved slip face on the downwind side of the dune. They form in areas where there is a hard ground surface, a moderate supply of sand, and a constant wind direction.



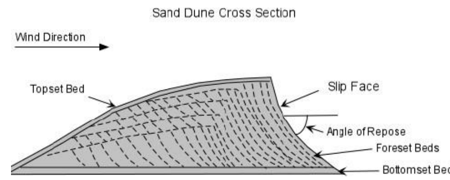


FIGURE NO 1.22

Transverse Dunes - large fields of dunes that resemble sand ripples on a large scale. They consist of ridges of sand with a steep face in the downwind side, and form in areas where there is abundant supply of sand and a constant wind direction.

FIGURE NO 1.23

Linear Dunes - long straight dunes that form in areas with a limited sand supply and converging wind directions.

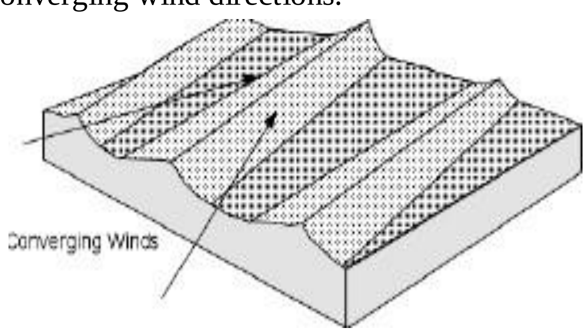


FIGURE NO 1.24

Parabolic (also called blowout) Dunes - "U" shaped dunes with an open end facing upwind. They are usually stabilized by vegetation, and occur where there is abundant vegetation, a constant wind direction, and an abundant sand supply. They are common in coastal areas.

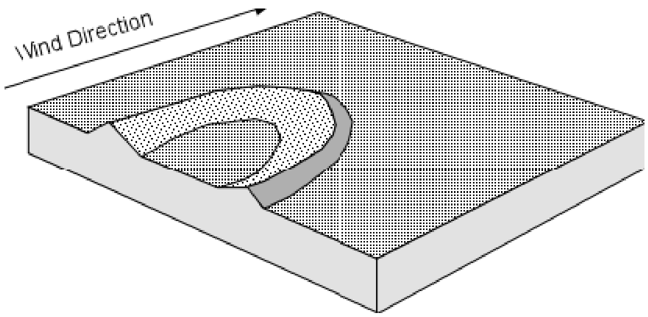


FIGURE NO 1.25

Star Dunes - are dunes with several arms and variable slip face directions that form in areas where there is abundant sand and variable wind directions.

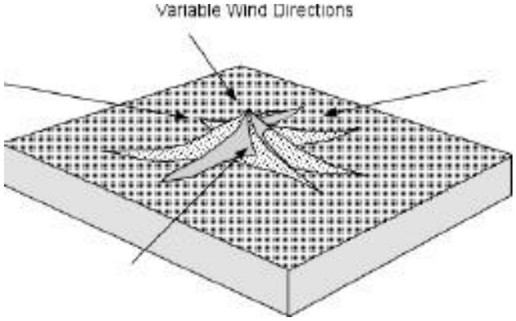


FIGURE NO 1.26

Loess is a clastic, predominantly silt-sized sediment, which is formed by the accumulation of wind-blown dust. Loess is an Aeolian sediment formed by the accumulation of wind-blown silt, typically in the 20–50 micrometer size range, twenty percent or less clay and the balance equal parts sand and silt that are loosely cemented by calcium carbonate. It is usually homogeneous and highly porous and is traversed by vertical capillaries that permit the sediment to fracture and form vertical bluffs.

FIGURE NO 1.27

GEOLOGICAL WORK OF SEA

A sea is an broadly developed continuous body of salt water having extension or embayment. Depth of sea is generally less than 4 km. large water body very wider than sea is called Ocean, it is greater than 4 km depth. The following are familiar Sea the Arabian Sea, The Mediterranean Sea and Red Sea. Few inland large water body actually lake but are called seas because of their size, some example Caspian Sea and the Red Sea. Over size of the water body are called Ocean. The Pacific Ocean, the Atlantic Ocean, the Indian Ocean, the Artic Ocean and the Antarctic Ocean.

- ✓ Continental shelf is the gradually slanting land part that remain partly submerged under the Sea water. It is narrow stretching for hundred of kilometers.
- ✓ Continental slope is beginning from the end of the continental shelf . It is continuous up to sea floor and its steep slope.
- ✓ A Continental rise is a slightly elevated region with in the continental slope.
- ✓ Oceanic rise is also elevated region within the Ocean floor.
- ✓ Mid-Oceanic ridges is continuous and extensively developed submarine mountain. Ex Atlantic and Indian Ocean have a Mid-Oceanic ridges.
- ✓ Marian water is spread over more than two-third of the Earths, surface and is classed among the most powerful geological agents operating on the earth.

- ✓ Sea water acts an agent of erosion, transportation and deposition.
- ✓ All the geological work performed by the marine waters is due to regular and irregular disturbances taking place in the body of water, mostly in its surface layers and distinguished as waves and currents.

The Sea Waves

These may be described as undulatory disturbance on the surface of the seawater due to strong rushing wind, earthquakes, attraction of sea water by the sun and the moon. Two Principal types of sea waves distinguished on the basis of shape of orbit are Oscillatory and Translatory waves.

Oscillatory waves

These are characteristic of deeper portion of the sea. In such waves, each particle moves in a circular orbit. In shallow depths, the particles find it impossible to describe a perfectly circular motion.

Translatory waves

These are typically of shallower depth in the sea and abound along the seashore. They are commonly produced after the oscillatory waves break and rush forward. In these waves, the water particles are actually moved or translated forward, rising and falling again and again.

Currents

These are layers of the sea water that are actually pushed forward in any particular direction. In most case, sea currents are the results of dissipation of extra volume of water thrust on the shore by advancing wanes. Following are two type of currents are more important in the geological work of the Sea. Littoral Currents and Rip Currents.

Littoral Currents

These are bodies of sea water of considerable volume moving along and parallel to

the shore. Rip Currents

These are bodies of sea water moving backward to sea after having reached and struck the seashore.

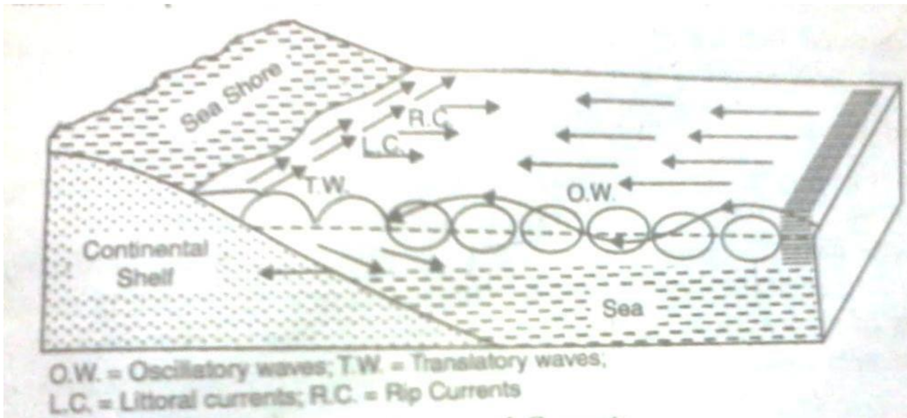


FIGURE NO 1.28

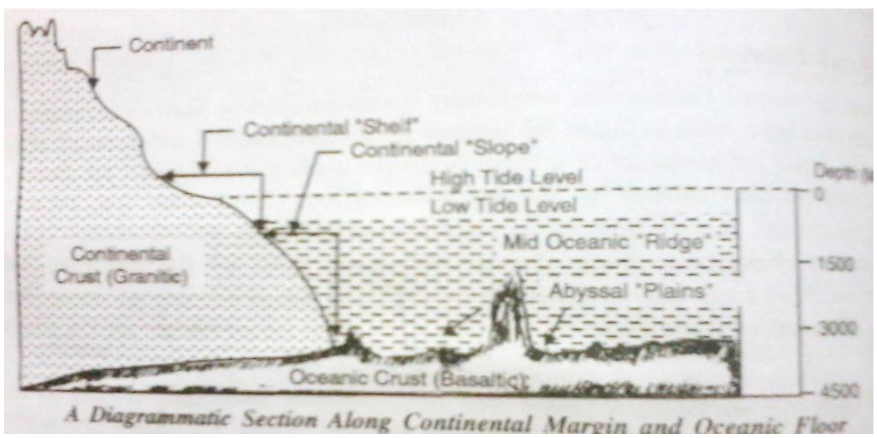


FIGURE NO 1.29

The work of erosion is accomplished in three ways: Hydraulic action, abrasion and corrosion.

Hydraulic Action

This is the process of erosion by water involving breaking, loosening and removing out of rock from their original place by the strong forces created by the impact of the sea wave and currents.

Marine Abrasion

The involving rubbing and grinding action of sea water on the rock of the shore with help of sand particles and other small fragments that are hurled up again and again against these rocks. This process gradually leads to smoothing of irregularities of the shore rock and its developed of many erosional features such as a Headlands, Bays, Sea Cliffs and wave-cut terraces.

Corrosion

It is solvent action of sea water, which particularly strong in environments where the shore rock is of a vulnerable chemical composition.

Erosional Features

Headlands

In an originally uniform sloping shoreline composed of soft and hard rock materials. Sea water enter the inland space so created along the shore. These form the Bays. The stronger rocks, however, resist erosion to a great extent and stand outstanding for considerable time. These may get smoothed and variously modified but still stand as projecting parts of original shoreline as headlands. In this manner an originally unbroken or continuous shoreline is dissected into the bays and headlands. It is a typical seashore morphology.

Sea Cliffs

A Sea cliff is a seaward facing steep front of a moderately high shoreline and indicates the first stage of the work of waves on the shore rocks. There may be a number of sea cliffs seen on a shoreline. They are outstanding rock projections having been smoothened here and plucked there, pitted at one place and polished at another spot by a combined action of waves and currents. Their basal regions are especially prone to undercutting by the wave action. These cliffs may ultimately be worn down due to continued undercutting. The shoreline is then reduced to a smooth, free from irregularities, seaward sloping surface.

Wave-cut Terraces

A wave-cut terrace is a shallow shelf type structure, carved out from the shore rocks by the advancing sea waves. The waves first of all cut a notch where they strike against the cliff rock again and again. The notch is gradually extended backwards to such a depth below the overlying rock that the latter becomes unsupported from below. The cliff eventually falls down along the notch. A platform of bench is thus created over which the seawater may rush temporarily and periodically. The resulting structure is often called a wave-cut terrace, a platform or simply a bench.

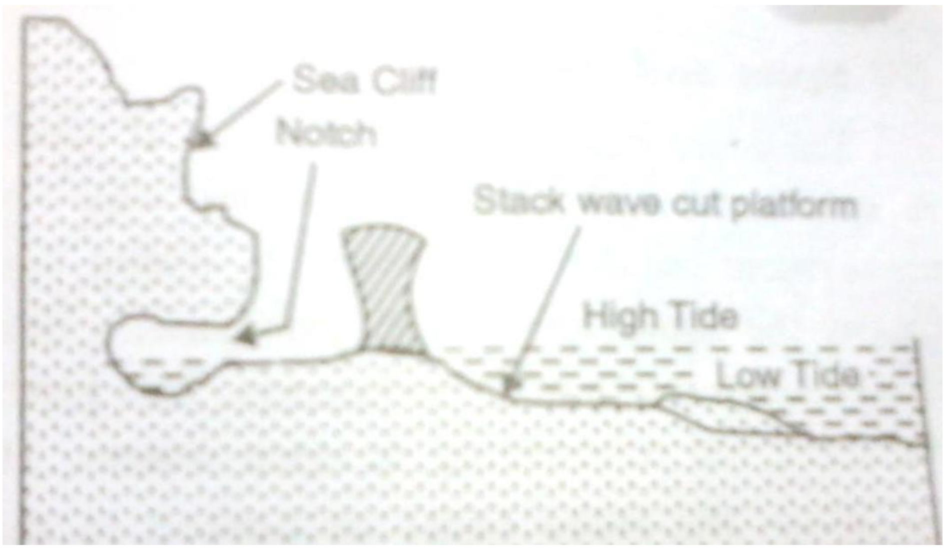


FIGURE NO 1.30

Depositional

Feature

Beaches

These are loose deposits made by the sea near the shore from the material eroded from nearby Regions. The lower margin of a beach is commonly beneath the waves whereas the upper margin is a few meters above the still water. Waves and currents play a great part in the formation of a beach.

Streams entering the sea generally drop their load at some distance from the shore into the sea. Apart of the sea sediments is brought back to the shore by the advancing waves the that deposit them their due to a check in velocity. Because formation is very much favored when the continental as a gentle slow.

Barrier beaches may be formed parallel to and some distance from the shore due to gradual removal of material from shore towards the sea by under current. The material may be accumulate from the distance from the shore where the current weakness and dies and give rise to the beach.

Tombola

it is a form of war that connect an head land and Island or one with another Island. Tombola is developed in some way as a spit or a bar, which is by the deposition of materials carried away by current to deep water along the shore.

Spit and Bar

These are ridge shaped deposit of sand and single that often extend across the embayment. As spit is formed somewhat in this way when a sediment laden shore current comes near on embayment on the coast. There is strong tendency for it to keep it normal coast rather then to follow the shore line of the embayment it moves through deeper and quieter water were it lays down much of its sediments this process may result in an incomplete reach in continuity with the shore terminating in open water this is the spit.

When the ridge were formed in the above manner close the mouth of the embayment completely it is known as the bar

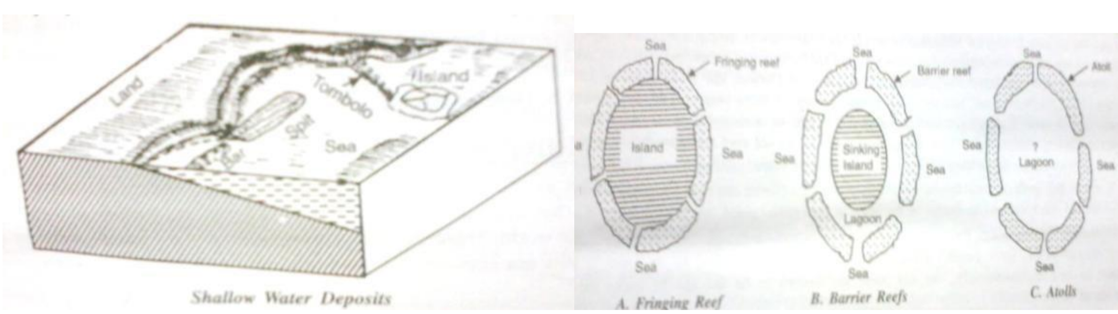


FIGURE NO 1.31

Geophysical Methods for Subsurface Investigation Seismic and Electrical Methods

- ✓ Geophysical Methods and its Application
- ✓ In geophysical prospecting certain physical properties of the underground rocks are
- ✓ measured from surface
- ✓ The properties are density magnetism electrical conductivity and elastity
- ✓ The measured data are then interrupted to give information about the presence of ore
- ✓ bodies buried anticlines, faults, igneous intrusions and other geological structure
- ✓ The main geophysical prospecting methods
- ✓ Gravity methods
- ✓ Magnetic method
- ✓ Electrical method
- ✓ Seismic method
- ✓ Radioactive method
- ✓ Electrical Method:

It is used mainly for exploration of metallic mineral deposits. There are four typs

- ✓ Self potential method
- ✓ Equi potential methods
- ✓ Electromagnetic method
- ✓ Resistivity method

Electrical Resistivity

- ✓ It is used to measure the fluid content and porosity of rocks.
- ✓ It help in making distinguished between saturated and unsaturated rocks

Wenner Method

- ✓ In resistivity surveying various electrode arrangement in show by wenner widely used,
- ✓ spacing between electrode are kept equal. The spacing is designated ad –dǁ.
- ✓ The current introduced into the ground by two currents electrodes C1 and C2. The potential difference between the inner electrode P1 and P2 is measured
- ✓ The entire four electrodes are place in lines

Uses of Resistivity Method

Resistivity survey is very effective in investigation of horizontal or gently dipping rocks these are used in detecting following

- ✓ The thickness of overburden or depth to bed rocks is determined
- ✓ It have been used in the exploration of glacier deposit and bedded deposit
- ✓ Exploration of ground water , pressure of aquifers can be determined
- ✓ Fault zone may be determined as they contain electrolyte in solution
- ✓ Discovering the sub surface structure and lithology. Buried anticline can be traced by determine depths to strata of greater or lesser resistivity used in exploration of petroleum.

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UNIT – II – MINEROLOGY - SCIA1305

PHYSICAL PROPERTIES OF MINERALS

MINEROLOGY

- Mineralogy is that branch of geology which deals with various aspects related to minerals such as their individual properties, their mode of formation and mode of occurrence.

(1) <u>COLOUR</u>

- The colour of any object is a light dependent property: it is the appearance of the particular object in light (darkness destroys colour).

On the basis of colour, a mineral may belong to any one of the three types:

- **Idiochromatic** having a characteristic, fairly constant colour related primarily to the composition of mineral. **Metallic minerals (e.g. of copper group) belong to this category.**
- **Allochromatic** having a variable colour; the variety colour is generally due to minute quantities of colouring impurities thoroughly dispersed in the mineral composition. **non-metallic minerals like quartz, calcite, fluorite and tourmaline etc.**
- **Pseudochromatic** showing a false colour. Such an effect generally happens when a mineral is rotated in hand; it is then seen to show a set of colours in succession..

Some of the peculiar phenomena connected with colour in minerals are briefly explained below.

<u>Play of Colours</u>

- It is the development of a series of prismatic colours shown by some minerals on turning about light.
- The colours change in rapid succession on rotation and their effect is quite brilliant and appealing to the eye.
- These are caused by the interference of light reflected from numerous cleavage

surfaces of the mineral. Example: diamond.

Change of Colours.

- It is similar to play of colours except that the rate of change of colours on rotation and their intensity is rather low. Example: labradorite.

Iridescence

- Some minerals show rainbow colours (similar to those appearing in drops of oil spilled over water) either in their interior or on the exterior surface. This is called iridescence.

Tarnish

- This may be described as a phenomenon of change of original colours of a mineral to some secondary colours at its surface due to its oxidation at the surface. Example: Bornite and Chalcopyrite.

(2) LUSTRE

- It is the shine of a mineral. Technically speaking, it is intensity of reflection of light from the mineral surface and depends at least on three factors:

(1) The refractive index of the mineral.

(2) The absorption (of light) capacity of the mineral.

(3) The nature of reflecting surface.

Classification of lustures

Metallic lusture

- Metallic lusture are characteristic of high density, high refractive index and opaque minerals like galena, pyrite and chalcopyrite.

Non-Metallic Luster

- The reflection may vary from very brilliant shine as that of diamonds to very feeble greasy luster of olivine and nepheline.

Streak

- It is an important and diagnostic property of many colored minerals. Simply defined, streak is the colour of the finely powdered mineral as obtained by scratching or rubbing the mineral over a rough unglazed porcelain plate.
- Colourless and transparent minerals will always give a colourless streak that has no significance.

(3) HARDNESS

- Hardness may be defined as the resistance, which a mineral offers to an external deformation action such as scratching, abrasion, rubbing or indentation. Hardness of a mineral depends on its chemical composition and atomic constitution.

F.Mohs proposed a relative, broadly quantitative **"scale of hardness‖** of minerals assigning values between 1 and 10.

(4) CLEAVAGE

- It is defined as the tendency of a crystallized mineral to break along certain definite directions yielding mote or less smooth, plane surfaces. mineral.
- A mineral may have cleavage in one, two or three directions.
- Since cleavage directions are always parallel to certain crystal faces in a mineral, these may be described as such.
- For instance, cubic cleavage (galena and haylite), rhombohedral cleavage (calcite) and prismatic cleavage, basal cleavage and octahedral cleavage.

(5) PARTING

- It is a property of minerals by virtue of which it can split easily along certain secondary planes.
- Parting is actually due to the presence of secondary twin-planes and gliding planes along which the mineral may split easily.

- Parting is attributed to the presence of a substance of different composition along the parting planes or to the stresses that might have operated during or after the formation of the particular crystals. Ex: cordonum

(6) FRACTURE

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

Common types of fractures are:

Even When the broken surface is smooth and flat. Example: chert.

Uneven When the mineral breaks with an irregular surface which is full of minute ridges and depressions. It is a common fracture of many minerals. Example: Fluorite.

Conchoidal The broken surface of the mineral shows broadly concentric rings or concavities which may be deep or faint in outline. In the latter case, the fracture may be termed as subconchoidal. Example: Quartz.

Splintry When the mineral breaks with a rough woody fracture resulting in rough projection at the surface. Example: kyanite.

Hackly The broken surface is highly irregular with numerous sharp, fine, pinching projections. Example: Native Copper.

Earthy. The surface is smooth, soft and porous. Example Chalk.

(7) TENACITY

- The behaviour of a mineral towards the forces that tend to break, bend, cut or crush it is described by the term tenacity.
- **Sectile** When a mineral can be cut with a knife, it is described as sectile.
- **Malleable** If the slices cut out of it can be flattened under a hammer, it is said to be malleable.
- **Brittleness** Most minerals exhibit the property of brittleness, by virtue of which they change into fine grains or powder when scratched with a knife or when brought wider the hammer.

- **Flexible** A mineral is said to be flexible when it can be bent, especially in thin sheets. Chlorites are flexible.
- **Elastic** Some minerals are not only flexible but elastic, that is, they regain their shape when the force applied on them is removed. Micas are best example. The flexible and elastic fibres of asbestos can be woven into fire-proof fabric.

As such, in terms of tenacity mineral may be sectile, brittle, flexible, plastic and elastic, the last two qualities being of diagnostic importance.

(8) <u>STRUCTURE</u> (Form)

- The physical make up of a mineral is expressed by the term structure and is often helpful in identifying a particular mineral.

Following are a few common structural forms (habits) observed in minerals

<u>Tabular</u> The mineral occurs in the form of a flattened, square, rectangular or rhombohedral shape. In other words, flattening is conspicuous compared to lengthwise elongation. Examples: Calcite, orthoclase, barite etc.

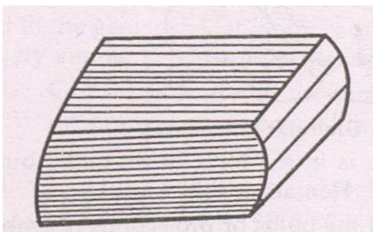


FIGURE NO. 2.1

<u>Elongated</u> When the mineral is in the form of a thin or thick elongated, column-like crystals. Examples: Beryl, quartz, hornblende.

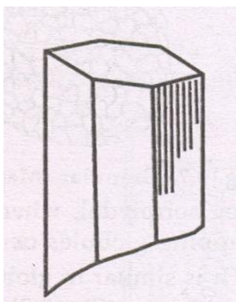


FIGURE NO. 2.2

<u>Bladed</u> The mineral appears as if composed of thin, flat, blade-like overlapping a parts. Example: Kyanite.

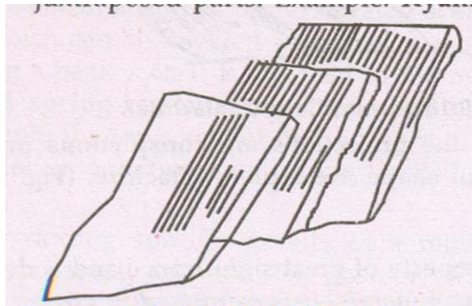


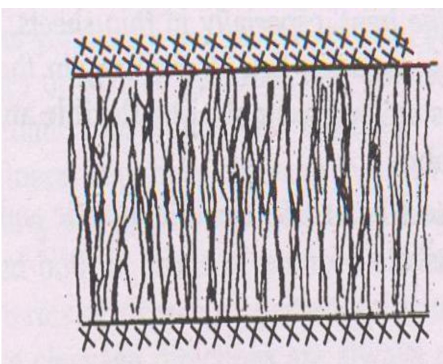
FIGURE NO. 2.3

Lamellar. The mineral is made up of relatively thick, flexible, leaf-like sheets. Example: Vermiculite.

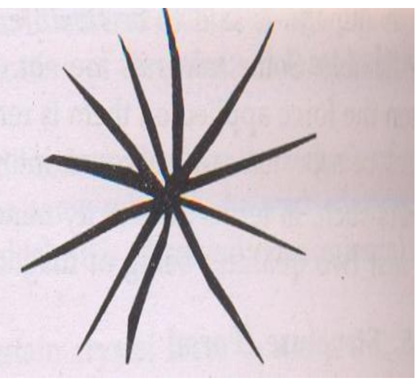
Foliated. The structure is similar to lamellar in broader sense but in this case the individual sheets are paper thin, even thinner and can be easily separated. Example:

Muscovite (mica)

Fibrous. When the mineral is composed of fibres, generally separable, either quite easily (example: asbestos) or with some difficulty (example: gypsum)



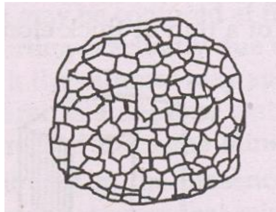
FIBROUS
FIGURE NO. 2.4

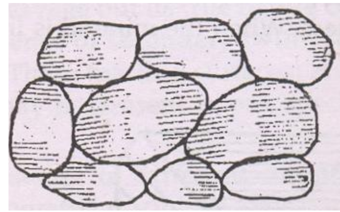


RADIATING
FIGURE NO. 2.5

Radiating. The mineral is made up of needle like or fibrous crystals which appear originating from a common point thereby giving a radiating appearance. Example:Iron pyrites

Granular The mineral occurs in the form of densely packed mass of small grain-like crystals. Example: Chromite



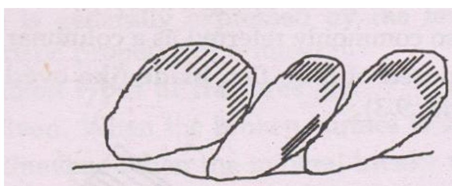


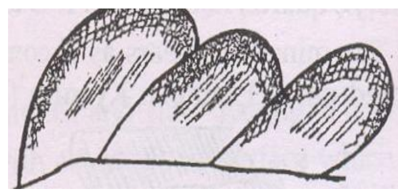
GRANULAR
FIGURE NO. 2.6

GLOBULAR
FIGURE NO. 2.7

Globular or botroiydal, when the mineral surface is in the form of rounded, bulb- like overlapping globules or projections. Example: Hematite

Reniform. It is similar to globular but the shape of the bulbs or projections resembles to human kidneys. Example: Hematite.





RENIFORM (HEMATITE)

FIGURE NO. 2.8

MAMMILLARY (MALACHITE).

FIGURE NO. 2.9

Mammillary. It is similar to globular but the projections are conspicuous in size, overlapping in arrangement and rounded in shape. Example: Malachite.

Specific Gravity

In mineralogy, the term specific gravity is used more frequently than density and signifies ―the ratio between the density of a mineral and that of water at 40 Celsius‖. Since it is a ratio it has nounits. Specific gravity of quartz is, for instance, 2.65. The specific gravity is also termed relative density.

STUDY OF FOLLOWING ROCK FORMING MINERALS

QUARTZ

Definition

- Sandstones are mechanically formed sedimentary rocks of Arenaceous Group.
- These are mostly composed of sand grade particles that have been compacted and consolidated together in the form of beds in basins of sedimentation.
- The component grains of sandstones generally range in size between 2mm and 1/16 mm. Silica in the form of very resistant mineral QUARTZ is the dominant mineral constituent of most sandstones.

Composition

- Some varieties of sandstone are made up entirely of quartz.
- Besides quartz, minerals like felspars, micas, garnet and magnetite may also be found in small proportions in many sandstones.
- In some sand stones the component grains may be cemented together by a cementing material that may be siliceous, calcareous, argillaceous or ferruginous in composition.
- In other sandstones, the component minerals may be welded together by natural pressures from overlying sediments

Texture

- Sandstones are, in general, medium to fine-grained in texture.
- The component grains show a great variation in their size, shape and arrangement in different varieties.
- Thus, when the texture is determined on the basis of the grade of the component grains, three types are recognized:
- The individual grains may be round or angular in outline, loosely packed or densely packed and in simple or interlocking arrangement.
- The shape and mutual arrangement of the component grains, or the texture, is greatly responsible for the engineering and other properties of sandstone.
- In fact, the properties of porosity and permeability of these rocks are the critical parameters that make them useful or useless in different situations.

Colour

- Sandstones naturally occur in a variety of colours: red, brown, grey and white being the most common colours.
- The colour of sandstone depends on its composition, especially nature of the cementing material.

Types

Siliceous Sandstones

- Silica (Si0) is the cementing material in these sandstones.
- The quality of the siliceous cement is so dense and uniform that a massive compact and homogeneous rock is formed.
- This is named QUARTZITE.
- This type of sedimentary quartzite, when subjected to loading fractures across the grains showing clearly very Constituent silica of the rock.

Calcareous Sandstones

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

Argillaceous Sandstones

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

Ferruginous Sandstones

As the name indicates, the cementing material is an iron oxide compound.

On the basis of mineralogical composition, following types of sandstones are commonly recognized:

Arkose

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

Greywacke

- These are broadly defined as grey coloured sandstones having a complex mineralogical composition.
- They contain a fine-grained matrix. In this matrix, grains of quartz and some felspars are found embedded side by side with fragments of rocks like felsites, granites, shales etc.
- The exact composition of the matrix is so complex that it may not be easily determined in most cases.
- The minerals and rock-constituents are generally angular to subangular outlines indicating least transport before compaction.

Flagstone

- It is a variety of sandstone that is exceptionally rich in mica dispersed in parallel or sub parallel layers.
- The abundance as well as arrangement of mica, typically muscovite, renders the stone weak and easily splitting. Hence its use in load bearing situations is not recommended.

Freestone

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

Ganister

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

Uses

- ❖ Sandstones of hard, massive and compact character are very useful natural resources.
- ❖ They are most commonly used as materials of construction: building stones, pavement stones, road stones and also as a source material for concrete.
- ❖ The Red Fort of India is made up of red sandstones.

Shale

Definition

- Shale is a fine-grained sedimentary rock of argillaceous (clayey) composition.
- Shales are generally characterized with a distinct fissility (parting) parallel to the bedding planes and are made up of very fine particles of silt grade and to some extent of clay.
- Besides fissility, some shales show the laminated structure.

Composition

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

FELSPAR GROUP

- The felspar are the most prominent group of minerals making more than fifty percent, by weight, crust of the Earth up to a depth of 30km.
- The group comprises about a dozen or so minerals of which 3-4 may be easily described as the most common minerals in rocks.

Chemical Composition

In chemical constition, felspars are chiefly alumino silicates of Na, K and Ca with following

$$\boxed{WZ_4O_8}$$

general formula in which W = Na, K, Ca and Ba and Z = Si and Al. The Si : Al shows a variation from 3:1 to 1:1.

Atomic Structure

- At atomic level, the felspars show a continuous three-dimensional network type of structure in which the Sio4 tetrahedra are linked at all the comets, each oxygen ion being shared by two adjacent tetrahedra.
- The Si04 tetrahedra is accompanied in this network by AIO4 tetrahedra so that felspars are complex three dimensional framework of the above two types of tetrahedra.
- The resulting network is negatively charged and these negative charges are satisfied by the presence of positively charged K, Na, Ca and also Ba.

Crystallization

The felspar group of minerals crystallise only in two crystallographic systems:

- Monoclinic and Triclinic.

Classification

- Felspars are classified both on the basis of their chemical composition and also on their mode of crystallization.
- Chemically, felspar fall into two main groups:
- The potash felspars and
- The soda time felspars.
- Common members of the two groups are as follows:

Potash Felspars

Orthoclase (K AL Si_3O_8), Sanidine (K AL Si_3O_8) and Microtine (K AL Si_3O_8)

Soda-Lime Felspars

These are also called the plagioclase felspar and consist of an isomorphous series of six feispars with two components: Na Al Si_3O_8 and Ca Al_2 Si_2 0_8 as the end members.

The series is also known as Albite-Anorthite series.

- Albite
- Labradoirte
- Oligoclase
- Bytwonite
- Artdesine
- Anorthite

Physical Properties

- They are generally light in colour, (because of absence of Fe and Mg),
- Have lower specific gravity (generally around 2.6),
- Have a double cleavage and a hardness varying between 6 — 6.5.

PYROXENES GROUP

- It is important group of rock forming minerals
- They are commonly occur in dark colours, igneous and metamorphic rocks
- They are rich in calcium, magnesium, iron, silicates
- It show single chain structure of silicate
- It is classified into orthopyroxene and clinopyroxene. It is based on internal atomic structure

Orthopyroxene:

Enstatite(mgsio3)

Hyperthene[(mg,fe)sio3]

Clinopyroxene:

Augite[(ca, na) (mg, fe, al) (al, si)2o6]

Diopside [camgsi2o6]

Hedenbergite[cafesi2o6]

Augite:

Crystal system: monoclinic

Habit: crystalline

Cleavage: good (primastic cleavage)

Fracture: conchoidal

Colour: shades of greyish green and black

Lustre: vitreous

Hardness: 5-6

Specific gravity: medium

Streak: white

Occurrence: ferro magnesium mineral of igneous rock (dolerite)

Uses: rock forming mineral

Compositon: [(ca, na) (mg, fe, al) (al, si)2o6]

Transparency: translucent/opaque

AMIPHOBLE GROUP

These are closely related to pyroxene group. It shows double chain silicate structure
Rich in calcium, magnesium, iron oxide and Mn, Na, K and H

CLASSIFICATION:

1. Orthorhombic
2. Monoclinic

a. Hornblende

b. Tremolite

c. Actinolite

Hornblende: (compound-complex silicate)

Crystal system: monoc;inic

Habit: crystalline

Cleavage: good(prismatic)

Fracture: conchoidal

Colour: dark green, dark brown black

Lustre: vitreous

Hardness: 5 to 6

Specific grravity: 3 to 3.5 (medium)

Streak: colourless or white

Composition: hydrous silicates of ca, na, mg, al

Transparency: translucent/opaque

Occurrence: found in igneous rocks

Uses: road material

MICA GROUP

Form sheet like structure can be spilt into very thin sheets along one direction aluminium and magnesium are rich occupy 4% of earth crust shows basal cleavage

classification:

light mica:

muscovite-kal2(alsi2o10)(oh)2-potash mica

paragonite-naal2(alsi3o10)(oh)2-soda mica

lepidolite-klial(si4o10)(oh)2 –lithium mica

dark mica:

biotite-k(mg,fe)3(alsi3o10)(oh)2.(fe mg mica)

phogopite-kmg3(al3si3o10)(oh)2-(mg mica)

zinwaldite-complex li-fe mica

general physical properties:

crystal system: monoclinic

hardness: 2-3

lustre: vitreous

habit: foliated

cleavage: perfect (basal)

light mica:

muscovite:

crystal system: monoclinic

hardness: 2-3

lustre: vitreous

habit: foliated

cleavage: perfect

specific gravity: 2.7-3

streak: colourless

composition: kal2(alsi2o10)(oh)2

occurrence: in igneous rock(granite and pegmatite) and accessory mineral in sedimentary rock

uses: electrical industry

transparency: transparent

fracture: even

colour: colourless

lepidolite:

crystal system: monoclinic

habit: granular

cleavage: good

fracture: even

color: colorless

lustre: pearly

hardness: 2-3

specific gravity: 2.8-3.3

streak: colourless

composition: naal2(alsi3o10)(oh)2

transparency: transparent

occurrence: in igneous rock

uses: fire proof material

dark mica:

biotite:

crystal system: monoclinic

habit: foliated

cleavage: perfect

fracture: even

colour: black, deep green

lustre: vitreous

hardness: 2.5-3

sp.gravity: 2.7-3

streak: colourless

composition:k(mg fe)3(al si3o10)(oh)2

occurrence: commonly found in igneous rocks, sedimentary rocks

transparency: translucent

uses: electrical industries

phogopite:[limited occurnece]

crystal system: monoclinic

habit: foliated

cleavage: perfect 2.5-3

sp.gravity: 2.7-3

streak: colourless

composition:k mg3(al3si3o10)(oh)2

transparency: translucent

occurrence: in igneous rock, metamorphic rock and rarely in sedimentary rock

uses: electrical industries

CALCITE

Crystal system: hexagonl

Habit: tabular

Cleavage: perfect

Fracture: even

Colour: milky white, grey, green, yellow, colourless,etc

Lustre: vitreous

Hardness: 3

Sp. Gravity: 2.71(low)

Streak: colourless

Composition: $CaCO_3$

Transparency: transparent

Uses: used for manufacture of cement and lime it is also used as fertilizer

Occurrence: rocking forming mineral in sedimentary rocks.

GYPSUM

Gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$.[3] It is widely mined and is used as a fertilizer, and as the main constituent in many forms of plaster, blackboard chalk and wallboard. A massive fine-grained white or lightly tinted variety of gypsum, called alabaster, has been used for sculpture by many cultures including Ancient Egypt, Mesopotamia, Ancient Rome, Byzantine empire and the Nottingham alabasters of medieval England. It is the definition of a hardness of 2 on the Mohs scale of mineral hardness. It forms as an evaporite mineral and as a hydration product of anhydrite.

Gypsum is moderately water-soluble (~2.0–2.5 g/l at 25 °C) and, in contrast to most other salts, it exhibits retrograde solubility, becoming less soluble at higher temperatures. When gypsum is heated in air it loses water and converts first to calcium sulfate hemihydrate, (bassanite, often simply called "plaster") and, if heated further, to anhydrous calcium sulfate (anhydrite). As for anhydrite, its solubility in saline solutions and in brines is also strongly dependent on NaCl concentration.

Gypsum crystals are found to contain anion water and hydrogen bonding.

CLAY MINERALS

These are phyllosilicates minerals Essentially hydrous aluminium silicates These are common weathering products Very common in sedimentary rock

CLASSIFICATION:

There are four group,

1. Kaolin
    a. Kaolinite
    b. Dictite
    c. Nacrite
    d. Halloysite

2. Smectite

   a. Montmorillonite

   b. Nontronite

   c. Hectorite

3. Illite

4. Chorite

PHYSICAL PROPERTIES:

KAOLIN GROUP:

KAOLINITE:

It is formed by weathering of aluminate- silicate minerals. The feldspar rick rocks are commonly weathered to kaolinite.

Crystal system: Triclinic

Habit: Massive

Colour: White sometimes brown

Cleavage: Perfect

Fracture: Even

Streak: White

Lustre: Dull earthy

Hardness: 2

Specific gravity: 2.6(low)

Transparency: Translucent

Composition: $Al_2Si_2O_5(OH)_4$

Occurrence: secondary mineral formed by alternation of alkali feldspar

Uses: ceramic industries, medicine, cosmetics and main components in porcelain

HALLOYSITE:

Crystal system: Monoclinic

Habit: Massive

Colour: white, grey, green, yellow, red, blue

Streak:

Cleavage: imperfect

Lustre: waxy or dull

Fracture: conchoidal

Hardness: 2-2.5

Sp. Gravity: 2-2.5 (low)

Transparency: Translucent

Composition: $Al_2Si_2O_5(OH)_4$

Occurrence: secondary mineral formed by alternation of alkali feldspar

SMECTITE GROUPS:

MONTMORILLONITE:

It is derived from weathering of volcanic ash

In contact with water it expands several times its original volumes

Act as drilling mud and it is main constituentsospetronite

Crystal system: Monoclinic

Habit: Lamellar/ Globular

Colour: White, blue or yellow

Streak:

Lustre: Dull Earthy

Fracture: Uneven

Cleavage: Perfect

Hardness: 1-2

Sp. Gravity: 1.7-2(low)

Transparecy: Translucent

Composition: $(Na, Ca)_{0.33}(Al\ Mg)_2\ Si_4O_{10}(OH)_2.nH_2O$

Occurrence: derived from volacanic ash also weathering of muscovite, illite, kaolinite

Uses: Mainly used for oil industry(drilling mud)

ILLITE:

The illite clay have a structure similar to that of muscovite. They form by alternate minerals like muscovite and feldspar.

Chemical composition: $(K, H)\ Al_2(Si\ Al)_4O_{10}(OH)_2\ XH_2O$

Uses: in oil industry

CHLORITE:

Crystal system: Foliated Monoclinic

Habit: Foliated

Colour: Grey, Green

Streak: White

Cleavage: Good

Fracture: Even

Lustre: Vitreous

Sp. Gravity: Low

Hardness: 2-3

Transparency:

ENGINEERING CONSIDERATIONS OF CLAY MINERALS:

Montmorillonite is a dangerous type of clay cut it when found in road or tunnel since it has expandable nature which causes slope or wall failure Kaolinite is used in ceramic industry , it is not expandable and wont absorb water Clay is used as important material in construction industries both as building material and as foundation or structure It has poor drainage because the soil tends to stay wet and soggy when it is affected by water, while it is wet it can be easily compacted It has poor aeration because the soil particles are small and closely spaced, it is very difficult for air to enter or leave the soil It has very high nutrients reserves, reducing the need for fertilization also because clay retains water plants growing in it often more drought tolerant than plants growing in sandy soil

CLAY MINERAL GROUP:

Minerals have been classified based on their influence on the performance of rocks/ soil. A partial listing of potential minerals are as follows,

SOLUBLE MINERALS:

Calcite ($CaCO_3$), Dolomite ($CaMg(CO_3)_2$), Gypsum ($CaSO_4.2H_2O$), Anhydrite ($CaSO_4$), Halite

($NaCl_2$), Zeolite

UNSTABLE MINERALS:

Marcasite, pyrhotite

PONTENTIALLY UNSTABLE MINERALS:

Nontronite (iron rich montmorillonite), Nepheline, Lucite, mica rich in iron

MINERALS WHICH RELEASE H2SO4 ON WEATHERING:

Pyrite, pyrrohotite, other sulphide minerals

MINERALS WITH LOW COEFFECIENT FRICTION:

Clay minerals, talc, chlorite, serpentine, mica, graphite, molybdenite

POTENTIALLY SWELLING MINERALS:

Clay minerals (illite, kaolinite, bentonite, montmorillonite)

Anhydrite, vermiculite

ALKALI REACTIVE MINERALS (INTERFERE WITH CEMENT):

Opal, volcanic glass, chert, chalcedony, gypsum, zeolite, mica, amorphous quartz

MINERALS WITH HIGH DENSITY:

Iron oxide, sulphide minerals, other metallic minerals, barites

MINERAL COMTRIBUTING ARSENIC TO GROUNDWATER:

Arseno-pyrite, arsenolite, proustite

FUNDAMENTALS OF THE PROCESS OF FORMATION OF ORE MINERALS

Current theories of the genesis of ore deposit can be divided into internal (endogene) and external (exogene) or surface processes. It must be understood that more than one mechanism may be responsible for the formation of an ore body. Example - stockwork porphyry copper deposit at depth (epigenetic) with a syngenetic massive sulfide deposit at the surface. The Table at the end of the document summarizes the principal theories of ore genesis,

Depending upon whether an ore deposit formed at the time of and together with the enclosing rock, or was introduced into it by subsequent processes, they are classed as:

Syngenetic - A deposit formed at the same time as the rocks in which it occurs. Ex. Banded Iron Formation

Epigenetic - A deposit introduced into the host rocks at some time after they were deposited. Ex. Mississippi Valley-type Deposits

Magmatic Deposits: Those deposits, not including pegmatites that have formed by direct crystallization from a magma. Two types:

Fractional Crystallization - Any process whereby early formed crystals can not re-equilibrate with the melt. Includes 1) gravitative settling; 2) flowage differentiation; 3) filter pressing and 4) dilation. Number 1 is the most important and results from the settling of early formed crystals to the bottom of the magma chamber. Rocks formed in this manner are termed cumulates and are often characterized by rhythmic layering. In ore deposits the alternating layers are often magnetite and/or chromite between layers of silicate. Ex. Bushveld igneous complex.

Immiscible Liquid - Typical example is oil and water. In ore deposits we deal with silicate and sulfide magmas. As a magma cools, sulfides coalesce as droplets and due to higher density settle out. Most common sulfides are iron sulfides, but nickel, copper and platinum also occur. Ex. Sudbury, Canada. The settling out of the heavier sulfides results in the peculiar net-textured ores often found in many of these deposits.

Pegmatitic Deposits: Pegmatites are very coarse grained igneous rocks. Commonly form dike-like masses a few meters to occasionally 1-2 km in length. Economic ore deposits are associated with granitic pegmatites since felsic magmas carry more water. Residual elements such as Li, Be Nb, Ta, Sn and U that are not readily accommodated in crystallizing silicate phases end up in the volatile fraction. When this fraction is injected into the country rock a pegmatite is formed. Temperatures of deposition vary from 250-750°C. Pegmatites are divided into simple and complex. Simple pegmatites consist of plagioclase, quartz and mica and are not zoned. Complex have a more varied mineralogy and are strongly zoned. Crystals in pegmatites can be large, exceeding several meters. Three hypotheses to explain their formation:

a. fractional crystallization
b. deposition along open channels from fluids of changing composition
c. crystallization of a simple pegmatite and partial to complete hydrothermal replacement

Hydrothermal Deposits: Hot aqueous solutions are responsible for the formation of many ore deposits. Fluid inclusion research indicates most ore forming fluids range in temperature from 50°C to 650°C. Analysis of the fluid in inclusions has shown that water is the most important phase and salinities are often much greater than those of seawater. The chemistry of ore fluids and the mechanism of deposition of ore minerals remains a subject of hot debate. Arguments boil down to a) source and nature of the solutions b) means of transport of the metals and c) mechanism of deposition.

Metamorphic/Metasomatic Deposits: Pyrometasomatic deposits (skarns) developed at the contact of plutons and host rock. Generally, host rock is a carbonate and new minerals formed are the calc-silicates diopside, andradite and wollastonite. Temperatures involved are thought to be 300-500°C, but pressure is probably quite low. Three stage process:

1. Recrystallization
2. Introduction of Si, Al, Fe, Mg
3. Hydration and introduction of elements associated with volatile fraction

Other metamorphic processes are relatively unimportant, but hydration/dehydration during regional metamorphism may concentrate metals at the metamorphic front. Sodic metasomatism of K-spar is thought to have been important in the concentration of gold at Kalgoorlie. Conversion of feldspar from K-spar (1.33A) to Na plag (.97A) resulted in the expulsion of gold (1.37A) which could no longer be accommodated in the feldspar lattice. Skip over Mechanical-chemical sedimentary processes since they are covered in the other course.

Volcanic Exhalative Deposits: Some ore deposits often show spatial relationships to volcanic rocks. They are conformable with the host and frequently banded suggesting sedimentary processes. Principal constituent is pyrite with lesser chalcopyrite, aphalerite, galena, barite and Ag-Au. These were thought until the late 60's to be epigenetic, but it is now realized they are syngenetic. They show a progression of types with three distinct end members:

1. Cyprus type - Associated with mafic volcanics and ophiolite sequences. Found in spreading centers and back arc basins. Consist predominantly of pyrite with lesser chalcopyrite. Typified by the Cyprus pyrite-cu ores.
2. Besshi type - Associated with basaltic to dacitic volcanism. Thought to form during the initial stages of island arc formation. Many Besshi type deposits occur in Precambrian rocks and these may have been generated in entirely different tectonic settings. Pyrite dominant, but chalcopyrite and sphalerite very common. Typified by many of the volcanogenic deposits of Canada.

3. Kuroko type - Associated with dacitic to rhyolitic volcanics. Form during the waning stages of island arc volcanism. Pyrite occurs, but is not dominant Usually galena or sphalerite are predominate with lesser chalcopyrite and tetrahedrite. Also significant silver in this type. Typified by the Kuroko deposits.

Although it is agreed ores are associated with volcanism the source of the ore bearing solutions continues to be debated. Many feel ore fluids are of magmatic origin, but others feel they are merely convecting seawater.

THEORIES OF ORE DEPOSIT GENESIS		
Origin Due to Internal Processes		
Magmatic Segregation	Separation of ore minerals by fractional crystallization during magmatic differentiation.	Pt—Cr deposits Bushveld, S.A. Titanium deposit Tahawas, N.Y.
	Liquid immiscibility. Settling out from magmas of sulfide, sulfide-oxide or oxide melts which accumulate beneath the silicates or are injected into country rocks or extruded on the surface.	Cu-Ni ores of Sudbury, Canada and the nickel extrusives of Kambalda, West Australia.
Pegmatitic Deposition	Crystallization as disseminated grains or segregations in pegmatites.	Li-bearing pegmatites of Kings Mtn. N.C.
Hydrothermal	Deposition from hot aqueous solutions of various sources.	Porphyry Cu-Mo deposits of the W. Cordillera.
Lateral Secretion	Diffusion of ore and gangue forming materials from the country rocks into faults and other structures.	Gold deposits of Yellowknife, B.C. and the Mother Lode, CA.
Metamorphic Processes	Pyrometasomatic (skarn) deposits formed by replacement of wall rocks adjacent to an intrusive.	W deposits at Bishop, CA. Fe deposits Iron Mtn UT.
	Initial or further concentration of ore elements by metamorphic processes.	Homestake Au Mine, Lead, South Dakota.

Origin Due to Surface Processes		
Mechanical Accumulation	Concentration of heavy minerals into placer	Placer Au deposits of Alaska and California.
Sedimentary Precipitation	Precipitation of certain elements in sedimentary environments.	Banded Iron Fm. of the Canadian Shield.
Residual Processes	Leaching of soluble elements leaving concentrations of insoluble elements.	Nickel laterites of New Caledonia and Arkansas bauxite.
Secondary or Supergene Enrichment	Leaching of certain elements from the upper part of a mineral deposit and their reprecipitation at depth to produce higher concentrations.	The upper portion of many porphyry copper deposits.
Volcanic Exhalative Process	Exhalations of sulfide-rich magmas at the surface, usually under marine conditions.	Mt. Isa, Aust., Sullivan and Kidd Creek,Canada, Kuroko,Japan.

COAL THEIR ORIGIN AND OCCURRENCE IN INDIA

Occurrence

Calcite is one of the most common rock forming minerals in sedimentary rock. Limestones are almost entirely made up of calcite and the dolomites contain this mineral to a good proportion. The recrystallized variety of calcite makes the well-known metamorphic rocks marbles. Calcite is principally a secondary mineral formed from the carbonate rich water of sea and oceans.

Varieties

Calcite occurs in numerous varieties including Aragonite, Iceland spar, Satin spar and chalk The Iceland spar is a transparent crystalline variety valued as a source material for optical instruments.

COAL

The term coal is generally applied to a sedimentary formation of highly carbonaceous character that is derived from vegetable matter involving set of processes such as burial, compaction and biochemical transformation.

Some varieties of coal are very rich in volatile matter.

Chemical Composition

- Coal is composed chiefly of carbon, oxygen, hydrogen, nitrogen, traces of sulphur and phosphorous, carbon being the major component.
- Coals may contain varying properties of mineral matter which may be residues of the mineral constituents of the plants from which coals are derived.
- The chemical composition of coal may be in the following range.

Carbon (60-90 percent),

Oxygen (2 - 20 percent).

Hydrogen (1-12 percent)

Nitrogen (1-3 percent).

Classification .,

- Coal is divided into four major classes: Peat, Lignite, Bituminous coals and Anthracite.

PEAT

Definition

- It is essentially a partly changed vegetable matter in the first stage of transformation to coal.
- The vegetable structure is easily visible and the evidence of its being in the process of transformation is also clearly seen.
- Peat is generally composed of remains of moss-like plants but occasionally may contain reeds and partially altered portions of trees of higher order.
- Chemically, it is very rich in moisture and consists of carbon, hydrogen, sulphur and nitrogen as important constituents.

Types

Two types of peat are commonly recognized

(i) Bog Peat, which is evolved out of lower type of vegetation, like mosses.

(ii) Mountain Peat, that is decomposed and partially altered form of higher types of trees.

Uses

Peat is a low value fuel in its application. It finds uses where available in abundance as

(i) domestic fuel, *(ii)* gas purifier, *(iii)* for steam raising, *(iv)* in thermal power stations and also as a soil treatment material.

LIGNITE

Definition

- It is a variously coloured (brown, black or light grey, earthy) variety of coal of lowest rank.
- In lignite, transformation of vegetable matter to coal-like material is almost complete.
- It is compact and earthy in texture and has a brown streak. Fibrous texture is also shown

by some lignites.

Composition

- A typical lignite has following composition:
- Fixed carbon: 50 percent; oxygen: 20-25 percent.
- Hydrogen: 05 percent; nitrogen: 02-05 percent, and
- Sulphur 01-02 percent.

Uses

- Lignites are used as domestic fuels and also in industry for distillation and gasification.
- This variety of coal has also been used in steam locomotives and for producing gas.

BITUMINOUS COALS

Definition.

- It is also known as the common coal, sometimes as coking coal and is, in fact, the most common and important variety of commercial coals.
- In this, the original vegetable matter has been fully transformed into carbonaceous material so that it forms a hard, brittle and compact mass.
- It burns with a yellow flame.

Types and Composition

- The common bituminous coal is sometimes distinguished into three different types on the basis of its carbon content: sub-bituminous, bituminous and semi- bituminous coals.
- In the sub-bituminous coals, the volatile constituents and moisture make the bulk of the coal matter. They possess no caking power (see below). Carbon is generally between 63-75 per cent and oxygen between 10-20 per cent.
- The proper bituminous coals often show a typically banded structure and are quite rich *in* carbon and poor in moisture content.

Their carbon content ranges between 70-90 per cent and the volatile matter is also quite high: 20 to 45 percent.

ANTHRACITE

- It is a coal of highest rank in which original organic source has been completely transformed into carbonaceous substance.
- Anthracite is very hard, jet black in colour, compact in structure and showing an almost metallic (steel grey) luster.
- It is difficult to ignite and burns with a typically blue flame without emitting any smoke.

Formation of Coal

Two types of sources yielded vegetable material for the formation of the coal:

(i) the higher vegetation including herbs, shrubs and trees, growing on the plains, plateaus, sub-mountainous and mountainous areas and characterized with wood tissue rich in cellulose and lignin (50-70%) and protein (10-15%); this type of source has been named as the humic sediment;

(ii) the lower vegetation, comprising chiefly planktonic algae, as is often found at the bottom of lakes and seas, submerged under water. This source has been named as sapropelic sediments.

Indian Occurrences

- India is one of five major producers of coal in the world.
- It is endowed with huge reserves of common or bituminous coal, chiefly of non-coking types.
- Fairly good but localized deposits of peat, lignite and anthracite have also been mined at different places.
- On the basis of their occurrence relative to geological age, coal deposits of India are often classified into two groups: Lower Gondwana Coals and Tertiary Coals, the former being of great economic importance.

(A) The Gondwana

- About 98 percent of coal annually produced in India comes from formations of Lower Gondwana age
- The Gondwana coal are derived from coal seams that occur interbedded commonly with sandstones and shales and sometimes with limestones.
- It is believed that these coals have been formed from Glossopteris types of vegetation deposited in shallow type of basins where they were transported by streams of fluvio-glacial and fluvial origin.
- Their occurrence in coal-bearing formations separated by totally barren (with respect to coal) formations are indicative of repeated climate changes during the Permian times- the geological period of their formation.
- The lower Gondwana coals are mainly of bituminous type, Major coalfields belonging to this class occur in Bihar, West Bengal, Orissa and Madhya Pradesh. These are:

(B) The Tertiary Coals

- These coals are found in the states of Assam, Arunachal Pradesh, Himachal Pradesh, Nagaland and Jammu and Kashmir.
- The Makum coalfield of Assam, spread over an area of 150 sq.km, is an important example, in which reserves of 235 million tones are estimated to occur.
- The coal is high in volatile matter (38-51%) and low in moisture content (2 to 9 percent). It is regarded as an ideal type for chemical industry.
- The Jangalgali and Kalakote coalfield of Jammu (Jammu and Kashmir state) are of semianthracitic type and low in moisture content 'and sulphur.

(C) The Lignite Deposits

- India has only scarce occurrence of lignite type of coal. Important deposits reported so far occur in Tamil Nadu, Pondichery, Kutch, Kerala and Uttar Pradesh.
- Of these, the Neyveli lignite field in Arcot district of Tamil Nadu is the most important which holds about 2600 million tones of the estimated total of 2900 million tones of lignite deposits in the country.

PETROLEUM - THEIR ORIGIN AND OCCURRENCE IN INDIA.

PETROLEUM

Definition

- Petroleum is a general term applied to a complex mixture of hydrocarbons and some other compounds that occur in a liquid form entrapped within the rocks of the surface of the earth.
- It is also termed as mineral oil and crude oil.
- The crude oil may be colour less or various shades of green or even black.

Chemical Composition

- Crude oil is chiefly a complex mixture of hydrocarbons which occur in an isomeric combination, that is, in inter-related brms.
- The main hydrocarbons that constitute crude belong to
- Paraffins (methane, ethane, propane and butane).
- Napthanes series and aromatic hydrocarbon.
- Besides hydrocarbons, small quantities of compounds of sulphur, (e.g. thiopane, thioether, mercaptanes), nitrogen and oxygen are also present in varying properties.
- The natural gas which is often associated with petroleum deposits is made up of gaseous hydrocarbons of the paraffin group (mentioned above) besides with an admixture of lowboiling liquid hydrocarbons like pentane and hexane.

Origin of Petroleum

These are

(i) the nature of the source material;

(ii) the process that resulted into the transformation of source material to the crude oil,

(iii) the environment that controlled such a transformation,

(iv) the migration of the oil from the place of actual (likely) formation to the present occurrence and

(v) also the complex chemical composition.

(A) Source Material

Inorganic theories suggest various possibilities like:

(i) Reaction of alkali-metals (which are common in the interior of the earth) with carbon dioxide forming

acetylides that combine with water to form hydrocarbons.

(ii) Reaction of iron carbide with percolating waters at very high temperature and pressure that leads

to the formation of hydrocarbons

(iii) Concentration of cosmic hydrocarbons that existed in the beginning of the earth,when it was still in astral state, followed by their absorption by substratum on cooling of the earth and subsequent concentration in the coolest layers of the lithosphere.

(iv) Decomposition of the terrestrial waters that percolated down into the body of the earth by radioactive and other sources into hydrogen and oxygen and combination of hydrogen so formed with carbon of magma rich in that gas.

Organic Theories

- These form the generally accepted view regarding the parent material of the oil. All such theories suggest an essentially organic nature for the source material of petroleum.
- Sufficient evidence exists to prove that there have been huge accumulations of organic matter - both of vegetable and animal kingdom - in geological times.

Transformation

- It is commonly accepted that the organic source material (of either type) is transformed into oil-like liquid through a set of stages.

- In the first stage, the carbon-rich organic remains collected over long geological times undergo biochemical decomposition through the agency of microorganisms.
- This change may result in conversion of original mass into thick, heavier, bituminous substance that subsides under its own weight to lower zones of higher temperature and higher pressure.
- The bituminous material undergoes activated degeneration in an oxygen free environment resulting in the liquid, gaseous a:1d solid fractions of hydrocarbons.

Environment

- Various views have been expressed regarding this aspect of the problem also and the most important conclusion is that oils were evolved out of organic debris deposited in anaerobic environment (places free of oxygen).
- The most ideal site for such conditions to prevail would be the cut off gulfs or isolated branches of seas where lack of oxygen could have been easiiy caused by non-circulation and virtual stagnation of water. T
- To support a continuous supply of organic debris to ensure good accumulation, this anaerobic layer should be succeeded by an upper oxygenated surface zone where source organisms could thrive.

Migration

- The sedimentary formations in which the oil occurs at present are called reservoirs or pools.
- These are not always the same rocks in which the oil was originally formed. The reservoir rocks may be situated at exceedingly large distances from the original site of oil formation.
- The journey of oil from the source to a reservoir rock is termed as migration and has been explained in various ways.
- Compaction of the source material is thought to be chiefly responsible for oil migration and it is believed to take places by a method called interface capture operating somewhat in the following manner:

  (i) A clay bed with appropriate concentration of organic matter is deposited; it is loose

and water-rich in the beginning.

(ii) Overburden increases due to continued sedimentation. This leads to expulsion of water by squeezing effect. Simultaneously, oil formed in the clay layer is also expelled alongwith the water.

INDIAN OCCURRENCES

- India, like many other countries of the world, is oil-deficient and imports huge quantities annually to meet its demands. At present, oil is extracted mainly from oil reserves in Assam, Gujarat and Maharashtra.
- In Assam, oil is extracted from the oil fields of Digboi, Nahorkatiya, Badarpur and Makum.
- The oil formations belong to Tipam (sandstone) series in Digboi and to Barail series in the Nahorkatiya field.
- These rocks range in geological age from Oligocene to lower Miocene.
- The well-known oilfields (and gas fields) Western India are: the Ankleshwar oil field of Gujarat, the Cambay gas fields, the Nawagam oil field and the Bombay High oil and gas field.

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DEPARTMENT OF CIVIL ENGINEERING

UNIT – III - PETROLOGY - SCIA1305

TABLE 3.1 CLASSIFICATION OF ROCKS

Igneous Rocks	Sedimentary rocks	Metamorphic rocks
Formed from the consolidation of magma	Formed from pre-existing igneous, sedimentary and metamorphic rocks	Formed from pre existing igneous, sedimentary and metamorphic rocks
Generally hard, massive, compact with interlocking grains.	Generally soft, stratified i.e., characteristically bedded	Generally hard, interlocking grains and bedded (if derived from stratified rocks)
Entire absence of fossils	Fossils common.	Fossils are rarely preserved in the rocks of sedimentary origin except slates.
Absence of bedding planes	Stratification, lamination, cross- bedding ripple marks, mud cracks, etc. are the usual structure	Foliated, gneissose, schistose, granulose, slaty etc., are the common structures
Enclosing rocks are baked	No effect on the enclosing or the top and bottom rocks.	Enclosing rocks are baked when formed from Igneous rocks.
Usually contain much feldspar	Quartz, clay minerals, calcite, dolomite, hematite are the common minerals	Common minerals are andalusite, sillimanite, kyanite, cordierite, wollastonite, garnet, graphite etc.
Classified into ➢ Volcanic rocks ➢ Plutonic Rocks ➢ Hypabyssal Rocks	Classified into ➢ *Clastic Rocks* ➢ *Chemically formed Rocks* ➢ *Organically formed Rocks*	Classified into ➢ *Foliated Rocks* ➢ *Non foliated Rocks*
Ex. Granite, Basalt	Ex. Limestone, Sandstone	Ex. Marble, Slate,

- IGNEOUS ROCKS
- SEDIMENTARY ROCKS
- METAMORPHIC ROCKS

IGNEOUS ROCKS

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

Important Conditions For The Original Material

- very high temperature and
- a molten state

Magma

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

Igneous rocks are divided into following three sub-groups

Volcanic rocks

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

oceans, the latter process being more common.

Plutonic Rocks

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

Hypabyssal Rocks

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

COMPOSITION

Chemical Composition

- Igneous rocks show a great variation in chemical composition and in fact no strict generalization is possible.
- Most reliable data is due to Clark and Washington who have shown that on an average the following elements (expressed in percentage terms of their oxides) are present in the igneous rocks

S.No	Element	Oxide (%)	*S.No*	Element	Oxide (%)
(i)	8:Oz	59.14	*(vi)*	MgO	3.49
(ii)	Alz03	15.35	*(vii)*	NazO	3.84
(iii)	FeO	3.80	*(viii)*	KzO	3.13
(iv)	Fez03	3.08	*(ix)*	HzO	1.15
(v)	CaO	5.08	*(x)*	Others	1.94

Mineralogical composition

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

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

TEXTURES OF IGNEOUS ROCKS

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

Factors Explaining Texture

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

Degree of Crystallization

- In an igneous rock, all the constituent minerals may be present in distinctly crystallized forms and easily recognized by unaided eye, or, they may be poorly crystallized or be even glassy or non-crystallized form.
- The resulting rock textures are then described as:

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

  (ii) Holohyaline: When all the constituents are very fine in size and glassy

  or non crystalline in nature.

- The term **merocrystalline** is commonly used to express the intermediate type,

i.e. when some minerals are crystallized and others are of glassy character in the same rock.

- Rocks with **holocrystalline** texture are also termed as phaneric and the holohyaline rocks

are referred as aphinitic. The term microcrystalline is used for the textures in which the minerals are perceivably crystallized but in extremely fine grain.

Granularity

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

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

  minerals are then easily identified with naked eye.

  (ii) **Medium-grained**. When the average grain size lies between 5 mm and 1

  mm. Use of magnifying lens often becomes necessary for identifying ail the

  constituent mineral

  components.

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

Fabric

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

(i) **Panidiomrphic**: when majority of the components are in fully developed shapes;

(ii) **Hypidiomorphic**: the rock contains crystals of all the categories: euhedral, subhedral or anhedral;

(iii) **Allotriomorphic**: when most of the crystals are of anhedral or irregular shapes

Types of Textures

These can be broadly divided into five categories:

. Equigranular textures

. Inequigranular textures

. Directive textures

. Intergrowth textures and

. Intergranular textures.

(1) Equigranular Textures

- All those textures in which majority of constituent crystals of a rock are broadly equal in size are described as equigranular textures.
- In igneous rocks, these textures are shown by granites and felsites and hence are also often named as granitic and felsitic textures
- In the granitic texture, the constituents are either all coarse grained or all medium grained and the crystals show euhedral to subhedral outlines.
- In the felsitic texture, the rock is micro granular, the grains being mostly microscopic crystals but these invariably show perfect outlines.
- Thus felsitic textures may be described as equigranular and panidiomrphic.
- Orthophyric texture is another type of equigranular texture, which is in between the granitic and felsitic textures. The individual grains are fine in size but not micregranular.

(2) Inequigranular Texture

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

Porphyritic texture may be caused by anyone or more of the following factors:

Difference in. molecular concentration

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

Change in physico-chemical conditions.

- Every magma is surrounded by a set of physico-chemical conditions like temperature, pressure and chemical composition, which influence the trend of crystallisation greatly.

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

Relative insolubility

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

(3) Directive Textures

- The textures that indicate the result of flow of magma during the formation of rocks are known as directive textures.
- These exhibit perfect or semi perfect parallelism of crystals or crystallites in the direction of the flow of magma.
- Trachytic and Trachytoid textures are common examples.
- The former is characteristic of certain felspathic lavas and is recognised by a parallel arrangement of felspar crystals; the latter is found in some syenites.

(4) Intergrowth Textures

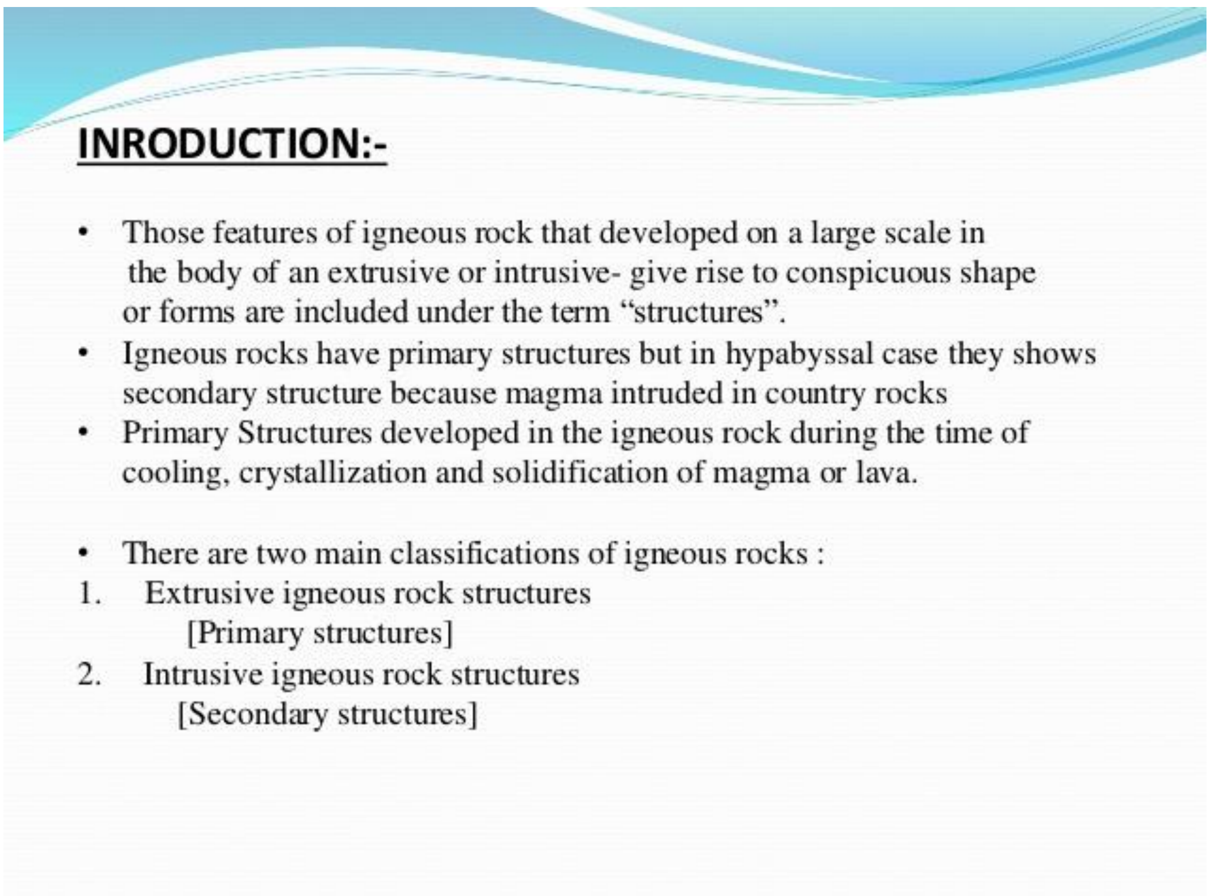
- During the formation of the igneous rocks, sometimes two or more minerals may crystallize out simultaneously in a limited space so that the resulting crystals are mixed up or intergrown.
- This type of mutual arrangement is expressed by the term intergrowth texture.
- Graphic and granophyric textures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

and felspar crystals. In granophyric textures the intergrowth is rather irregular.

(5) Intergranular Textures

- In certain igneous rocks crystals formed at earlier stages may get so arranged that polygonal or trigonal spaces are left in between them.
- These spaces get filled subsequently during the process of rock formation by crystalline or glassy masses of other minerals.
- The texture so produced is called an intergranular texture. Sometimes the texture is specifically termed intersertal if the material filling the spaces is glassy in nature.

STRUCTURE OF IGNEOUS ROCK



. Flow Structure:-

- Flow structures are formed by continuous and smoothly moving lava on the sloping surface of Earth.
- These structures formed when magma is less viscous and more mobile.

Pillow Structure:

- It's a pillow-shaped structures formed when lava is comparatively viscous and less mobile, extrusion of the lava is under water, or subaqueous extrusion.
- Pillows forms when hot viscous lava is suddenly exposed to cold water.

Pillow structures

Columnar Structures:

- This structure consists of columns (mostly commonly hexagonal in shape) that are separated by joints or fractures in the rock, formed when the rock contracted, most often during

. Spherulitic Structures:-

- Spherulitic Structures are Identified by the presence of the Needle like Mineral Grains in igneous rock masses.

Fig. columnar structures

Fig Spherulitic Structures

. Miarolitic Structures:

- In Miarolitic Structure are the cavities (formed during the cooling of Lava) are filled with some (one or more) different minerals.

Fig. Miarolitic structures

FORMS OF IGNEOUS ROCKS

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

(a) the structural disposition of the host rock (also called the country rock)

(b) the viscosity of the magma or lava

(c) the composition of the magma or lava

(d) the environment in which injection of magma or eruption of lava takes place.

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

- **Concordant and**
- **Discordant**.

CONCORDANT

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

Forms of concordant bodies

Sills

- The igneous intrusions that have been injected along or between the bedding planes or sedimentary sequence are known as sills.
- It is typical of sills that their thickness is much small than their width and length. Moreover, this body commonly thins out or tapers along its outer margins.
- The upper and lower margins of sills commo11ly show a comparatively finer grain size than their interior portions. This is explained by relatively faster cooling of magmatic injection at these positions
- In length, sills may vary from a few centimeters to hundreds of meters

Sills are commonly subdivided into following types:

(a) **Simple Sills**: formed of a single intrusion of magma;

(b) **Multiple Sills**: which consist of two or more injections, which are essentially of the same kind of magma;

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

(d) **Differentiated Sills**: these are exceptionally large, sheet-like injections of magma in which there has been segregation of minerals formed at various stages of crystallisation into separate layers or zones.

(e) **Interformational Sheets:** the sheet of magma injected along or in between the planes of unconformity in a sequence are specially termed as interformational sheets. These resemble the sills in all other general details.

<u>Phacoliths</u>

- These are concordant, small sized intrusive that occupy positions in the troughs and crests of bends called folds. In outline, these bodies are doubly convex and appear crescents or half-moon shaped in cross-section.
- As regards their origin, it is thought that when magma is injected into a folded sequence of rocks, it passes to the crests and troughs almost passively *i.e.* without exerting much pressure.

<u>Lopoliths</u>

- Those igneous intrusions, which are associated with structural basins, that are sedimentary beds inclined towards a common centre, are termed as lopoliths.
- They may form huge bodies of consolidated magma, often many kilometers long and thousands of meters thick.
- It is believed that in the origin of the lopoliths, the formation of structural basin and the injection of magma are "contemporaneous", that is, broadly simultaneous.

Laccolith

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

DISCORDANT BODIES

- All those intrusive bodies that have been injected into the strata without being influenced by their structural disposition (dip and strike) and thus traverse across or oblique to the bedding planes etc. are grouped as discordant bodies.
- Important types of discordant intrusions are dykes, volcanic necks and batholiths.

Dykes (Dikes)

- These may be defined as columnar bodies of igneous rocks that cut across the bedding plane or unconformities or cleavage planes and similar structures.
- Dykes are formed by the intrusion of magma into pre-existing fractures.
- It depends on the nature of magma and the character of the invaded rock whether the walls of the fracture are pushed apart, that is, it is widened or not.
- Dykes show great variations in their thickness, length, texture and composition.
- They may be only few centimeters or many hundreds of metes thick.
- In composition, dykes are generally made up of hypabyssal rocks like dolerites, porphyries and lamprophyres, showing all textures between glassy and phaneritic types.

- **Cone sheets and Ring Dykes** may be considered as the special types of dykes.
- The cone sheets are defined as assemblages of dyke-like injections, which are generally inclined towards common centres.
- Their outcrops are arcuate in outline and their inclination is generally between 30° - 40°.
- The outer sheets tend to dip more gently as compared to the inner ones
- **Ring Dykes** are characterised by typically arcuate, closed and ring shaped outcrops.
- These may be arranged in concentric series, each separated from the other by a screen of country rock.
- They show a great variation in their diameter; their average diameter is around 7 kilometers. Few ring dykes with diameters ranging up to 25 kms are also known.
- **Origin of dykes** It has been already mentioned that dykes are intrusions of magma into pre- existing fractures present in the rocks of the crust.
- These original fractures are generally caused due to tension.
- Their original width might have been much less than the present thickness of the dykes.
- This indicates widening of the cracks under the hydrostatic pressure of magmatic injection.

Volcanic Necks

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

Batholiths

- These are huge bodies of igneous masses that show both concordant and discordant relations with the country rock.
- Their dimensions vary considerably but it is generally agreed that to qualify as a batholith the igneous mass should be greater than 100 square kilometers in area and its depth should not be traceable. This is typical of batholiths: they show extensive downward enlargement

- In composition, batholiths may be made of any type of igneous rock.
- They also exhibit many types of textures and structures. But as, a matter of observation, majority of batholiths shows predominantly granitic composition, texture and structure.

IMPORTANT IGNEOUS ROCKS

- felspathic mineral. Theralites and teschenites are, of course, rare in occurrence.

DOLERITES

Definition.

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

Composition.

- Dolerites are predominantly made up of calcic plagioclase (e.g. anorthite and labradorite).
- Dark minerals like augite, olivine and iron oxide etc. are also present in good proportion in dolerites along with the plagioclase minerals.

Texture.

- Dolerites are mostly medium to fine grained rocks.
- Ophitic and porphyritic textures are quite common in many dolerites.

Occurrence.

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

SYENITES

Definition

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

Composition.

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

Texture

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

Types.

- **Nordmarkite**. a syenite that contains some amount of quartz in them.
- **Monzonite**. in which plagioclase felspars become almost equal to the potash felspars
- as essential minerals.
- **Larvikite**. it is also sometimes known as blue-granite; it is, however, actually a syenite that contains felspar labradorite as a predominant constituent.
- **Nepheline** (or Alkali) Syenites. These are a group of syenite rocks in which nepheline (a typical felspathoid) becomes an important constituent. Quartz is typically absent in nepheline syenites. Theralite is a special type of nepheline syenite containing felspar labradorite.
- **labradorite**. The syenite is known as teschenite if instead of nepheline, analcite is the

BASALTS

Definition

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

Composition.

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

  named collectively as Tholeiites.

Occurrence.

- Basaltic rocks form extensive lava flows on the continents and also on the oceanic floors in almost all the regions of the world.

- In India, the Deccan Traps, which are of basaltic and related rocks, are spread over more than four hundred thousand square kilometers in Maharashtra, Gujarat, Madhya Pradesh and adjoining parts of Indian Peninsula.

ENGINEERING IMPORTANCE

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

SEDIMENTARY ROCKS

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

. **FORMATION**

- The process of formation of sedimentary rocks is ever prevailing.
- The sediments so produced are transported to the settling basins such as sea floors where they are deposited, get compacted and consolidated and finally transformed

into a cohesive solid mass. That is a sedimentary rock.

- Some chemical processes especially evaporation and precipitation regularly operate on surface of water bodies containing dissolved salts and produce solids that settle down in those bodies.
- Sedimentary rocks are broadly grouped into three classes on the basis of their mode of formation: Mechanically formed or Clastic Rocks; Organically formed Rocks and Chemically formed Rocks
- The last two groups are considered as a single class and named as Non-Clastic Rocks.

Clastic (Mechanically Formed) Rocks

- A series of well-defined steps are involved in the formation of clastic rocks.

Decay and Disintegration

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

Transport of Sediments

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

terminating into lakes or seas.

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

Gradual Deposition

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

Diagenesis

- The process of transformation of loose sediments deposited in the settlement basins to solid cohesive rock masses either under pressure or because of cementation is collectively known as diagenesis.
- It may be achieved by either of the two methods: **welding or cementation**.
- **Welding** is the process of compaction of the sediments accumulated in lower layers of a basin due to the pressure exerted by the load of the overlying sediments.
- This results in squeezing out all or most of the water .from in between the sediments, thus bringing them closer and closer and consolidating them virtually in a solid rock mass.

- In fact the degree of packing of sediments in a sedimentary rock is broadly directly proportional to the load of the overlying sediments.
- **Cementation** is the process by which loose grains or sediments in a settlement basin get
held together by a binding material.
- The binding material may be derived from within the accumulated particles or the fluids that percolate through them and also evaporate or precipitate around those particles thus binding them in a rock like mass.

. **Chemically Formed (Non-clastic) Rocks**

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

Organically Formed (Non-clastic} Rocks

- These extensive water bodies sustain a great variety of animal and plant life.
- The hard parts of many sea organisms are constituted chiefly of calcium and/or magnesium, carbonates.
- Death and decay of these organisms within the water bodies gradually results into huge accumulations of carbonate materials, which get compacted and

consolidated in the same manner as the normal sediments.

- Lime stones are the best examples of organically formed sedimentary rocks

TEXTURES

***(i)*Origin of Grains**

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

***(ii)*Size of Grains**

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

Three textures recognized on the basis of grain size are:

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

***(iii)* Shape of Grains**

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

***(iv)*Packing of Grains**.

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

***(v)* Fabric of Grains**

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

***(vi)* Crystallisation Trend**

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

IMPORTANT SEDIMENTARY ROCKS

SANDSTONES

Definition

- Sandstones are mechanically formed sedimentary rocks of Arenaceous Group.
- These are mostly composed of sand grade particles that have been compacted and consolidated

together in the form of beds in basins of sedimentation.

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

Composition.

- Quartz (SiO_2) is the most common mineral making the sandstones. In fact some varieties of sandstone are made up entirely of quartz.
- Besides quartz, minerals like felspars, micas, garnet and magnetite may also be found in small proportions in many sand stones composition.

Texture.

- Sandstones are, in general, medium to fine-grained in texture.
- The component grains show a great variation in their size, shape and arrangement in different varieties.

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

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

Colour

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

Types

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

Siliceous Sandstones

- Silica (SiO_2) is the cementing material in these sandstones.

- Sometimes the quality of the siliceous cement is so dense and uniform that a massive compact and homogeneous rock is formed.
- This is named QUARTZITE. This type of sedimentary quartzite, when subjected to loading fractures across the grains showing clearly very dense nature and homogeneity

  of the cementing silica with the main constituent silica of the rock.

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

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

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

Arkose.

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

Greywacke.

- These are broadly defined as grey coloured sandstones having a complex mineralogical composition.
- They contain a fine-grained matrix. In this matrix, grains of quartz and some felspars are found embedded side by side with fragments of rocks like felsites, granites, shales etc.
- The exact composition of the matrix is so complex that it may not be easily determined in most cases.

Flagstone

- It is a variety of sandstone that is exceptionally rich in mica dispersed in parallel or sub parallel layers.
- The abundance as well as arrangement of mica, typically muscovite, renders the stone weak and easily splitting. Hence its use in load bearing situations is not recommended.

Freestone.

- It is a massive variety of sandstone that is rich in quartz and does not contain bedding planes or any mica. It is compact, dense, massive and a strong rock suitable for construction demanding high crushing strength.
- Ganister. It is another type of sandstone consisting of angular and sub angular quartz grains and cement of secondary quartz with some kaolin.

Uses

- Sandstones of hard, massive and compact character are very useful natural resources.
- They are most commonly used as materials of construction: building stones, pavement stones, road stones and also as a source material for concrete.
- The Red Fort of India is made up of red sandstones.

Distribution.

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

LIMESTONES

Definition

- These are the most common sedimentary rocks from the non-clastic-group and are composed chiefly of carbonate of calcium with subordinate proportions of carbonate of magnesium.
- They are formed both bio-chemically and mechanically.

Composition

- Pure limestone is invariably made up of mineral calcite ($CaC03$).
- In terms of chemical composition, limestone's are chiefly made up of CaO and CO_2, Magnesium Oxide is a common impurity in most limestone's; in some its percentage may exceed 2 percent, the rock is then called magnesian limestone.
- Other oxides that may be present in limestone are: silicon dioxide, ferrous and ferric oxides (or carbonates); and aluminium oxide. Strontium oxide is also present in some. limestone's as a trace element.

Texture.

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

Types.

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

Following are common types of limestones.

Chalk.

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

Shelly Limestone.

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

Argillaceous Limestone

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

Lithographic Limestones

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

Kankar

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

- It is non-marine in origin.

Calc-Sinter.

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

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

CONGLOMERATES

Definition

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

rock.

<u>Types</u>

<u>On the basis of the dominant grade of the constituent gravels in following three types</u>:

Boulder-Conglomerates	Cobble-Conglomerate	Pebble-Conglomerate
(gravels> 256mm)	(gravels: 64-256 mm)	(gravels: 2-64 mm)

<u>On the basis of *source* of the gravels, as</u>

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

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

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

<u>On litho logical basis</u>

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

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

<u>ENGINEERING IMPORTANCE</u>

- Sedimentary rocks cover a great part of the crust of the earth; they make up more that 75 percent of the surface area of the land mass.

- It is with these types of rocks that an engineer has to deal with in majority of cases.
- It is, therefore, essential for a civil engineer to know as much as is possible about the salient features of these rocks.
- He has to see, for instance, if such rocks would withstand loads under heavy construction and also, if they could be trusted in cuts and tunnels in highway construction and also as reservoirs.
- They are the most important rocks to act as natural reservoirs of oil and ground water supplies.

METAMORPHIC

ROCKS

<u>METAMORHISM</u>

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

<u>METAMORPHIC ROCKS</u>

<u>Definition</u>

- Metamorphic rocks are defined as those rocks which have formed through the operation of various types of metamorphic processes on the pre-existing igneous and sedimentary rocks involving changes in textures, structures and mineralogical compositions.

Stress Minerals

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

MINERALOGICAL COMPOSITION

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

(i) the composition of the parent rock;

(ii) the type and degree of metamorphism undergone by the rock.

Two broad groups of minerals formed during metamorphism are:

- Stress minerals and
- Anti-stress minerals

Stress minerals

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

Anti-Stress Minerals

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

Textures of Metamorphic Rocks

These can be broadly grouped under two headings:

(a) **Crystalloblastic**

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

(b) **Palimpsest (Relict)**

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

CLASSIFICATION OF METAMORPHIC ROCKS

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

(a) **Foliated Rocks**

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

(b) **Non-Foliated Rocks**

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

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

IMPORTANT METAMORPHIC ROCKS

QUARTZITE

Definition

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

Composition

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

Origin

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

Uses

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

MARBLE

Definition

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

banded structure also; coarse varieties may exhibit a variety of structures.

Composition

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

Varieties

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

Origin

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

Uses

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

SCHIST

Definition

- Schists are megascopically crystalline foliated metamorphic rocks characterised by a typical schistose structure.
- The constituent flaky and platy minerals are mostly arranged in parallel or sub parallel layers or bands.

Texture and Structure

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

Composition

- Platy and rod-like acicular minerals form the bulk of most of the schists.
- Micas (both muscovite and biotite), chlorite, hornblende, tremolite, actinolite 'and kyanite are quite common constituents of most of the schists
- Quartz and felspars are comparatively rare but not altogether absent.
- Porphyroblasts of granular minerals like staurolite, garnet and andalucite make their appearance in many schists.

Varieties

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

a) **Low-grade schists**

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

b) **High-grade schists**

- These are formed under conditions of regional metamorphism and are rich in minerals that are stable at high temperatures such as andalusite, cordierite, gamet, staurolite and sillimanite etc.
- Gamet-schists, cordierite-schists and sta1'rolite-schists are common examples.

Origin

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

ROCK MECHANICS

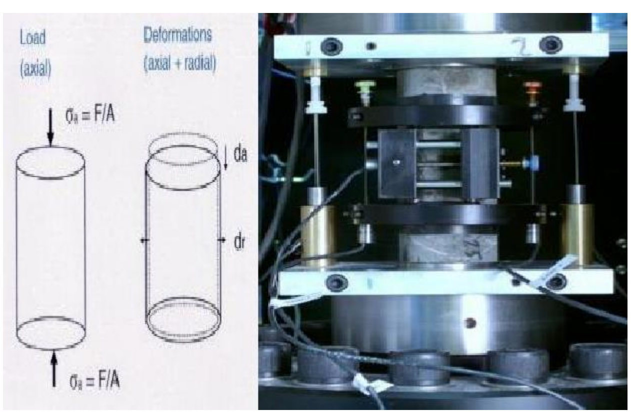
Introduction

Rock mechanics is a theoretical and applied science of the mechanical behavior of rock and rock masses; it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment. Rock mechanics is concerned with the application of the principles of engineering mechanics to the design of structures built in or of rock. The structure could include- but not limited to- a drill hole, a mining shaft, a tunnel, a reservoir dam, a repository component, or a building. Rock mechanics is used in many engineering disciplines, but primarily used in Mining, Civil, Geotechnical, Transportation, and Petroleum Engineering.

Laboratory test

Uniaxial compressive strength,

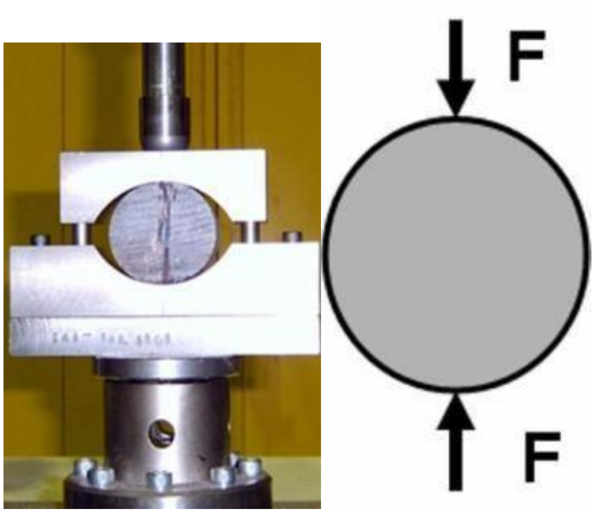
Specimens from drill cores are prepared by cutting them to the specified length and are thereafter grinded and measured. There are high requirements on the flatness of the endsurfaces in order to obtain an even load distribution. Recommended ratio of height/diameter of the specimens is between 2 and 3.



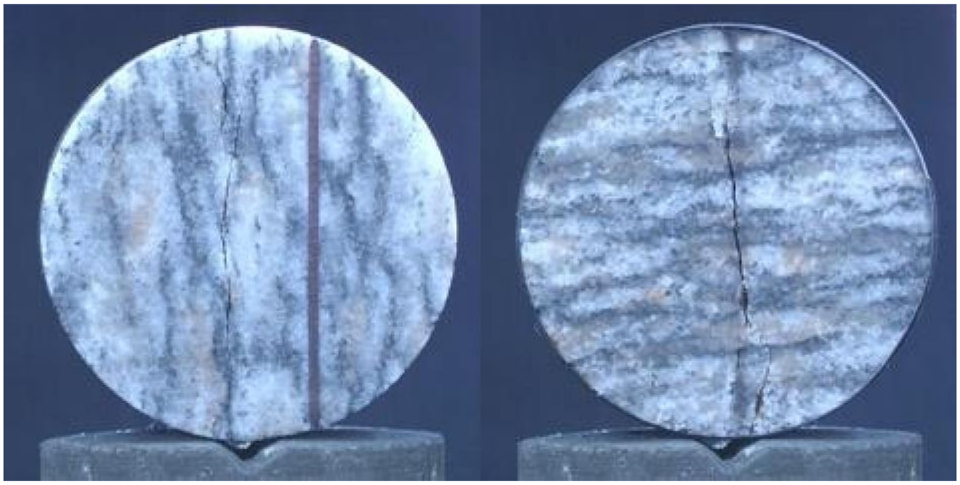
The specimens are loaded axially up to failure or any other prescribed level whereby the specimen is deformed and the axial and the radial deformation can be measured using a special equipment, see figures below.

Tensile test

A cylindrical specimen is loaded diametrically across the circular cross section. The loading causes a tensile deformation perpendicular to the loading direction, which yields a tensile failure. By registering the ultimate load and by knowing the dimensions of the specimen, the indirect tensile strength of the material can be computed. Below is a figure showing the load fixture and a principal picture of the loading.



A load situation for an indirect tensile strength test



Specimens loading to failure along (left) and across (right) the direction of the foliation.

SHEAR STRENGTH

A bar shaped specimen held with grips and supported at both the ends below is loaded from above slowly at a constant rate. Rupture occurs as shear strength of the specimen is exceeded and is indicated by failure along two planes. Shear strength S is then obtained by the relationship

$$S=\{1/2P\}/A$$

MODULUS OF ELASTICITY

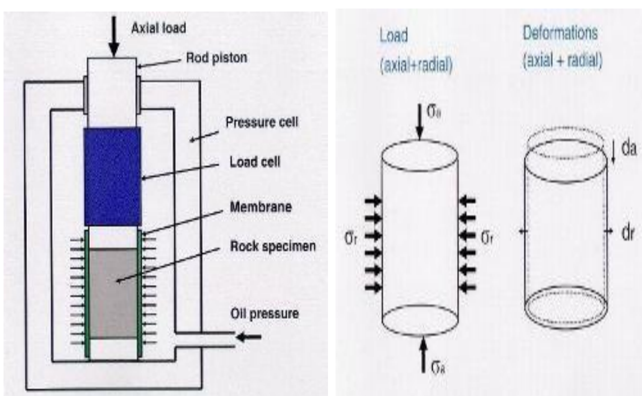
The **modulus of elasticity** (also known as the **elastic modulus**, the **tensile modulus**, or **Young's modulus**) is a number that measures an object or substance's resistance to being deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region:[1] A stiffer material will have a higher elastic modulus. An elastic modulus has the form.

TRIAXIAL TEST

Specimens from drill cores are prepared by cutting them to the specified length and are thereafter grinded and measured. There are high requirements on the flatness of the endsurfaces in order to obtain an even load distribution. Recommended ratio of height/diameter of the specimens is between 2 and 3.

A membrane is mounted on the envelope surface of the specimen in order to seal the specimen from the surrounding pressure media. Deformation measurement equipment are mounded on the specimen and the specimen is inserted into the pressure cell whereupon the cell is closed and filled with oil. A hydrostatic pressure is applied in the first step. The specimen is then further loaded by increasing the axial load under constant or increasing cell pressure up to failure or any other pre-defined load level.

- Cell pressure up to 100 MPa
- Air-hole pressure up to 100 MPa
- Breaking stress
- Angle of friction
- Parameter of elasticity: E, ν
- Post-failure



Stress state and deformations during the test.

Specimen inserted in between the loading platens, with equipment for deformation measurement attached on the specimen, before the cell is closed. - See more at:

FIELD TEST

JACK TEST

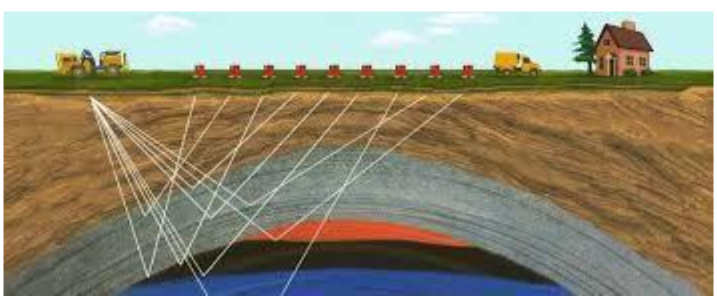
It is a static test conducted to determine in situ deformation characteristic of site rocks.

SHEAR TEST

The shear strength of a discontinuity in a soil or rock mass may have a strong impact on the mechanical behavior of a soil or rock mass. The shear strength of a discontinuity is often considerably lower than the shear strength of the blocks of intact material in between the discontinuities, and therefore influences, for example, tunnel, foundation, or slope engineering, but also the stability of natural slopes. Many slopes, natural and man-made, fail due to a low shear strength of discontinuities in the soil or rock mass in the slope. The deformation characteristics of a soil or rock mass are also influenced by the shear strength of the discontinuities. For example, the modulus of deformation is reduced, and the deformation becomes plastic (i.e. non-reversible deformation on reduction of stress) rather than elastic (i.e. reversible deformation). This may cause, for example, larger settlement of foundations, which is also permanent even if the load is only temporary. Furthermore, the shear strength of discontinuities influences the stress distribution in a soil or rock mass

SEISMIC TEST

It is a way to obtain an image of rock formations below the Earth's surface. Seismic uses reflective technology similar to that of sonar used in mapping the ocean floor but in this case it maps the various rock formations below the Earth's surface.



Seismic Data

Seismic data is an image of the earth below the surface of the ground. Seismic data shows different rock formations as layers of reflectors. Different rock types and the fluids in the rocks cause seismic reflection events. Seismic data is collected in the field, processed in a computer center, and interpreted by a geophysicist. There is 2, 3, and 4 dimensional seismic data (2D, 3D, 4D) being collected around the world at this time. 2D seismic shows a single slice of the earth. 3D seismic shows a volume of earth. 4D seismic shows a 3D volume at different times in the life of an oil and/or gas field. 3D seismic is the primary choice of data collection today for oil and gas exploration.

Seismic Data Collection

The "Reflection Seismic Method" is a geophysical technique used to map in 2D or 3D, an image of the earth's subsurface. Reflection Seismic is used by Oil & Gas, Coal Seam Gas, Minerals and Coal Exploration and Production companies to develop a clear understanding of subsurface rock structure and other geologic properties. Sound waves are sent into the ground using an energy source such as vibrators, air guns or dynamite. The sound waves pass through the earth and are reflected off of, and transmitted through, the rock layers. (think of sonar, an MRI, or a cat scan) A seismic crew goes into the field and collects the data.

When is seismic data collected?

Seismic data is collected when the environmental requirements and weather conditions permit. This can be during the day or night. Usually, it is done when there is the least cultural (people) activity. In the countryside acquisition is usually during the day. In the more densely populated areas it may be while most people are sleeping

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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – IV - STRUCTURAL GEOLOGY - SCIA1305

INTRODUCTION

A detailed study of such structural features like folds, faults, joints or architectural pattern of the rocks is known as structural geology.

Technical terms

The following technical terms, which will be mostly used in this chapter and are important from the subject point of view, should be clearly understood at this stage.

1. **Dip:** The inclination of the bedding planes, with the horizontal is called dip and is always expressed in degrees.

While studying the geological maps, we come across the following two types of dips:

True dip: It is the maximum inclination of bedding planes with the horizontal. Or, in other words it is the inclination of the direction in which water would flow, if poured on the upper surface of the bed.

Apparent dip: The inclination of the bedding planes, with the horizontal, in any other direction, other than the direction of the true dip, known as the apparent dip. It is thus obvious that the value of apparent dip is always less than the true dip.

2. **Strike:** It is direction, measured on a horizontal surface, of a line formed by the intersection of dipping bed with the horizontal plane. It is always expressed in terms of main directions i.e., North, South, East or West. It may be noted that the strike is always at right angle to the dip of the beds.

3. **Outcrop:** It is the actual area exposed by a bed on the surface of the earth. A little consideration will show that the outcrop of a rock is affected by the angle of dip.

FOLDS

Folds may be defined as undulations or **bends** or curvatures developed in the **rocks** of the **earth crust** as a result of **stresses.**

Sometimes strata of the earth’s crust are tilted out of the horizontal and are bent into folds. Such a fold may range from a microscopic to great arches and through even up to 100 kilometers across. A set of such arches and troughs is called folds.

Parts of a fold

(i) Axial plane: Axial plane is an imaginary plane, which bisects the angle of a fold and divides it as symmetrically as possible. Axial plane may be vertical, inclined or even horizontal.

(ii) Axis of a fold: If we draw the axis of a fold, showing limbs (of an anticline or syncline) the line which will divide the section of the fold is called *axis of the fold*. It may be noted that the axis of a fold represents the projection of the axial plane on the section.

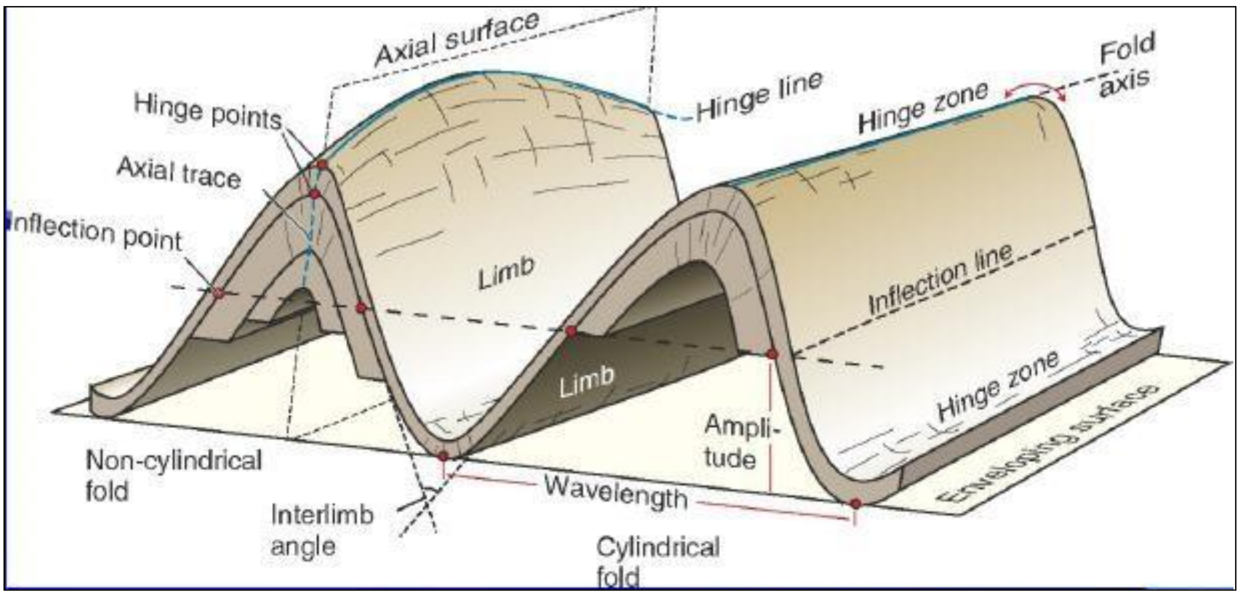

FIGURE 4.1

(iii) Limbs: Limbs are the layers which from the sides of a fold after buckling.

Classifications of folds

Anticline: When the beds are **up folded** in an arch-like structure, it is called an <u>anticline.</u>

Syncline: When the beds are **down folded** in a trough-like structure, it is called a <u>syncline</u>.

It may be noted that in an anticline the oldest rock is in the centre, whereas in a syncline the youngest rock is in the centre.

In their actual existence folds are far from simple and have been variously classified on the basis of following parameters:

I.	Position of the axial plane	V.	Plunge of the folds
II.	The degree of compression	VI.	Profile of the outer surface
III.	Behaviour with depth	VII.	Mode of occurrence
IV.	Relative curvature of the outer and inner arcs	VIII.	Miscellaneous types

I. Position of the axial plane

1. Symmetrical fold: These are also called normal or upright folds. The axial plane is essentially vertical. The limbs are equal in length and dip equally in opposite directions and may be described as symmetrical anticline / syncline.

2. Asymmetrical fold: All those folds, anticlines or synclines, in which the limbs are unequal in length and these dip unequally on either side from the hinge line are termed as Asymmetrical folds. The axial plane in an asymmetrical fold is essentially inclined.

3. Overturned fold: The folds with inclined axial planes in which both the limbs are dipping essentially in the same direction. The amount of dip of the two limbs may or may not be the same.

(i) Over fold: It indicates very severe degree of folding. The reversed limb comes to occupy the present position after having a rotation more than 90 degrees.

(ii) Fan fold: Due to extreme compression from opposite sides results in bringingthe limbs close to each other. The anticlinal limbs dip towards each other and the synclinal limbs dip away from each other. This type of fold is called as a Fan fold.

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

5. Recumbent fold: A fold, in which the axial plane is absolutely horizontal and the limbs are also more or less horizontal, is called a recumbent fold.

6. Conjugate fold: A pair of folds may have mutually inclined axial planes. Such folds are described as conjugate folds.

7. Box fold: A special type of fold with exceptionally flattened top and steeply inclined limbs almost forming three sides of a rectangle. (See fig. conjugate fold)

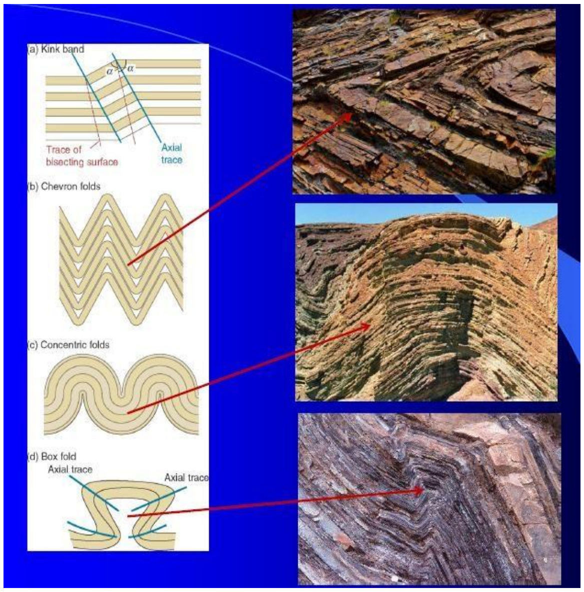

FIGURE 4.2

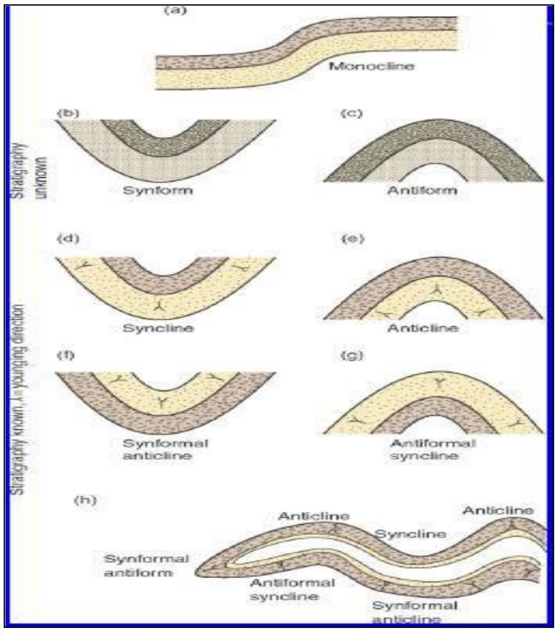

FIGURE 4.3

II. The degree of compression

1. Open fold: A fold, in which the limbs are folded in such a way that the thickness of the limbs remains the same throughout the fold, is called an open fold.

2. Closed fold: A fold, in which the limbs are folded in such a way that the thickness of the limbs is more at the crests and trough (i.e. anticlines and synclines) than that between the crests and troughs, is called a closed fold or tight fold.

III. Behaviour with depth

1. Concentric folds: The effect of the tangential compression in such a way that the thickness of the involved layers remained uniform and constant even after folding.

(i) anticlines become sharper with depth
(ii) synclines become sharper with upwards

2. Similar folds: The degree of folding is observed to be similar for indefinite depths are grouped as similar folds.

In such folds, the axial regions are thicker than the limb regions indicating a plastic type of movement of the material of rocks from the limb regions to the axial regions during the process of folding.

3. Supratenuous folds: The crest regions of the anticline folds may become thinner due to excessive erosion on the outstanding areas and the trough regions may become thicker due to deposition in these low lying areas. Such folds are often described as Supratenuous folds.

IV. Relative Curvature

Ramsay divides all types of folds in three main classes on the basis of relative curvature of the outer and the inner arcs of a fold.

1. Class - 1 folds: All those folds in which the degree of curvature in the outer arc of the fold is less than that of the curvature of the inner arc.

2. Class - 2 folds: All those folds in which the degree of curvature in the outer arc and the inner arc is equal.

3. Class - 3 folds: These are just the reverse of class – 1 folds, in these folds, the degree of curvature of the outer arc is greater than that of the inner arc.

V. Plunge of the folds

1. Plunging fold: The fold axis is not horizontal, i.e. it makes an angle with the horizontal, may be described as a plunging fold. (plunging anticline / plunging syncline)

2. Non-Plunging fold: Any fold in which the axis of fold is essentially horizontal, i.e. the folding continues indefinitely in the direction of the axis of the fold, is specitically described as non-plunging fold (non-plunging anticline / non-plunging syncline)

VI. Profile of the outer surface

Folds may develop distinctly different profiles as seen in cross sections: sharp angled, broadly curved, flat topped, semi-cylindrical and even elliptical and so on.

1. Cheveron folds: These are characterized with well-defined, sharp hinge points and straight planar limbs

2. Conjugate folds: These are composite folds with two hinges and three planar limbs in which the central limb is flattened, sometimes referred as box folds

3. Cuspate folds: The limbs are not planar, curved becoming concave upwards in the case of anticlines and concave downwards in the case of synclines.

VII. Mode of occurrence

1. Anticlinorium: An exceptionally large sized fold, in which the trend of the folding is anticlinal in character, is called **anticlinorium.**

2. Synclinorium: An exceptionally large sized fold, in which the trend of the folding is synclinal in character, is called **synclinorium.**

3. Dome: A fold, in which the limbs are up folded in an arch-like structure and **dip away** in all directions from a common centre, is called a **dome.**

4. Basin: A fold, in which the limbs are down folded in a trough-like structure and **dip-in** from all directions to a common centre, is called a **basin.**

VIII. Miscellaneous types

1. Monocline folds: A fold, in which the limbs are folded locally in a single bend or curvature which lies at different levels and on opposite sides of the bend, is called a monocline fold.

2. Homocline: A sequence of strata dipping in the same general direction at a uniform angle, especially when such structure is established to be a limb of a major fold.

3. Drag fold: As minor folds developed within the body of weaker rocks surrounded on both the sides by layers of stronger rocks

ENGINEERING CONSIDERATIONS

It has been observed that the folded rocks are always under a considerable strain and the same is released whenever the folds are disturbed by some external force or whenever excavation is done through them.

This release of energy may damage the site in many ways, depending upon the nature and intensity of the deformational stresses and the nature of the rocks.

It has also been observed that stones obtained from synclinal formations are harder and tougher than those obtained from anticline formations, as the latter are usually fractured.

It a stone of tougher and harder variety is required, special care should be taken to obtain it from synclinal formations.

This type of duty is slightly difficult to perform, as the labourers would always like to quarry stones from anticline formation, because quarrying is much easier from anticline formations than synclinal formations.

Folds are also important to a water supply engineer, specially when he has to select a suitable site for digging wells for water supply purposes.

It has been observed that if the excavation of a well is done through impervious strata, it will not yield any amount of water. (As in the case of well 'A').

If another well is excavated through pervious strata (As in the case of well 'B') which may be of the same depth as that of 'A', it will yield water in abundance.

Other factors, of course, also play a dominant role, which will be discussed in the later pages of the book.

FAULTS

Faults are fractures, along which the movement of one block, with respect to other block, has taken place.

This movement may vary from a few centimeters to many kilometers depending upon the nature and magnitude of the stresses and the resistance offered by the rocks.

Parts of fault

(i) Fault plane
(ii) Hanging-wall
(iii) Foot-wall
(iv) Hade
(v) Throw
(vi) Heave

(i) Fault plane

A plane along which the rupture has actually taken place and one block has moved with respect to the others is knows as a fault plane.

It may be noted that such a plane is generally formed along the line of least resistance.

(ii) Hanging wall Foot wall

As already mentioned a fault plane separates the two blocks, and when the fault plane is inclined with the horizontal the upper block (it may or may not be at higher level) or in other words the block above the fault plane is called the *hanging wall*.

(iii) Foot wall

The block below the fault plane or in other words beneath the fault plane is called the f*oot wall*.

(iv) Hade

It is the inclination of the fault plane with the vertical.

(v) Throw

It is the vertical displacement between the hanging wall and the footwall.

(vi) Heave

It is the horizontal displacement between the hanging wall and the footwall.

Classification of faults

Faults are classified on the basis of their apparent displacement, i.e. the direction of movement, of one block with respect to the other along the fault plane.

1. **Normal fault:** A fault, in which the hanging wall has apparently come down with respect to the foot wall, is known as a *normal fault.*

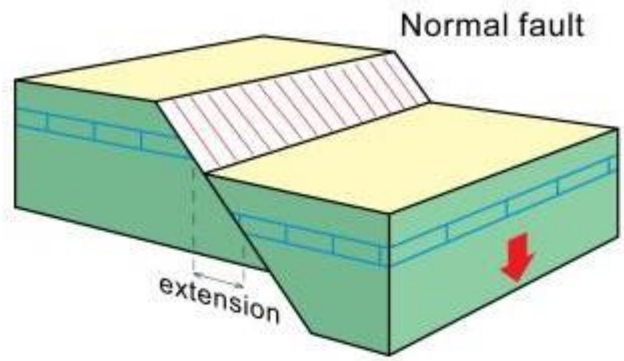

FIGURE 4.4

2. **Reverse fault:** A fault, in which the hanging wall has apparently gone up with respect to the foot wall, is known as a reverse fault.

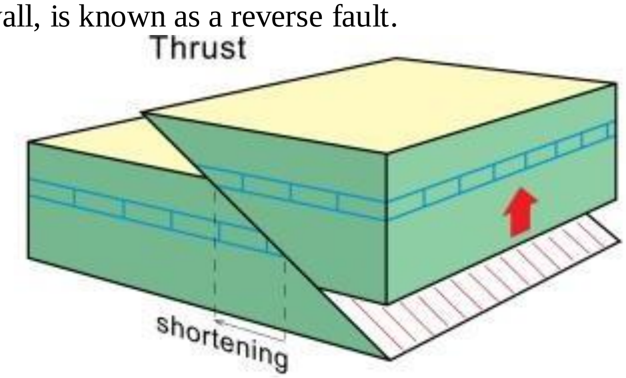

FIGURE 4.5

3. **Thrust fault:** A fault, which has a very small angle of hade (i.e., inclination of the fault plane with the vertical is very small) and the hanging wall has apparently gone up with respect to foot wall is called a *thrust fault.*

4. **Vertical fault:** A fault, in which the fault plane is vertical (or having an angle of hade up to 5^0) and either of the walls has moved upwards or downwards is called a vertical fault.

5. **Horst fault:** Horst (German, *Horst*=Up throw) fault is one, in which a wedge shaped block has gone up with respect to the side blocks.

6. **Graben fault (or) Trough fault:** Graben fault (German, *Graben*=Trench) is one in which a wedge shaped block has come down with respect to the side blocks. The only difference between a Horst fault and a Graben fault is, that in

a Horst fault a wedge shaped block has gone up. Whereas in a Graben fault the wedge shaped block has come down with respect to the side blocks.

7. **Strike fault:** A fault, in which the fault trace or fault plane is absolutely parallel to the strike of the adjacent rocks, is known as a strike fault.

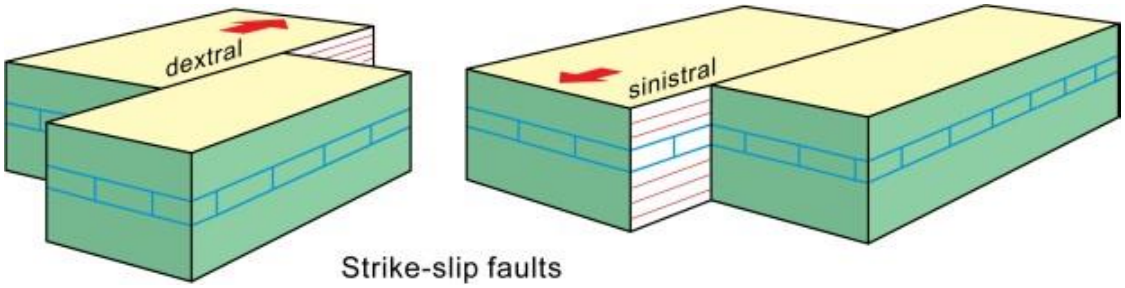

FIGURE 4.6

8. **Dip fault or traverse fault:** A fault, in which the fault trace or fault plane is absolutely parallel to the direction of the dip of the adjacent rocks, or in other words at right angles to the strike of the beds, is known as a dip fault or traverse fault.

9. **Parallel fault:** It is a series of faults, which occur absolutely in the same direction *i.e.* strike and have the same inclination.

10. **Step fault:** A step fault is a particular type of a parallel fault, in which the movement of each successive block takes place in such a manner that the structure gives a stair-like or step-like appearance.

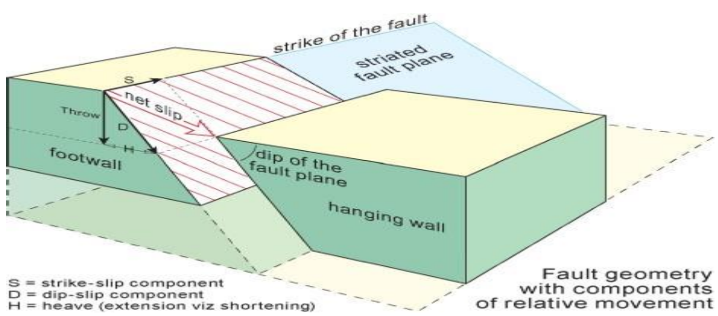

FIGURE 4.7

ENGINEERING CONSIDERATIONS

Strictly speaking no site should be selected on a fault for any major project and the least in an area where the fault or faults are 'active' due to recent earth movements;

Because movement along the existing fault plane is much easier than any other plane or along a crack. Even a slight disturbance is sufficient for a movement to take place and to damage the structure, built on it.

Sometimes an engineer is unable to avoid faults, as in the case of a reservoir. In such cases a fault affects the side adversely in two ways.

Faults cause leakage in the water, and after some time when the strata under the fault become sufficiently moistened, it loses its cohesive power which causes more displacement of blocks or new blocks to displace.

Such displacements make the position from bad to worse. In such cases the faults should be thoroughly improved either by grouting or removing the loose material and refilling it with cement concrete, whichever is possible, depending upon the intensity of the fault and nature of the rocks.

If the project is very important like a dam, a tunnel or a multistoried building, and at the same time the extent to which the fault has taken place is large, it is evident that the structure is not safe, if constructed on such a fault.

The structure may collapse at any moment even due to a slight disturbance. It is therefore advisable that such a site should be avoided. If the project is of a scattered nature like electric or telegraphic poles, the work can be carried out without much of a risk.

In general a few safety factors should be provided in any building constructed over a fault by suitable modifications in the architectural and engineering design of the building to bear the initial shocks of an earthquake of low intensity.

JOINTS

Joints are defined as divisional planes or fractures along which there has been **no relative displacement.**

FIGURE 4.8

Joints may be **open** or **closed** in nature.

Open joints are those in which the blocks have been separated or opened up for small distances in a direction at right angles to the fracture surface

Closed joints, there is no such separation. Even then, these joints may be capable of allowing water and gases.The joints may be small in their extension, confined to only a part of a layer or mass of rock, or they may be quite important and extending for considerable depth and thickness. The more important continuous joints are often called the **master joints**

Grouping -Joints generally occur in groups of two or more joint planes

Joint set is a group of two or more joint surfaces trending in the same direction with almost the same dip.

Joint system is a group of two or more joint sets.

Classification of joints

I. spatial relationship

1. Systematic joints (regular joints):

A distinct regularity in their occurrence which can be measured and mapped easily. Such joints occur in parallel or sub-parallel joint sets that are repeated in the rocks at regular intervals.

(i) Sheet jointing: In granites and other related igneous rocks, a horizontal set of joints often divides the rock mass gives an appearance of a layered sedimentary structure, called **sheeting structure**.

(ii) Mural jointing: In granitic and other rock masses, there may occur three sets of joints in such a way that one set is horizontal and the other two sets are vertical, all the three sets being mutually at right angles to each other.This sort of geometrical distribution of joints dividing the rock mass into cubical blocks or **murals** is called **mural jointing**.

(iii) Columnar jointing: These types of joints are typical of volcanic igneous rocks although they may also be observed in other rocks. These are also called prismatic joints. The joints divide the rock mass into polygonal blocks, each block being bounded by three to eight sides. Five and six sided blocks are common.

2. Non-systematic joints (irregular joints)

These joints do not possess any regularity in their occurrence and distribution.

II. Geometry

1. Strike joints:

The joint sets strike parallel to the strike of the rocks.

2. Dip joints:

The joint sets strike parallel to the dip direction of the rocks.

3. Oblique joints:

The joints where the strike of the joints is at any angle between the dip and the strike of the layers. These are also called diagonal joints.

4. Bedding joints:

Some joints may develop essentially parallel to the bedding planes

III. Genesis (origin)

1. Tension joints:

It is developed due to the tensile forces acting on the rocks. The location of such joints in folded series is on the outer margins of crests and troughs.

2. Compression joints:

Rocks may be compressed to crushing and numerous joints may result due to the compressive forces.

3. Shear joints:

These are commonly observed in the area of fault planes and shear zones where the shearing forces is clearly established.

Engineering considerations

Study of joints in a rock is always essential for an engineer, which is helpful to him in many ways. It may be noted that joints always play a major role in the geological survey of a site. Some of the engineering problems, directly or indirectly related to the joints, are briefly discussed here.

(i) Quarrying operations:

Quarrying is a manual or mechanical process of taking out stones, of various sizes from an earth depression or open from one side. It has been experienced that joints always facilitate the extraction of stones and cut down the expenses involved in the quarrying operations. This charming and attractive property of joints sometimes concentrates and attracts mind of an engineer to select such a quarry, for the extraction of stones, especially when the stones are required for road metal or other forms of crushed stones. Sometimes a jointed quarry has to be rejected, especially when the stones of large sizes are required, but the joints are closely spaced in the quarry under consideration.

(ii) Tunnelling:

It has been experienced that if the joints are in abundance or closely spaced, it practically makes the rocks insecure and lot of grouting[1] is required to hold the rock in its original position.

Sometimes when grouting does not seem to be sufficiently safe, heavy liming has to be provided. It is therefore advisable that a rock, which is heavily jointed, should preferably be avoided for a tunnel to be driven through. It may be noted that if the tunnel is required for the conduction of water, badly or heavily jointed rock may permit considerable leakage of water.

(iii) Reservoir site:

It has been experienced that the joints always permit considerable leakage of water. It joints in a reservoir site are in abundance, it makes the site sometimes worthless. In limestone- formations joints may be enlarged by solution.

The only remedy, that can be done at the best is grouting. But such a cure is hardly practicable unless the joints are local in character or the area affected is small, in such cases grouting improves the site and may be relied upon.

UNCONFORMITY

An unconformity is a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous. In general, the older layer was exposed to erosion for an interval of time before deposition of the younger, but the term is used to describe any break in the sedimentary geologic record.

Disconformity

A disconformity is an unconformity between parallel layers of sedimentary rocks which represents a period of erosion or non-deposition. Disconformities are marked by features of subaerial erosion. This type of erosion can leave channels and paleosols in the rock record. A paraconformity is a type of disconformity in which the separation is a simple bedding plane with no obvious buried erosional surface.

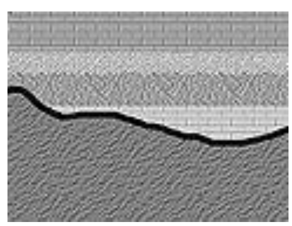

FIGURE 4.9

Nonconformity

A nonconformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock. Namely, if the rock below the break is igneous or has lost its bedding due to metamorphism, the plane of juncture is a nonconformity.

Angular unconformity

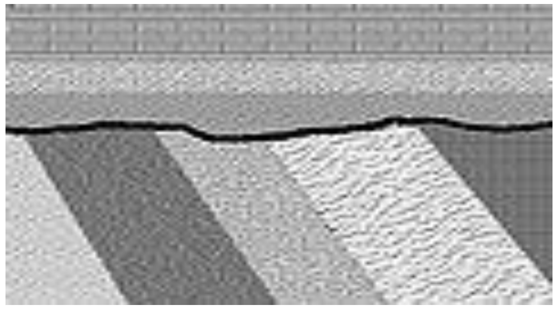

FIGURE 4.10

An angular unconformity is an unconformity where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers, producing an angular discordance with the overlying horizontal layers. The whole sequence may later be deformed and tilted by further orogenic activity. A typical case history is presented by the paleotectonic evolution of the Briançonnais realm (Swiss and French Prealps) during the Jurassic.

Paraconformity

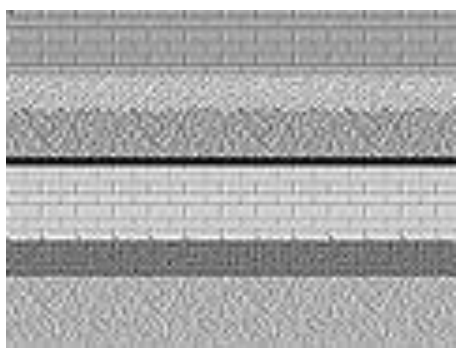

FIGURE 4.11

paraconformity is a type of unconformity in which strata are parallel; there is no apparent erosion and the unconformity surface resembles a simple bedding plane. It is also called nondepositional unconformity or pseudoconformity.[9][10]

Buttress unconformity

A buttress unconformity occurs when younger bedding is deposited against older strata thus influencing its bedding structure.[11]

Blended unconformity

A blended unconformity is a type of disconformity or nonconformity with no distinct separation plane or contact, sometimes consisting of soils, paleosols, or beds of pebbles derived from the underlying rock.[12]

PROSPECTING OF GROUNDWATER

Groundwater is water that exists in the pore spaces and fractures in rock and sediment beneath the Earth's surface. It originates as rainfall or snow, and then moves through the soil into the groundwater system, where it eventually makes its way back to surface streams, lakes, or oceans.

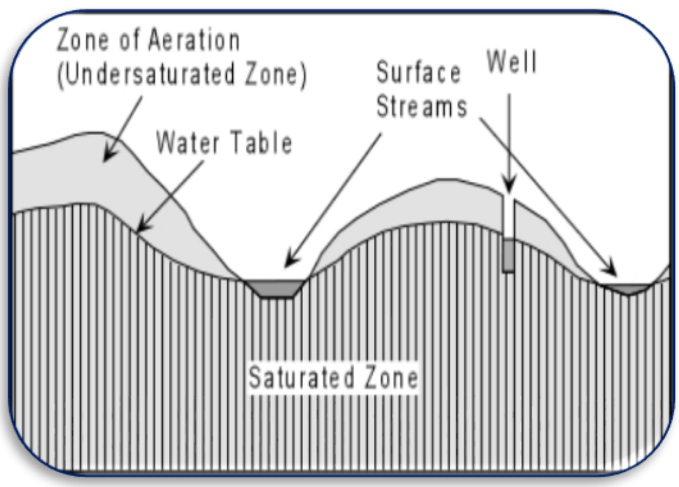

FIGURE 4.12

- Groundwater makes up about 1% of the water on Earth (most water is in oceans).
- Groundwater occurs everywhere beneath the Earth's surface, but is usually restricted to depths less that about 750 meters.
- The volume of groundwater is a equivalent to a 55 meter thick layer spread out over the entire surface of the Earth.

Rain that falls on the surface seeps down through the soil and into a zone called the zone of aeration or unsaturated zone where most of the pore spaces are filled with air. As it penetrates deeper it eventually enters a zone where all pore spaces and fractures are filled with water. This zone is called the saturated zone. The surface below which all openings in the rock are filled with water (the top of the saturated zone) is called the water table

The water table occurs everywhere beneath the Earth's surface. In desert regions it is always present, but rarely intersects the surface

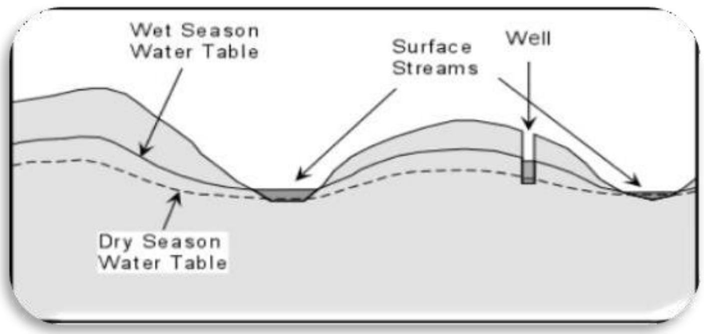

FIGURE 4.13

In more humid regions it reaches the surface at streams and lakes, and generally tends to follow surface topography. The depth to the water table may change, however, as the amount of water flowing into and out of the saturated zone changes. During dry seasons, the depth to the water table increases. During wet seasons, the depth to the water table decreases.

Porosity is the percentage of the volume of the rock that is open space (pore space). This determines the amount of water that a rock can contain.

In sediments or sedimentary rocks the porosity depends on grain size, the, and the degree of and the cementation degree of cementation.

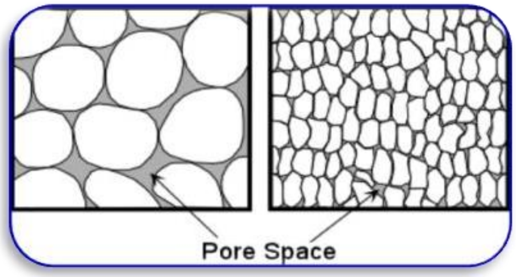

FIGURE 4.11

Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments, because the grains do not fit together well.

Poorly sorted sediments usually have lower porosity because the fine-grained fragments tend to fill in the open space.

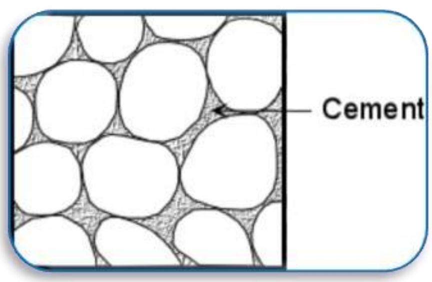

FIGURE 4.12

Since cements tend to fill in the pore space, highly cemented sedimentary rocks have lower porosity.

In igneous and metamorphic rocks porosity is usually low because the minerals tend to be intergrown, leaving little free space. Highly fractured igneous and metamorphic rocks, however, could have high porosity.

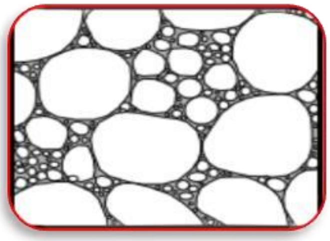

FIGURE 4.13

Permeability is a measure of the degree to which the pore spaces are interconnected, and the size of the interconnections. Low porosity usually results in low permeability, but high porosity does not necessarily imply high permeability. It is possible to have a highly porous rock with little or no interconnections between pores. A good example of a rock with high porosity and low permeability is a vesicular volcanic rock, where the bubbles that once contained gas give the rock a high porosity, but since these holes are not connected to one another the rock has low permeability.

A thin layer of water will always be attracted to mineral grains due to the unsatisfied ionic charge on the surface. This is called the force of molecular attraction. If the size of interconnections is not as large as the zone of molecular attraction, the water can't move. Thus, coarse-grained rocks are usually more permeable than fine-grained rocks, and sands are more permeable than clays.

Table 4.1

Sediment	**Porosity (%)**	**Permeability**
Gravel	25 to 40	excellent
Clean Sand	30 to 50	good to excellent
Silt	35 to 50	moderate
Clay	35 to 80	poor
Glacial Till	10 to 20	poor to moderate
Rock	**Porosity (%)**	**Permeability**
Conglomerate	10 to 30	moderate to excellent
Sandstone		
Well-sorted, little cement	20 to 30	good to very good
Average	10 to 20	moderate to good
Poorly sorted, Well cemented	0 to 10	poor to moderate

Springs

A spring is an area on the surface of the Earth where the water table intersects the surface and water flows out of the ground. Springs occur when an impermeable rock (called an **aquiclude**) intersects an permeable rock that contains groundwater (an aquifer). Such juxtaposition between permeable and impermeable rock can occur along geological contacts (surfaces separating two bodies of rock), and fault zones.

Wells

A well is human-made hole that is dug or drilled deep enough to intersect the water table. Wells are usually used as a source for groundwater. If the well is dug beneath the water table, water will fill the open space to the level of the water table, and can be drawn out by a bucket or by pumping. Fracture systems and perched water bodies can often make it difficult to locate the best site for a well.

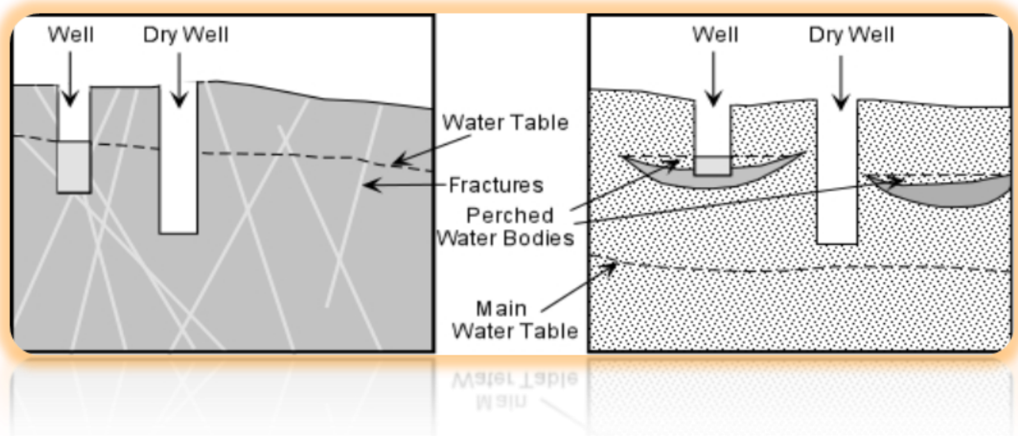

FIGURE 4.14

Aquifers: An aquifer is a large body of permeable material where groundwater is present in the saturated zone. Good aquifers are those with high permeability such as poorly cemented sands, gravels, and sandstones or highly fractured rock. Large aquifers can be excellent sources of water for human usage such as the High Plains Aquifer (in sands and gravels) or the Floridian Aquifer (in porous limestones) as outlined in your text. Aquifers can be of two types

Unconfined Aquifers - the most common type of aquifer, where the water table is exposed to the Earth's atmosphere through the zone of aeration. Most of the aquifers depicted in the drawings so far have been unconfined aquifers.

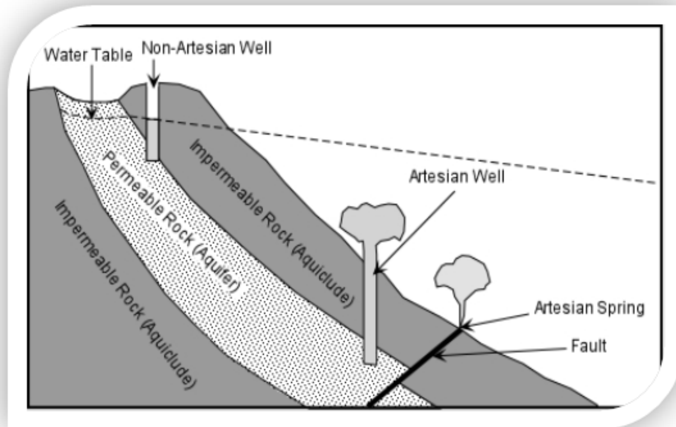

FIGURE 4.15

Confined Aquifers - these are less common, but occur when an aquifer is confined between layers of impermeable strata. A special kind of confined aquifer is an artesian system, shown below. Artesian systems are desirable because they result in free flowing artesian springs and artesian wells.

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SCHOOL OF BUILDING ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – V - ENGINEERING APPLICATIONS IN GEOLOGY - SCIA1305

GEOLOGICAL CONDITIONS NECESSRY FOR CONSTRUCTION OF DAMS

DEFINITION

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

SELECTION OF SITES

Topographically

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

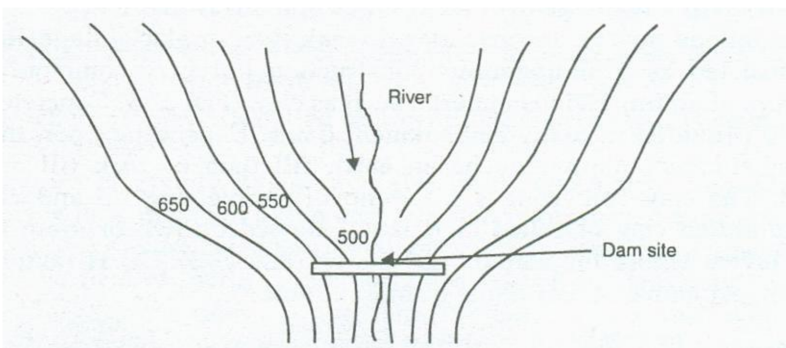


FIGURE 5.1

Technically

- The site should be as sound as possible: strong, impermeable and stable.
- Strong rocks at the site make the job of the designer much easy: he can evolve best deigns.
- Impermeable sites ensure better storage inventories.

- Stability with reference to seismic shocks and slope failures around the dam, especially upstream, are a great relief to the public in general and the engineer in particular.
- The slips, slides, and slope failures around and under the dam and susceptibility to shocks during an earthquake could prove highly hazardous.

Constructionally

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

Economically

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

Environmentally

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

GEOLOGICAL CHARACTERS FOR INVESTIGATION

Geology of the Area

Preliminary geological surveys of the entire catchments area followed by detailed geological mapping of the reservoir area have to be conducted. These should reveal

- main topographic features,
- natural drainage patterns,
- general characters and structures of rock formations such as their stratification, folding and faulting and igneous intrusions, and
- the trend and rate of weathering and erosion in the area.

Geology of the site

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

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

➢ While mapping these features, special attention is given to recording their attitude, spacing and nature.

➢ Shear zones have to be searched, mapped and treated with great caution.

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

FOLLOWING IS A BRIEF ACCOUNT OF THE INFLUENCE OF MORE IMPORTANT STRUCTURAL FEATURES OF ROCKS ON DAM FOUNDATIONS

Dip and Strike

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

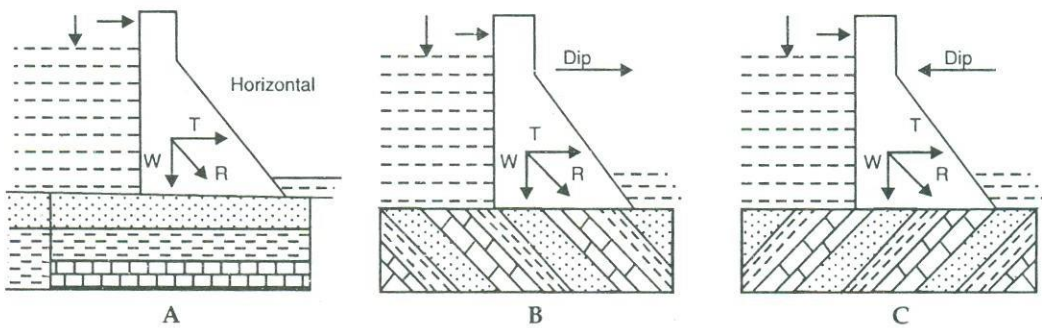


FIGURE 5.2

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

Faults

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

- The faulted rocks are generally shattered along the rupture surfaces;
- Different types of rocks may be present on either side of a fault plane. Hence, sites with fault planes require great caution in calculating the design strength in various sections of the dam.

- Dams founded on beds traversed by fault zones and on major fault planes are more liable to shocks during an earthquake compared to dams on non-faulted rocks.

TUNNELS

<u>Definition</u>

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

<u>Geological Investigations</u>

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

<u>Selection of Tunnel Route</u> (Alignment).

- There might be available many alternate alignments that could connect two points through a tunnel.
- the final choice would be greatly dependent on the geological constitution along and around different alternatives

<u>Selection of Excavation Method</u>.

- Tunnelling is a complicated process in any situation and involves huge costs which would multiply manifolds if proper planning is not exercised before starting the actual excavation.
- And the excavation methods are intimately linked with the type of rocks to be excavated.
- Choice of the right method will, therefore, be possible only when the nature of the rocks and the ground all along the alignment is fully known.
- This is one of the most important aim and object of geological investigations.

Selection of Design for the Tunnel.

- The ultimate dimensions and design parameters of a proposed tunnel are controlled, besides other factors, by geological constitution of the area along the alignment.
- Whether the tunnel is to be circular, D-Shaped, horse-shoe shaped or rectangular or combination of one or more of these outlines, is more often dictated by the geology of the alignment than by any other single factor.
- Thus, in self-supporting and strong rocks, either, D-shape or horse-shoe shape may be conveniently adopted but these shapes would be practically unsuitable in soft ground or even in weak rocks with unequal lateral pressure.

Assessment of Cost and Stability.

- These aspects of the tunnelling projects are also closely interlinked with the first three considerations.
- Since geological investigations will determine the line of actual excavation, the method of excavation and the dimensions of excavation as also the supporting system (lining) of the excavation, all estimates about the cost of the project would depend on the geological details.
- Similarly tunnels passing through hard and massive rocks even when left unsupported may be regarded as stable.

Assessment of Environmental Hazards:

- The process of tunnelling, whether through rocks or through soft ground, and for whatsoever purpose, involves disturbing the environment of an area in more than one way.
- The tunnelling methods might involve vibrations induced through blasting or ground cutting and drilling, producing abnormal quantities of dust and last but not the least, interference with water supply system of the nearby areas.
- A correct appreciation of geological set up of the area, especially where tunnel alignment happens to be close to the populated zones, would enable the engineer for planning and implementing plans aimed at minimizing the environmental hazards in a successful manner.

Methods

A. Preliminary Surveys

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

The general topography

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

The litho logy

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

The hydrological conditions

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

The structural condition

- The structural condition of the rock, that is, extent and attitude of major structural features such as folding, faulting, unconformities, jointing and shearing planes, if developed.
- Existence of buried valleys are also established during the preliminary surveys.

B. Detailed Surveys

Bore-Hole Drilling

- bore-hole drilling along proposed alignments and up to desired depths;
- the number of bore-holes may run into dozens, scores or even hundreds, depending upon the length of the tunnel;

- rock samples obtained from bore holes are analysed for their mechanical and geo-chemical properties in the laboratories;

Drilling Exploratory

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

Driving Pilot Tunnels

- Driving pilot tunnels which are essentially exploratory in nature but could better be used as a main route if found suitable by subsequent enlargement.
- The actual number of bore holes and shafts and adits and their depth and length are decided by the length and location of the proposed tunnel.
- For tunnels with little overburden, these may be driven close to the proposed tunnel.

GEOLOGICAL CONSIDERATIONS IN TUNNELLING

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

- consolidated and
- unconsolidated or soft

ground. Only a brief accounts is given below.

(A) Consolidated Rocks

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

Lithology

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

- the method of tunneling
- the strength and extent of lining and, thus

- the cost of the project.

Hard and Crystalline Rocks

These are excavated by using conventional rock blasting methods and also by tunnel boring method. In the blasting method, full face or a convenient section of the face is selected for blasting up to a pre-selected depth. These are loaded with predetermined quantities of carefully selected explosives of known strength. The loaded or charged holes are ignited or triggered and the pre-estimated rocks get loosened as a result of the blast. The blasting round is followed by a mucking period during which the broken rock is hauled out of the excavation so created.

The excavations in hard and crystalline rocks are very often self supporting so that these could be left unlined and next round of blasting in the new face created is undertaken, ensuring better advance rate. Rocks falling in this group include granites, diorites, syenites, gabbros, basalts and all the related igneous rocks, sandstones, limestones, dolomites, quartzites, arkose, greywackes and the like from sedimentary group and marbles, gneisses, quartzites, phyllites and slates from the metamorphic groups. When any one of these rocks is stressed, such as during folding or fractured as during faulting, tunnelling in these rocks proves greatly hazardous. Rock bursts which occur due to falling of big rock blocks from roofs or sides due to release of stresses or falling of rock block along fractures already existing in these rocks often cause many accidents.

Soft Rocks

This group includes shales, friable and poorly compacted sandstones, chalk and porous varieties of limestones and dolomities, slates and phyllites with high degree of cleavage and also decomposed varieties of igneous rocks. Their excavation cost, volume for volume, might be lower than those in hard rocks. Hence, temporary and permanent lining becomes necessary that would involve extra cost and additional time. Rocks like clays, shales, argillaceous and ferruginous sandstones, gypsum bands and cavernous limestones have to be viewed specially with great caution during tunnelling

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

(b) Geological Structures

Dip and Strike

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

Horizontal Strata

When encountered for small tunnels or for short lengths of long tunnels, horizontally layered rocks might be considered quite favourable. In massive rocks, that is, when individual layers are very thick, and the tunnel diameter not very large, the situation is especially favourable because the layers would then over bridge flat excavations by acting as natural beams
But when The layers are thin or fractured, they cannot be depended upon as beams; in such cases, either the roof has to be modified to an arch type or has to be protected by giving a lining. Sides of tunnels, however, could be left unsupported except when the rocks are precariously sheared and jointed.

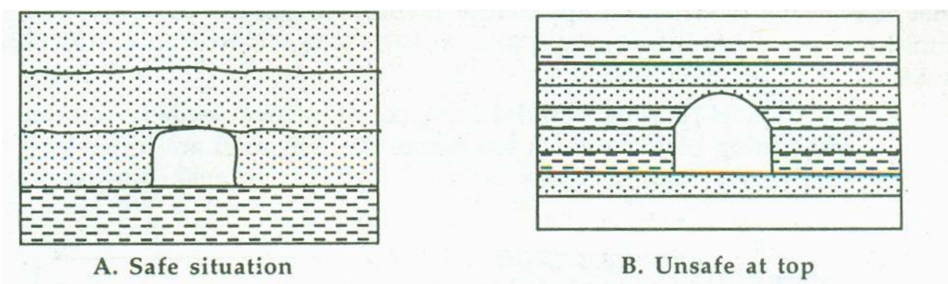


FIGURE 5.3

Moderately Inclined Strata.

- Such layers that are dipping at angles up to 45° may be said as moderately inclined.
- The tunnel axis may be running parallel to the dip direction, at right angles to the dip direction or inclined to both dip and strike directions.
- In the first situation, that is, when the tunnel axis is parallel to the dip direction the layers offer a uniformly distributed load on the excavation.

- The arch action where the rocks at the roof act as natural arch transferring the load on to sides comes into maximum play.
- Even relatively weaker rocks might act as self-supporting in such cases.
- It is a favourable condition from this aspect.
- it also implies that the axis of the tunnel has to pass through a number of rocks of the inclined sequence while going through parallel to dip

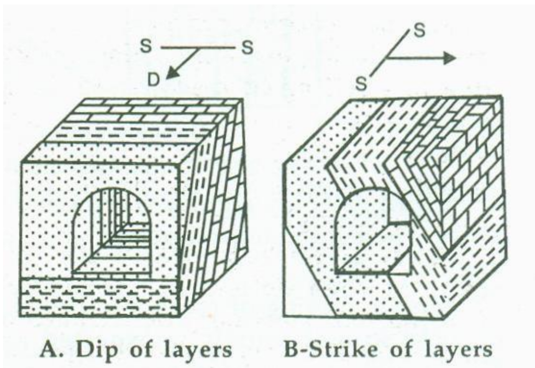


FIGURE 5.4

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

Steeply Inclined Strata

- ➢ In rock formations dipping at angles above 45°, quite complicated situations would arise when the tunnel axis is parallel to dip or parallel to strike or inclined to both dip and strike directions.

- In almost vertical rocks for example, when the tunnel axis is parallel to dip direction, the formations stand along the sides and on the roof of the tunnel as massive girders.
- An apparently favourable condition, of coarse, provided all the formations are inherently sound and strong

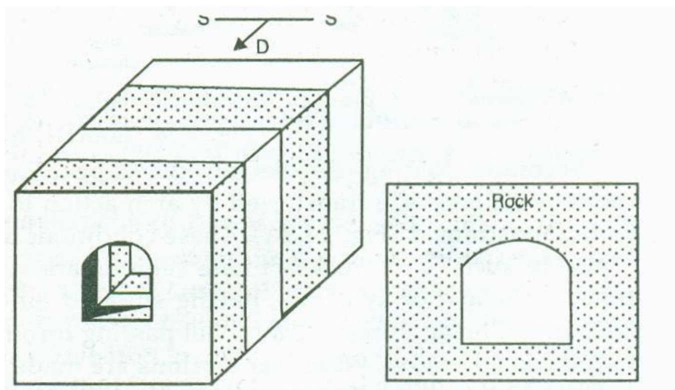


FIGURE 5.5

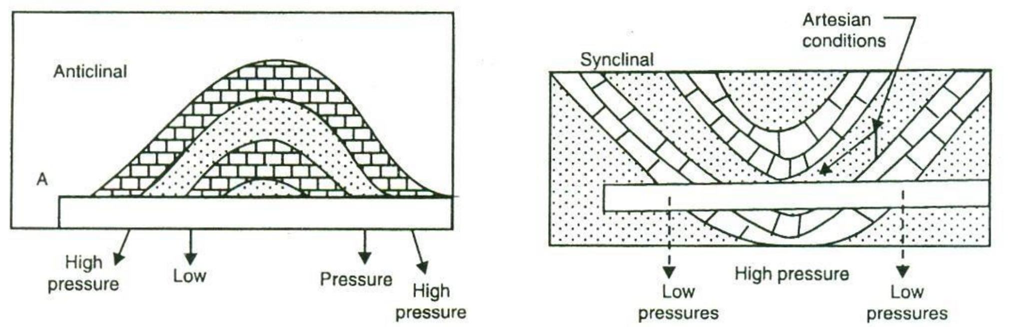
Folding

- Folds signify bends and curvatures and a lot of strain energy stored in the rocks. Their influence on design and construction of tunnels is important from at least three angles:
- Firstly, folding of rocks introduces considerable variation and uncertainty in a sequence of rocks so that entirely unexpected rocks might be encountered along any given direction.
- This situation becomes especially serious when folding is not recognized properly in preliminary or detailed surveys due either to its being localized or to misinterpretation.
- Secondly, folding of rocks introduces peculiar rock pressures.
- In anticlinal fold, loads of rocks at the crest are transferred by arch action to a great extent on to the limbs which may be highly strained
- These conditions are reversed when the folds are of synclinal types.
- In such cases, rocks of core regions are greatly strained.
- Again, the axial regions of folds, anticlinal or synclinal, having suffered the maximum

bending are more often heavily fractured.

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

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



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

FIGURE 5.6

- Thirdly, folded rocks are often best storehouses for artesian water and also ideal as aquifers.
- When encountered during tunnelling unexpectedly, these could create uncontrollable situations.
- The shattered axial regions being full of secondary joint systems are highly permeable.
- As such very effective drainage measure are often required to be in readiness when excavations are to pass through folded zones.

Faulting

- Similarly, fault zones and shear zones are highly permeable zones, likely to form easy avenues for ground water passage.
- Inclined fault planes and shear zones over the roof and along the sides introduce additional complications in computation of rock pressure on the one hand and of rock strengths on the other.

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

Joint Systems

- Joints are cracks or fractures developed in rocks due to a variety of causes.
- Although all types of joints tend to close with depth (due to load of overburden), their presence and orientation, has to be investigated.
- Joints are planes of weakness and must always be suspected when the rocks are folded and faulted.
- Even originally closed joints may become reactive and open up in the immediate vicinity of tunnel excavation.
- Jointed rocks cannot be considered as self-supporting although these might belong to massive

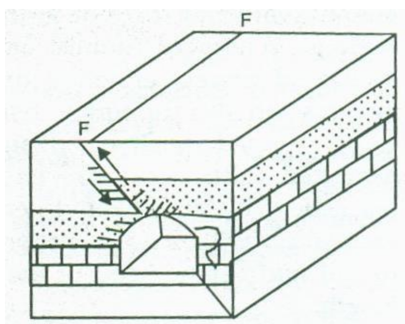


FIGURE 5.7

Ground Water Conditions

- Determination of ground water conditions in the region of tunnel project is not to be under-estimated at any cost.
- In fact ground water level vis-à-vis tunnel axis is a major factor governing computations of overhead loads on tunnels and also in the choice of method of tunnelling.
- Groundwater conditions effect the tunnel rocks in two ways

- Firstly, through its physico-chemical action, it erodes and corrodes (dissolves) the susceptible constituents from among the rocks and thereby alters their original properties constantly with the passage of time.
- It might have already done much of this type of job when the tunnel is excavated through such water-rich rocks.
- Secondly, it effects the rock strength parameters by its static and dynamic water heads.
- Such an action may become highly pronounced when an artesian acquifer is actually intercepted by tunnel excavation.

RESERVOIR

Millions of people throughout the world depend on dams and reservoirs for electricity, water and flood protection. Dams require significant investment to build and maintain, and yet their usefulness and integrity are constantly threatened by leakage and sedimentation. Isotope hydrology techniques, combined with conventional analytical methods, are a cost-effective tool to reduce such threats. The International Atomic Energy Agency is promoting their use to protect these investments and improve management, particularly by supporting specialized teams of scientists and engineers to investigate dam leakage in African countries on request.

Dams, ancient and modern

The oldest dams, for which there is documentary evidence, were located in Jordan some 5,000 years ago. Most ancient dams have long since disappeared but, exceptionally, some are still operational 1,000 years after being built. Modern, large dam construction continues today and represents a considerable initial investment and recurring maintenance costs thereafter. Studies have shown that large dams have an average lifespan of 22 years which means that many of those constructed in the ‘70s are today nearing the end of their useful life. Millions of people depend on dams and reservoirs for domestic, industrial and agricultural water supply, for flood protection and for electricity. National economies are often highly dependent on the power generated by such dams. Furthermore, even when a dam comes to the end of its economically useful life, ensuring that it remains safe is a continuing economic burden. Prolonging the useful life of a dam is a priority for operators and national governments. Even newly constructed dams are expected to lose, on average, 1% of reservoir capacity every year as a result of sedimentation, and millions of US dollars are invested in grouting and sealing due to real and suspected leaks.

Seepage vs. leakage

All dams are designed to lose some water through seepage. This helps make a dam more stable. Controls to keep seepage at an acceptably low level are designed and incorporated into the dam and its foundations. Leakage occurs when seepage concentrates through a weak area in the dam

or works its way in the foundation or abutment. Leakage can present a serious problem, especially if it also carries sediment - an indication that erosion could threaten dam stability. Field investigations When a dam appears to be leaking, there are enormous pressures on operators to repair the leak without delay. This is not only to ensure continued efficient power generation, for example, but also for safety reasons. Very large sums of money are spent on construction engineering to repair or mitigate:

- Leaks from reservoirs that flow under and around dams;
- Leakage through dams, foundations and abutments; and
- Sedimentation within the reservoir.

Isotope Hydrology

One of the most efficient and least costly methods of detecting the origin of leaks is to use isotope investigations, specifically natural and artificial tracers, to follow the movement of water.

GEOLOGICAL WORK OF EARTHQUAKE

An earthquake is a sudden vibration of earth surface by rapid release of energy. This energy released when two parts of rock mass move suddenly in relation of to each other along a fault.

EFFECTS OF EARTHQUAKE:

Buildings are damaged

Roads are fissured, railway lines are twisted and bridges are

destroye Rivers change their coarse

Landslides may occur in hilly region.

TERMINOLOGY:

FOCUS:

The point of origin of an earthquake within the earth crust is called focus.It radiates earthquake waves in all direction

EPICENTRE:

The point lying vertically above the earth surface directly above focus is called epicentre.
In the epicentre the shaking is most intense. The intensity gradually decrease

ISOSEISMAL LINES:

The line connecting points of equal intensity on the ground surface are called isosesimal lines

EARTHQUAKE INTENSITY: It is a measure of the degree of distraction caused by an earthquake. It is expressed by a number as given in the earthquake intensity scale

SESIMOGRAPHS:

Seismographs are instruments which detect and record earthquakes.

EARTHQUAKE WAVES (SEISMIC WAVES):

1. P-Waves (primary waves)

2. S-Waves (secondary waves)

3. L-Waves (surface waves)

During earthquake elastic waves are produced are called seismic waves.

P-Waves

These are longitudinal waves having short wavelength. They travel very faster and reach seismic station first. Their velocity is 1.7 times greater than s-waves. They passes through solid, liquid, gaseous medium.

S-WAVES

These are shear waves which are traverse in nature. They travel only in solid medium.

L-WAVES

When p and s- waves reached earth surface they are called l- waves. Herevelocity is much less.

CLASSIFICATION OF EARTHQUAKE:

CLASSIFICATION –I: Depending on mode of origin

1. **DUE TO SURFACE CAUSES**: Generated by land slopes and collapse of root of underground waves

2. **DUE TO VOLACANIC CAUSES**: It may also produce earthquake but very feeble.

3. **DUE TO TECTONIC PLATES**: Most numerous and disastrous and caused by shocks originated in earth crust due to sudden movement of faults.

CLASSIFICATION-II: Depending on depth of focus

1. **SHALLOW FOCUS**: Depth of focus upto 55kms.

2. **INTERMEDIATE FOCUS:** Depth between 55-300kms.

3. **DEEP FOCUS**; Depth from 300-600kms.

The shallow earthquake are more violent at the surface but affect smaller area.

EARTHQUAKE INTENSITY SCALE:

ROSSI FOREL SCALE: It has 9 divisions *INTENSITY-I*: Weakest earthquake *INTENSITY-IV*: Cause damage to property

INTENSITY-IX: Strongest earthquake that cause massive destruction to manmade structure and natural objects.

RICTHER SCALE: Devised by *Charles .F. Ritcher* an American seismologist

MAGNITUDE EFFECTS

2.5 Not felt but recorded

4.5 Local damage

6.0 Can be destructive in popular region

7.0 Major earthquake inflict series damage

8.0 Great earthquake cause total destruction

DISTRIBUTION OF EARTHQUAKE:

The zones where earthquake occurs are known as seismic belts.

CIRCUM PACIFIC BELT: (PACIFIC OCEAN): 80%of the world earthquake occur in this belt

ALPINE HIMALAYAN BELT: Europe to East Indies **RIFT VALLEY REGION**: East and Central Africa **MAGNITUDE:**

The total amount of energy release during an earthquake.

ENGINEERING CONSIDERATION:

SEISMIC HISTORY:

Study of seismic events in particular region to know the intensity and magnitude. By seismic zoning , area are classified on their varying earthquake and also geological setting of areas

PROBLEMS:

To know the seismic history of area

To access the magnitude and probable loss or damage in quality or quantity due to

likely seismic shocks in the period of the structure

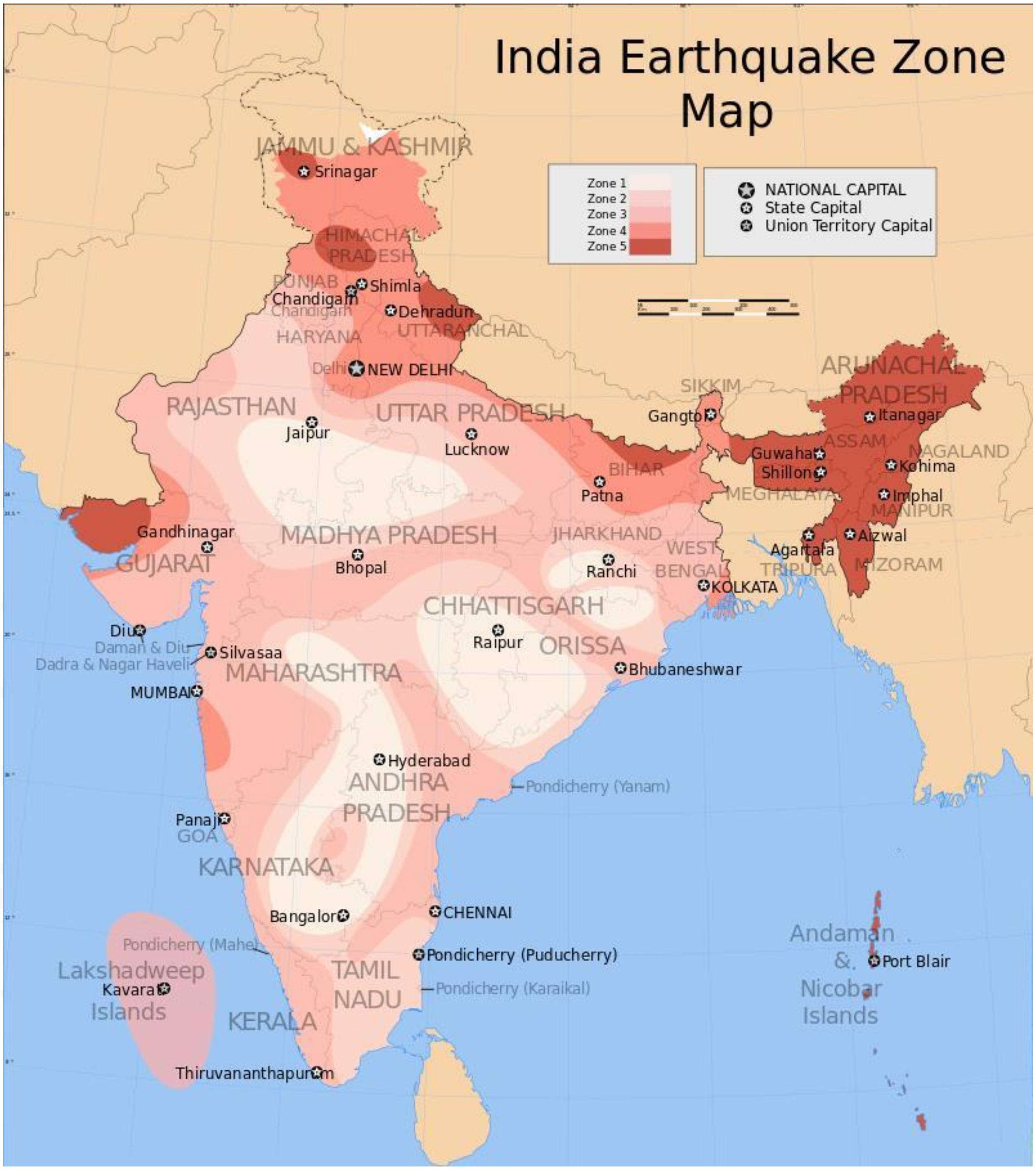
To introduce safety factors in new construction and possible to safeguard early structure

ASSESMENT OF SEISMIC RISK:

Seismic risk is the probability of occurrence of a critical earthquake during the projected life period

CRITICAL EARTHQUAKE:

An earthquake occurred in area as past T- yans and has recorded the magnitude capable of producing horizontal and accelerate greater than a minimum value at that particular locality.



Center for Seismology, Ministry of Earth Sciences is nodal agency of Government of India dealing with various activities in the field of seismology and allied disciplines. The major activities currently being pursued by the Center for Seismology include, a) earthquake monitoring on 24X7 basis, including real time seismic monitoring for early warning of tsunamis,

b) Operation and maintenance of national seismological network and local networks c)

Seismological data centre and information services, d) Seismic hazard and risk related studies e)

Field studies for aftershock / swarm monitoring, site response studies f) earthquake processes and modelling, etc.

The MSK (Medvedev-Sponheuer-Karnik) intensity broadly associated with the various seismic zones is VI (or less), VII, VIII and IX (and above) for Zones 2, 3, 4 and 5, respectively, corresponding to Maximum Considered Earthquake (MCE). The IS code follows a dual design philosophy: (a) under low probability or extreme earthquake events (MCE) the structure damage should not result in total collapse, and (b) under more frequently occurring earthquake events, the structure should suffer only minor or moderate structural damage. The specifications given in the design code (IS 1893: 2002) are not based on detailed assessment of maximum ground acceleration in each zone using a deterministic or probabilistic approach. Instead, each zone factor represents the effective period peak ground accelerations that may be generated during the **maximum considered earthquake** ground motion in that zone.

Each zone indicates the effects of an earthquake at a particular place based on the observations of the affected areas and can also be described using a descriptive scale likeModified Mercalli intensity scale[4] or the Medvedev–Sponheuer–Karnik scale.[5]

Zone 5

Zone 5 covers the areas with the highest risks zone that suffers earthquakes of intensity MSK IX or greater. The IS code assigns zone factor of 0.36 for Zone 5. Structural designers use this factor for earthquake resistant design of structures in Zone 5. The zone factor of 0.36 is indicative of effective (zero period) level earthquake in this zone. It is referred to as the Very High Damage Risk Zone. The region of Kashmir, the western and central Himalayas, North and Middle Bihar, the North-East Indian region and the Rann of Kutch fall in this zone.Generally, the areas having trap rock or basaltic rock are prone to earthquakes.

Zone 4

This zone is called the High Damage Risk Zone and covers areas liable to MSK VIII. The IS code assigns zone factor of 0.24 for Zone 4. The Indo-Gangetic basin and the capital of the country (Delhi), Jammu and Kashmir fall in Zone 4. In Maharashtra, the Patan area (Koyananager) is also in zone no-4. In Bihar the northern part of the state like- Raksaul, Near the border of India and Nepal, is also in zone no-4.

Zone 3

The Andaman and Nicobar Islands, parts of Kashmir, Western Himalayas fall under this zone. This zone is classified as Moderate Damage Risk Zone which is liable to MSK VII. and also 7.8 The IS code assigns zone factor of 0.16 for Zone 3.

Zone 2

This region is liable to MSK VI or less and is classified as the Low Damage Risk Zone. The IS code assigns zone factor of 0.10 (maximum horizontal acceleration that can be experienced by a structure in this zone is 10% of gravitational acceleration) for Zone 2.

Zone 1

Since the current division of India into earthquake hazard zones does not use Zone 1, no area of India is classed as Zone 1.Future changes in the classification system may or may not return this zone to use.

Application of Remote Sensing and GIS Applications in Civil Engineering

Introduction

Remote sensing observations provide data on earth's natural resources in a spatial format. The remote sensing (RS) data has the advantage of synoptic view and large area coverage. The information required in the field of civil engineering is derived mainly from analysis of image patterns present in the data. These patterns reflect the influence of the type of parent material, geological processes undergone, the climatic, biotic and physiographic environment and man's activity. Thus applications of remote sensing to engineering involve the recognition of basic landforms as indicated by the pattern elements on the image.

Spatial data can be efficiently handled using Geographic Information System (GIS), a tool which allows synergism of map data and tabular data. GIS also allows the integration of these data sets for deriving meaningful information and outputting the information derivatives in map format or tabular format.

In civil engineering projects, RS and GIS techniques can become potential and indispensable tools. Various civil engineering application areas include regional planning and site investigation, terrain mapping and analysis, water resources engineering, town planning and urban infrastructure development, transportation network analysis, landslide analysis, etc.

Regional Planning and Site Investigations

Site investigations in general require topographic and geologic considerations. Remote sensing data permits such an assessment. In case of dam site investigation, information on topography is essential. Geological consideration involves the different soil and rock types and physical properties.

In selecting river-crossing sites for bridges and pipelines, an important consideration is the stability of slopes leading down to and up from the water crossing. Such slopes include riverbanks, terrace faces and valley wall. History of river erosion and sedimentation would give clues needed for locating the sites where scour is likely to occur. High spatial resolution satellite data with stereo vision capability can facilitate depth perception in the above said investigations and also for regional planning of large commercial airports, harbors, industrial towns and recreational sites. The hydro geological and geomorphologic information along with geological structures derived from satellite data are very useful in sitting the ground – water bore holes.

Terrain Mapping and Analysis

Assessment of the performance of the terrain for specific developmental activities can be made through terrain evaluation. For this, terrain information can be acquired from RS data and by generating the Digital Terrain Model (DTM). A DTM is an ordered array of numbers representing the spatial distribution of terrain characteristics stored in a computer so as to enable the determination of any quantitative data pertaining to terrain. DTMs facilities investigation of a number of alternative horizontal and vertical alignments of canals, roads, pipelines or corridors for any such applications. In engineering construction like dam, the knowledge of material comprising the terrain is essential for proper planning, location, construction and maintenance of engineering facilities. For computation of hydrograph parameters like peak runoff rate, time of concentration and time to peak, the height and slope information derived from Digital Elevation Model (DEM) are useful.

The information on regional engineering soils is essential for general planning and site evaluation purposes. High spatial resolution satellite data can be analyzed to delineate various landforms, mapping of soil classes of significance to engineering construction, delineation of landforms – engineering, soil relationships and grouping of landforms with various physiographic setting or terrain associations.

Remote sensing based inventory of construction material such as boulders, quarry rock, sand – clay mixtures etc., would help to locate suitable sites of construction materials for building up of water resources engineering projects like dams, bridges, etc., across the rivers.

Water Resources Engineering

By analyzing multidate RS data, it would be possible to monitor the effects of dam construction. Remotely sensed data of pre and post dam construction can reveal the forest and other land at different water levels. This would also help in preliminary investigation of finding suitable areas for human resettlement. To study the feasibility of inter basin transfer of surplus flood flows, RS data can be cost effective. In large area reconnaissance studies, various technically feasible and economically viable alternatives in locating surplus flow diversion routes to water deficient basins can be arrived at. Also, reservoir sites to store the surplus flows in these basins could be identified. Such projects of large dimensions require considerations of land use / land cover, soil and geological mapping, terrain evaluation, construction material inventory etc. the latter are derived from satellite remote sensing data of particular resolution depending upon the scale on which such information is required.

The water storage built in through reservoirs, tanks, etc., are often reduced due to sedimentation. Remotely sensed data can be used to monitor the water bodies over time and assess the silting condition. In case of gauged reservoirs of medium to large sizes, RS data can provide an assessment of sediment volume and reduction in the capacity of sediment volume and reduction in the capacity of the reservoir. In case of small water bodies such as tanks, it is possible to come out with a list of problematic tanks with symptoms of heavy siltation and loss of water holding capacity. The condition of tank bunds, fore shore encroachment, etc., also can be analysed with the help of high spatial resolution RS data.

Characterization of water bodies in terms of geological, geomorphological, hydro geological, soil and land use / land cover parameters carried out using RS data enables conservation of land and water resources. The RS based input integrated with ground based information through GIS is useful for broad reconnaissance level interpretation of land capability, irrigation suitability, potential land use, water harvesting areas, monitoring the effects of soil and water conservation measures, estimation of run off and sediment yields and monitoring land use change including land degradation.

The commercial areas of irrigation projects are fed by different sources of irrigation like reservoir, tanks, ponds and wells. Assessment of command areas and crops would be highly useful in water release policy or conjunctive use of water in the overall project command area. Satellite data has been advantageously used to obtain such information on surface irrigation projects.

In case of floods, appropriate flood management work has to be executed to reduce the damages and utilize the floodwaters. For this purpose satellite RS provides comprehensive, reliable and timely information (multidate) on flood inundated and drainage congested areas, extent of damage to crops, structure etc., river configuration, silt deposits and vulnerable areas of bank erosion. Flood mapping and damage assessment, using satellite data, is being done in India for more than two decades. Satellite derived snow cover assessment is being extensively used as an important input in snow melt runoff prediction models to assist in multipurpose reservoir operations. Seasonal snow melt inflow forecasts for Bhakra reservoir in Sutlej basin are being operationally issued every year with the accuracy better than 90% to Bhakra Beas Management Board.

Town Planning And Urban Development

The unprecedented growth of urbanization in India has given rise to problems of housing, sanitation, power, water supply, disposal of effluents and environmental pollution. Systematic mapping and periodic monitoring of urban land use is therefore necessary for proper planning, management and policy making (with the help of RS and GIS optimal master plan for development and management of urban settlements can be prepared).

For sustainable development of urban agglomeration, optimal urban land use plans and resources development models need to be generated by integrating the information on natural resources, demographic and socio – economic data in a GIS domain with the currently available satellite data.

Transportation Network Analysis

With the help of high spatial resolution data, mapping of road and rail network can be accomplished. This facilitates in deciding optimal routing for transport of construction materials. Even, identification of village roads is possible in certain cases.

Landslide Studies

Landslides are the most common and recurring hazards in mountainous areas causing enormous loss of life and property every year. The parameters that contribute directly or indirectly include litho logy and structure, landform, slope, aspect, relief, vegetation cover, climatic and human activities. Information on these aspects can be collected and integrated for preparing a landslide hazard zone map that can be done through RS and GIS.