Civil EG UNIT- 3,4,5

12

STRATIGRAPHY

Aims: The aims of this chapter are:

1. To briefly describe what is stratigraphy and how it is studied.
2. To describe important features of major stratigraphical units of India.

INTRODUCTION

Stratigraphy is the chronological study of sedimentary rocks. Among the different groups of rocks, only sedimentary rocks are amenable to such study because of the principle of the order of superposition (which means in a set of undisturbed sedimentary beds, successively younger beds occur upwards or successively older beds occur downwards).

Stratigraphy (*strata* = a set of sedimentary beds, *graphy* = description) reveals various details of the history of the earth during the different periods of the geological past, from the beginning till the present. Through stratigraphy we can know the past details of climate, geography (i.e., land-sea relations or marine transgressions and marine regressions), glaciation, orogeny, epeirogeny, evolution and migration of plants and animals, palaeomagnetism, etc., during different periods of the earth's history. Thus, as this branch of geology reveals the history of our mother planet, it is also appropriately called *"historical geology"*.

The basic fact which makes this study possible is that the sedimentary rocks have been forming at some place or the other, right from the formation of the earth. It was possible because the earth's surface being irregular (i.e., by virtue of numerous elevations like hills, mountains and plateaus, on the one hand and numerous depressions like pits, lakes, seas and oceans, on the other) had been providing suitable conditions for the deposition of sediments and thereby for the formation of sedimentary rocks. Thus sedimentary rocks representing the different ages of earth's history are available as scattered in different parts of the earth's surface. Of course, due to tectonic effects, the complete chronological sequence of rocks cannot be expected to occur at any given single place. The two points about which we should be clear at this stage are: (i) Sedimentary rocks of any given geological period may be found at some places and may not be found at other places. This depends on whether the favourable conditions for sedimentation had prevailed or not during that geological period in any particular place. (ii) Even in places where they have been formed, depending on many factors which favour the deposition of sediments, at some places, the development of sedimentary rocks (strata) may be good or ideal and in other places, it may be poor.

12.1 AIMS OF STRATIGRAPHY

The aims of stratigraphy are: (i) to study the chronological sequence of scattered strata of different places, (ii) to correlate them with that of the worldwide or established regional chronological framework (this second step shall fix the mutual time relationship) and (iii) to interpret the geological history of the earth as a whole from the foregoing data.

Such a study paves the way for the arrangement of the sedimentary rocks in the chronological sequence in which they were laid down on the surface of the earth.

12.2 PRINCIPLES OF STRATIGRAPHY

The aims of stratigraphy are achieved mainly in three different ways which are named as *principles of stratigraphy.* They are lithology, order of superposition and fossil content. All these three natural phenomena become effective means because of the logical fact that the *"present is the key to the past"*. It will now be appropriate to appreciate the significance of this phrase, which was first enunciated by Hutton in 1785.

Present is the Key to the Past

This may be briefly explained as follows: By careful study it is possible to link a particular geological period with the lithology, order of superposition and fossil content concerned. From the present-day observations, we know that different types of rocks with distinctive minerals and composition are formed under different environments, (such as dry, humid, glacial, marine, fluvial, lacustrine and terrestrial). This means, in the past too, depending on different environmental conditions that had prevailed during different geological periods, different types of rocks have been formed. This fact helps in correlation and also in revealing the past history of the earth.

Thus, the occurrence of feldspar-rich arkose type sandstone or boulder beds (tillites) reveal intense cold climatic (glacial) conditions that had prevailed during their formation. Further, their peculiarities (feldspars as sand grains and occurrence of boulders as constituents of conglomerates) make it easy to correlate them with the rocks of a similar kind in other places. All of them might have been formed during the same geological period. Of course, since glacial periods had occurred again and again in the geological past, to make a proper correlation, other aspects, i.e., order of superposition, fossil content, etc., also have to be taken into consideration.

The study of heavy minerals is another similar tool provided by lithology for such a purpose. In a similar way, the order of superposition and fossil content can also be interpreted.

12.2.1 Lithology (*litho* = rock, *logy* = study)

The term lithology is synonymous to petrology (*petro* = rock, *logy* = study). But the term petrology is widely used, whereas the term lithology is used in general only in stratigraphy.

This refers to the study of chemical and mineral composition of rocks. The fact that "rocks of a similar kind with similar chemical and mineral composition are formed at a given time in different (but not very far off) places" is very important and useful in correlation. Sometimes, special stress is laid on heavy mineral studies. Lithology may also reveal some environmental aspects of the sequence and types of rocks. For example, in the Cuddapah system of rocks, the lithology comprises alternating occurrence of sandstones and shales, which, in turn, indicates that the Cuddapah basin had sunk several times and favoured the deposition of fine argillaceous sediments of shales.

12.2.2 Order of Superposition

The chronological importance of the order of superposition in sedimentary rocks was first recognized by N. Steno in the year 1669. According to this principle, in a set of strata, successively younger beds lie upwards. This is natural because when sedimentation takes place, it commences from the bottom of the basin. Therefore, the bottommost layer is the first to be formed and hence the oldest of the set. Over this layer lies the next formed one and above it lie still younger beds. Thus successively younger beds occur upward in an undisturbed sequence of beds.

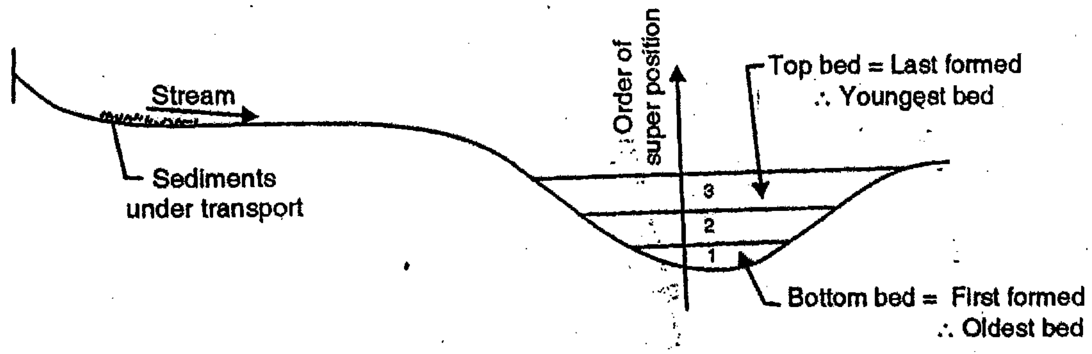


Fig. 12.1 Principle of order of superposition

Of course, when the beds are overturned (as in a recumbent fold), the order of superposition appears in reverse. However, by verifying the actual top and bottom of beds (with the help of various clues), it is possible to know the proper order of superposition.

An important fact of the order of superposition is that similar sequences of rocks (i.e., order or superposition) are expected to develop in different places during the same geological period, under similar conditions.

Based on this fact, correlation of different scattered sequences of rocks can be made.

12.2.3 Fossils

Fossils may be defined as "the relicts and remnants of ancient animals and plants that have been preserved inside the rocks by natural processes".

Occurrence of fossils in sedimentary rocks is a matter of chance because only under very favourable conditions they occur. This means all sedimentary rocks do not possess fossils. But if they are present, they are very useful because they give valuable information.

The fossils – and the rocks which possess them – belong to the same age, i.e. the rocks which had formed in a particular geological period will be having the relicts of only those animals and plants which were existing at that time.

We find today that different plants and animals flourish under different environments (such as land or water, cold or hot, dry or wet, fluviatile or marine and high land or low land). If we keep in mind that the "present is the key to the past", with the help of fossils, we can understand the history of the earth from different angles.

The important benefits of the fossils from the stratigraphy point of view can be listed as follows:

1. Some organisms like graptolites and ammonoids lived for a very short period in geological history. Hence, if their fossils are found in any unknown rock, their *age* can easily be predicted. Such fossils of chronological importance are named as zone fossils.
2. Fossils help easy *correlation* of different sequences of rocks.
3. Fossils reveal the *climatic* conditions of the geological past.
4. They also help in knowing land-sea relations in the past, i.e., *marine transgressions and regressions* of the past can be known through them.
5. Fossils provide unique and unquestionable evidence of *evolution and migration* of life during the geological past.
6. They also throw light on *orogeny* (as in the case of Alps and Himalayas) and *epeirogeny* (as in the case of the continental drift).

In addition to these three basic principles of stratigraphy, sometimes other factors like different structural features and degree of metamorphism also help in correlation of rocks. We now briefly discuss structural features.

Structural Features

Sometimes structural features like folds, faults and unconformities are of great help in correlating strata which may be at far off places at present. For example, the details of attitudes of structures and lithology found along the western coast of Africa and the eastern coast of South America help not only in their mutual correlation but also indicate that at the time of their formation these two land masses were together and had undergone folding, etc., as a single, undivided unit.

Similarly, certain unconformities, like the "Eparchaean unconformity" which occurs in many parts of the world, also help in correlation.

Due to the active role played by tectonic forces, the land masses are frequently uplifted causing a break in deposition. Thus, the stratigraphy record of any place on the earth's surface is incomplete and a number of unconformities intervene. If the duration of unconformity represents a very long geological period, then it is called as hiatus (refer to Sec. 9.5.3).

12.3 GEOLOGICAL TIME SCALE

It is believed that the earth came into existence nearly 4500 million years ago. Therefore, its history is spread over all this lengthy period. For the sake of convenience of study and reference and also for relative comparison of ages of different sequences of rocks found in different places on the earth's surface, it is necessary to have a proper framework of geological time. This need is fulfilled by the "geological time scale", which is internationally accepted. It is like the calendar of an year. As an year is divided into different months, each month into weeks, each week into days, each day into hours and so on, the geological time scale is also *similarly* subdivided into smaller and smaller units to suit stratigraphical study and correlation.

The geological time scale is subdivided into number of *eras*. Each era comprises a number of *"periods"*, which, in turn, are subdivided into *"epochs"*. A number of *"ages"* make up an *epoch*. The subunits of an age are sometimes called *"hemeras"* or *"phases"*.

The similarity of the mode of subdivision of year and geological time scale is up to this extent only. Because, unlike the duration of months which have a nearly equal number of days, the duration of different geological eras differs very greatly. For example, the Proterozoic era represents a duration of nearly 1900 million years, whereas Kainozoic era represents a duration of only 65 million years. The commencement of eras is interlinked to the occurrence of major tectonic events (such as extraordinary orogenic or epeirogenic activity or intense glaciation) that have occurred in the geological past.

The duration or time interval between any two such successive extraordinary events is described as an era. Thus, based on this principle, the geological time scale, which represents the entire period of the earth's history, has been subdivided into six eras. They are: Archaean era (the oldest), Precambrian era, Primary era, Secondary era, Tertiary era and Quarternary era (the last or the youngest).

In our routine measurement of time, sixty seconds make a minute, sixty minutes make an hour, twenty-four hours make a day, and so on. But in the geological time scale, eras or periods or epochs do not have any such fixed number of subdivisions. They differ from one another. For example, the Primary era is subdivided into six periods, whereas the Secondary era is subdivided into three periods only.

A close look at the names of different eras raises the question why is the Primary era, which literally means first era, listed as the third era? This is done because fossils which form the main study of stratigraphy have been recorded only from this era onwards. Thus it is logically called the Primary era and the eras succeeding it are called Secondary (meaning second era), Tertiary (meaning third era) and Quarternary (meaning fourth era).

Under fossils (refer to Sec. 12.1.2) it has already been stated that the record of fossils provides an authentic evidence of the evolution of life (from the most elementary or primitive to the most modern) through the geological ages. To reflect this, the aforementioned six eras are given other names also. They are as follows:

1.	Archaean era	=	Azoic era	(*Zoe* = life; *Azoic* = lifeless, meaning an era without life).
2.	Precambrian era	=	Proterozoic era	(*Protero* = very early, meaning an era with very early life, which is not recorded as fossils).
3.	Primary era	=	Palaeozoic era	(*Palaeo* = ancient or old, meaning the era with first important life which is recorded as fossils).
4.	Secondary era	=	Mesozoic era	(*Mesos* = middle, meaning an era with life, which is neither old nor recent).
5.	Tertiary era	=	Cenozoic era or Kainozoic era	(*Ceno* or *kaino* = recent, meaning an era with recent life).
6.	Quarternary era	=	Psychozoic era	(*Psycho* = reasoning or thinking, meaning an era with life which has reasoning or thinking capacity, i.e., the final form of evolution as at present).

This geological time scale with its subdivisions of eras and periods along with their respective durations and remarks is given in a tabular form (Table 12.1).

Note: In Table 12.1 figures without brackets show the total duration of the era or period in millions of years, while those within parentheses show the lapse of time from the beginning of the particular period to the present. It may be noted that the eras or periods are listed from bottom to top, keeping in view the principle of order or superposition.

Table 12.1 Geological time scale

Era (group)	Periods (systems)	Remarks (chief fossils)
Quarternary era *or* Psychozoic era 1	Recent (or Holocene) (0.01) Pleistocene (1)	Present-day living animals and plants. Man appears. Many mammals die during glacial periods.
Tertiary era *or* Kainozoic era 65	Pliocene = 7 (8) Micocene = 17 (25) Oligocene = 13 (38) Eocene = 27 (65)	Mammals, mollusca and flowering plants dominant. Divisions are mainly based on proportion of living species to extinct species of mollusca and the presence of mammal species.
Secondary era *or* Mesozoic era 180	Cretaceous = 75 (140) Jurassic = 60 (200) Triassic = 40 (240)	Giant reptiles and ammonites disappear at the end. Flowering plants become numerous. Ammonites abundant. First birds, flowering plants and sea urchins. Ammonites, reptiles and amphibia abundant, arid climate.
Primary era *or* Palaeozoic era 370	Permian = 50 (290) Carboni-ferous = 60 (350) Devonian = 60 (410) Silurian = 35 (445) Ordovician = 60 (505) Cambrian = 100 (605)	Trilobites become extinct at the end. Many non-flowering plants, first reptiles appear. Abundance of corals, brachiopoda, first amphibians and lung fish. Graptolites disappear at the end, first fishes, probably first land plants. Abundance of trilobites and graptolites. Abundance of trilobites.
Pre-Cambrian era or Proterozoic era	(2500)	Soft bodied animals and plants.
Archaean era *or* Azoic era	(3600?) (4500?)	Lifeless. (The oldest rocks recorded yet are 3600 million years in age.)

By virtue of predominant occurrence, the Cambrian period is called the "age of trilobites"; the Ordovician is called the "age of graptolites"; the Devonian is called "the age of fish"; the Mesozoic era is called "age of reptiles" or "age of ammonoids"; the Tertiary era is called the "age of mammals" and the Quarternary era is called the "age of man".

The terms eras, periods and so on refer to the subdivisions of time of geological history. Since sedimentary rocks have been forming all the time, different subdivisions of time have *corresponding* geological formations (i.e., sedimentary rocks). The rocks formed during an era are called *group* of rocks; rocks belonging to a period are called *system* of rocks. Similarly, rocks representing an epoch, age and hemera are, respectively, called *series, stage* and *zone*. These details may be seen at a glance from the following chart:

Geological time	(corresponding)	Geological formations
Era	⟶	Group
↓		↓
Period	⟶	System
↓		↓
Epoch	⟶	Series
↓		↓
Age	⟶	Stage
↓		↓
Hemera (phase)	⟶	Zone

The same name is given both to the time unit and the rock unit with an appropriate suffix. Thus, for example: the first geological era is called the *Archaean era* and the corresponding geological formations are called the *Archaean group*.

12.4 GEOLOGICAL DIVISIONS OF INDIA

The physiographical map shows clearly that India is divisible into three parts, each having distinguishing characters of its own. These three parts are: (i) extra-peninsula, (ii) Indo-Gangetic alluvial plains and (iii) peninsula. The extra-peninsular part is the mountainous region of the giant Himalayan ranges. The Indo-Gangetic plains are the vast plain lands stretching across northern India from Assam and Bengal in the east, through Bihar and Uttar Pradesh to Punjab and Sind in the west. The peninsular part lies to the south of the Indo-Gangetic plains.

The clear differences that we notice among these three parts of our country from the geological point of view can be appreciated well in terms of topography (i.e., physiography), stratigraphy and structure. The following discussion gives the salient features of these aspects, briefly.

12.4.1 Physiographical Divisions

Based on surface features, i.e., physiography, the threefold division of India can be well appreciated as follows: The peninsula is an ancient plateau which has been exposed for long ages to denudation and approaching peneplain. Its mountain ranges are of the relict type, i.e., they represent the survival of the harder masses of rock which have withstood weathering and erosion. Its rivers move, for the most part, over a flat country with low gradient and have built up shallow and broad valleys. The extra-peninsula, on the other hand, is a highly irregular region of folded and overthrust mountain chains of geologically recent origin. Its rivers are youthful and are actively eroding their beds along their courses and carving out deep and steep sided gorges. The Indo-Gangetic plains are broad, monotonous, plain expanses.

These are built up of recent alluvium through which the rivers flow sluggishly towards the seas, their destination.

12.4.2 Stratigraphical Divisions

The types and ages of geological formations occurring in the aforementioned three parts differ so much from one another that the threefold division of India from this angle also is very glaring. This is as follows: The peninsula is composed of geologically ancient rocks. Over these ancient rocks lie pre-Cambrian rocks and extensive lava flows of the Deccan trap formation. Only a few Mesozoic and Tertiary sediments are found along coastal regions. The extra-peninsula, on the other hand though it contains some very old rocks, is predominantly a region in which the sediments laid down from Cambrian to early Tertiary have been folded, faulted and elevated at the end of the Mesozoic era. The Indo-Gangetic plains are built up of sediments of geologically very recent times (Pleistocene and Recent periods), filling up a deep depression between the other two units (i.e., peninsula and extra-peninsula).

12.4.3 Structural Divisions

The geological structures also differ greatly among the three divisions of India. The peninsular part represents the ancient stable block of the earth's crust, which has remained unaffected (shield area) by mountain-building movements from the close of the Pre-Cambrian era. In contrast to this, the extra-peninsula has recently undergone earth movements (i.e., tectonic movements) of a very great magnitude. Its strata are marked by complex folds, reverse faults, overthrusts and nappes of great dimensions. Even now it is believed that these movements are continuing. This being the cause of instability of the region is contributing to the occurrence of frequent earthquakes of varying intensities. The Mediterranean seismic belt passes through the foothill region of the Himalayas. The Indo-Gangetic plains owe their origin to a sag (i.e., a depression on the surface) in the crust, probably formed at the time of uplift of the Himalayas. This sag has since been filled up by sediments derived from both sides and especially from the lofty mountain chains of the Himalayas which are actively being eroded by the many energetic rivers traversing through them. The little geological interest which these plains hold is confined to the rich soils and to the history of the river systems. Of course, this alluvium conceals the solid geology of its floor. From the human history point of view, however, the alluvial plains are very important. These plains are highly populated and closely interlinked with numerous developments and events in the cultural and social history of our country. The thickness of this structurally simple sedimentary column is of the order of about 5000 to 20,000 ft.

12.5 MAJOR STRATIGRAPHICAL UNITS OF INDIA

Before commencing the description of stratigraphical units of India, a general outline shall be useful.

More than half of the peninsula is occupied by gneissic and schistose rocks of the *Archaean* times. The rocks of the *Cuddapah* system, the *Vindhyan* system, the *Gondwana* group and the *Deccan traps* occupy the rest of the area except parts of the coastal regions.

In the extra peninsula, marine sedimentary formations predominate though parts of the sub-Himalayas and the main axis of the Himalayas are occupied by ancient metamorphic rocks and intrusive igneous rocks.

The Indo-Gangetic plains which lie in between the peninsula and the extra-peninsula consist of alluvium of recent times; this means they have no important geological history of their own.

Now, at this stage, we may note that: (i) the extra-peninsular region is largely inaccessible to field geological studies and also it has a very adverse climate throughout the year, except for a brief spell of a month or two. Due to these practical difficulties, the available details of stratigraphy of the extra-peninsula are relatively very little and sketchy only.

(ii) The Indo-Gangetic plains are without any geological history. In view of these two facts, it shall be appropriate to limit discussion only to Archaeans, Cuddapahs, Vindhyans, Gondwanas and Deccan traps which can be rightly claimed as the major stratigraphical units of India.

From the civil engineering point of view also, it is proper to avoid unnecessary and less useful details of stratigraphical study. Hence to suit the purpose of this text, the discussion of these major stratigraphical units is further limited only to the salient details of lithology, fossil content, structures, succession of *type area* and economic mineral occurrences in addition to a brief mention of a few other relevant details. *This may be the proper tine of approach to this otherwise major branch of geology.*

12.5.1 The Archaean Group

The Archaean group represents the oldest rocks of the earth's crust. This term was introduced by J.D. Dana in the year 1872 to refer all those rocks which are older than the Cambrian period. But, later, T.H. Holland limited the use of this term to refer to only those rocks which lie below the Eparchaean unconformity. Now this is generally accepted.

Archaean rocks have undergone repeated tectonic activity. Hence, they have complex structural features. Further, they are totally unfossiliferous. Rock types too are of a complex nature. In view of all these factors, Archaeans pose difficulties in correlation. The result is that there is no universally accepted standard nomenclature for the subdivisions of this era.

As far as our country is concerned the earlier formations of Archaeans are called Dharwars (named after the town Dharwar, in Karnataka state, the type area of these rocks).

Lithology and Structure

The Archaeans are mainly made up of granites, gneisses and schists. In some places sedimentary rocks like conglomerates and banded hematite quartzites also occur. All these rocks are traversed by igneous intrusions.

Being the oldest rocks, Archaeans form the platform or *basement* over which the other younger geological formations rest. The geological structure and composition of these rocks are highly *complex*. Reflecting these facts and the predominant or *fundamental* occurrences of gneisses, the Archaeans are often described as "gneissic complex" or "basement complex" or "fundamental gneiss".

By virtue of their ancient nature and due to the repeated tectonic disturbances experienced, the places where Archaeans occur have attained reasonable stability: This means in such places natural calamities such as earthquakes either do not occur or, even if they occur, they shall be of very less intensity. Hence such places are rightly described as "shield areas" (shield meaning protection). Peninsular shield, Brazilian shield and Siberian shield are examples of this kind.

Distinct sedimentary structures like ripple marks and current bedding have been recorded in some places.

Fossil Content

Though Archaeans are found abundantly at many places and represent the lengthiest period, they are totally unfossiliferous. This indicates that life did not exist on the earth's surface during Archaean times. Hence this era is appropriately called the "Azoic" era (meaning an era without life).

Occurrence or Distribution

In India, Archaeans occupy nearly 2/3 of the peninsula (comprising the states of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Orissa and parts of Bihar and Madhya Pradesh) spreading from Kanya Kumari to Madhya Pradesh and Bihar. These probably continue below the Indo-Gangetic alluvium and occur in Assam. Similarly, these continue below Deccan traps and extend into some parts of Gujarat and Rajasthan. They also occur along the whole length of the Himalayas, but are studied only at some places. Thus the Archaeans represent the most widely distributed group of rocks in our country (Fig. 12.2).

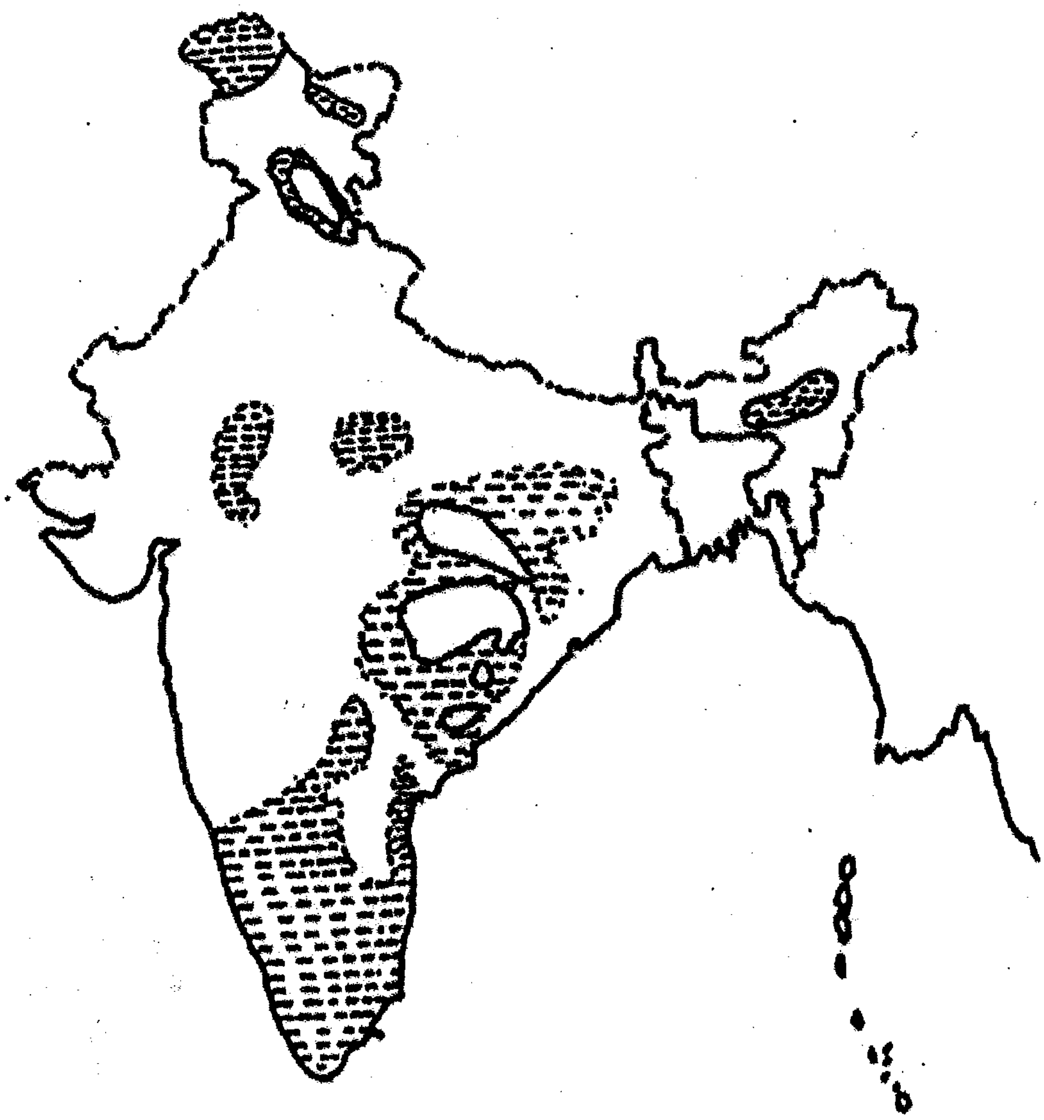


Fig. 12.2 Distribution of Archaean group of rocks

The Archaeans are the best developed in Karnataka state at Dharwar (type area). The Archaean rocks of *Kashmir-Hazara* area are called "Salkhala series", while those of *Kumaon* and *Spiti* valley are called the *Vaikrita system*. In *Shimla* and *Garhwal*, the schistose Archaean rocks are described as "Jutogh" and "Chail" series. Similarly, the rocks of other places are given different names.

Succession (order of superposition or order of formation of rocks)

As mentioned in the previous para Dharwar of Karnataka state is the type area of Archaeans, i.e., the place where they have the best development. It was first studied by R. Bruce Foote in the 1880s, later by W.F. Smeeth (1915), B. Rama Rao (1940) and others.

The rock types and the outlines of the succession as proposed by Rama Rao are as follows:

——— Eparchaean unconformity ———

ARCHAEANS	Post-Dharwars	Closepet granite Charnockites Peninsular gneisis Champion gneiss	
	——— Unconformity ———		
	Dharwars	Upper Dharwars	Quartzites, conglomerates and argillaceous rocks
		Middle Dharwars	Granites, gneisses, schists, conglomerates, banded iron stones
		Lower Dharwars	Micaceous quartz, schists, gneisses hornblende schists

——— Base not known ———

Economic Importance

In India, Archaeans contain many rich economic mineral deposits. Therefore, they are appropriately described as our "storehouse of mineral wealth". It is not an exaggeration to state that expect for coal, oil and gas and a few other minor deposits, all other mineral wealth of our country belongs to Archaeans. It will naturally be interesting to know about these deposits. But as these are not of concern from the civil engineering point of view, only very important ones are mentioned here (within parentheses, names of districts/places are given).

Metallic ore deposits

1. Gold : Karnataka (Kolar Gold Fields), Andhra Pradesh (Anantapur).
2. Copper : Bihar (Singhbhum), Andhra Pradesh (Guntur), Sikkim.
3. Iron ore : Bihar (Singhbhum), Orissa (Keonjhar), Madhya Pradesh (Bastar and Dung), Maharashtra (Chanda), Karnataka, Andhra Pradesh.
4. Lead-zinc ores : Rajasthan (Zawar) deposits.
5. Chromite : Orissa (Keonjhar, Dhenkanal, Mayurbhanj), Karnataka (Hasan), Bihar (Singhbhum), Tamil Nadu (Salem), Andhra Pradesh (Krishna).
6. Manganese ore : Madhya Pradesh (Balaghat, Chindwara), Maharashtra (Nagpur), Orissa (Keonjhar), Bihar, Andhra Pradesh

Non-metallic minerals

1. Diamonds : Andhra Pradesh (Anantapur)
2. Gemstones : Kashmir, Rajasthan, Bihar, Andhra Pradesh, Tamil Nadu.
3. Mica (muscovite) : Bihar (Hazaribagh, Gaya, Monghyr), Rajasthan (Ajmer, Jaipur; Mewar), Andhra Pradesh (Nellore)
4. Kyanite : Bihar (Singhbhum — Lapsa baru deposits)
5. Magnesite : Tamil Nadu (Salem), Karnataka (Hasan, Mysore)
6. Graphite : Orissa (Kalahandi, Koraput), Andhra Pradesh (Visakhapatnam).
7. Apatite : Bihar (Singhbhum), Orissa (Mayurbhanj).

Building Stones

Archaeans provide inexhaustible reserves of the best quality of building stones of different kinds. Granites, gneisses, charnockites, quartzites, marbles, limestones belong to this variety. Of course, schists and khondalites, which also occur in plenty, are not durable, hence unsuitable.

The following are a few popular examples of temples, monuments and other structures constructed out of Archaean rocks:

1. Hampi temples : Pink gneisses
2. Mahabalipuram temples : Charnockites
3. Bhubaneswar, Puri and Konark temples : Khondalites, schists
4. Taj Mahal : (Makrana) Marble
5. Madras and other harbours : Granites and Charnockites
6. Victoria Memorial Hall : Marble

12.5.2 The Purana Group

The end of the Archaean era was marked by factors such as large-scale diastrophism, orogenic (i.e., mountain-building) activity and igneous activity. These were accompanied by a large-scale, widespread unconformity. As this unconformity occurs above the Archaean group of rocks, it is appropriately called the Eparchaean (Epi-Archaean) unconformity. Over this unconformity rest the rocks of the succeeding era, i.e., Precambrian (or Proterozoic) era This group of rocks is called, in Indian stratigraphy, the *purana group* of rocks. Two distinct sets of rocks make up this group. The older set is called the *Cuddapah system* and the younger set is called the *Vindhyan system*. Though both these sets are well developed and suitable to bear fossils, they are unfossiliferous. The Cuddapah system of rocks is relatively more disturbed, structurally, while the Vindhyan system of rocks is nearly undisturbed.

12.5.2.1 The Cuddapah System

Occurrence and distribution: The name Cuddapah system has been derived from the Cuddapah basin where it is best developed. This is the type area of this system. This basin is crescentic (i.e., half moon shaped) with the concave side facing the east. It is 340 km long, between Singareni Coalfields in the north and the Nagari Hills (near Madras city) in the south. It has a maximum width of 145 km and occupies an area of 42,000 sq. km. Near the eastern concave margin, the strata have maximum thickness of 3000 to 4000 metres.

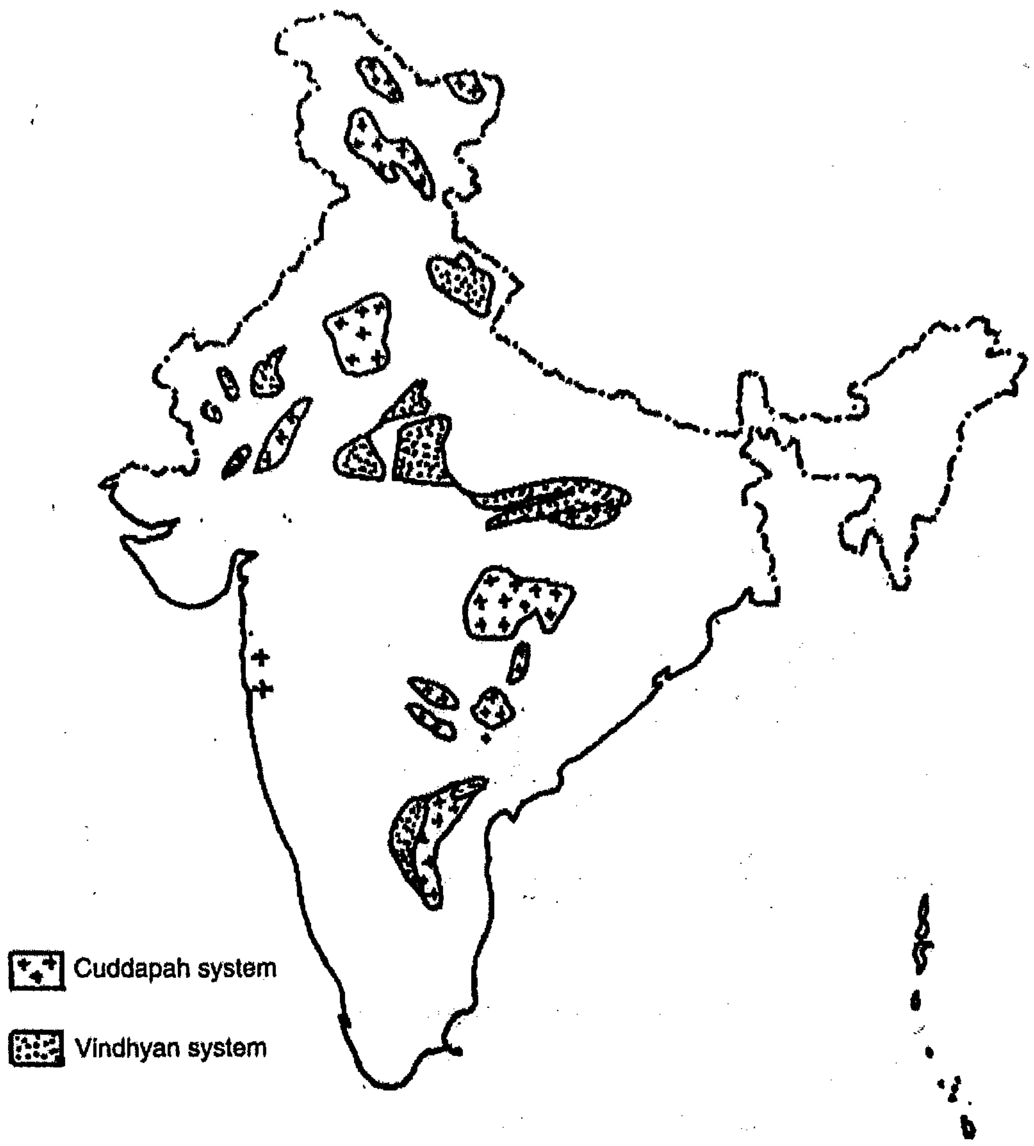


Fig. 12.3(a) Distribution of purana group of rocks

In addition to the aforementioned type area, rocks of this period also occur in many other parts of the peninsula and extra-peninsula. Such places and the names given to the local formations are as follows:

1. Rajasthan : The Delhi system
2. Parts of Madhya Pradesh : The Gwalior system, Chandrapur series, Raipur series
3. South of Bombay : Kaladgi series
4. Singhbhum (Bihar) : Kolhan series
5. Central Himalayas : The Hemanta system.

In addition to these, equivalent rocks of the Cuddapah system also occur in Simla Hills, and parts of Kashmir and Punjab.

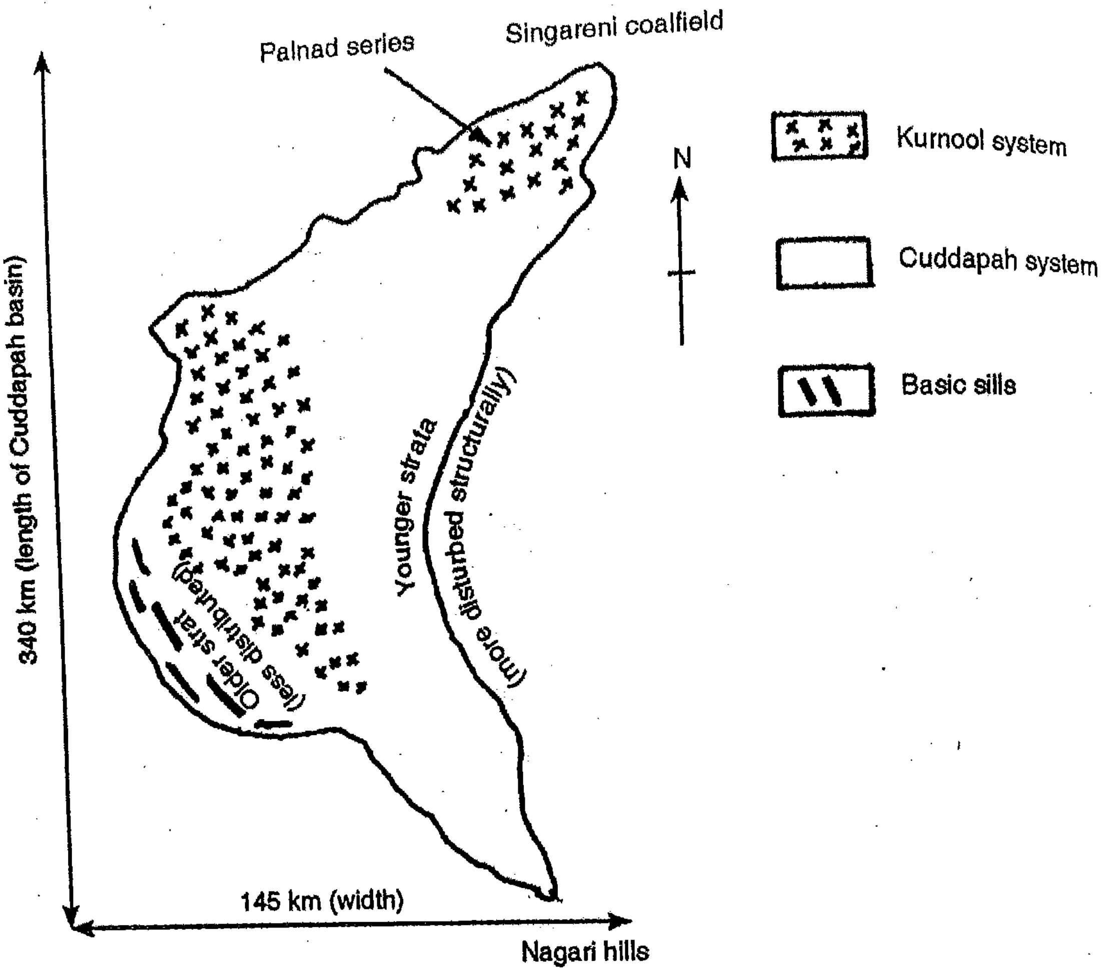


Fig. 12.3(b) Cuddapah basin

Lithology

Quartzites and shales are the main rock formations of this system. In addition to these, sandstones, limestones and conglomerates also occur. Some of the formations are intruded upon by basic sills, and along the contacts of such intrusion, in some places, economic minerals like asbestos, barytes, steatite and lead-zinc ores have formed.

The alternating arrangement of sandstones/quartzites and shales, which occurs in the type area, perhaps indicates that at the beginning of each series the depositional basin was shallow and later became deep.

Succession (in type area): The Cuddapah system of rocks is nearly 20,000 feet in thickness and are subdivided into four series. Each series is separated from the others by unconformity. The following is the outline of the geological succession of this system in the Cuddapah basin, as worked out by W. King.

The following chart indicates that the Cuddapah system commences with the Gulcheru quartzites stage of the Papaghni series and ends with the stage of Srisailam quartzites of the Krishna series. The formations of this system comprise alternating quartzites and shales. The quartzites occur in association with sandstones, whereas shales often occur along with limestones. Conglomerates are found along unconformities. Among the different series, the Cheyair series are the thickest, being 10,500'. The

Vempalle stage of rocks is intruded by basic igneous rocks. The Nallamalai series occupy the largest area and are highly folded and faulted.

The Kurnool system of rocks of the Vindhyan age

System	Series	Rocks
	Unconformity	
Cuddapah system	Krishna series 2000′	Srisailam quartzites Kolamnala shales Irlakonda quartzites
	Unconformity	
	Nallamalai series 3400′	Cumbum shales Bairenkonda quartzites
	Unconformity	
	Cheyair series 10 500′	Pullampet (or Tadpatri) shales Nagari (or Pulivendula) quartzites
	Unconformity	
	Papaghni series 4500′	Vempalle limestones and shales Gulcheru quartzites
	Eparchaean unconformity	

Gneisses and schists of Archaeans

Structure: The structure is as follows:

1. As mentioned earlier, the different series are separated by unconformities.
2. The western side of the basin shows an undisturbed sequence of Cuddapah rocks, made up of quartzites and shales. In the eastern side, the same rocks have been folded and metamorphosed too.
3. The effect of diastrophism is the most marked along the concave (eastern) margin where the formations are considerably crushed, folded and faulted.
4. The western side has the older formations.
5. The Vempalle limestones have been intruded upon by sills of basic igneous rocks in many places.
6. The ripple marks are found frequently in sandstones of the Cheyair series.

Fossil content: The thick beds of limestones and shales of the Cuddapah system are particularly suitable for containing fossils. But they are completely unfossiliferous. This may indicate that life was either not existing at that time, or the life forms were too minute and without any hard parts.

Economic importance: The Cuddapah system of rocks contains good building stones and some important economic mineral deposits which are listed as follows: Deposits like talc, asbestos and barytes occurring in Vempalle limestones owe their origin to the basic intrusions.

1. *Talc:* Excellent type occurs in Andhra Pradesh in Kurnool and Anantapur districts. It also occurs near Beawar and Ajmer in Rajasthan.

2. *Asbestos:* Good chrysotile asbestos occurs in Cuddapah district of Andhra Pradesh.
3. *Barytes:* In Andhra Pradesh, Cuddapah, Kurnool and Anantapur districts; also occurs in Alwar in Rajasthan.
4. *Copper and cobalt ores:* In Rajasthan (Alwar and Jaipur). In Andhra Pradesh Cu-Pb-Zn ores occur in Guntur district. The lead ore occurs in Cuddapah district.
5. *Building stones and others:*

1. Quartzites	:	As building stones.
2. Limestones	:	As building stones and also for the manufacture of cement.
3. Slates	:	School slates are produced in Markapur (Kurnool district of Andhra Pradesh) and in Kund (Alwar in Rajasthan)
4. Refractory clays	:	Useful in the ceramic industry.

12.5.2.2 The Vindhyan System

The Vindhyan system is named after the Vindhyan range of mountains. This system has been studied by many great geologists like E. Vredenburg, R.D. Oldham, H.B. Medlicott, W. King and others. These formations occur uncomformably over the older rocks, i.e., Cuddapahs or Archaeans. Therefore, they are younger to the Cuddapah system of rocks. The Vindhyan system covers a vast area of over 40,000 square miles and exhibits a maximum thickness of about 14,000 feet.

Lithology: Sandstones, quartzites, shales and limestones are the main geological formations of the Vindhyan system. The lower part is made up mainly of calcareous and argillaceous sediments which were deposited under the marine environment. On the other hand, the upper part of Vindhyans is mainly made up of arenaceous rocks of fluviatile origin.

Structure: From the structure point of view, the Vindhyan system exhibits no signs of remarkable diastrophism. Based on structure and lithology, this system has been divided into lower and upper parts. The lower Vindhyans which are mainly calcareous and argillaceous have been subjected to folding at some places. The upper Vindhyans which are arenaceous are undisturbed and hence they are more or less horizontal. Both these divisions are separated by unconformity.

Fossil content: Like Cuddapahs, these rocks also, though highly suited for containing fossils, are unfossiliferous. But F. Chapman and M.R. Sahni have described some *doubtful* organic remains (two genera of primitive brachiopods, i.e., Fermoria and Krishnania) from Suket shales of the lower Vindhyan age. Further, shales and limestones of lower Vindhyans are said to contain spores, thalluses, etc., of ancient plants.

Occurrence and distribution: The Vindhyan system of rocks are well developed in the Sone valley. In most of the parts only upper Vindhyans are present. But in the Sone valley, both lower and upper Vindhyans occur and hence it is considered as a type area [Fig. 12.3 (a)].

Some of the other places where equivalents of Vindhyans occur are as follows:

1. Karauli and Chittor areas of Rajasthan
2. Kurnool system, Bhima series, etc., of A.P.
3. Jeypore-Bastar-Raipur area of M.P. and Orissa

} of the lower Vindhyan age.

4. Ralam series of Kumaon
5. Haimanta system of Spiti
6. Jaunsar series of Garhwal

} of extra-peninsula.

Succession: In the type area, i.e., Sone valley, the lower Vindhyans are called "Semri series". And the upper Vindhyans are subdivided into three series, namely, Kaimur series, Rewa series and Bhandair series. All these series are separated from one another by unconformities. Diamond-bearing conglomerates occur along the unconformities of the upper Vindhyans.

The succession and lithology of respective series of Vindhyan system, in the type area, are as follow:

System	Division	Series	Composition	Types of rocks
Vindhyan system	Upper Vindhyans	Bhandair series (150 - 300 m)	= Mainly arenaceous and calcareous	Shales, limestones and sandstones
		Diamondiferous conglomerate bed		
		Rewa series (150 – 300 m)	= Mainly arenaceous	Sandstones and shales
		Diamondiferous conglomerate bed		
		Kaimur series (150 – 300 m)	= Mainly arenaceous	Quartzites, shales grifts, conglomerates; some of these show current bedding.
		Unconformity		
	Lower → Vindhyans	Semri series (300 – 900 m)	Mainly = calcareous	Conglomerates, limestones, shales and basic instrusions
		Unconformity		
		Older formations		

Economic importance: The important economic mineral deposits of the Vindhyan system are as follows.

1. *Diamond:* This occurs as pebbles in the Banaganapalli group of Kurnools and in conglomerates separating the different series of upper Vindhyans in Panna of Madhya Pradesh and also outside the Cuddapah basin in Sambalpur, Orissa. The Wajrakarur region of Anantapur district of A.P. is still reputed for the occurrence of diamonds.
2. *Pyrite:* The Bijaigarh shales of lower Kaimurs contain a massive fine grained bed of pyrite of nearly 5 feet thickness. It is of good quality with 45% of sulphur, free from arsenic. It is said to be a deposit of several million tons.
3. *Limestone:* Vindhyans provide inexhaustible reserves of limestone for the manufacture of cement in Bihar, U.P., M.P. and A.P. They are also used as building stone.

In Cuddapah and Kurnool districts, flaggy limestones are cleaved out as thin slabs of appropriate size for use as roofing or flooring material, as table tops, as steps and as paving stones. They are popularly called "Cuddapah slabs". "Shahabad stones" found near Hyderabad are of a similar type.

4. *Building stones:* Limestones and sandstones of this system are widely used for constructional purposes. The Vindhyan sandstones make one of the best building materials.
   Some of the notable constructions using these rocks are:

   1. Buddhist sculptures of Amravati – limestones.
   2. Buddhist stupas of Saranath and Sanchi.
   3. Fatehpur Sikri.
   4. Palaces and forts of Agra, Delhi and Lahore.

   } Sandstones (items 2–4)

   Use of Cuddapah slabs and Shahbad stones has already been mentioned.
5. *Glass sand:* Good quality of glass sand derived out of the weathering of Vindhyan sandstone occurs over an area of more than 100 sq. miles in U.P. and neighbouring states.
   In addition to the foregoing, ochres, fire clay, chalk, etc., also occur in Vindhyan formations.

12.5.3 The Gondwana Group

The name Gondwana was introduced by H.B. Medlicott in 1872. It was named after the Gond kingdom of Madhya Pradesh, where these formations were studied by him. Later this term was extended to all equivalent rocks in different parts of the world.

After the formation and uplift of Vindhyan rocks, there was a very long break in sedimentation in the Indian peninsula. This break was from the beginning of the Cambrian period to the Upper Carboniferous period, i.e., nearly 300 million years. But in the Upper Carboniferous period, the sedimentation which resumed, continued till the Lower Cretaceous period. Such deposition, again for a long period (i.e., over 150 million years) has given rise to a massive sequence of sedimentary rocks of 20,000 to 30,000 feet thickness. These are called the "Gondwana group" of rocks. Such enormous thickness was possible because of the simultaneous sinking of the basin when deposition was going on.

Occurrence or Distribution

The Gondwana rocks are mainly developed along two sides of a great (inverted) triangular area, the third side of which is the northern part of the east coast of the peninsula. The northern side corresponds roughly to Damodar, Sone and Narmada valleys, tending nearly east-west. The southern side runs along the Godavari valley with the NW-SE trend. In the interior of this triangle is a subsidiary belt along the Mahanadi valley. These long and narrow tracts are actually a series of faulted troughs (Fig. 12.4).

In addition to the foregoing, Gondwanas are also found along foothills of the Himalayas, Assam and Kashmir. They also occur at some places along the east coast of India, in Rajmahal Hills, Madhya Pradesh, Gujarat, etc.

Outside India, Gondwanas have extensively developed in Australia, South America, South Africa, and even in Antarctica.

Lithology and Structure

The Gondwana group of rocks are of fluviatile or lacustrine origin and were deposited in a series of large river or lake basins which later sank along *trough faults* amidst the ancient rocks. It is due to this faulting that we owe the preservation of the Gondwana strata along with their rich coal seams in our country. Similar to the lithology of the Cuddapah system of rocks (which reflects the periodical sinking of the Cuddapah basin giving rise to the repetition of cycles of sediments), Gondwanas also show cycles of sediments. In the latter, each individual cycle commences with coarse sands, followed by the deposition of clay and ending with the accumulation of plant remains on top of the sequence.

This means sandstones, shales and coal seams occur in repetition in Gondwanas. Grits and conglomerates are two other associated rock types.

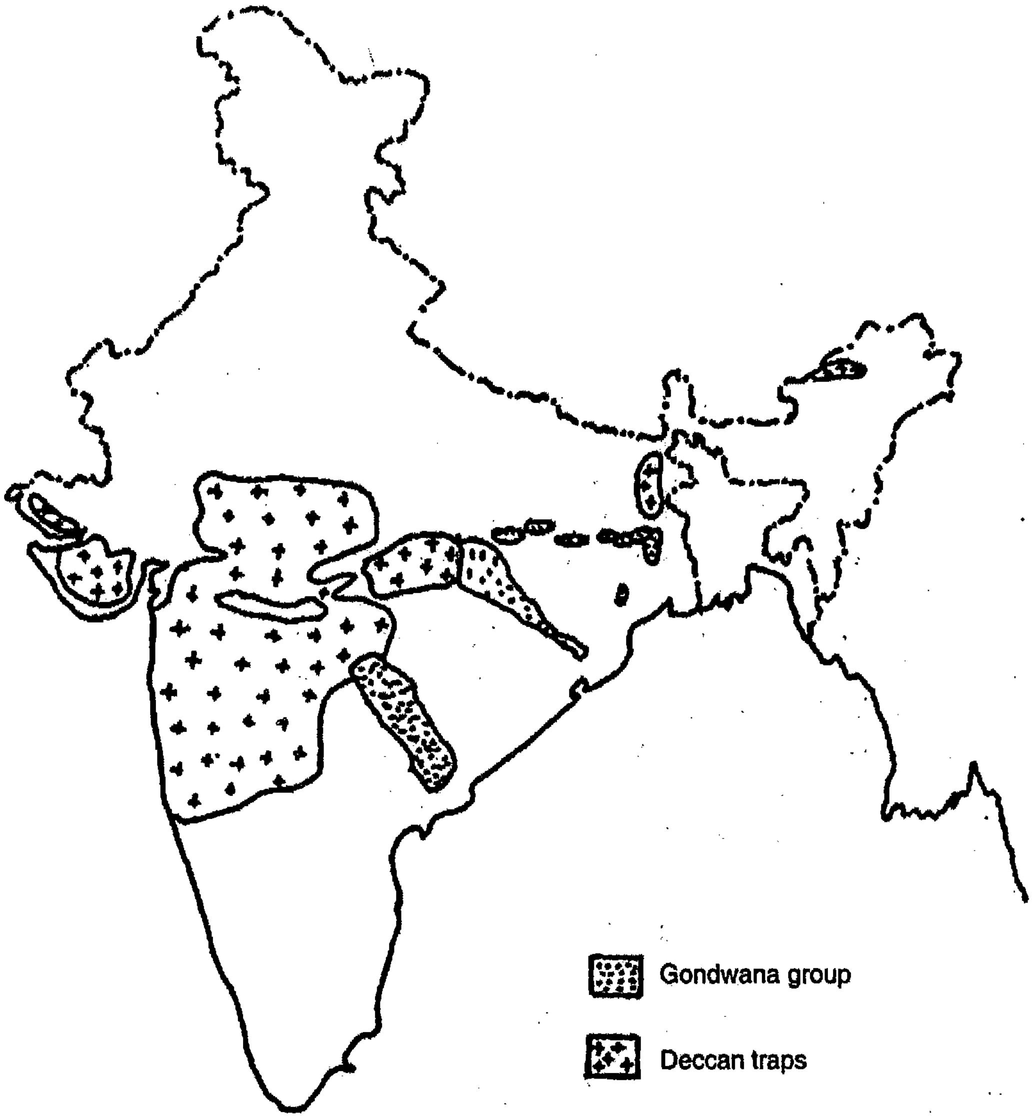


Fig. 12.4 Distribution of Gondwana group and Deccan traps

In addition to faulting, Gondwanas are also intruded upon by sills and dykes. The peridotite intrusions in lower Gondwanas have burnt the coal and changed it to Jhama, a useless material. The coal fields of upper Gondwanas are intruded upon by dolerites of the Deccan trap age, but these are not harmful.

Classifications

There are two different classifications of the Gondwana group of rocks, i.e., the twofold classification and the threefold classification.

Based on the evidence of plant fossils (i.e., flora) the Gondwanas are subdivided into lower and upper parts. The lower Gondwanas are characterized by the presence of Glossopteris and Gangamopteris flora and comprise the earlier three series, i.e., Talchir series, Damuda series and Panchet series. The upper Gondwanas, on the other hand, are characterized by the presence of Ptillophyllum flora which represent more advanced groups of plants. These comprise the later three series, i.e., Mahadeva series, Rajmahal series and Jabalpur series. Further, the occurrence of a clear unconformity between Panchet and Mahadeva series also supports this twofold classification.

The threefold classification is based on the evidence of animal fossils (fauna) and the prevailing climatic conditions. In this classification, lower Gondwanas represent the Upper Carboniferous and the Permean periods. It was a period of warm and humid climate. The middle Gondwanas represent the Triassic period with warm and dry climate. These have characteristically the remains of amphibians and reptiles. The upper Gondwanas represent the Jurassic and lower Cretaceous period. This was again a period of warm and humid climate.

Of these two classifications, the twofold classification is more commonly followed.

Succession

The established geological succession of the Gondwana group along with its subdivisions, age relation and concerned rock types are illustrated in the chart given below.

Among the different series in the Gondwana group, Damuda series are of particular importance in view of their great thickness, area extent and economic importance.

		Series (Geological time)	Stages	Concerned rock types
Gondwana group	Upper Gondwanas	Jabalpur (Upper Jurassic and Lower Cretaceous)	Umia Jabalpur	Sandstones, oolitic limestones, shales. Sandstones, carbonaceous bands.
		Rajmahal (Lower and Middle Jurassic)	Kota Rajmahal	Basic lava flows, sandstones and shales
		Mahadeva (Upper Triassic)	Maleri Pachmari	Sandstones and clays
		Unconformity		
	Lower Gondwanas	Panchet (Lower Triassic)	Panchet	Sandstones and shales
		Damuda or Damodar (Permian)	Raniganj Barren Measures Barakar Karharbari	Sandstones, shales and Coal scans
		Talchir (Upper carboniferous)	Rikba Talchir Boulderbed	Boulderbeds, shales and sandstones

There are four stages in Damuda series. They are the Karharbari stage, the Barakar stage, Barren Measures and the Raniganj stage. The Karharbari stage which is the earliest in the Damuda series is well developed in Giridih coalfields. This is mainly made up of grits, sandstones and coal seams. It is 200' to 400' in thickness. The overlying Barakar stage is well developed in Jharia coalfields. It is nearly 2500' in thickness. This stage is mainly made up of sandstones, shales and coal seams. Grits and conglomerates also occur in some places. The Barakar stage contains a number of coal seams and it is the most important coal-bearing strata in our country. Barakars have more than two dozen coal seams of more than four feet thickness. Some of them like Korba and Kargali seams (of Madhya Pradesh) are about 100' thick. It will be interesting to know that one-ninth of the total thickness of the Barakar stage comprises coal seams. The cycle (sequence) of the sandstone-shale-coal seam occurs repeatedly in this stage. The Barakars are overlain by Barren Measures. These are 1400' to 2000' thick and consist of sandstones and carbonaceous shales with nodules of clay iron stone. This stage has no coal seams, but contains workable deposits of iron ore in the Raniganj coal fields. Above the Barakars stage, the Raniganj stage occurs. This stage which is the youngest of the Damuda series is about 3000' thick and is made up of sandstones, shales and coal seams. This stage is well developed in Raniganj coal fields, where they contain important coal seams. As in the case of the Barakar stage, in this stage too, repeated cycles of sandstone-shale-coal seam occur.

Fossil Content

The Gondwana group of rocks are rich both in plant fossils (flora) and animal fossils (fauna). The lower Gondwanas have relatively more of plant fossils and are particularly characterized by the presence of Glossopteris and Gangamopteris flora. Pteridosperms, cordaitales, and sphenophyllales are typical of these earlier Gondwanas.

The upper Gondwanas are marked by the advent of ptillophyllum (or Rajmahal) flora. These are dominated by the advanced groups (or more developed forms) of plants like ferns, cycades and conifers.

A good number of animal fossils, both vertebrates and invertebrates, have been found in middle Gondwanas. These include crustacea, insects, fishes, amphibia and reptiles.

Economic Importance

Coal: The main economic importance of the Gondwana group centres around rich coal deposits. Such deposits are not only extensive but also are of good quality. All of them are rich bituminous coals. Coking and steam coals are abundant in the Barakar series. The reserves of workable seams are estimated to be around 35,000 million tons, of which six thousand million tons are said to possess very good quality. West Bengal, Bihar, Madhya Pradesh, Orissa and Andhra Pradesh have rich deposits of Gondwana coal. Among these, Bihar is the most productive. Coal seams also occur in the Himalayan area.

Clays: Rich fire clay beds occur in association with coal seams. They are useful in making refractory bricks. Suitable clays to make pottery, bricks, terra cotta and chinaware also occur in the Gondwanas. White clay and moulding sand are obtained from Mangalhat and Rajmahal Hills. Bentonitic clay which is used for bleaching also occurs in plenty.

Sandstones: Gondwana sandstones are not as good as Vindhyan sandstones, but they are commonly used as building stones. The Athgarh sandstones (upper Gondwanas) have been used in the famous Orissa temples (in Bhubaneswar, Puri and Konark). The Khandagiri caves, near Bhubaneswar, are carved out from Athgarh sandstones only.

Gondwana sandstones are also used as millstones and abrasive stones.

Iron ore: The beds of sideritic and limonitic iron ore, occurring in Raniganj coalfield, were used in blast furnaces of the Bengal Iron Company. Their reserves are estimated to be 2000 million tons. These consist of relatively low grade iron ore only, because they contain about 40-45% of iron and 16 to 19% of silica. These occur in Barren Measures.

125.4 Deccan Traps

The end of the Mesozoic era was marked by the unique outpouring of enormous lava flows which covered extensive areas in the peninsula. These lava flows occurred mainly through long and narrow fissures. Therefore, they are called "fissure eruptions". At a few places like Girnar Hills and Ranpur, however, the eruptions were of the "central type". Based on the fact that these lava flows occur in Deccan (i.e., South India) and produce step-like appearances of their outcrops, they are called "Deccan traps". Similarly, as these are basaltic in composition and have produced flat topped plateau-like features, these are also called "plateau basalts".

Occurrence or Distribution

The present area occupied by Deccan traps is over 500,000 sq. km. They are found in Gujarat (Kutch), Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh. They occur more or less as a single huge patch. They extend up to Belgaum (in Karnataka) in the south, Rajahmundry (in Andhra Pradesh) in the south east, Amarkantak in the east, and Kutch in the north-west (Fig 12.4).

From the following facts, it appears that the present Deccan traps represent only a small relict of what they originally were:

1. The traps are the thickest near the west coast and thin down towards the east. This indicates that the fissures of eruptions were near (and parallel to) the western coast and the (westerly flowing) lava flows would have covered large areas in the Arabian side too.
2. The occurrence of the Deccan traps on the floor of the Arabian Sea and the nearly straight nature of the western coastline indicate that due to faulting, the western part of the Deccan traps has been thrown down below the sea.
3. The effect of erosion of the Deccan traps right from their formation (for a pretty long period of more than 66 million years) also would have reduced considerably their areal extent. Thus, the present extent of the Deccan traps, though very large, still represents only a relict of their much more extensive original formations. It is believed that they originally had extended over an area of more than 1.25 million sq. km.

Lithology

The Deccan traps are essentially basalts. They are either vesicular or amygdaloidal. Sometimes, they occur intercalated with Inter Trappeans and ash beds. The Inter Trappeans are fluviatile or lacustrine sedimentary formations and have a rich fossil content. They have been formed during the intervals of successive eruptions.

Deccan traps have some other varieties (ultrabasic or acidic) of igneous rocks also, but these are rare.

The upper Gondwanas in Madhya Pradesh are intruded upon by sills of the Deccan traps. The traps themselves are intruded upon by numerous but haphazardly distributed dykes.

The Deccan traps are known for their unique uniformity in chemical and mineral composition. The variation is very less. Hence they exhibit consistency in their colour (dark greenish grey with a brownish or purplish tint).

Fossil Content

Many animal and plant fossils have been found in the Inter Trappeans which occur in between the Deccan traps. The remains of algae, palm and dicotyledonous trees occur as important plant fossils. The animal fossils include those of gasteropods, frogs, tortoise and crustacea.

Structure

The important topographic and structural features of the Deccan traps are as follows:

1. These have produced characteristic, flat topped hills and step-like terraces.
2. The traps are either massive or vesicular or amygdaloidal.
3. They are in some places mutually separated by intercalating Inter Trappeans or volcanic ash beds.
4. Columnar jointing occurs in these rocks in Malwa and at Andheri in Bombay.
5. Individual flows vary in thickness from a few feet to over 120'.
6. Some of these lava flows have spread over 100 km and this is attributed to the high degree of superheat at the time of eruption.
7. The Deccan traps occur generally horizontal, but at places they show dips of 5° to 20°.
8. Gentle folding of traps occurs in the Satpura region of Madhya Pradesh.
9. Traps exhibit faulting in some places in Madhya Pradesh.
10. The Deccan traps are the thickest near Bombay (over 7000') but are thin towards the east.

Classification

The Deccan traps have been subdivided into three parts as shown below. The formations which occur below these rocks are either Infra Trappeans or Lameta beds or Bagh beds:

	Subdivisions	Remarks
Deccan Traps	Upper Traps (450 metres)	These occur along with numerous ash beds and Inter Trappean beds.
	Middle Traps (1200 metres)	In these many ash beds occur in the upper portion, but Inter Trappean beds are absent.
	Lower Traps (150 metres)	These occur along with Inter Trappean beds, but ash beds are rare.

The lower traps occur in Madhya Pradesh and further eastwards. The middle traps, which are the thickest, occur in Madhya Pradesh and some parts of Maharashtra. As these do not have any Inter Trappeans, they are unfossiliferous. The upper traps occur typically in Maharashtra and Kutch. The Inter Trappeans of these are highly fossiliferous.

Economic Importance

1. *Building material:* Being dense, hard and durable, Deccan traps make good building stones. But as their colour is black, they are used limitedly. The "Gateway of India" in Bombay is built of these rocks.

   As road metal, the traps are excellent for macadam or tarred roads. They are hard, tough, wear-resistant and have a good binding property. They are also very good for use as aggregate in cement concrete.

2. *Gemstones:* Many semi-precious stones like agate, onyx, carnelian and amethyst occur as geodes in traps.
3. *Bauxite:* Weathering of the Deccan traps has produced very high grade bauxite deposits at many places. Bauxite deposits of Gujarat, Kolhapur, Katni, Jabalpur, Mandla, Sarguja, etc., have been formed this way.
4. *Laterite:* Iron-rich laterites are used in some places as building (dimension) stones.
5. *Black (cotton) soil or regur:* The black soil formed out of Deccan traps, known as regur, is highly suitable for growing cotton.
6. *Ground water:* The vesicular structure and associated interconnected joints or fissures help these traps to possess reasonable ground water potential.

12.6 IMPORTANCE OF THE STUDY OF STRATIGRAPHY FROM THE CIVIL ENGINEERING POINT OF VIEW

The comprehensive study of stratigraphy of any place (say, a proposed site for the construction of a dam) should provide details of: 1. Occurrence of different types of geological formations, i.e., rock types and their area-wise distribution. 2. Their order of superposition and thickness details of different formations. 3. Geological structures associated with *in situ* rock along with the details of factors such as their strike and dip. 4. Occurrence of economic minerals, fossils, etc., in the concerned rocks.

(a) With these details, properties of civil engineering importance such as strength, durability and workability can be assessed for the rocks concerned and their suitability as foundation rocks (for dam) can be predicted.

(b) The knowledge of geological structures associated with these rocks helps to assess the safety, stability, etc., of the latter to serve as sites for construction.

(c) The knowledge of the order of the superposition helps in taking necessary precautions if an incompetent bed lies below a competent bed which may be serving as the foundation.

(d) The knowledge of area-wise distribution of rocks helps to estimate the availability of suitable building material.

(e) The knowledge of occurrence of economic minerals, fossils, etc., helps to study their economic or academic significance and take suitable measures.

Thus detailed information of stratigraphy is of immense value from the civil engineering point of view.

13

EARTHQUAKES

Aims: The aims of this chapter are:

1. To give basic information about the probable causes of occurrence of earthquakes.
2. To give their mode of occurrence and places of occurrence.
3. To give details of their effects, particularly from the civil engineering point of view.
4. To give possible measures to prevent damage to civil engineering structures due to earthquakes.

INTRODUCTION

The very term "earthquake", when mentioned, generally creates a sense of panic and calamity in the minds of people, since many earthquakes have taken heavy tolls of life and property in the past, in many countries. Even now, with the prevailing highly advanced state of knowledge, earthquake occurrence still remains a mystery and is unpredictable.

Since earthquakes are capable of causing severe damage to any civil engineering structure, it is necessary to know what they are, why they occur, how they occur, what kind of harmful effects they will produce from the civil engineering point of view, what precautionary measures can be taken to minimize such harm, and other related factors.

An earthquake may be simply described as a sudden shaking phenomenon of the earth's surface for some reason or the other. It is also variously described as a sudden vibrating or jerking or jolting or trembling or shivering phenomenon of the earth's surface. The intensity of this jolting may be too insignificant at one extreme or it may be highly catastrophic at the other extreme. From physical geology point of view, an earthquake may be described as a natural force which originates below the earth's surface, works randomly and creates irregularities on the earth's surface. Therefore, it is an endogenous geological agent. Study of earthquakes is known as "seismology". The records of earthquakes are known as "seismograms" and the recording instruments are known as "seismographs" (In Greek, *seismos* means shaking.)

13.1 EARTHQUAKE TERMINOLOGY

1. The place of origin of the earthquake in the interior of the earth is known as *focus* or *origin* or *centre* or *hypocentre.*
2. The place on the earth's surface, which lies exactly above the centre of the earthquake, is known as the *"epicentre"*. For obvious reasons, the destruction caused by the earthquake at this place will always be maximum and with an increasing distance from this point, the intensity of destruction also decreases. The point on earth's surface diametrically opposite to the epicentre is called the *anticentre.*
3. The imaginary line which joins the centre and the epicentre is called the *"seismic vertical"* and this represents the minimum distance which the earthquake has to travel to reach the surface of the earth.
4. An imaginary line joining the points of same intensity of the earthquake is called an *"isoseismal"*. In plan, the different isoseismals will appear more or less as concentric circles over a plain, homogeneous ground if the focus of the earthquake is a point. On the other hand, if the focus happens to be a linear tract, the isoseismals will occur elongated. Naturally, the areas or zones enclosed by any two successive isoseismals would have suffered the same extent of destruction.
5. An imaginary line which joins the points at which the earthquake waves have arrived at the earth's surface at the same time is called a *"coseismal"*. In homogeneous grounds with plain surfaces, the isoseismals and coseismals coincide. Of course, in many cases due to surface and subsurface irregularities, such coincidence may not occur.
6. The enormous energy released from the focus at the time of the earthquake is transmitted in all directions in the form of waves, known as *"seismic waves"*.

13.2 CLASSIFICATIONS AND CAUSES OF EARTHQUAKES

Earthquakes are grouped on the basis of different principles. For example, based on the depth of their origin, earthquakes are described as shallow or intermediate or deep. Earthquakes with a focus depth less than 60 km are called shallow earthquakes. If the depth is more than 60 km but less than 300 km, they are called intermediate earthquakes. Others which have a focus depth more than 300 km are called deep earthquakes. Earthquakes originating at depths greater than 700 km are extremely rare. It will be interesting to know that out of the 5605 earthquakes, recorded in Italy, Oldham has found that 90% of them had a focus at less than 8 km depth, 8% had a depth between 8 km and 30 km and only 2% had a focus deeper than 30 km.

Based on the causes responsible for their occurrence, earthquakes are described as *tectonic* or *non-tectonic.*

Tectonic Earthquakes

Tectonic earthquakes are exclusively due to internal causes, i.e., due to disturbances or adjustments of geological formations taking place in the earth's interior. Generally, they are less frequent, but more intensive and hence more destructive in nature.

Non-tectonic Earthquakes

The non-tectonic earthquakes, on the other hand, are generally due to external or surfacial causes. (Of course, earthquakes which occur due to volcanic eruptions are also termed as non-tectonic earthquakes.) This type of earthquake is very frequent, but minor in intensity and hence generally not destructive in nature. Such earthquakes occur due to a variety of reasons, some of which are as follows:

1. *Due to huge waterfalls:* When huge quantities of water pound a particular place, tremors develop in the ground there.
2. *Due to avalanches:* Avalanches are generally the parts of valley glaciers which get detached from the main body under certain circumstances and hence roll down with considerable momentum along the steep slopes of mountains. When they hit the ground forcefully minor tremors are produced.
3. *Due to meteorites.* Meteorites are heavenly bodies of various sizes wandering in space. When they come under the influence of the earth's gravity field, they suddenly fall on the earth's surface. Of course, most of them do not reach earth's surface because they get totally burnt out and vaporize due to intense frictional heat produced at the time of their passage through the atmospheric zone which envelops the earth. However, some larger meteorites may survive this process and reach the earth's surface. Their violent impact creates tremors in the ground.
4. *Due to the occurrence of sudden and major landslides:* The impact of such landslides will be capable of causing earthquakes. (Of course, in some instances the landslide occurrences themselves may be due to earthquakes.)
5. *Due to volcanic eruptions:* Some volcanoes like Stromboli (Italy) erupt calmly without any fanfare and quietly pour out lava. But some erupt very violently with thunderous noise, throwing out tongues of fire, smoke, pyroclasts, etc., to great heights, accompanying the terrific blowup of the crater. It is particularly so in the Pelean type of volcanoes. Such violent eruptions sometimes cause earthquakes. The earthquake occurrence of 1883 in Indonesia due to the eruption of the Krakatoa volcano is a striking example of this kind.
6. *Due to tsunamis:* Tsunamis are the giant sea waves formed due to submarine earthquakes. They move shorewards and dash against the coastline violently sometimes causing earthquakes. The Lisbon earthquake of 1755 is an extraordinary example of this type.
7. *Due to man-made explosions:* During mining the economic mineral deposits and during quarrying the building material, many explosions are carried out. These naturally produce tremors locally.
8. Minor tremors may also develop due to collapse of caves, tunnels, etc.
9. *Due to dams and reservoirs:* This is a strange phenomenon noticed in recent times. The reservoir areas which were *aseismic* started showing signs of earthquake occurrences when the reservoir was filled with water. This may be due to the great lateral thrust of reservoir water contributing to stress imbalances or due to the reactivation of subterranean faults by the newly developed stresses or due to increased pore pressure in the adjoining rocks which lowers their shearing strength, resulting in earthquake occurrence. The Koyna (in Maharashtra) earthquake (1967) is a typical example of this kind.

13.3 SEISMIC BELTS AND SHIELD AREAS

Seismic belts are those places where earthquakes occur frequently and shield areas are those places where earthquakes occur either rarely or very mildly.

Occurrence of an earthquake in a place is an indication of underground instability there. In other words, all such places which are unstable are prone to earthquake occurrences. Generally, the tectonically formed mountainous regions and steep coasts are the places of subterranean instability. Hence, earthquakes occur frequently there. Statistics have revealed that nearly 50% of earthquakes have occurred along mountain ridges and 40% of earthquakes along steep coasts.

The study of recorded earthquakes shows that they take place on land most frequently along two well-defined tracts, i.e., seismic belts. One belt is the *Circum Pacific belt* which accounts for 68% of earthquake occurrences. The other belt is called the *Mediterranean belt,* which extends east-west from Portugal, through central Europe, Asia minor, Himalayas and Burma to the East Indies with a branch through Tibet and China. This belt accounts for 21% of earthquake occurrences. A minor belt of epicentres occurs along the *mid-Atlantic ridge.*

In the aforementioned belts, orogenic forces are still active and the crust is therefore still in an unstable condition. Consequently, crustal adjustments are still taking place and occasionally stresses are relieved by the movement of rock masses giving rise to earthquakes.

Under stratigraphy, we have learnt that the regions where Archaean formations occur are very stable and more or less free from earthquake occurrences. Therefore, such areas are rightly described as shield areas or aseismic areas. Of course, they are not totally devoid of earthquake occurrences. But generally intense earthquakes are rare. Occasionally, minor earthquakes may occur there. In fact, there is no place on the earth entirely free from seismic disturbances.

In India, the entire northern part of the country consisting of foothills of the Himalayan ranges and a major portion of Indo-Gangetic plains is prone to the occurrence of major earthquakes. The peninsular area is a stable shield area, though some occasional intense earthquakes like the Koyna earthquake of 1967 have occurred.

13.4 EARTHQUAKES AND FAULTING

Tectonic earthquakes, which are often disastrous, are associated with the faulting phenomenon. The *elastic rebound hypothesis* has been postulated by Reid to explain the mode of origin of tectonic earthquakes. It is as follows: Underneath the earth's surface, the beds or masses of rocks are deformed and strained due to the differential stresses to which they are subjected occasionally by tectonic forces. In the initial stages, accumulation of strain is accommodated by elastic deformation, i.e., bending. But when the stress acts further and the elastic limit of the formation is exceeded, it no longer bends further, but breaks suddenly along a fracture at the bend and the broken halves spring (i.e., move) to the positions of no strain. As a result of this process of elastic rebounding phenomenon, faulting appears. During fracturing of the formation, the enormous energy (strain) stored gets released instantaneously, causing severe vibrations which are propagated in the form of earthquake waves. (See Fig. 13.1.)

Although tectonic earthquakes occur in this way due to the relative displacement of blocks along the cracks at great depths, the effect of such movement is rarely seen on the surface in the form of well-defined faults. The great Alaskan earthquake of 1899 which had recorded a rise of 47' may be cited as one rare case.

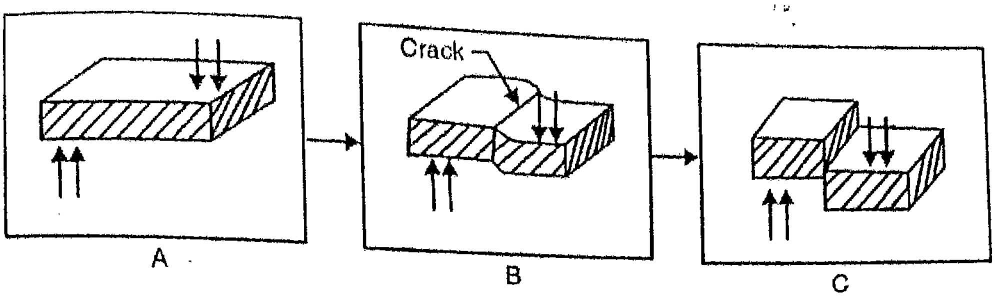


Fig. 13.1 Elastic rebound hypothesis. (A) A bed over which stress begins to act. (B) The bed affected by stresses has deformed elastically and a crack is developing at the bend. (C) Along the crack, the two fractured blocks rebound to the positions of no strain. As a result the crack becomes a fault.

Earthquakes are likely to reoccur at the same place because, at the first instance of displacement, the broken blocks encounter great friction along the crack which means only partial structural adjustments take place. Again, when stresses develop, strain also accumulates and when it reaches a certain limit, it overcomes the frictional resistance and faulting/earthquake reoccurs. This means the displacement of blocks again, at the same old site. Such phenomena will get repeated till total structural adjustment is achieved in the region.

13.5 EARTHQUAKE WAVES

Earthquake vibrations originate from the *focus* and are propagated in all directions. These vibrations travel through the rocks in the form of elastic waves. Mainly, there are three types of waves called P waves, S waves and L waves. Of course, there are subvarieties among them. The important features of these three kinds of waves are as follows:

P waves

These are variously called primary waves, push-pull waves, preliminary waves, longitudinal waves, compressional waves, etc. These are the fastest among the seismic waves. They travel as fast as 8 to 13 km per second. Therefore, when an earthquake occurs, these are the first waves to reach any seismic station and hence the first to be recorded. The P waves resemble sound waves because these too are compressional or longitudinal waves in nature. Hence, the particles vibrate to and fro in the direction of propagation (i.e., *longitudinal particle motion*). These waves are capable of travelling through solids, liquids and gases.

S waves

These are also called shear waves, secondary waves, transverse waves, etc. Compared to P. waves, these are relatively slow. They travel at the rate of 5 to 7 km per second. For this reason these waves are always recorded after P waves in a seismic station. In nature these are like light waves, i.e., the waves move perpendicular to the direction of propagation. Hence, *transverse particle motion* is characteristic of these waves. These waves are capable of travelling only through solids.

S waves may sometimes show the polarization phenomenon. If the particle motion is parallel to prominent planes in the medium they are called SH waves. On the other hand, if the particle motion is vertical, they are called SV waves.

L waves

These are called long waves or surface waves. These are the slowest among the seismic waves. Therefore these are the last to be recorded in the seismic station at the time of occurrence of the earthquake. They travel at the rate of 4 to 5 km per second. *Complex and elliptical particle motion* is characteristic of these waves. These waves are capable of travelling through solids and liquids. The destruction at the time of the earthquake is caused by these waves only. These are called surface waves because their journey is confined to the surface layers of the earth only. In other words, they do not travel towards the interior of the earth from the focus. They are complex in nature and are said to be of two kinds, namely, Raleigh waves and Love waves.

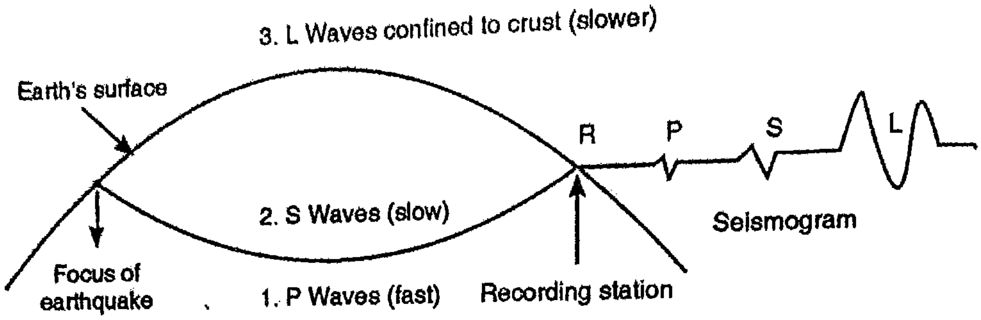


Fig. 13.2 Paths followed by P, S and L waves generated by an earthquake at F and recorded at R; and a seismogram sketch

13.6 INTENSITY OF EARTHQUAKES

The intensity of an earthquake refers to the degree of destruction caused by it. In other words, intensity of an earthquake is a measure of severity of the shaking of ground and its attendant damage. This, of course, is empirical to some extent because the extent of destruction or damage that takes place to a construction at a given place depends on many factors. Some of these factors are as follows:

1. *Distance from the epicentre:* Destruction decreases with increasing distance from the epicentre. Therefore, this is an important factor of influence in terms of damage caused to a construction.
2. *Compactness of the underlying ground:* If the ground over which a construction exists is loose or fractured, the extent of damage due to an earthquake will be relatively less because the shock waves are absorbed effectively by such ground and hence damage to the construction will be less. This is true vice versa too.
3. *Type of construction:* All other factors being equal, a properly reinforced construction will suffer less damage while a weak, non-reinforced structure gets affected badly.
4. *Magnitude of the earthquake:* The term magnitude refers to the absolute energy released at the time of the earthquake. Naturally; earthquakes with a greater magnitude cause greater destruction and vice versa.
5. *Duration of the earthquake:* Earthquakes, generally, are of short duration. They normally last only a few tens of seconds. Rarely do they last over a minute. The duration of earthquakes is very important because the destructive effects increase greatly with an increase in the length of time.
6. *Depth of the focus:* The extent of damage depends on the depth of the focus. Very shallow earthquakes cause only local damage.

The Modified Mercalli Scale

In spite of the foregoing factors, it is necessary to have a scale of intensity of earthquakes for comparison and other purposes. Though there are different scales or classifications of earthquake intensity, the following one is relevant from the civil engineering point of view because it takes into account the factor of acceleration produced in the units of mm/sec/sec. This is the modified Mercalli scale of earthquake intensities having 12 divisions. Since the intensity can be better appreciated from the effects produced on buildings, ground, people, and so on, those details are also included.

The intensity of the earthquake at any place is represented by isoseismals, which are the contour lines depicting the same intensity.

Table 13.1 The Mercalli scale

S.No.	Type	Acceleration in mm/sec/sec	Effects produced
1.	Instrumental	< 10 ...	Not felt by people; recorded only by seismic instruments.
2.	Very feeble	> 10 ...	Felt by people at rest only.
3.	Slight	> 25 ...	Felt by people indoors. The vibration is felt like the passing of a truck.
4.	Moderate	> 50 ...	Sensation similar to a heavy truck striking a building. Loose objects disturbed; walls make a cracking sound.
5.	Rather strong	> 100 ...	Unstable objects are overturned. Many are awakened if sleeping; dishes broken, bells ring, pendulum clocks stop.
6.	Strong	> 250 ...	Felt by all, slight damage to constructions, heavy furniture moved, cracking of plaster of walls, etc.
7.	Very strong	> 500 ...	General alarm, felt by people moving in vehicles, weak structures are considerably damaged.
8.	Destructive	> 1000 ...	Heavy furniture overturned, substantial damage to many buildings, etc.
9.	Ruinous	> 2500 ...	Pipes are broken, ground cracks, great damage even to good constructions including partial collapse, etc.
10.	Disastrous	> 5000 ...	Twisting of rails, many buildings destroyed.
11.	Very disastrous	> 7500 ...	Collapse of bridges, broad fissures develop in the ground, very few structures are left standing.
12.	Catastrophic	> 9800 ...	Objects thrown upward into the air, waves seen on ground surface, total destruction.

13.7 MAGNITUDE OF THE EARTHQUAKES

The intensity of an earthquake is a function of the magnitude of that earthquake. This magnitude may be defined as the rating of an earthquake based on the total amount of energy released when the earthquake occurs. In other words, the earthquake magnitude is a measure of the amount of energy released by the earthquake; the size of an earthquake is related to the scale of magnitude of seismic waves generated. As we know, this released energy (E) travels in the form of seismic waves through the subsurface geological formations. In doing so, part of the energy is absorbed by the medium and only part of it reaches the recording station. This is taken as the basis to determine the magnitude (M) by linking it to ground acceleration (a). The relation between M, E and a is given as follows: $\log_{10}E = 4.4 + 2.14M - 0.054M^2$. In this equation E is obtained from the formula

$$\sqrt{E} = C(a/h)\left(D^2 + h^2\right)$$

where E = the total amount of energy released, in erg,

a = the ground acceleration,

h = depth of focus in, km,

D = distance of the recording station from the epicentre, in km,

C = a constant, equal to 0.625.

It is important to understand that although the intensity of an earthquake varies from place to place, the magnitude remains the same.

The Richter Scale

The Richter magnitudes are quite familiar because they are reported by the news media within a few hours of an earthquake. Charles Richter of the California Institute of Technology proposed this scale, using the size of the surface waves as recorded by a particular type of seismograph (i.e., the Wood-Anderson type torsion seismograph) located at a distance of 100 km from the focus of the earthquake. In other words, it is a study of the size of wriggles written by a standard specially designed seismometer.

A massive earthquake can give surface wave readings 10,000 to 100,000 times larger than a just perceptible earthquake and so Richter numbered his scale in steps logarithmically with each step representing an earthquake record 10 times larger than the previous step.

Earthquakes may have Richter magnitudes from 3 to 9 (the maximum known is 8.9 only), but no shock smaller than 5 causes severe damage. Magnitude 2 is the smallest tremor that can be felt. Many of the destructive earthquakes are greater than magnitude 6.

Several different properties are given as a function of the Richter magnitude in the Table 13.2.

An earthquake of magnitude 5 may cause damage within a radius of about 8 km, but that of magnitude 7 may cause damage in a radius of 80 km, and that of 8 over a radius of 250 km. The felt areas of these earthquakes will have their radius equal to about 150,400 km and 600 km respectively. The Koyna earthquake of 11 December 1967 had a felt area of 400 km radius and the damage area of 60 km radius.

The energy released in earthquakes of different magnitudes is as follows. This gives their relative destructive power.

M (Richter)	=	5.0	6.0	6.5	7.0	7.5	8.0	8.4	8.6
$E(10^{20}$erg)	=	0.08	2.5	14.1	80	446	2500	10,000	20,000

Table 13.2 Magnitudes of earthquakes and their effects

The Richter magnitude	Height of surface waves on standard record (in metres)	Length of fault along which slippage occurs (in km)	Approximate diameter of area where people feel earthquake (in km)	Number of similar earthquakes per year, in the whole world	Energy per earthquake in W-sec.
9	Largest earthquakes ever recorded are between magnitudes 8 and 9				
8	100.000	800.0	1200	1.5	4×10^{16}
7	10.000	40.0	800	15	8×10^{14} *
6	1.000	8.0	450	150	4×10^{13} **
5	0.100	3.0	300	1500	8×10^{11}
4	0.010	1.3	160	15,000	4×10^{10}
3	0.001	0.5	30	150,000	8×10^{8}

* This energy release is approximately the same as the energy released by the largest hydrogen bomb.
** This energy release is comparable to that of an "ordinary" atom bomb.

Table 13.3 Details of a few Indian earthquakes

S.No.	Date	Place	Magnitude (*M*)	Death toll
1.	16 June 1819	Kutch	8.0	Many thousands
2.	12 June 1897	Shillong	8.7	1600
3.	4 April 1905	Kangra	8.0	20,000
4.	15 January 1934	North Bihar	8.3	20,000
5.	15 August 1950	North-east Assam	8.6	1500
6.	11 December 1967	Koyna	6.5	200

The maximum intensity of shaking attained during an earthquake of a given magnitude depends upon the depth of focus and the soil condition below the foundation of structures. For shallow focus earthquakes of 30 km depth or less, an approximate relationship between magnitude and maximum intensity in the epicentral area is as follows:

Richter scale ⟶	5.0;	6.0;	6.5;	7.0;	7.5;	8.0
Maximum intensity	VI-VII;	VII-VIII;	VIII-IX;	IX-X;	X-XI;	XI

On an average, 15 earthquakes having a magnitude of 8.0 or greater intensity occur every year somewhere in the world. If we compare the energy of an earthquake with that of an atomic explosion, the energy released by the Hiroshima type atom bomb is 8×10^{20} erg or equal to an earthquake of magnitude 6.33. Thus in terms of energy release, an earthquake of the kind that hit Assam (8.6 *M*) will be equivalent to 2500 such, bombs exploded together.

13.8 LOCATING THE EPICENTRE OF AN EARTHQUAKE

As already described, the epicentre of an earthquake is the point on the earth's surface vertically above the focus. This point can be located easily for any earthquake taking advantage of the time lag noticed between P and S waves. When the earthquake waves are recorded at different stations, it will be observed that the time lag between the arrival of P and S waves increases gradually with the distance from the epicentre. Thus this factor gives a measure of the distance between the epicentre and the seismic station. Therefore, if seismic recordings are made at three different well-spaced stations (A, B and C) and circles with measures of distance as radius are drawn, they (i.e., circles) intersect at a common point. This point is the epicentre of the concerned earthquake. (See Fig. 13.3.)

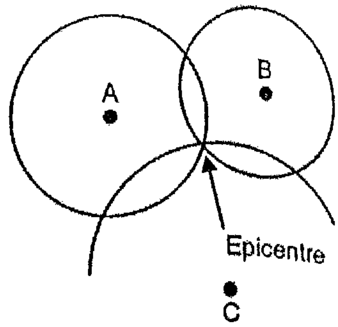


Fig. 13.3 Epicentre location

13.9 DETERMINING THE DEPTH OF THE FOCUS OF AN EARTHQUAKE

According to Oldham, the depth of the focus can be estimated by comparing the intensities at the epicentre and at another station Figure 13.4 illustrates this aspect.

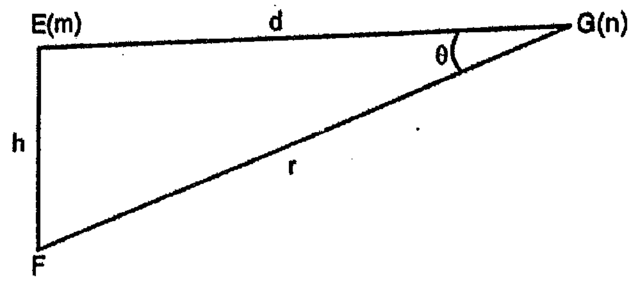


Fig. 13.4 Determination of depth of earthquake origin

where E = epicentre
G = a station where the intensity is known
m = intensity at the epicentre
n = intensity at G
d = distance between E and G
h = depth of focus.

First, θ is calculated as follows:

$$n/m = h^2/r^2 = \sin^2\theta$$

Based on the θ value h is known: $h = d\tan\theta$.

13.10 EFFECTS OF EARTHQUAKES

Most of the earthquakes are minor and go unnoticed. But the major ones, though occasional, are responsible for heavy loss of life and property. Some of their effects are as follows:

1. Destruction of various civil engineering constructions like dams, bridges, tunnels, roads and railway tracks.
2. Creation of irregularities (i.e., ups and downs) and cracks (open fissures) on the ground, contributing problems for communication systems.
3. Causing landslides and unstable conditions along hill slopes. Landslides may cause blocking of roads and railway lines in some places.

4. Changes in courses of rivers due to faulting across them.
5. Formation of new lakes, springs and waterfalls due to disturbances caused in surface and subsurface conditions. The same conditions may cause disappearance of old lakes, springs and waterfalls.
6. Submarine earthquakes cause tsunamis, which are giant tidal waves. When they dash against the shores they lead to destruction of coastal lines and occurrence of landslides, earthquakes and floods.
7. *Subsidence of land mass:* The vibratory movement in the ground causes compaction and closure of fissures, sometimes leading to the subsidence of the ground.
8. *Heavy loss of life and property:* Such instances are many, but we may cite just two cases now: (i) In Shensi province of China, in 1556, an earthquake had caused the death of 800,000 people. (ii) In 1923, an earthquake in Japan caused the death of 140,000 people and a property loss of three billion dollars.

The foregoing details indicate that earthquakes cause heavy loss of life and property directly due to failure of multimillion projects like dams and tunnels. Earthquakes also increase the misery indirectly by causing sudden floods (due to dam failures), by leading to the failure of water supply (in some cases) and by starting fires (due to shortcircuiting of electric wires during earthquake disturbances).

It is obvious from the aforementioned effects that earthquakes are a matter of severe concern to everyone and more so to a civil engineer who is keenly interested in the safety and stability of the various constructions.

13.11 CIVIL ENGINEERING CONSIDERATIONS IN SEISMIC AREAS

Seismic areas are the places which experience earthquakes frequently. When an earthquake occurs, it causes vibratory motion in the mass of the earth through which the energy waves pass and this motion is transmitted to the engineering structures standing on the earth's surface. As a result these structures get severe jolts both in horizontal and vertical directions. These jolts, in turn, cause additional shears and moments in the structures, leading to their failure unless they are suitably designed to withstand them. These complications do not rise in places where earthquakes do not occur. Therefore, constructions in seismic and aseismic (i.e., stable) areas differ in terms of their design.

The civil engineering constructions can be saved in seismic areas if the earthquakes can be stopped or if the constructions can be made strong and earthquake-proof. Of these two alternatives, earthquakes cannot be stopped because they are natural and represent inherent crustal adjustments of the earth. Therefore, a civil engineer should only think of making his constructions immune to earthquakes. To achieve total success or perfection in this regard is obviously impossible. But the possible harm can be effectively minimized by taking suitable precautions, keeping in mind the economical aspects involved. The difficulties in achieving this objective arise due to the fact that it is not possible to predict crucial factors like (i) the exact place of earthquake occurrence (this is important because the epicentral region will be the worst affected and hence needs maximum protection), (ii) the magnitude of the earthquake (this is important because the cost of construction increases steeply with the increase in safety measures required), (iii) the duration of the earthquake (this is also important because the extent of damage will be more if the duration is more) and (iv) the direction of movement of the ground at the time of the earthquake.

In all such cases, the epicentres lay within the reservoir area.

Such cases clearly show that there is some sort of link between the location of reservoirs and commencement of seismic activity there. Many scientists have carefully examined this aspect and some views expressed are as follows:

1. According to Cardar, such places had very old inactive faults underground and when the reservoir was filled with water, the load of the water reactivated those faults and earthquakes followed.
2. According to Evan, Hubbert and Rubey, these earthquakes related to reservoirs should be attributed to the increased pore pressure. They felt that the increase in pore pressure lowers the shearing strength of the rock formations and this results in releasing the tectonic strain in the form of earthquakes.

To prevent the occurrence of such earthquakes, reservoirs can be filled to a limited safe level and the pore pressure is reduced by draining the water from the weak zone. However, it is also noticed that after reaching the maximum, when the reservoir is full, these shocks tend to become not only weak but also less frequent.

13.12 PLATE TECTONICS AND EARTHQUAKE DISTRIBUTION

Earthquakes do not occur randomly but do so along certain narrow continuous belts. These belts link up together such that they encircle and enclose large regions which are quiet, i.e., free from earthquakes. These are known as plates. (They are like huge crustal blocks of considerable thickness floating over the unstable viscous asthenosphere.) These plates move slowly, at the rate of a few centimetres per year. This is responsible for earthquake occurrence. Plate movement occurs because the outer cold

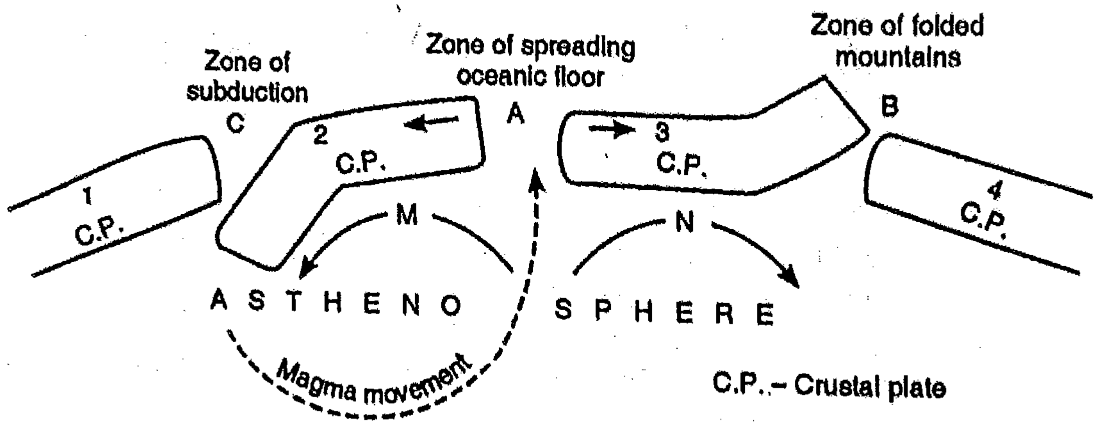


Fig. 13.5 Principle of plate tectonics

M and *N* = convection currents in asthenosphere,
1, 2, 3 and 4 = plates of the crust,
A = midoceanic ridge,
B = buckling up land mass into folded mountains when plate 3 has collided with plate 4.
C = land mass pushed down into asthenosphere when plate 2 has collided with plate 1. This land mass melts and the magma so formed may fill up the gap formed at A and contributes to spreading of the sea floor.

UNIT: 4 STRUCTURAL GEOLOGY

FOLDS: These are one of the most common geological structures found in rocks. These are best displayed by stratified formations such as sedimentary or volcanic rocks or their metamorphosed equivalents.

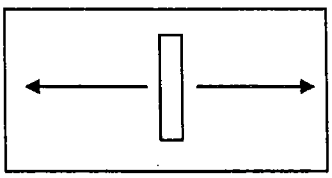
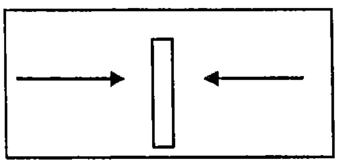
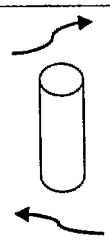
When a set of horizontal layers are subjected to compressive forces, they bend either upwards or downwards eg: Granitic gneisses, quartzites, Schists, Limestones etc are common rocks in which folds occur.

Explanation:

Tension: A body is said to be under tension when it is subjected to external forces that tend to pull it apart.

Compression: A body is said to be under compression when it is subjected to external forces that tend to compress it.

Torsion: It results from twisting. If the two ends of a rod or plate are turned in opposite directions, the rod or plate is subjected to torsion

		
TENSION	**COMPRESSION**	**TORSION**

STRIKE: The strike of a bed is its trend measured on a horizontal surface. Strike refers to the direction in which a geological structures such a bed, a fault plane is present.

When a bed is exposed on the surface , its direction of occurrence, its direction of inclination can be measured by using a clinometre or Brunton compass (a magnetic compass –like instrument).

DIP: The dip of a stratum is the angle between the bedding plane and a horizontal plane.

PARTS OF A FOLD:

In nature, folds found in rocks and vary in terms of their length and breadth. However, the bends noticed in rocks are called as folds. Following are the parts of a fold:

CREST & TROUGH: The curved portions of the fold at the top and bottom are called crest and trough respectively. The curved portions are smoothly bent or sharp or angular.

LIMBS / FLANKS: These are the sides of a fold. There are two limbs for every fold and one limb common to the adjacent fold.

AXIAL PLANE: This is the imaginary plane which divides the fold into two equal halves. Depending upon the nature of the fold, the axial plane may be vertical, horizontal or inclined.

WAVE LENGTH: The distance between the successive crests or troughs is called wavelength.

HINGE: The hinge of a fold is the line of maximum curvature in a folded bed.

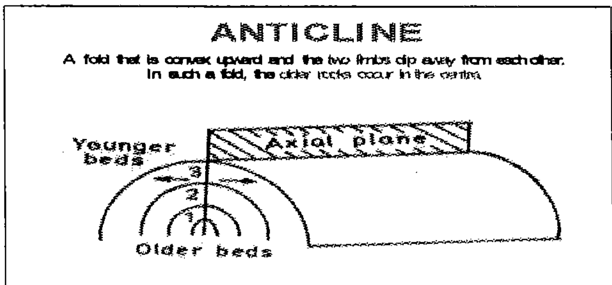
AXIS: The intersection between the axial plane and the crest or trough of the fold. (that means the axis is a line parallel to the hinges)

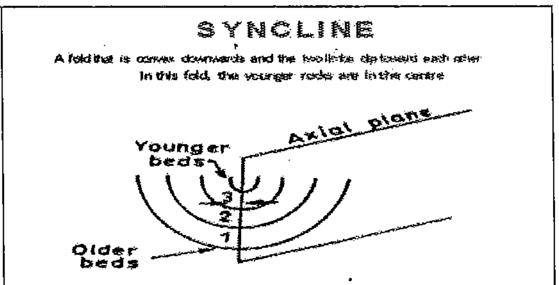
TYPES OF FOLDS: Folds are classified on the basis of (i) Symmetrical character (ii) Upward or down ward bend (iii) occurrence of plunge (iv) Uniformity of bed thickness (v) Behavior of the fold pattern with depth etc

- ANTICLINE & SYNCLINAL FOLDS
- SYMMETRICAL & ASYMMETRICAL FOLDS
- PLUNGING & NON-PLUNGING FOLDS
- OVERTURNED FOLD
- OPEN AND CLOSED FOLDS
- CHEVRON FOLD
- ISOCLINAL & RECUMBENT FOLDS
- BOX FOLD
- FAN FOLD
- Anticlinorium and Synclinorium Folds
- DRAG FOLD

Anticline: It may be defined as a fold that is convex upward; and the two limbs dip away from each other. In such a fold, the older rocks occur in the centre.

Syncline: It may be defined as a fold that is convex downwards and the two limbs dip toward each other. In this fold, the younger rocks are in the centre.

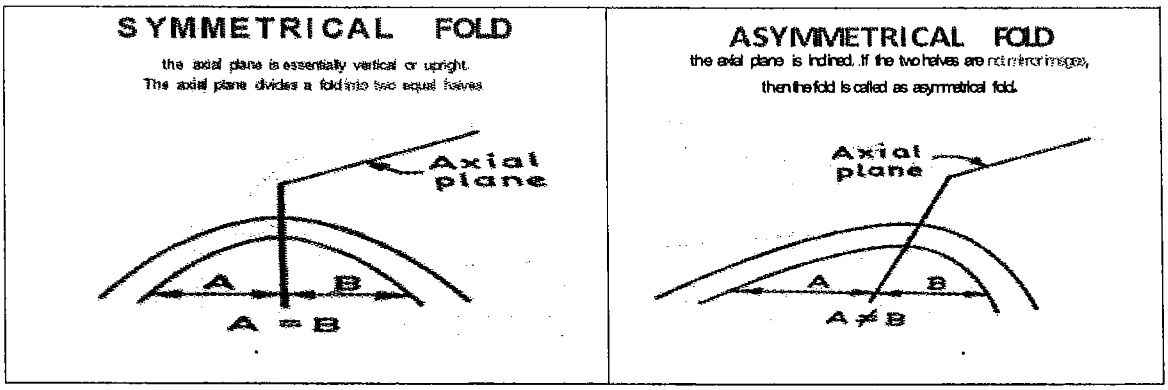




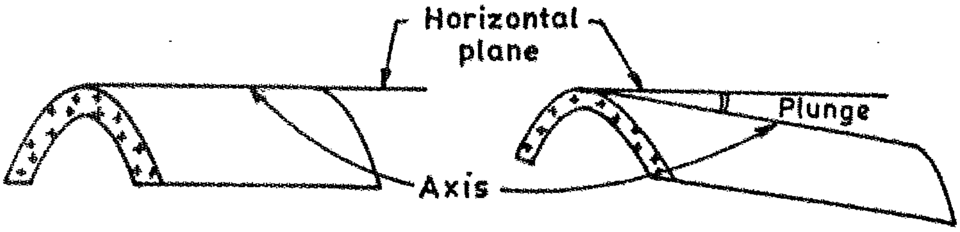
UNIT: 4 - 2

Symmetrical fold: a symmetrical fold is one in which the axial plane is essentially vertical or upright. The axial plane divides a fold into two equal halves in such a way that one half is the mirror image or another.

Asymmetrical fold: An asymmetrical fold is one in which the axial plane is inclined. If the two halves are not mirror images, then the fold is called as asymmetrical fold.

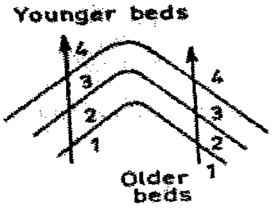


Plunging and Non-Plunging Fold: If the axis of a fold is inclined, then it is called plunging fold. On the other hand, if the axis of the fold is horizontal, then the fold is called Non-plunging fold.

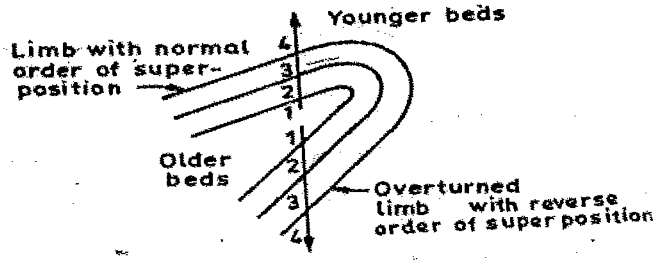


Non-Plunging Anticline **Plunging Anticline**

Overturned Fold: In a simple fold, the limbs show the order of superposition of beds. But when one of the limbs is overturned, the order of superposition of beds in that particular limb will be in reverse order, such a fold is called an overturned fold.



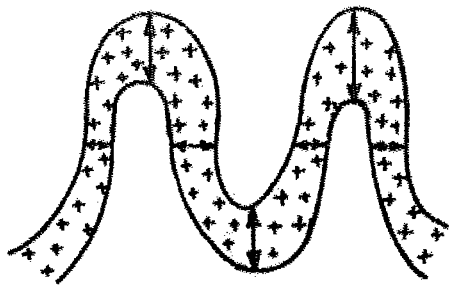
Simple fold



overturned fold

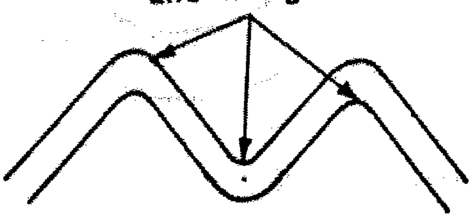
Open and Closed folds: If the thickness of beds is uniform throughout the fold, it is called an open fold. On the other hand, if the beds are thinner in the limb portions and thicker at the crests and troughs, such fold is called a closed fold.

Open Fold

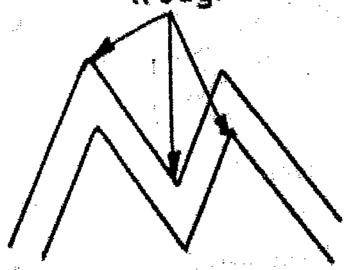


Closed Fold

Chevron Fold: A Chevron fold is one in which the hinges are sharp and angular.



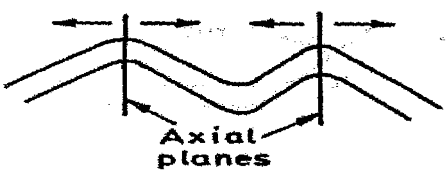
Normal type of fold



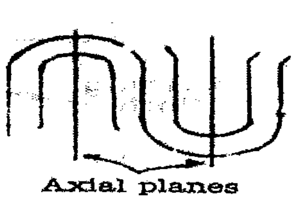
chevron fold

Isoclinal Fold: An Isoclinal Fold in which, the two limbs dip at equal angles in the same direction. These isoclinals folds may be vertical or inclined or horizontal

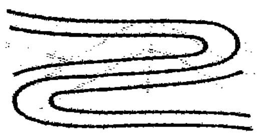
Recumbent Fold: A recumbent fold is one in which, the axial plane is essentially horizontal. All recumbent folds if satisfactory exposures are available, may be traced back to the Root Zone - ie the place on the surface of the earth from which they arise. Also characterized by the presence **of digitations** (look like great fingers extending from a hand).



Normal Type of Fold



Isoclinal Fold



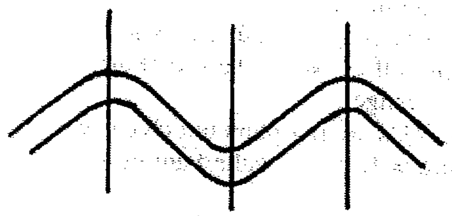
Recumbent Fold

UNIT: 4 - 4

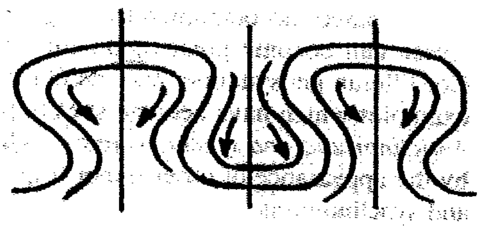
Box Fold: Usually, the crests and troughs of beds are smooth, broad and flat.

Fan Fold: In simple anticline, the limbs dip away from one another and in simple syncline, the limbs dip towards each other. **In case of Fan Folds, this is just opposite.**

In Fan Fold, the two limbs dip toward each other in case of Anticlinal Fan folds and the two limbs dip away from each other in case of Synclinal Fan Fold.

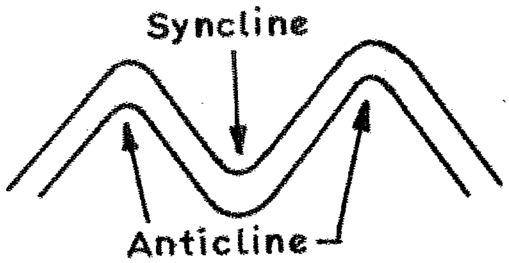


Normal Type of Fold

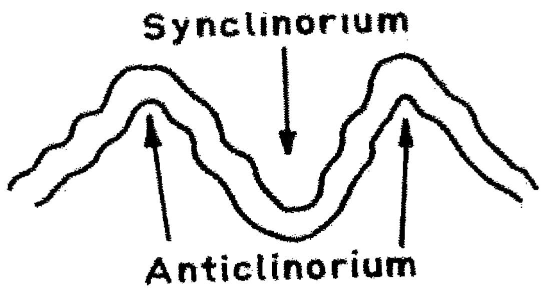


Fan Fold

Anticlinorium & Synclinorium: A major anticline that is composed of many smaller folds is called an Anticlinorium . Similarly, a Synclinorium is a large syncline also composed of many smaller folds too.



Normal Fold



Anticlinorium and Synclinorium Fold

Geo-anticlines and Geosynclines: The Anticline and Synclines with a normal shape but of very large magnitude are called Geo-anticlines (Giant anticlines) and Geosynclines. Geosyncline is a large depression, hundreds of miles long and tens of miles wide in which sediments accumulate to greater feet.

Eg: Appalachian (North America) Geosyncline was 40,000 feet depth.

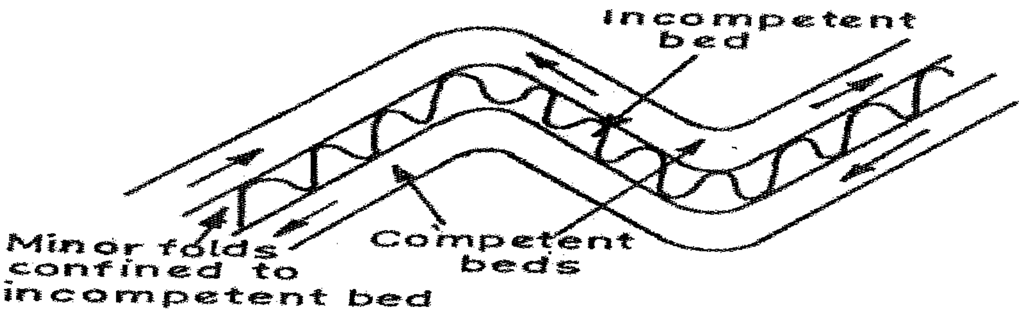
The Cordilleran (North America) Geosyncline

The Ouachita (North America) Geosyncline

The Geosynclines can become great mountain ranges and the examples are mentioned above.

Drag Fold: Drag Folds are those that develop in an incompetent bed (weaker beds) lying between two competent beds (strong beds).

In the broader sense, drag folds refer to any minor folds genetically associated with major folds. When the competent beds (stronger beds) slide past in opposite directions due to shearing effect / dragging effect, the drag folds (minor folds) develop in the incompetent beds (weaker beds).



IMPORTANCE OF FOLDS IN CIVIL ENGINEERING POINT OF VIEW:

Folding of rocks takes place by different ways of stress acted upon it. Most of the folds are due to tectonic causes and a few folds are due to non-tectonic causes such as landslides etc...

Due to weathering and erosion, the Anticlines will change over to Valleys while the Synclines change over to Hills. This feature is called as Paradoxical phenomenon is popularly expressed as ANTICLINAL VALLEY & SYNCLINAL HILL.

Folds as a result, the affected rocks get deformed, distorted or disturbed. This results in the occurrence of great strain in rocks which may cause bulging , caving etc.. Because of folding, the affected rocks possess fractures of different types in different parts of folds ie limbs, crest, trough and becomes weak. Such type of locations especially for construction of dams, reservoirs, tunneling, etc.. Leads to collapse the civil structures.

For eg: At the dam site, the beds of limb shall be dip in the upstream direction to hold the accumulated water as a load.

FAULTS

Faults may be described as fractures along which relative displacement of adjacent blocks has taken place. The relative displacement caused during faulting may be horizontal, vertical and inclined.

UNIT: 4 - 6

Some faults are only a few inches long, and the total displacement is measured in fractions of an inch while there are faults that are hundreds of miles long. The strike and dip of a fault are measured in the same way as they are for bedding planes. The magnitude of faulting obviously depends on the intensity and the nature of shearing stress (various tectonic forces) involved.

Occurrence of faulting is often accompanied by earthquakes and it is an indication of subsurface instability of the region concerned.

PARTS OF A FAULT

Fault plane, foot wall, hanging wall, slip, hade, heave and throw which are important parts of a fault

Fault Plane: This is the plane along which the adjacent blocks were relatively displaced. Like, bedding plane (or axial plane) the fault plane can be expressed by strike and dip. Its intersection with the horizontal plane gives the *strike direction*. The direction along which the fault plane has the maximum slope is its *true dip direction*. The amount of inclination of fault plane with reference to the horizontal plane along the true dip direction is called its *true dip amount*. *Hade* is the angle between the inclined fault plane and a vertical plane. Dip + Hade = 90^0

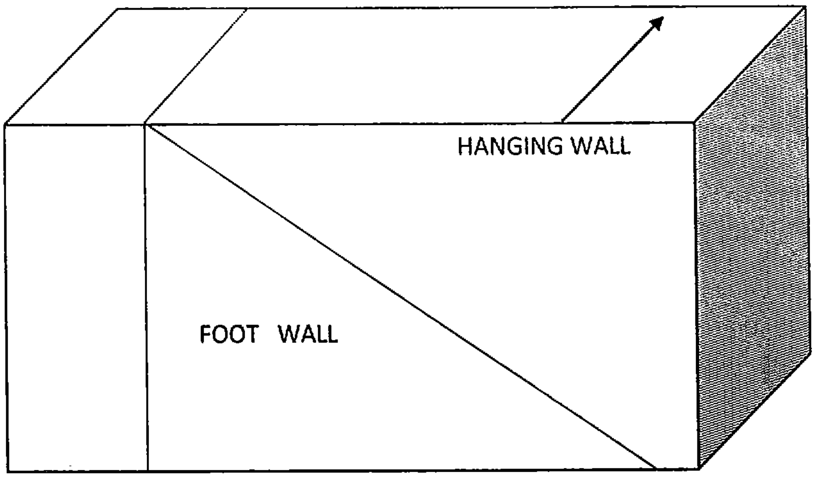
Foot wall and Hanging wall: When the fault plane is inclined, then the faulted block which lies below the fault plane is called the foot wall and the other block which rests above the fault plane is called the hanging wall.

Slip: The displacement that occurs during faulting is called the slip. This may be along strike direction (i.e. Strike slip) or along dip direction (i.e. Dip slip) or along both (Strike and Dip slip). *Eg: The fault is an inclined plane that strikes N-S at dips 35° East and has a* **Hade** of 55° East.

Hade: The angle between the fault plane and a vertical plane.

Heave: The horizontal displacement of the blocks is called as heave. Heave can be seen only in vertical faults.

Throw: The vertical displacement of the blocks is called as Throw. Throw can be seen only in vertical faults.



Classification and types of faults: Faults like folds may be classified on the basis of geometry or their genesis or different principles as follows.

1. Type of displacement along the fault plane.
   (Eg: Translation fault; Rotational Faults)

2. Relative movement of FW & HW.
   (Eg: Normal Fault / Gravity Fault; Thrust / Reverse Fault).

3. Types of slips involved (classification based on Net Slip)
   Eg: Strike Slip Fault; Dip Slip Fault; Oblique Slip Fault)

4. Mutual relation of attitudes of the fault plane.
   (Eg: Strike Fault; Dip Fault; Oblique Fault)

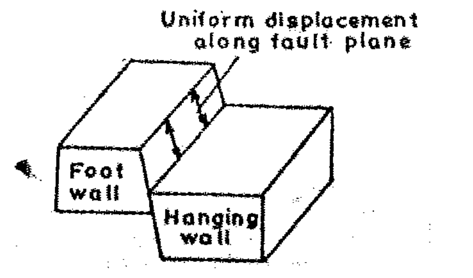
5. Inclination of the fault plane.
   (Eg: High Angle Fault; Low Angle Fault)
6. Mode of occurrence of faults.
   (Eg: Radial Fault; Arcuate Fault; Enehelon Fault)

7. Miscellaneous Faults: (eg: Step Fault; Parallel Fault; Horst & Graben Faults)

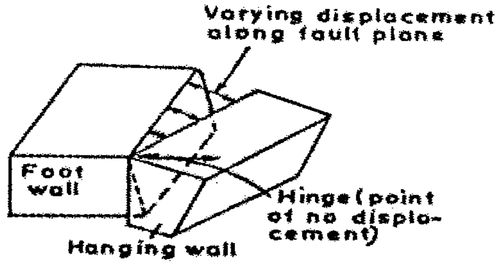
1. Type of Displacement: Based on the displacement principle, faults are divisible into **Translational faults and Rotational faults.**

Translational Faults: The displacement of the foot wall with respect to the hanging wall is uniform along the fault plane.

Rotational Faults: In rotational faults, the FW and the HW appears to have been fixed at a place or can be seen the gradual changes in displacement.



Translational Fault

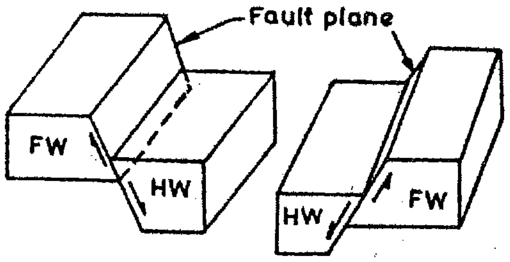


Rotational Fault

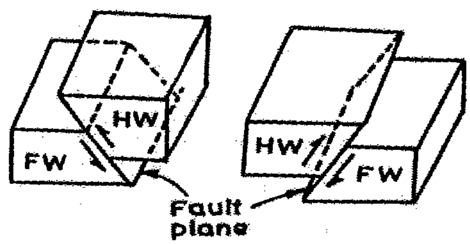
2. Relative Movement of FW/HW: (In case of inclined faults)

Normal Fault: If the HW goes down with respect to the FW, it is called the Normal Fault. Since the blocks are expected to move or slide down along the influence of gravity, it will be also called as **Gravity Fold.**

Reverse Fault: If the HW goes up with respect to the FW, it is called as Reverse Fault. This is also called as Thrust **Fault**



Normal Fault / Gravity Fold



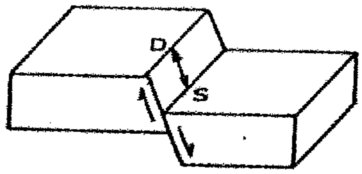
Reverse Fault / Thrust Fault

3. Type of Slips: The displacement that occurs during faulting is called the slip. The total displacement is known as the **Net slip.** The net slip may be along the strike direction **(strike slip)** or the dip direction **(Dip slip)** or along both

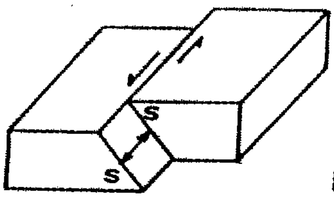
Strike slip fault / Wrench Fault: The displacement is only along the strike direction of the fault plane, such a fault is described as strike slip fault.

Dip Slip Fault: If the displacement is completely along the dip direction of the fault plane it is called a dip slip fault.

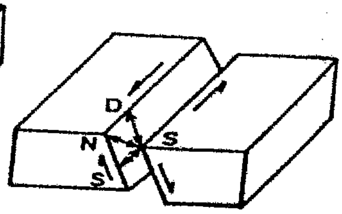
Oblique Slip Fault: If the displacement occurs partly along the strikes direction and partly along the dip direction, such a fault is called as oblique slip fault.



Dip Slip Fault



Strike Slip Fault



Oblique Fault

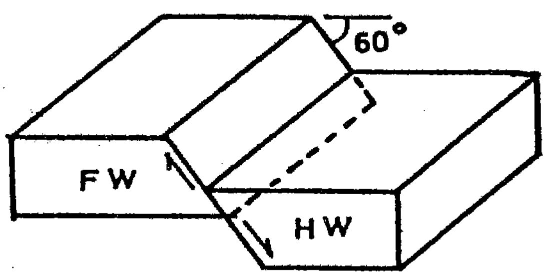
4. Mutual relation of attitudes of the fault plane:

If the strike direction of fault plane is parallel to the strike of the beds of adjacent strata, such fault is called as **strike fault**. On the other hand, if the strike direction of the fault plane is parallel to the true dip direction of adjacent strata, such fault is described as a **dip fault**. If strike direction of fault plane is neither parallel to strike direction nor parallel to dip direction of adjacent beds, it is called **oblique fault.**

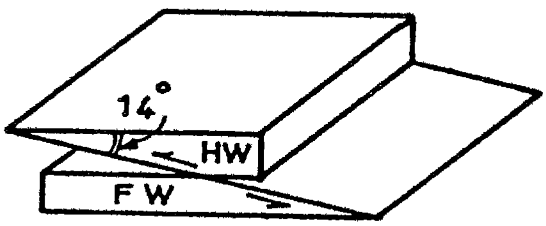
5. Inclination of the fault plane: This is simple classification which makes account the dip amount of the fault plane. If it is steep i.e. more than 45^0, the fault is called a high angle fault and if it is gently sloping i.e. less than 45^0 the fault is called a low angle fault. Generally, normal faults / gravity faults are high angle faults, while Reverse / thrust faults are low angle faults.

High angle Fault: If the dip amount of the fault plane is > 45°, the fault is called a high angle fault.

Low angle Fault: If the dip amount of fault plane is < 45° the fault is called a low angle fault.



High Angle Faults



Low Angle Faults

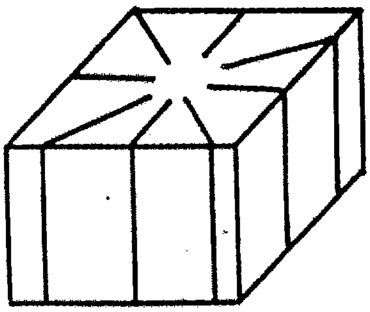
UNIT: 4 - 10

6. Mode of occurrence of faults: Based on the mode of occurrence or pattern in the field, the following types of faults are examples:

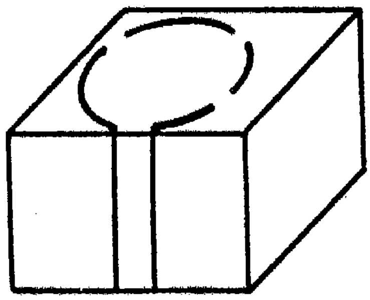
Radial Faults: When a set of faults occur on the surface and appears to be radiating from a common point, they are called radial faults.

Arcuate Faults: A set of faults occur in a peripheral manner, enclosing more or less a circular area.

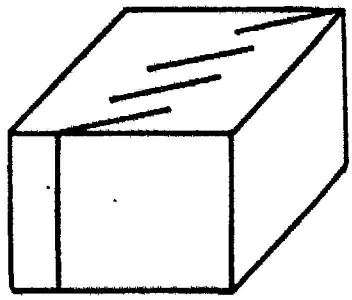
Enechelon Faults: A set of faults which appear to be overlapping one another.



Radial faults



Arcuate faults

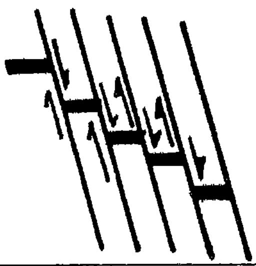


Enechelon faults

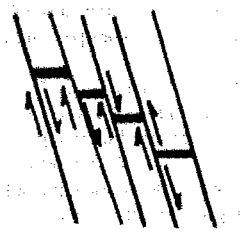
MISCELLANEOUS FAULTS

STEP FAULTS: When a set of parallel normal faults occur at regular intervals, they give a step-like appearance and are called step faults.

PARALLEL FAULTS: When a set of parallel normal faults occur without a regular interval, such type of fault is called as Parallel fault though similar appearance of step faults.



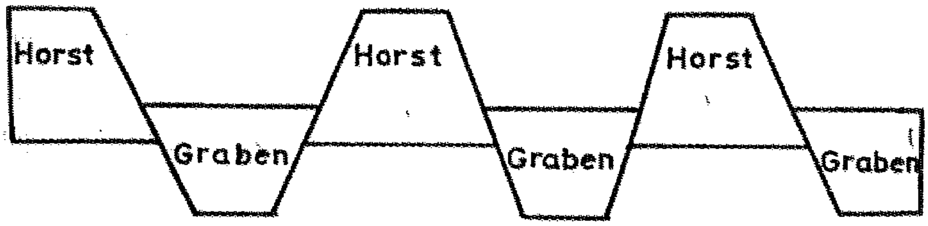
Step faults



Parallel faults

HORST AND GRABENS: When normal faults with mutually diverging or converging fault planes occur, then a few wedge-shaped blocks called " **horsts**" are displaced upwards and a few other (alternated with the raised blocks) called **"grabens"** are displayed downwards.

Horsts and Grabens of large magnitudes are called BLOCK mountains and RIFT valleys, respectively .Eg:(1) Ruby mountains of Navada in Russia (2)Teton Mountain Range in USA are good examples for Horsts.



EFFECTS OF FAULTS FROM THE CIVIL ENGG POINT OF VIEW

- Faults are the most unfavorable and desirable geological structures, for any
  LOCATION OF RESERVOIR
  FOUNDATION FOR CONSTRUCTION OF A DAM
  BRIDGES / BUILDINGS
  TUNNELLING
  LAYING ROADS OR RAILWAY TRACKS.

- As long as the faults are active, the site is unstable and susceptible to upward or downward movement along the fault plane. eg; St Francis Dam, California & Austin dam in Texas

JOINTS

Joints are fractures found in all types of rocks. These are cracks or openings formed due to various reasons. Naturally, the presence of joints divides the rock into a number of parts or blocks. Usually, the openings of joints are filled up by secondary minerals such as calcite, quartz etc as veins.

Joints occur in a definite direction and as a set. Some places 2,3,4 or even more sets of joints may occur. Every set of joints shall have their own strike and dip.

Joints may be measured only a few cms in length but some may be large measuring mts. In nature joints may occur as vertical or horizontal or inclined. Most joints are smooth but some display plumose markings (ridges & depressions a mm).

CRACKS, ON THE OTHER HAND LIKE FRACTURES ARE RANDOM OR IRREGULAR IN THEIR MODE OF OCCURRENCE.

VARIOUS TYPES OF JOINTS:

Columnar Joints which may occur due to Tensional forces (pull apart) eg Basalts.

Shear Joints develop where shearing forces prevail (due to stress)

Longitudinal / Transverse Joints: These joints are sometimes described whether they are parallel to or across some large scale features such as mountain ranges .

Sheet Joints : A set of joints may develop which are more or less parallel to the surface of the ground. Eg: sandstones; cuddapah slabs, flaggy limestones.

Shrinkage Joints: as a result of cooling, by tensional forces, these joints develop in the rocks.

IMPORTANCE ON CIVIL ENGG POINT OF VIEW:

Joints cause the leakage of water in case of reservoir. Joints may pose groundwater problems in tunneling. The orientation of joints is very significant in engineering projects. Large joint dipping in the construction site cause a landslide. Quarry operations obviously greatly influenced by the joints.

Jointed rocks allow the movement of fluids and may act as AQUIFERS. Bore wells drilled in civil construction areas for water supply will be more productive in highly jointed rocks than in less jointed rocks.

LANDSLIDES

The term landslide refers to the downward sliding of huge quantities of land masses. Such sliding occurs along steep slopes of hills or mountains.. It may be sudden or slow in its occurrence. Also, in magnitude, it may be major or minor.

Often, loose and unconsolidated surface material undergoes sliding. But sometimes, huge blocks of consolidated rocks may also be involved. If landslides occur in places of importance such as highways, railway lines, valleys, reservoirs, inhabited areas and agricultural lands leads to blocking of traffic, collapse of buildings, harm to fertile lands and heavy loss to life and property. In India, landslides often occur in Kashmir, Himachal Pradesh and in the mountains of Uttar Pradesh.

CLASSIFICATION OF EARTH MOVEMENTS: All movements of land masses are referred to as landslides and grouped them under "earth movements". The classification of earth movements us as follows:

EARTH MOVEMENTS	EARTH FLOWS	Solifluction
		Creep
		Rapid flows
	LANDSLIDES	Debris slides and slump
		Rock slides
		Rock falls
	SUBSIDENCE	Compaction
		Collapse

Earth Flows: There are three types of earth flows viz., solifluction; creep and rapid flows. Solifluction refers to the downward movement of wet soil along the slopes under the influence of gravity.

Creep refers to the extremely slow downward movement of dry surface material. This is very imp from the civil engg point of view due to slow movement of mass. On careful examination, bending of strata ; dislodgement of fence posts ; telephone poles, curvature of tree trunks; broken retaining walls etc offer clues to recognize creep.

Rapid flows are similar to creep but differ with reference to the speed. Rapid flows generally accompany heavy rains. Mud flows are similar to rapid flows.

Landslides include Debris slides, rock slides and rock falls.

Debris slides are common along the steep sides of rivers, lakes. Debris slides of small magnitude are called slumps..

Rock slides are the movements of consolidated material which mainly consists of recently detached bedrocks. For eg: a rock slide that took place at Frank, Alberta in 1903 killing 70 people.

Rock falls refer to the blocks of rocks of varying sizes suddenly crashing downwards along steep slopes. These are common in the higher mountain regions during the rainy seasons.

Subsidence may take place to the compaction of underlying material or due to collapse.

Subsidence due to compaction: Sediments often become compact because of load. Excessive pumping out of water and the withdrawal of oil from the ground also cause subsidence.

Subsidence due to collapse: In regions where extensive underground mining has removed a large volume of material, the weight of the overlying rock may cause collapse and subsidence.

CAUSES OF LANDSLIDES: Landslides occur due **to internal causes** (inherent). The internal causes are again of various types such as Effect of slope; Effect of water; Effect of Lithology; Effect of associated structures; Effect of human factors etc..

1.Effect of slope: This is a very important factor which provides favourable conditions for landslide occurrence.

Steeper slopes are prone to land slips of loose overburdens due to gravity influence. However, it should be remembered that hard consolidated and fresh rocks remain stable even against any slope.

2.Effect of water: The presence of water greatly reduces the intergranular cohesion of the particles of loose ground causing weakness of masses and prone to landslide occurrence.

Water, being the most powerful solvent, not only causes decomposition of minerals but also leaches out the soluble matter of rocks. This reduces the compaction of rock body and makes it a weak mass.

3.Effect of Lithology; Rocks which are highly fractured, porous and permeable are prone to landslide occurrence because they give scope for the water to play an effective role. In addition, rocks which contain clay minerals, mica calcite, glauconite, gypsum etc are more prone to landslide occurrence because, all these minerals are easily leached out.

4.Effect if associated structures ; The geological structures such as bedding planes, joints, faults or shear zones are planes of weakness and cause landslide occurrence.

5.Effect of human factors Human beings sometimes, interfere with nature by virtue of their activities and cause landslides. For eg: laying roads ; railway tracks etc..

When construction works are carried out on hill tops, the heavy loads on the loose zone of overburden create a sliding of rock masses.

Land slides in India: Land slides are reported in the hilly terrains in different regions of India. The most disastrous land slides that have taken place in recent past are in the Himalayan terrain in the North and the Nilgiri hill region in south.

In July 1970, heavy debris from Patalganga valley has been transported into Alaknanda in the Garhwal region of Uttaranchal. The flooding in Alaknanda due to these landslides has resulted in a silt and rock fragment accumulation of about 9 M cum.

Another disastrous land slide took place on 18^{th} Aug 1998 in Malpa village which is located on the banks of Kali River in Pithorgarh district of Kumaon Himalayas. The piled debris was around 20 m in height.

In 1968, numerous landslides occurred during heavy rainfall of about 500 to 1000 mm in the Darjeeling and Sikkim regions where the 60 km highway between Darjeeling (West Bengal) and Gangtok (Sikkim) was disrupted.

EFFECTS OF LANDSLIDES: From the civil engineering point of view, landslides may cause
(1) disruption of transport
(2) damaging roads and railways and telegraph poles
(3) obstruction to the river flow in valleys
(4) damaging sewage and other pipe lines.
(5) destruction of buildings and civil structures

PREVENTION OF LANDSLIDES:

1. Provision of adequate surface and subsurface to enable water to freely drain out . Construction of suitable ditches and waterways along slopes to drain off the water from the loose overburden.
2. Construction of retaining walls against slopes, so that the rock masses which rolls down is not only prevented from further fall but also reduces the slope.
3. Modifying the slopes to stable angles.

4. Growing vegetation to hold the material together.
5. Avoiding heavy traffic and blasting operations near the vulnerable places naturally helps in preventing the occurrence of landslides.

UNIT - V: GROUNDWATER (Part-II)

Hydrogeology deals with occurrence, storage and movement of groundwater in the subsurface. All water below the earth surface is referred to as the **groundwater** or **subsurface water**.

The surface water percolates or infilters into the ground through the fractures/cracks and its distribution and movement in the subsurface is controlled by the Porosity and Permeability of the geological rock materials such as soils, rocks etc....

Porosity in the rock formations facilitates the storage while permeability contributes to movement of groundwater.Based on the porosity and permeability characteristics all geological formations are named as **aquifers, aquiclude, aquitard** and **aquifuse**.

Aquifers: A geological formation that yield significant quantities of water has been defined as an aquifer. A few Sedimentary rocks are permeable considered as good aquifers (eg: porous Sandstone, gravels, cavernous limestones) while Igneous and Metamorphic rocks are relatively impermeable and hence serve as poor aquifers

Aquiclude:A rock formation has porosity but no permeability, then it is called aquiclude. That means it can store water and the flow of water does not take place. Eg: clay.

Aquitard:A saturated but poorly permeable strata that impedes groundwater movement and does not yield water freely but may transmit appreciable water to the adjacent aquifers. Eg: Sandy clay with a small quantity of silt.

Aquifuse:A rock neither containing water nor transmitting water.Eg: Solid granite

AQUIFER PARAMETERS: The quantity of water stored by an aquifer and the quantity of water released by the aquifer depend on the nature and composition of the rocks through certain parameters such as Porosity, Permeability etc.

Groundwater can be drawn either from consolidated rocks or unconsolidated sediments. The occurrence of groundwater in a geological formation and scope for its exploitation primarily depend on **porosity** and **permeability** properties of that formation.

Porosity (α): In simple terms, porosity may be described as the amount of openings (or) interstices (or) empty spaces present in a rock. However, Porosity may be defined as "<u>the ratio of openings or pores or voids (Vi) in the soil/rock to the total volume of the soil / rock (V) expressed as percentage</u>".

If α is the porosity, then α = Vi/ V where Vi is the volume of interstices and V is the total volume.The average porosity values for some common geological formations are as follows:

Rock	Porosity %
Granite, Quartzite	1.5
Shale, Slate	4
Limestone	5-10
Sand with gravel	20-30
Only Gravel	25
Only Sand	35
Only Clay	45

Prob: A rock sample has (dry weight) of 0.655 kg. After saturation with water its weight is 0.732 kg. It is then immersed in water and found to displace 0.301 kg of water. What is the porosity of the sample?

Solution:

Sample (dry) weight W1 = 0.655 kg

Wt of saturated sample with water W2 = 0.732 kg

Wt of the water required to saturate the sample (W2 – W1) = 0.732 – 0.655 = 0.077kg

Wt of water displaced by the saturated sample (W3) = 0.0301 kg

Porosity of the sample: (W2 – W1) / W3 = 0.077 / 0.301* 100 = 25.58 %

Permeability: The permeability of a rock or soil defines its ability to transmit a fluid or water. Permeability depends on the porosity and interconnected pores character of the rock. Permeability in a rock is measured in *darcies (1 darcy = 0.987 μ m^2)..square micrometer*

Eg: 1.Shales are porous but less permeable because of fine grained nature which does not allow water to pass through the rock due to less interconnected pores.

Eg: 2. Vesicular basalts are highly porous but less permeable because the vesicles in them are not interconnected (i.e., the effective porosity is less).

HYDRAULIC CONDUCTIVITY OR COEFFICIENT OF PERMEABILITY (K): The movement of groundwater depends on the prevailing effects of gravity, velocity and pressure of water. According to DARCY's law, the flow of water through porous medium is proportional to a factor known as Hydraulic conductivity or coefficient of

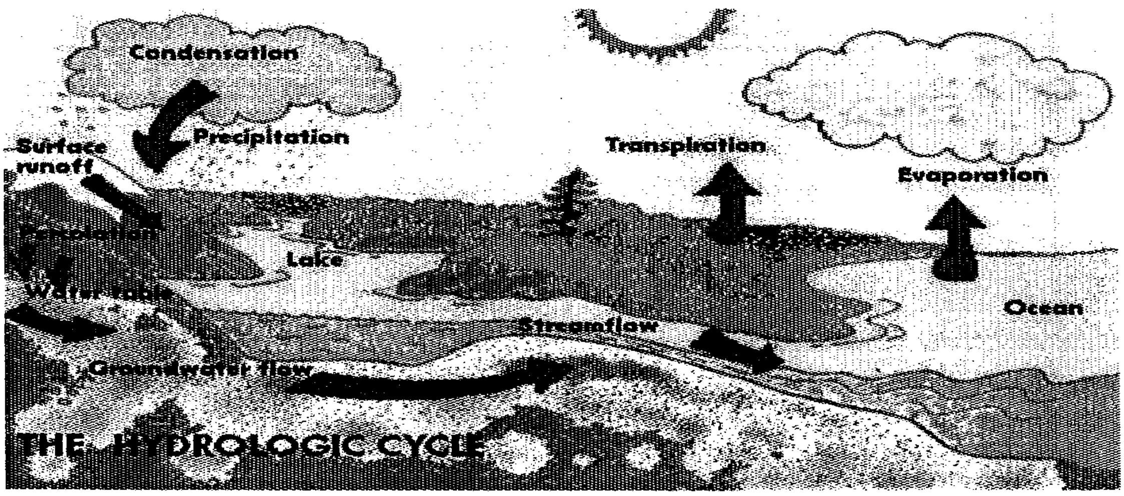
Permeability (k). It is expressed as Q=KiA where Q= volume of water flowing/unit time through a cross sectional area(A) under a hydraulic gradient (i) usually i = 1.

Hence K= Q/iA(K will be called as velocity of flow) .
For some geological formations, the permeability coefficient values are as follows:

Formation	Co-efficient values	Formation	Co-efficient values
Granite-	0.04	Quartzite	0.04
Slate	4.0	Shale	4.0
Sandstone	400	Sand	4000
Sand & gravel	40000	Gravel	400000
Clay	0.04	Limestone	4.0

Hydrologic Cycle: Groundwater is one of the components of the hydrologic cycle in nature. Hydrologic cycle enables a clear understanding of the recharge, storage and movement of water in the subsurface.

The continuous circulation of water from land, water bodies etc., which joins the atmosphere and finally condenses into the form of precipitation.A part of water is lost by evapo-transpiration and certain portion percolates into the ground to form ground water reservoir and the remaining water flows on the ground as runoff and joins the streams, rivers and finally into sea. This cycle is continuously repeated.



Uses of water: Water is needed for daily use for organisms, for irrigation, industries, electricity production and domestic use. Hence, water is an important resource in all economic activities ranging from agriculture to industry.About 97% of it is salt water in the seas & oceans, 2.6% is trapped in polar ice caps & glaciers. Only 0.4% is available as fresh water.

Fresh water occurs mainly in two forms namely **Ground water**and **Surface water**. The distribution of fresh water is geographically uneven varying greatly from country to country & even one region to another region.

1. DOMESTIC USE: Water used in the houses for the purposes of drinking, bathing, washing, cooking, sanitary & other needs. The recommended value according to Indian Standard specification for domestic use is 135 liters/ day.

2. INDUSTRIAL USE: Water is required for various industries such as cement, mining, textile, leather industries.

3. PUBLIC USE: This includes water used for public utility purpose such as watering parks, flushing streets, jails etc.

4. FIRE USE: Water is used in case of accidents and to prevent the fire issues.

5. IRRIGATION: To grow crops which is the main sources for food.

6. OTHER USES: Hydro electric power generation requires water.

Effects of over use of ground water: Over use of groundwater has following ill effects:

1. Lowering of water table: Excessive use of ground water for drinking, irrigation and domestic purposes has resulted in rapid depletion of ground water in various regions leading to lowering of water table & drying of wells.

2. Ground subsidence: When ground water withdrawal is greater than its recharge rate, the sediments in the aquifer become compacted. This is called ground subsidence which may cause damage of buildings, destroy water supply systems etc.

The reasons for shortage of water are:

1. Increase in population,
2. Increasing demand of water for various purposes.
3. Unequal distribution of fresh water.
4. Increasing pollution of existing water sources cause over exploitation.
5. People depend on ground water as it is considered to be fresh water.

How we contaminate groundwater ?

Any addition of undesirable substances to groundwater caused by human activities is considered to be ***contamination***. It has often been assumed that contaminants left on or under the ground will stay there. Groundwater often spreads the effects of dumps and spills far beyond the site of the original contamination. Groundwater contamination is extremely difficult, and sometimes impossible, to clean up.

Point sources

- On-site septic systems
- Leaky tanks or pipelines containing petroleum products
- Leaks or spills of industrial chemicals at manufacturing facilities
- industrial waste
- Municipal landfills
- Livestock wastes
- Chemicals used at wood preservation facilities
- Mill tailings in mining areas
- Fly ash from coal-fired power plants
- Sludge disposal areas at petroleum refineries
- Land spreading of sewage or sewage sludge
- Graveyards
- Wells for disposal of liquid wastes
- Runoff of salt and other chemicals from roads and highways
- Spills related to highway or railway accidents
- Coal tar at coal gasification sites
- Asphalt production and equipment cleaning sites

Non-point (distributed) sources

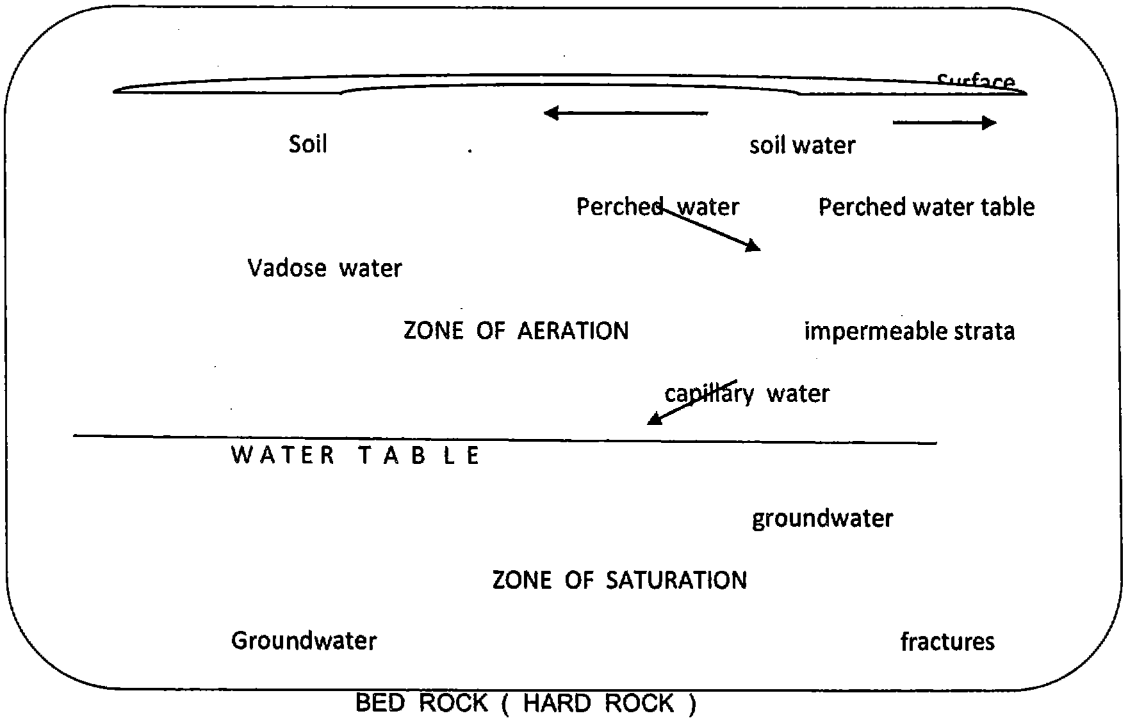
- Fertilizers on agricultural land
- Pesticides on agricultural land and forests
- Contaminants in rain, snow

Water Table: The land surface is covered by loose soil due to natural weathering phenomenon. Since the effect of weathering decreases gradually with depth, a fractured zone of rocks exists below the soil zone. Further, below this zone, occurs the hard formations (bed rock) which are free from fractures.

Groundwater flows slowly through water-bearing formations (aquifers) at different rates. In some places, where groundwater has dissolved limestone to form caverns and large openings, its rate of flow can be relatively fast but this is exceptional.

Many terms are used to describe the nature and extent of the groundwater resource. The level below which all the spaces are filled with water is called **the *water table***. Above the water table lies the ***unsaturated zone***. Here the spaces in the rock and soil contain both air and water. Water in this zone is called ***soil moisture***. The entire region below the water table is called the ***saturated zone***, and water in this saturated zone is called ***groundwater.***

Hence, when rainfall occurs in any region, the rain water moves downwards through fractures under the influence of gravity until it reaches the bed rock. Then, the percolation/infiltration of water leads to the development of a zone above the bed rock which is called as **zone of saturation**,in which all openings or pores of the rocks are filled with water. Such water is called as **groundwater**.The upper surface of the zone of saturation is calledWATER TABLE.Above the zone of saturation and below the ground surface is the **zone of aeration** in which water fills only a portion of the pore space.



Types of groundwater occuring in zone of AERATION:

1. Soil Water:Water which occurs in the soil and is available to the roots of plants existing on the surface.
2. Vadose Water: (Gravity water): A fraction of rainfall which percolates downwards under the influence of gravity and slowly reaches the water table. In other words, the groundwater recharged thisway.
3. Perched Water: When a groundwater body is separated from the main groundwater by a relatively impermeable strata of small areal extent within the zone of aeration at a particular place is called as Perched water. Wells tapping ground water from these sources yield only a small quantities of water. .

4. Capillary Water:This exists just above and in contact with the water table.
5. Meteoric Water: Due to rainfall, water is being soaked into the underlying rock.

Types of groundwater occuring in the zone of SATURATION:

1. **Free groundwater (unconfined aquifer):** The ground water which lies below the water table under atmospheric pressure more freely upwards or downwards within the aquifer.
2. **Confined water:** This waters occur below the water table and is confined between aquicludes or aquifuse under hydrostatic pressure.
3. **Connate water:** Occasionally a sediment or rock may retain some quantity of water from the beginning of their formation.
4. **Juvenile water:** Water which has not previously been a part of the hydrosphere but which forms / rises from a deep, magmatic source.
5. **Magmatic water:** It is the water derived from magma.

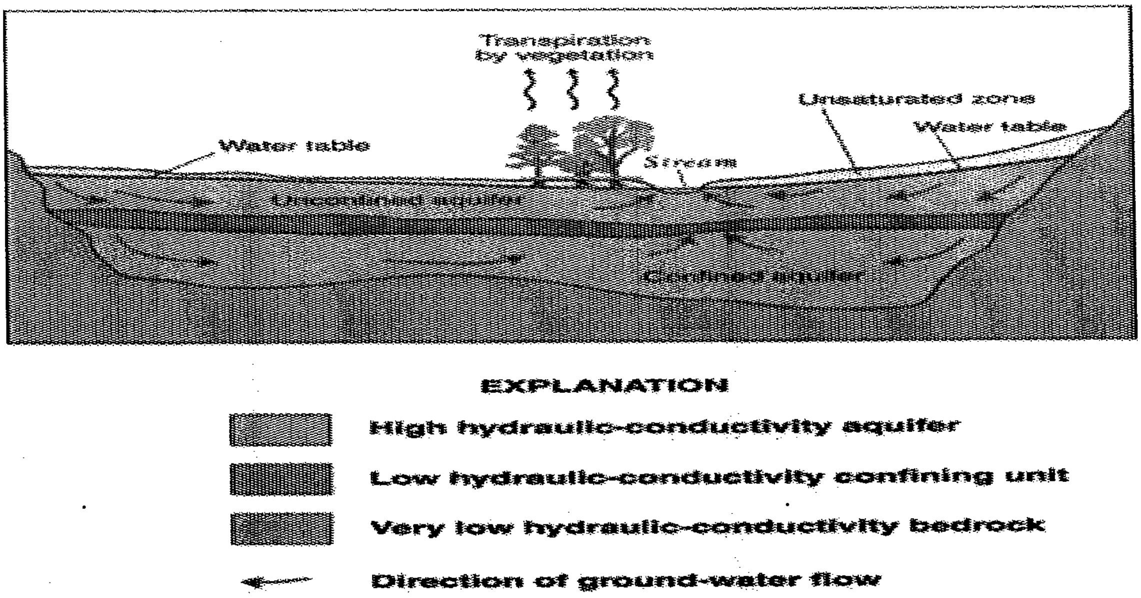
Types of Aquifers: Most aquifers are of large areal extent and may be visualized as underground storage reservoirs. Aquifers may be classified as unconfined or confined depending on the presence or absence of water table.

Unconfined Aquifer: An unconfined aquifer is one in which a water table varies depending on recharge and discharge (pumping form wells) in a region. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer.Wells dug in such an aquifer will have the water level equal to the level of the water table. The water table is under atmospheric pressure only.

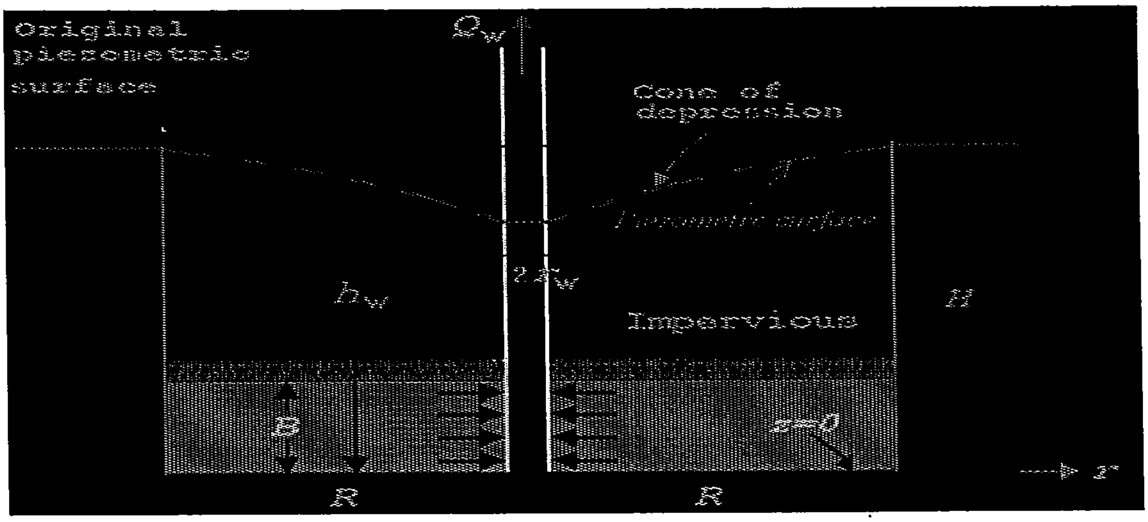
Confined Aquifer: These are also called artesian aquifers. In this case, the groundwater should be under pressure more than atmospheric pressure and sandwiched between two aquicludes or two impermeable formations i.e., clay /shally formations.Unlike the unconfined aquifer, the confined aquifer stores less water.

The wells in the confined aquifer are thus artesian wells operating under the piezometric pressure of the aquifer. If the piezometric surface of any well is above the ground surface the water level rises above the ground surface. In such a situation, the well is known as an***artesian flowing well.***

Confined aquifer diagram



Piezometric surface:A piezometer is a special tool that is used to take measurements within an aquifer. It is submerged within a well beneath the saturated zone, through less porous rock. Many piezometer wells are drilled within a confined aquifer at certain locations. The piezometric surface of water is the level of water within a piezometric well in a confined aquifer. A hydro-geologist can determine recharge and discharge rates and most importantly groundwater-flow direction and rates.



GEOLOGICAL CONTROLS ON GROUNDWATER MOVEMENT: Groundwater movement in the zone of aeration takes place under the influence of gravity while in the zone of saturation are of different kinds based on:

a) The permeability character of rocks is one of the most influencing factors of groundwater movement.

b) Secondary Porosity associated with the rocks viz. well-developed joints, sheet joints, presence of faults etc also influence the groundwater to move along them.

c) The groundwater movement in the zone of saturation also depends on attitude of bedding places (The percolated water moves along the inclined bedding planes, folded beds etc). Sometimes, tilted beds, if accompanied by faults, joints, intrusives lead to the occurrence of springs and seepages.

d) The buried river channels and conformities also influence the groundwater movement as they are porous and permeable.

e) Presence of dolerite dykes, quartz veins in the associated country rocks may act as barriers to the natural flow of groundwater and accumulate on one side part of the dyke.

f) Another factor which influences groundwater movement is the hydraulic gradient (ie., slope or difference in the water table) .

Fluctuation in the level of the water table in unconfined aquifer is of two different types ie., *SEASONAL and CONE OF DEPRESSION.*

The water table level rises considerably during rainy seasons because of heavy rainfall and high recharge. In summer, the water is pumped out without any recharge. This leads to a significant fall in the level of water table, thus, this type of fluctuation in the water table is seasonal.

When water is pumped out in a considerable measure from a dug well, the level of water goes down, and leading to the depression in the water table around the dug well in the form of an inverted cone. This phenomenon is called the **Cone of depression** (or) **the cone of exhaustion.**

This is a temporary fluctuation in the level of water table because the original position is restored within a short period due to the seepage of ground water from the sides of the dug well

The boundary of the cone of depression is known as the ***GROUNDWATER DIVIDE.*** The area enclosed by the Groundwater Divide is known as the ***AREA***

OF PUMPING DEPRESSION. The distance between the well and the Groundwater Divide is termed as the ***RADIUS** of **INFLUENCE***.

When water is pumped out from an open well, immediately the level of water in it goes down, leading to the hydraulic gradient i.e., the difference in the level of the water table of the aquifer and dug well water level.

The difference between the original level of water in the dug well and level after pumping is called ***DRAWDOWN.*** If the pumping is continued, the drawdown increases further and the radius of influence of the well also increases. In a good aquifer , the draw down keeps at the same level. It is interesting to know that in all aquifers, the drawdown rate decreases with pumping time. (5' in 1 hour and further 5' in 5 hours and still 5' in another 10 hours).

Springs:A spring is a continuous flow of water on the ground surface. Springs are located at the points of interaction of groundwater table with the surface of ground.

Groundwater and engineering: Groundwater can also have dramatic implications for engineering and geotechnical studies. The study of groundwater is essential for engineers who construct dams, tunnels, water conveyance channels, mines, and other structures. Groundwater must be considered whenever the stability of slopes is important, whether the slope is natural or constructed. Groundwater must also be taken into account when devising measures to control flooding. In all of these situations, groundwater flow and fluid pressure can create serious *geotechnical problems*.

Groundwater, for example, may create structural weaknesses in dams, or it may flow underground right around the structure. Water flowed so efficiently through the rock formations surrounding the reservoir that the dam would hold no water, even though it was structurally sound.

GROUNDWATER QUESTIONS:

1. Origin and occurrence of groundwater
2. Short notes on:
    a) Water table,
    b) springs,
    c) cone of depression,
3 Detail the three possible mechanisms of Arsenic release into groundwater?
4. Short notes on :
    a) Types of aquifers
    b) Geological controls and groundwater movement

5. What are effects of water logging in canal–command areas ? Give Indian examples.

6. What are possible sources of groundwater pollution ?

UNIT – IV GEOPHYSICAL STUDIES (Part – II)

Geophysics is the study of the earth by making use of the principles of Physics.

By measuring certain physical properties of rock types, the subsurface data, the location of ore deposits, groundwater conditions etc can be achieved by using Geophysical investigations. To ensure safety, economy in construction of civil engineering structures, it is necessary to aware of the geology and subsurface structure of the concerned site. In order to acquire the subsurface details, only two approaches exist. They are:

Direct observations by means of digging, trenching and drilling of the ground. Such processes are expensive and time consuming process.

Indirect inferences are drawn by means of Geophysical methods which provide the subsurface date quickly without much expensive.

The other advantages include:
Large areas can be investigated in short period and hence time is saved. The Geophysical devices are simple, portable and can be operated easily. The Geophysical investigation does not include any consumables and these methods are economical.

CLASSIFICATION OF GEOPHYSICAL METHODS
These include:

- GRAVITY METHODS
- MAGNETIC METHODS
- ELECTRICAL METHODS
- SEISMIC METHODS
- RADIOMETRIC METHODS
- GEOTHERMAL METHODS

Importance of geophysical methods: The Geophysical investigations are multipurpose. The obtained data can be interpreted for knowing the subsurface rock types, regional geology of an area; geological structures which are favorable for accumulation of oil and gas; groundwater potential and its quality; locating and estimation of ore deposit reserves and also to solve the Engineering Geology problems such as:

1. To determine the thickness of overburden
2. Locating fault zones, shear zones which act as places of leakage in reservoirs or as places of weakness in foundation sites;
3. To locate places where building materials occur at a shallow depth
4. To solve some of the Non-geological problems such as

- location of buried iron pipe lines (by magnetic methods);
- location of areas of buried pipes carrying oil & gas (by electrical methods);
- location & liquidation of underground fire (by geothermal methods)
- location of cavities in masonry constructions of dams (by radio wave absorption methods)

GRAVITY METHODS: In gravity methods, the nature of distribution of gravity (g) on the surface is analyzed. The instruments for gravity prospecting may be divided into three types.

(a) Pendulum

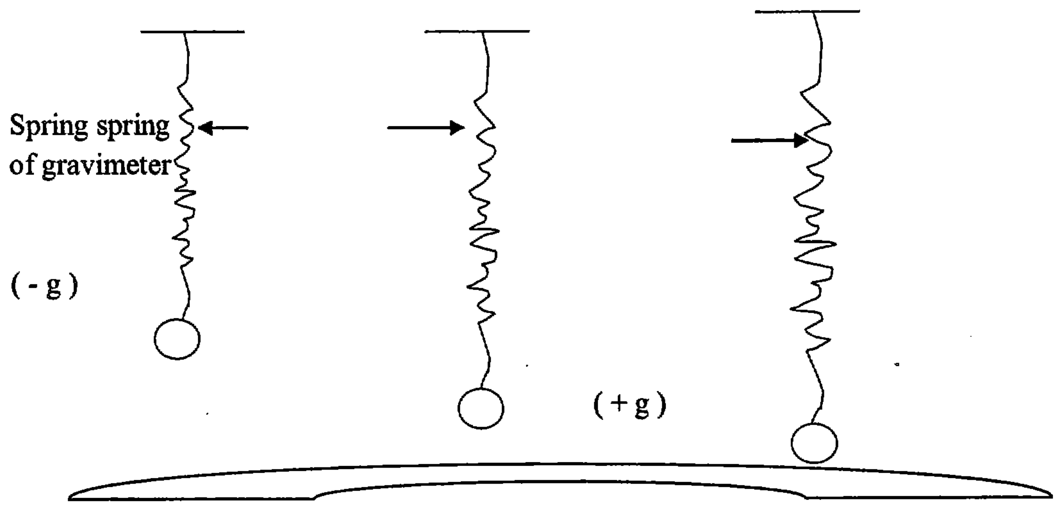
(b) Torsion balance

(c) Gravimeters (WORDEN GRAVIMETER)

Among these, only gravimeters are very popular. A gravimeter measures the relative variations in the vertical component of the gravitational force. It is somewhat like a spring balance which weighs a constant mass and detects the relative difference in weight with great accuracy of the region.

If the subsurface has a relatively heavier body, the gravity pull is more there (+g) and the spring extends becoming longer. If the subsurface has relatively a lighter body there the gravity pull is less (-g) and the spring contracts becoming shorter. Hence, g values reflect the subsurface geological strata.

Gravity methods are carried out during oil and gas exploration. These investigations are also useful in finding iron ore, manganese ore, graphite, coal, Chromite and bauxite deposits.



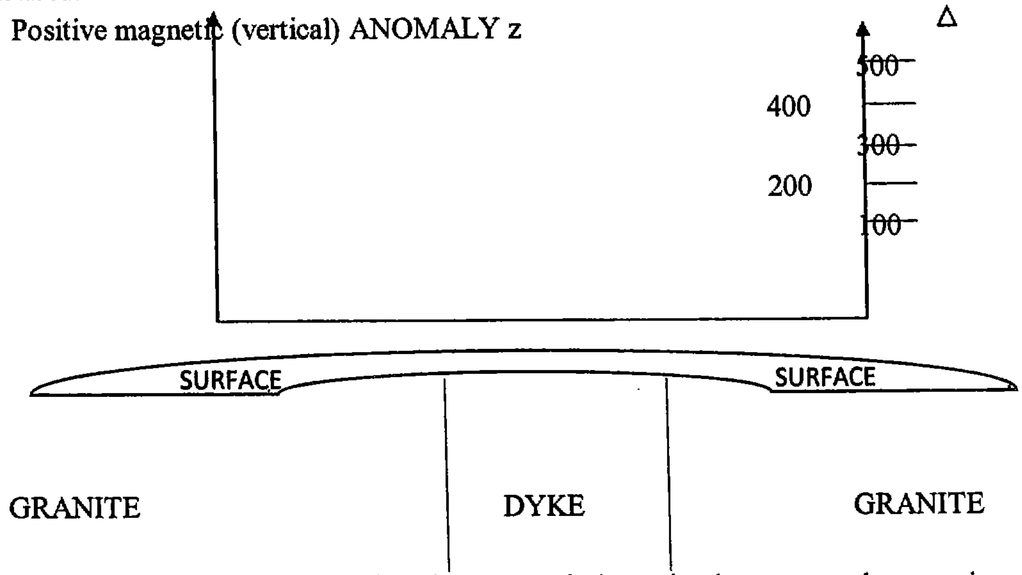
Lighter body local body heavier body

Thus in a particular region, if subsurface bodies whose densities are different from the surrounding rocks exist, the gravity field deviates from the normal value that is expected. From these deviations, it is possible to locate the in homogenous bodies in the subsurface.

Geological age	Lithology	Av density (gm/cc)
Gondawanas	Calcareous Sandstones	2.55
	Ferruginous sandstones	2.33
Vindhyans	shales	2.65
	Limestones with shale intercalations	2.72
	sandstones	2.13
Cuddapahs	Calcareous shales	2.77
	limestones	3.10
	Phyllites	2.72
	Quartzites	2.65
Archaeans	Granites	2.65
	gneisses	2.65
	charnockites	2.82
	Khondalites	2.50

MAGNETIC METHODS: Like gravity methods, these investigations also related to the findings of subsurface geology. In general, the magnetic field of the earth or one of its components (vertical or horizontal component) is measured on the surface to know the subsurface bodies data by studying the anomaly. Any deviations in the measured quantities help to locate the anomalous objects.. For eg a dolerite dyke which is occurring in a granitic terrain shows variations in the magnetic anomalies.

During the magnetic surveys in the field, when the dyke is approached the magnetic intensities ($_z$) becomes m∆re and then becomes less after the dyke is crossed. Away from the dyke, on either side ($_z$) is nearly same and only over the dyke ∆nomaly can be noticed.



The different parameters measured during magnetic investigations are total magnetic field and different space components (ie vertical com∆nent z; horizontal component $_H$; inclination I and declination D). Th∆ magnetic field is m∆asured in terms of gamma.

Different magnetometers are available at present for conducting magnetic surveys. Some of them are as follows:

The SCHMIDT MAGNETOMETER
TORSION MAGNETOMETER
FLUX GATE MAGNETOMETER

A **magnetometer** is a measuring instrument used to measure the strength or direction of magnetic fields.

The SI unit of magnetic field strength is tesla. As this is a very large unit for most practical uses, scientists commonly use the nanotesla (nT) as their working unit of measure. Engineers often measure magnetic fields in Gauss (1 Gauss = 100,000 nT, or 100,000 gamma).

The Earth's magnetic field (the magnetosphere) varies both temporally (there is a daily variation of around 30 nT at mid latitudes and hundreds of nT at the poles) and spatially (from around 20,000 nT near the equator to 80,000 nT near the poles) for various reasons, such as the in homogeneity of rocks and the interaction between charged particles from the Sun and the magnetosphere.

Applications:

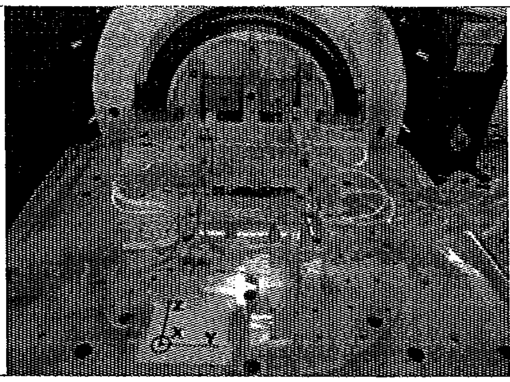
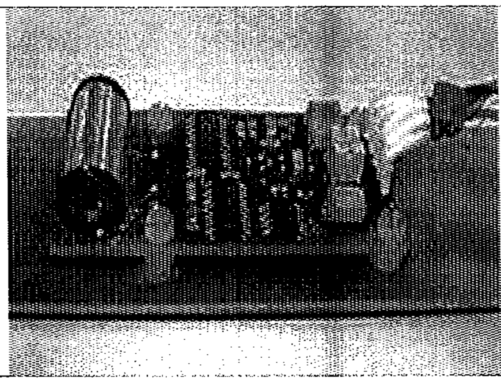
Magnetometers can detect magnetic (ferrous) metals. Magnetometers can be used to help map basin shape at a regional scale, and commonly used to map hazards in coal mining. Also used to demarcate the basaltic intrusions such as dykes, sills etc

Magnetometers can also locate zones ignited by lightning and map siderite (an impurity in coal).Modern surveys generally use magnetometers with GPS technology to automatically record the magnetic field and their location.

Magnetometers are one of the primary tools used to locate the deposits of gold, silver, copper, iron, tin, platinum and diamonds.

Types: Magnetometers can be divided into two basic types:

- **Scalar magnetometers** measure the total strength of the magnetic field to which they are subjected, and
- **Vector magnetometers** have the capability to measure the component of the magnetic field in a particular direction, relative to the spatial orientation of the device.

	
Scalar magnetometers	**Fluxgate magnetometer**

Vector magnetometers: The Earth's magnetic field at a given point is a vector. *A vector magnetometer* measures both the magnitude and direction of the total magnetic field.. Examples of vector magnetometers are fluxgates.

Scalar magnetometers: Scalar magnetometers measure the total magnetic field strength but not its direction. A magnetograph is a magnetometer that continuously records data.

Since magnetic surveys have certain inherent limitations (ie orientation of instruments), magnetic prospecting is often carried out alongwith gravity or other geophysical methods for accurate solutions. Magnetic investigations are employed for solving the following geological issues:

1. Delineation of large structural forms where usually accumulation of oil and gas deposits takes place
2. Detection & demarcation of basic and ultrabasic bodies such as dykes.
3. Locating iron ores and other deposits such as chromite, manganese and bauxite deposits.
4. Also to demark the ore bodies of copper and nickel sulphides.

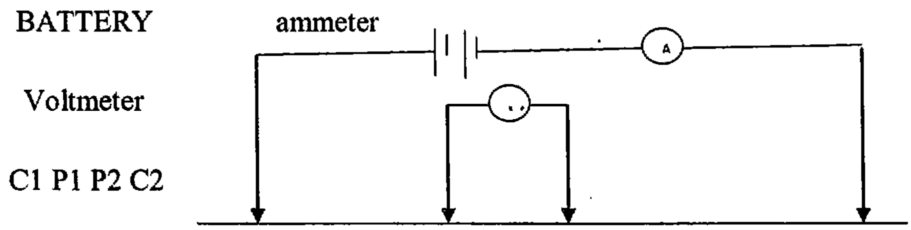
ELECTRICAL METHODS: Electrical resistivity methods, electromagnetic methods, self-potential methods and induced polarization methods are the important categories of electrical methods. All geological formations have a property called electrical resistivity (ρ) and this resistivity is expressed in the units of Ohm-meters (Ωm). The electrical resistivities of subsurface formations vary from one another if they are inhomogeneous and are studied with the help of the electrical resistivity methods.

The various geological factors which influence the electrical resistivity of the subsurface formations are:

1. Mineral content (most of the rock forming minerals have high resistivity except sulphide minerals)
2. Compactness

3. Moisture (moisture may occur in the rocks)
4. Salinity of moisture.
5. Texture of the rock (fine grained rocks show a higher resistivity compared to coarse grained ones)

EQUIPMENT: A resistivity meter is used in carrying out the electrical methods to calculate the apparent resistivity (***Pa).*** It is necessary to remember that what is measured in the field during resistivity investigation is the "Apparent resistivity" and not the true resistivity of the subsurface. To get true resistivity, the apparent resistivity is to be multiplied by a constant (K) as per the spacing pattern. Electrical resistivity values decreases considerably if the rocks contain moisture in the pore spaces (not for always).
Fig shows the pattern of distribution of current and equipotential lines in a homogeneous ground. Current is sent inside the ground through metallic electrodes C1 and C2. The potential difference is measured by non-polarising electrodes P1 and P2.



C 1 and C2 = current electrodes & P1 and P2 = Potential electrodes
- - - - - - distribution of current lines
______ distribution of equipotential lines

Resistivity methods are classified into:

1. Profiling Method (Lateral exploration)
2. Sounding method (Vertical exploration)
3. Potential Method

Profiling is done to detect lateral changes in resistivity which reflects the subsurface lithology in a large area whereas sounding (also known as Vertical Electrical Sounding VES) is done to determine vertical changes in resistivity which reveals the changes in Lithology at a particular place with increasing depth.

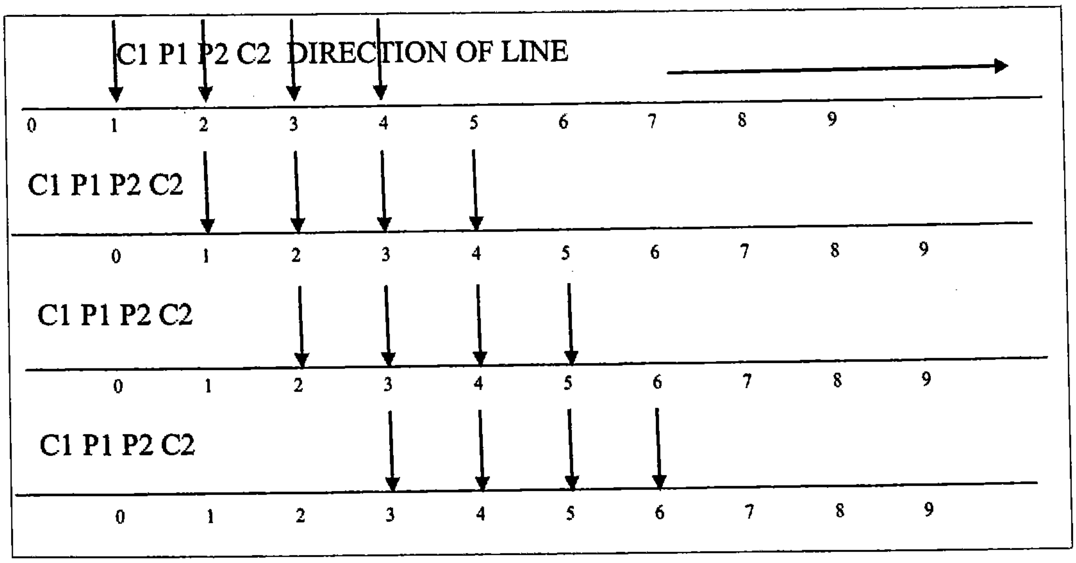
In profiling or sounding, there is scope for electrode arrangements to be made in different ways in the field as such arrangements are called "electrode configurations".
Profiling method is carried out by adopting the Wenner configuration.

The Wenner configuration: This method was developed by Wenner in 1915. In this configuration, the outer electrodes, C1 and C2 are used to send current into the ground and the inner electrodes, P1 and P2 are used to measure the potential. The important feature of this setup is that the distance between any two successive electrodes is equal. The apparent resistivity measured in the Wenner method is given *by* ***Pa = 2πa(V/I)*** *where*

a = Electrode separation
v = Potential difference measured
I = Current sent into the ground
*P*a = apparent resistance (ohm-mts)

Profiling Method: This is also known as Lateral Electrical investigation. In this process, the electrode array i.e., setup as a whole is moved from place to place with same intervals (constant electrode spacing) along a given line and the *P*a value at each of the station is determined. The changes in *pa indicate* lateral variations in the subsurface to a certain depth.

It is obvious that the profiling technique will be useful in detecting only the dyke bodies or vertical beds. The presentation of profiling data is done on a ordinary graph sheet on X-axis (station) and true resistivity values on Y-axis (ohm-mts). The interpretation of profiling data can demarcate the high and low resistivity values of the sub-surface.



PROFILING METHOD (The diagram shows four steps, denoting how an electrode arrangement with fixed separation is moved along successive stations of a traverse line) .
C1 and C2 are current electrodes & P1 and P2 are Potential electrodes.

The Schlumberger Configuration: This method was developed by Schlumberger in 1916. In this method, potential electrodes are kept at smaller side compared to the current electrodes. In general, the electrode separation MN ≤ 1/5 AB relation is maintained in this investigation. Here A and B are the current electrodes and M and N are the potential electrodes. The apparent resistivity measured in the Schlumberger configuration is given by ***Pa*= K (V/I)** where K is a constant and the value varies as per AB distance

Sounding: This method is popularly known as Vertical Electrical Sounding (VES). In this method, a number of *ρ*a values are measured at the same place by increasing the distances between the current electrodes each time after taking the reading. The successive increasing in distance makes the current penetrate more and more deeply. Generally, the depth of penetration of the current (ie depth) is about 1/3rd of the distance between the current electrodes. It is necessary to cancel the self-potential before taking V and I readings for every electrode separation. From I/V values of each electrode separation, *ρ*a is obtained and it is multiplied by the configuration constant (K) to obtain true resistivity values.

The values are plotted on log–log sheet by plotting the electrode separation (station/distance) on x-axis and true resistivity values (ohm-mts) on y-axis. The obtained curve is to be matched with master curves.

Self-Potential methods: In self-potential methods, the natural electric field existing in an area is investigated whereas in other methods, the ground is charged by an artificial electric field and the results on the surface are investigated.

Self-potential method involves measuring the potential between the potential electrodes for different electrode spacing without any current into the ground. This method is also known as the "Spontaneous Polarization method". This means the potential measured is the natural potential existing in the ground all the time. Several sulphide ores such as pyrite, pyrrhotite, chalcopyrite, molybdenite, cobaltite etc.. show spontaneous polarization. Anthracite (coal) and graphite are known to give strong SP effects.

The instruments required for carrying out SP surveys are:

(1) A pair or non-polarizing electrodes to pick up the potentials from the ground.

(2) A devise ie DC potentiometer or electronic milli volt meter to measure the value of the potentials (voltages) in the ground picked up through electrodes.

The ground immediately above the ore body will therefore be an area of lowest potential, theoretically speaking the negative centre. The location of such negative centres is the target of S.P. surveys, since the ore body can be discovered usually below such centres.

The negative centres can be located either by determining the lines of equal electric potential (ie **equi-potential lines**) directly on the ground. The ore body is often met below the negative centre.

SEISMIC METHODS

Seismology, the science dealing with the natural phenomena relating to earthquakes. The Greek word *seismos* means shaking. Earthquakes are vibrations or oscillations due to sudden disturbances in the earth, which produce elastic waves which travel away in all directions from the point of origin. These elastic waves are called seismic waves.

In seismic prospecting, artificial explosions (explosives, dynamites may produce elastic waves if they fire) are made to study the travel times of seismic waves through geological formations, suffer reflection or refraction and arrive at the surface of the earth where they are detected by geophones.

With the help of geophones fixed at suitable intervals on the ground, the different seismic waves (P,S and L waves) reaching the surface are recorded and time-distance curves (hodographs) are constructed.
Seismic waves are classed into three types:

1. Primary waves or P waves
2. Secondary waves or S waves
3. Surface waves or L – waves

Terminology of an earthquake:

- **Focus**: Place of origin of the earthquake in the interior of the earth.
- **Epicenter:** A point on the ground surface, which is vertically above the focus.
- **Seismic waves**: The enormous energy released from the focus at the time of earthquake is transmitted in all directions in the form of waves.
- **Elastic waves**: A wave propagated by a medium having inertia and elasticity in which displaced particles transfer momentum to neighbouring particles and are themselves restored to original position.
- **Isoseismal**: The imaginary line joining the points of same intensity of the earthquake.
- **Hodograph**: time - distance curve
- **Seismograph**: an instrument is used to detect/ record the seismic waves
- **Seismogram**: Recorded data in seismic methods

Of all geophysical methods, seismic prospecting is more complicated and expensive. However, seismic method consists of a number of geophones; an amplifier and a galvanometer are used in addition to explosive material.

Seismic methods are effective for depths more than a km but are not suitable for shallow exploration. Seismic methods are important to locate the anticline and synclinal structures in oil exploration, and to identify fault zones. It is also helped a great deal in understanding the internal structure of the earth.

Many seismological observations have been established in India. The major ones among them are at New Delhi, Colaba (Mumbai) Alipore (Kolkatta); Shillong etc maintained by the Indian Meteorological Department and at Hyderabad by the National Geophysical Research Institute.

CLASSIFICATION AND CAUSES OF EARTHQUAKES: Earthquakes are grouped based on their depth of origin, and described as shallow or intermediate or deeper earthquakes. Earthquakes with a focus depth < 60 km are called shallow earthquakes. If the depth is > 60 kms but < 300 kms, they are called intermediate earthquakes. Other which have a focus depth > 300 kms are called deeper earthquakes. Earthquakes originating at depths > 700 kms are extremely rare.

TYPES: Based on the causes responsible for their occurrence, earthquakes are described as TECTONIC EARTHQUAKES AND NON-TECTONIC EARTHQUAKES.

<u>Tectonic earthquakes</u> are exclusively due to internal causes (ie disturbance of geological formations) that takes place in the earth's interior. Generally, Tectonic earthquakes frequency is less with high intensity and more destructive in nature.

<u>Non-tectonic earthquakes</u> are generally due to external causes. These are very frequent but minor intensity and not destructive in nature.

These earthquakes occur due to variety of reasons as follows:

- Due to huge water falls.
- Due to meteorites: Meteorites are bodies of various sizes wandering in space. When they come under the influence of the earth's gravity field, they suddenly fall on the earth's surface.
- Due to landslides
- Due to volcanic eruptions: Some volcanoes pour lava by throwing out the fire, smoke etc to greater heights. Such violent eruptions sometimes cause earthquakes. eg: Indonesia volcano(1883) due to eruption of volcano.
- Due to tsunamis: Tsunamis are giant sea waves. They move shore wards and dash against the coastline. Eg: Lisbon earthquake of 1775.
- Due to man-made explosions: During mining, and quarrying, many explosions are carried out.
- Due to collapse of caves, tunnels etc..
- Due to dams and reservoirs: when the reservoir was filled with water shows the signs of tremors. This is due to lateral thrust of reservoir water contributing stress.

SIZE OF EARTHQUAKES: The size of an earthquake is defined by its intensity and magnitude. **Intensity** is expressed based on the degree of destruction caused and varies from place to place. It is maximum around the epicentral area.

Earthquake intensities

Intensity	Effects
I	Not serious
II	Felt by few persons at rest, particularly on upper floors of buildings
III	Vibrations similar to a moving truck
IV	Windows and doors rattle; loose objects disturb
V	Breakage of dishes; wall plaster breaks
VI	Walls crack
VII	Slight to moderate damage in well-built structures
VIII	Falling of walls
IX	Ground cracks; breakage of underground pipes; considerable damage to buildings
X	Bending of rails; occurrence of land slides
XI	Buildings destroy
XII	Total destruction, surface displacements; objects thrown into air

The intensity at a place depends on several factors such as distance from the epicenter; depth of focus, geological formations and also on the type of construction of a structure..

Magnitude: Energy released during the time of an earthquake is commonly expressed as Richter's magnitude. Magnitude of an earthquake does not vary from place to place.

Energy released (E) is obtained from the expression: $\sqrt{E} = c\,(a/h)(d^2 + h^2)$
Where E = total energy released (ergs)
c = constant (taken as 0.625)
a = ground acceleration
d = distance (km) of the recording station from the epicenter
h = depth of focus (km)

Richter's scale has magnitude numbers upto 10. But the maximum known magnitude is around 9.6 only. An earthquake magnitude of 6.0 involves energy of around 2.5×10^{20} ergs (equivalent to that of an atom bomb) while for magnitude of earthquake is 7.0, it is around 80×10^{20} ergs (equivalent to that of a Hydrogen bomb). For an earthquake of magnitude is 8.0, then the energy may be around 2500×10^{20} ergs (most powerful).

The magnitudes of some of the important earthquakes in India are given below:

City	Date	Magnitude of earthquake	
Shillong	June12, 1897	8.7	
Kangra	April 4, 1905	8.0	
North Bihar	Jan 15, 1934	8.3	
Assam	Aug 15, 1950	8.6	
Koyna (Maharashtra)	Dec 11, 1967	6.4	
Chamoli (Uttaranchal)	Oct 20, 1991	6.5	Sand and mud with water was ejected
Killari (Latur)	Sept30, 1993	6.5	
Jabalpur (MP)	May 22, 1997	6.0	
Bhuj (Gujarat)	Jan 26, 2001	7.5	Vertical & partial collapse of a building
Andamans	Dec 26, 2004	9.0	

SEISMIC BELTS & SEISMIC ZONING MAP OF INDIA: On a seismic map, the country has been divided into 7 zones in terms of severity (magnitude). First seismic map (zoning map) was prepared in 1962 on the basis of historical data available regarding the occurrence of earthquakes all over the country. Subsequently the zoning map was revised in 1966.

Many of the areas in zone V and VI were merged into one because of their high risk. In the zone map brought out in the year 2000, the earlier zones II and I were merged. So the number of zones got reduced from 7 to 5. Zone – I is least severe and the Zone VI is most severe.
Entire NE regions, parts of Uttaranchal, Rann of Kutch (Gujarat) & Srinagar are included in zone V where the earthquake severity is high. All regions in Southern India are included in Zone III. Rest of the parts of India are included in Zone I & II. Zone 4 is also treated as severity.

Precautionary measures for the construction of buildings, dams/reservoirs etc in seismic areas: To make suitable constructions in seismic areas, IS codes 1893 – 2970 give guidelines.

For Construction of Buildings: In addition to the safety factors considered there are other precautionary measures which help in increasing the stability of buildings in seismic areas. They are as follows:

- Buildings should be founded on hard bedrock and never on loose soils or fractured rocks. This is so because loose ground can easily expose to earthquake vibrations.
- Foundation should be of same depth throughout for continuity.
- Buildings situated near hill sides, near steep slopes, on undulating ground or on marshy ground always suffer more when earthquake occurs. Therefore these situations may be avoided.
- Buildings should have light walls.

- Different parts of a building should be well tied together so that the whole structure behaves like a single unit to the vibrations.
- Proper proportionate of cement and mortar should be used.
- Doors and windows should be kept to a minimum and they should not be in vertical rows but preferably along the diagonals.
- The building should have uniform height and additional features such as parapets, cantilevers, domes and arches are undesirable.
- Buildings should have flat RCC roofs and they should be designed not to yield to lateral stress.
- Projections above the roofs are undesirable.

For Construction of Dams: Dams being very costly projects their consideration in seismic areas needs careful study to ensure their safety precautionary measures which are as follows:

- Forces in the dam due to reservoir water and due to the dams weight are to counter balanced by introducing additional stress in the design of the dam.
- Design of the dam is to be made such that during an earthquake they move along with the foundations below.
- Dams should not ordinarily be built along or across the faults because possible slipping along these planes during earthquakes will introduce additional complications.
- The resonance factor value (vibrations due to sound) should be given due consideration because a coincidence in the period of vibration of the dam and the earthquake vibrations can produce cumulative effects.

RADIOMETRIC METHODS: The nuclei of certain elements are unstable (U, Th) and change spontaneously into the nuclei of other elements. This change is accompanied by emission of radiations known as alpha; beta and gamma rays. Hence, these rays are measured in the study of radiometric methods. Instruments used in radiometric prospecting are called radiometers. A radiometer consists of three basic components:

(i) a detector of radiations
(ii) an amplifying and recording unit and
(iii) a power supply unit .

The radioactivity is different in various types of rocks.

In igneous rocks, the radio activity decreases with decreasing acidity as:
Plutonic rocks basic rocks ⟶ ultrabasic rocks ⟶
(Radioactivity is high) .... (Radioactivity is least)

In sedimentary rocks, the radioactivity decreases as :
Shales ⟶ sandstones ⟶ limestones

Thus based on radioactivity, it is not only distinguish different rock types but also to detect ore bodies. Under favourable conditions, it may be possible to identify geological structures such as faults and folds in the subsurface.

Radiometric methods of investigation are useful in:

- Exploration of U and Th mineral deposits
- Indirect location of rare elements such as Zr, Be, Li etc occurring in pegmatites and Tantalum, Niobium etc occurring in some alkaline rocks.
- In case of exploration of oil and gas due to the low values of gamma rays.
- By means of radioactive techniques, it is possible to study the velocity of ground water, its direction, salt water bodies etc.
- Radioactive tracer techniques may be utilized for finding leakages in water storage structures.

GEOTHERMAL METHODS: Geothermal methods deals with measurements of the physical properties of the earth. The emphasis is mainly related to **temperature** and **fluid content** of the rocks. The important physical parameters in a geothermal system are: temperature; porosity; permeability; chemical content of fluid (salinity); and (pressure)

The aim can be to delineate a geothermal resource, to locate aquifers, or structures that may control aquifers etc..
Temperature distribution on the surface of the earth is due to three different sources. They are:

(i) Heat received from the sun (varies with the time of the day and with the season) up to a few meters depth only.
(ii) Heat conveyed from the hot interior of the earth due to conduction and convection processes
(iii)Heat due to decay of radioactive minerals in the crust of the earth.

By eliminating (i) and (ii), the solar heat component and the heat contribution of radioactive mineral decay, the only one is to interpret the values of temp of the earth's surface. For the measurement of the temperature on the surface of the earth, in shallow holes or in deep bore holes, THERMISTOR THERMOMETÈRS and PLATINUM RESISTANCE THERMOMETERS can achieve an accuracy of 0.01°C are used. The geothermal methods find application to locate structural bodies, oil and gas structures, ore deposits, ground water studies etc…

Thermal methods include direct measurements of temperature and/or heat, and thus correlate better with the properties of the geothermal system than other methods. To measure temperatures close to the surface, in the uppermost part of the earth crust is fairly simple. Knowledge about status at deeper levels is based on the existence of wells, usually shallow gradient wells (e.g. 30-100 m deep), from which the thermal gradient can be calculated and possibly the depth to the exploitable geothermal resource. Drilling is though usually fairly expensive, and puts practical limits to the use of the method. Furthermore, shallow wells are not always adequate to get reliable values on the thermal gradient.

The heat exchange mechanism in the earth is important for interpretation of thermal methods. A distinction is made between:

• Conduction, which is based on atomic vibrations, and is important for transfer of heat in the earth's crust;
• Convection, which transfers heat by motion of mass, e.g. natural circulation of hot water; and
• Radiation, which does not influence geothermal systems.

The parameter k, the thermal conductivity (W/m°C), is a material constant, which ranges between 1 and 5 W/m°C, with the low values usually associated with sedimentary formations and the higher for crystalline rocks. The thermal gradient,)T/)z, gives information on the increase of temperature with depth, and its distribution can be important information for understanding and delineation of the geothermal resource, both on a regional scale and local scale. If the conductive hear transfer, Q, is 80- 100 mW/m2 or higher, it may indicate geothermal conditions in the subsurface.

FUNDAMENTAL ASPECTS OF ROCK MECHANICS: "Rock mechanics" is the name given to the study of behavior of rocks under loads imposed upon them in the laboratory with all possible combinations.

From civil engineering point of view, rocks are used for various purposes ie for laying foundations, as building stones (for walls, columns, lintels and arches); as concrete aggregate, as roofing material, as flooring material, as polished stones for face work, as paving stones of roads, for making statues, as road metal, as railway ballast, as construction stones for bridges, piers, abutments, retaining walls, light houses, dams, for tunneling and so on..

Certain rock mechanics (physical properties of rocks) are necessary to make rocks suitable for certain purposes. A number of IS codes are available to determine the different engineering properties for rocks such as Crushing strength, shearing strength, density, toughness, resistance to abrasion, durability. For eg:

Strength of a rock is important for foundation purposes to withstand heavy loads (colour, appearance etc are unimportant).

Resistance to abrasion is also important when rocks are used for flooring purposes.
Durability (resistance to weathering) for roofing purpose
Absence of reaction with chemicals for concrete aggregates;
Softness for carving purpose
Lightness is important for rocks/stones used in arches and so on.

Eg: Marble, is well known for its pleasant colors, good appearance, easy workability, ability to take a high degree of polish is selected for sculpture works whereas it is unsuitable to serve as a foundation rock whereas basalt is just the opposite of marble in its nature and suitability.

Hence, the engineering properties of rocks can be studied under:

(i) For construction purposes especially foundation of dams
(ii) Rocks utilized as materials of construction ie building stones
(iii) Rocks used as aggregate (small broken pieces) of concrete.

Engineering properties to be tested for rocks

Foundation purposes	Building stone for construction purpose	As aggregates for concrete purpose
Uniaxial compressive strength	Crushing strength	Hardness test
Tensile strength	Transverse strength	Toughness test
Shear strength	Porosity	Binding properties
Modulus of elasticity	Density	Crushing strength
	Abrasive resistance	
	Frost & fire resistance	
	Durability	

Uniaxial compressive strength: This test is carried out on cylindrical specimens with a length - diameter ratio of 2 and the results are reduced to a length – diameter ratio of 1 by using the formula:

$Co = Cs [0.8 + (0.2 / (L/D)]$ where Co is the observed compressive strength, Cs is the standard Uniaxial compressive strength ; L is the length of the cylinder and D is the diameter of the cylinder.

Tensile Strength: The test consists of loading a test cylinder diametrically in such a way that the applied loads would develop tensile rupturing along the diametrical plane of the specimen. The loads are gradually increased till the cylinder is fractured. The load P at rupture thus being known, Transverse strength Ts is calculated by using the formula: $Ts = 2 P / DL$; where D and L are the diameter and length of the specimen respectively and P is the load.

Shear strength: A bar shaped specimen is held under grips and supported at its ends below. It is loaded from above and rupture occurs as a result of failure along two planes when the shearing strength is exceeded. The shearing strength is calculated by using the formula $(P/2) / A$, where P is the load at failure and A is the area of cross-section of the specimen under load.

Modulus of Elasticity (Young's modulus): The modulus of elasticity of rocks indicates their deformation under loads. Such deformation is recovered when loads are removed. The value of E is required especially in tunnel works and the abutments of arch dams. E is expressed by the relation s / e where s is the stress and e is the strain.

NECESSITY OF GEOPHYSICAL INVESTIGATIONS

To ensure safety, success and economy in construction of major civil engineering structures, it is necessary to be thoroughly aware of the geology of the concerned site. The relevant details can be readily obtained if a suitable and large number of outcrops of *in situ* rocks are noticed on the surface. This happens due to various reasons such as occurrence of soil cover, intense weathering of exposed rocks, sprawling cultivated lands, townships, forests, surface water bodies and so on at the concerned site. In such cases in order to acquire the subsurface details only two approaches exist. They are: *direct observations* or *indirect inferences.*

(i) Direct observations can be made by digging, trenching or drilling the ground. Such processes are expensive, laborious and time consuming. But they give exact data of the existing subsurface conditions of the site.

(ii) Indirect inferences are drawn by means of geophysical methods of investigation. These provide quick, inexpensive, easy and fairly reliable means to get subsurface details.

IMPORTANCE OF GEOPHYSICAL INVESTIGATIONS: Geophysical investigations are gaining importance very rapidly because of their success in solving a vast variety of problems. The other advantages are:

(1) These investigations are carried out quickly. This means large areas can be investigated in a reasonably short period and hence *time is saved.*

(2) The geophysical instruments used in the field are simple, portable (mostly) and can be operated easily. This means the fieldwork is not laborious.

(3) Since the work is carried out quickly and only physical observations are made without the use of consumables (like chemicals), it *is economical too* (particularly in the case of gravity, magnetic and some electrical methods of investigations).

(4) Different inferences to suit different purposes can be drawn from the same field data.

(5) *Scope to check* the correctness of conclusions is possible

(6) To suit the requirements and to be economical, geophysical investigations are amenable to be carried out on different scales. This means that if only preliminary information is required; reconnaissance surveys are enough. Then the scale of survey may range from 1: 100,000 to 1: 1,000,000. However, if more details are required, detailed surveys can be taken up with the scale of survey ranging from 1: 1000 to I: 10,000.

Applications of geophysical investigations which account for their inherent importance are as follows:

(I) *Non-geological:* Detecting hidden treasures, ammunition dumps, buried Pipeline patterns or pipes come under this category. Such applications are not many.

(2) *Geological:* Such applications are numerous, important and widely varied.

These can be broadly grouped into five kinds as follows:

(i) Investigations aimed at solving problems of regional geology;
(ii) Investigations aimed at locating geological structures which are favourable for accumulation of oil and gas;
(iii) Investigations aimed at locating and estimating economically important Mineral deposits;
(iv) Investigations aimed at locating and assessing ground water potential and its quality; and
(v) Investigations aimed at solving problems connected with "engineering geology". "Exploration geophysics" comprises five branches, namely; regional geophysics, oil and gas geophysics, ore geophysics, ground water geophysics and engineering geophysics

UNIT - V: DAMS& RESERVOIRS

The enormous requirement of water for irrigation, industries, power generation, constructional activities, domestic and other purposes are met either by surface water resources (like tanks, lakes and rivers) or underground water. Surface water resources are fairly amenable for definite assessment and exploitation. Among the surface water resources, rivers provide copious supplies of water which can be stored in man-made reservoirs by constructing dams across the rivers.

A dam is a prestigious civil engineering structure which blocks a river channel and compels the running water to accumulate within the reservoir. In other words dams are constructed for impounding water.

Dams are the costliest *multipurpose* civil engineering constructions. They deliver beneficial results for a long time to mankind. But the same dams, if they fail, create a heavy toll of life and property through lightning floods. They may even cause the failure of other dams built along the downstream course. Each dam consumes millions of tons of building materials including cement, aggregates, sand and steel and other items.

Whenever this accumulation of water exceeds the desired limit of storage in reservoir, the surplus water is allowed to flow downstream. The openings which control the discharge of surplus water from reservoir together constitute the SPILLWAY. The Spillway is commonly placed on a sound foundation within or outside the body of the dam and the openings are controlled by suitably designed gates.

Among various constructions, dams throw the toughest challenge to the civil engineer. Barrages are similar to dams and are mainly meant to raise the level of water along the course of a river to reap certain advantages.

The location of a dam or the selection of a dam site is mainly based on the Geology of the site because the stability or success and the cost of dam are dependant on different geological conditions of the site.

In India, more than 90% of the dams operating are primarily for irrigation. Various purposes of dam construction are:

- To generate hydro-electric power
- For flood control
- For water supply to meet domestic, industrial..

Parts of a Dam: The chief parts of a dam are as follows:

Heel: It is the part where the dam comes in contact with the ground on the upstream side

Toe: It is that part where the dam comes in contact with the ground on the downstream side

Free board: It is the difference in level between the top of the dam wall and the highest storage level.

Galleries: These are small rooms left within the dam for checking operations.

Spillway: An arrangement is made in a dam near the top or inside to allow excess water of the reservoir to the downstream side

Sluice: It is an opening in the dam near the ground level. It is useful in clearing the silt of the reservoir.

Cut-off wall: It is an underground wall-like structure of concrete in the heel portion. It is useful in preventing leakage under the foundation.

Abutment: These are the sides of the valley on which the dam structure rests.

TYPES OF DAMS & BEARING OF GEOLOGY OF SITE IN THEIR SELECTION

Dams are of different types. Either they can be totally of reinforced concrete or totally of earth materials or a combination of both.

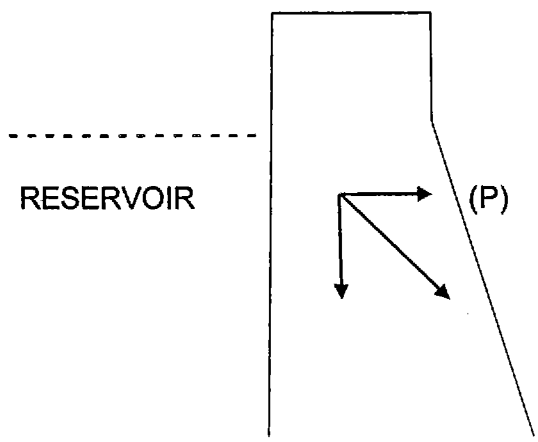
Based on the construction material used, dams are grouped into **concrete dams**, (masonry dams) and **earth dams.**

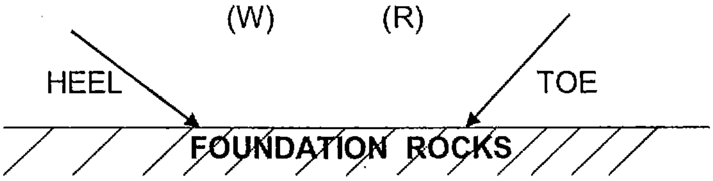
Based on design, the concrete dams may be further grouped in to Gravity dams, Buttress dams and Arch dams.

Similarly, Earth dams too are grouped in to Earth Fill dams and Rock Fill dams (based on the kind of material used.)

Gravity dams: It is a heavy concrete structure. The weight of the dam acts vertically (whole weight acts vertically downwards) and plays an important part in its stability. The stability of a gravity dam depends on the pressure distribution. This type of dam is to be selected only in such places where competent and stable rocks occur.

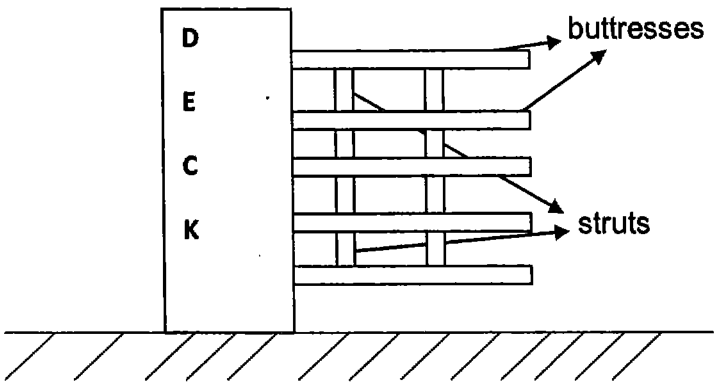
For the dam to be stable, the resultant R of the force, [W (weight of the dam) and the lateral thrust of the reservoir water (P)] must be within the middle of the dam. Foundation treatment like grouting is adopted in case of any incompetent foundation material present.





Buttress dams: These are concrete structures in which there is a DECK sloping upstream, supported by BUTTRESSESS (or walls) placed at right angles to the dam axis. These buttresses are further strengthened by cross-walls known as STRUTS.

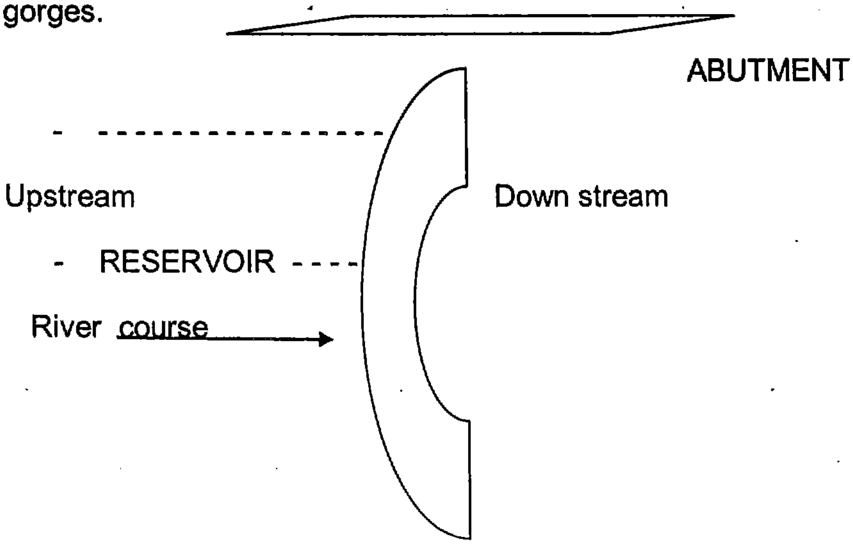
The entire system with all these components distributes the load over the foundation. Since the load distribution is over a wide area, even formations relatively weak are considered.



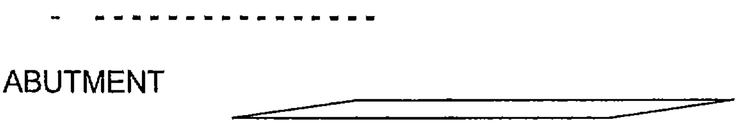
FOUNDATION ROCKS (top view of buttress dam)

Arch dams: This type of dam is preferred for narrow and deep river gorges. The arch is convex to the upstream side. It can be a single arch dam or multiple arches. The design of an arch dam is such that the whole part of the load is transformed to the abutments.

Since a substantial part of the load is transmitted to the abutments, the formations constituting the abutments must be very competent. Arch dams need better monitoring. Arch dams are best suited to narrow, deep, river-cut gorges.



(top view of an arch dam)



NOTE: Masonry dams are suitable where the geological formations at the dam site are very strong and stable, so as to withstand heavy loads associated with the dams.

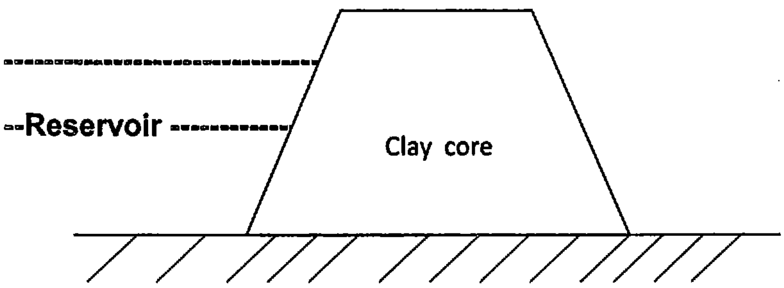
EARTH DAMS: These structures are large in size and trapezoidal in shape. These are preferred in broad valleys and where the foundation material is weak or where suitable competent rocks occur at a great depth.

The earth dams, relatively of smaller height are lighter structures and broad based. Because of the broad nature of the dams, the weight of the dam is distributed over a wide base and the force per unit area is consequently less.

The earth materials used in the construction are gravel, sand, silt and clay is called an Earth Fill Dam and if the material used is rock, it is called a Rock Fill Dam.

The side slopes are maintained at 1 in 2.5 and an impervious clay core is provided to arrest seepage across the structure.

Eg: Ft. Peck, Wyoming dam.... It is 4 1/2 miles long, 4000 feet thick at the base and 250 feet high.



FOUNDATION ROCKS

LOCATION OF A DAM: The ideal site for location of a dam should satisfy the following requirements:

- A narrow river valley along with steeper side slopes
- Stable slopes both at the dam location and along the reservoir sides
- Absence of weathered formations
- Competent geological formations devoid of weak zones
- Absence of clay and fractured material
- Absence of fault zones
- Stability of formations below the dam and reservoir area
- Easy access and supply of materials for construction of the structure

It may be mentioned here that all these attributes never exist in any one particular site. Consequently, appropriate foundation treatments are resorted for making the dam site and reservoir area most suitable.

GEOLOGICAL CONSIDERATIONS for selection of a dam site:

(A) Topography and geomorphology of the site: At the proposed dam site, if the valley is narrow, only a small dam is required, which means the cost of dam construction will be less. On the other hand, if the valley is wide, a bigger dam is necessary which means the construction cost will be very high.

Therefore, it is preferable, from the economy point of view, to select such a site along the river valley which has the narrowest part of the river. However, narrow river valley may have severe defects which may lead to leakages.

Quite often the valleys have TALUS and flood deposits along the slopes, thus giving a narrow appearance to the valley but in fact it may be a wider river valley.

(B) Impact of Geological structures (occurrence of rock formations at shallow depths) :

The rock formations at the dam site should be dipping towards upstream or horizontal. This will counter the seepage, compared to the situation where the formations dip in the downstream direction.

To ensure the safety and stability of a dam, it should necessarily rest the dam on strong (physically) and very stable rocks (structurally).

- Usually the foundations will have greater stability when the load is normal in case of horizontal formations or with low dip formations.
- Fault zones present in the formations result weakness in the rock formations.
- Extensive joints in the rocks threaten the safety of the structures by means of seepage.
- Presence of Anticlinal or Synclinal structures in the rocks also contribute to the seepage.

To know the bedrock profile (ie the depths at which bedrock occurs at different places) in the river valley along the axis of a proposed dam, geophysical investigations such as '*Electrical Resistivity* " or "*Seismic Refraction*" methods are to be carried out.

Following examples reveal the impact on dams where the cost was high as well as the presence of structures in the rock formations:

1. Bhakranangal dam on sutlez river, the bed rocks were at a great depth caused more excavation for foundation .

2. Koyna dam is located on an excellent competent basalts with 6 to 7 metres thick but followed by weak volcanic breccia upto 20 mts below the ground level. This naturally rise in the construction cost of the dam.
3. Presence of a fault and incompetent rocks of conglomerate in St. Francis dam of California caused for enormous leakage of water through the conglomerates and failed

4. Similarly the presence of cavernous limestones in the foundations caused for the collapse of Halesbar dam on the Tennessee river.

(C)Competent rocks to offer a stable foundation (Lithology of the formations):

Among the Igneous rocks, (either plutonic or hypabyssal rocks) Granites, Syenites, Diorites, Gabbros, and volcanic rocks viz., Basalts (fine grained) are most desirable at the dam site. However, adverse effects will be noticed in basalts only when they are highly vesicular and permeable.

In case of sedimentary rocks, particularly shales, poorly cemented sandstones and cavernous limestones shall be undesirable to serve as foundation rocks. However, well cemented siliceous sandstones have good compressive strength and suitable for the dam foundation.

Laterites and conglomerates are undesirable at dam site. Clay, if present in any of sedimentary rocks is totally to be excavated since it swells on saturation with water.

Among the **metamorphic rocks**; gneisses are generally competent whereas schists are undesirable due to their well developed cleavages and foliation.

Quartzites are very hard and highly resistant to weathering and suitable for foundation of dam sites.

Slates bear a typical slaty cleavage and soft nature are undesirable at dam sites.

Khondalites which are feldspar rich and contain soft graphite, and are usually weathered and hence unsuitable at dam sites

Much attention is needed in case where the contact of igneous intrusives (for example dolerite) with the host rocks often are fractured and jointed.

- Eg: (1) In the Ukai dam site in Gujarat, the contacts of basalts and the dolerite dyke were the weak zones.

- Eg: (2) Similarly, at the contacts of a dolerite dyke with the host granite gneisses in the Nagarjuna sagar dam area, shear zone with heavily crushed rock was found. Of course, back filling with grouting was adopted.

(D)Influence and Effects of various factors:

1. The extent of weathering should be carefully assessed (through trial pits) to ascertain whether a rock is suitable or unsuitable for the required purpose.

2. Study of intrusives such as dolerites and quartz veins is important factor. If they are present they contribute to the heterogeneity at the dam site causing leakage.

3. Fracturing is a common phenomenon observed in all kinds of rocks and represents a reduction in the cohesion or compactness of the rock. Suitable remedial measures taken up to make the site rocks fit for the location of the dam.

4. Alternating soft and hard beds when inclined are bad and the situation leads to a variety of problems including slipping of hard beds over softer ones at the time of excavation.

In civil Engineering point of view, the following cases of geological structures at damsite are important:

I. Case of undisturbed strata.

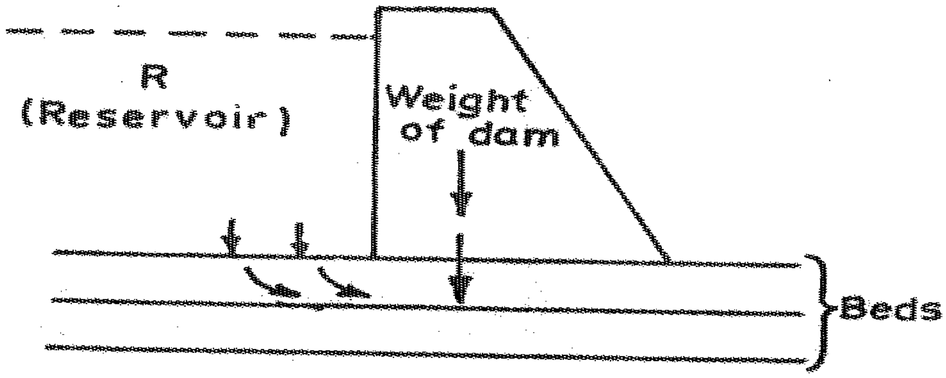


Fig. 18.8 A gravity dam over horizontal beds

Horizontal Strata: This geological situation is good at the dam site because the load of the dam acts perpendicular to the dam site.

II. Beds Dipping towards Upstream Side

a. Gently Inclined beds:

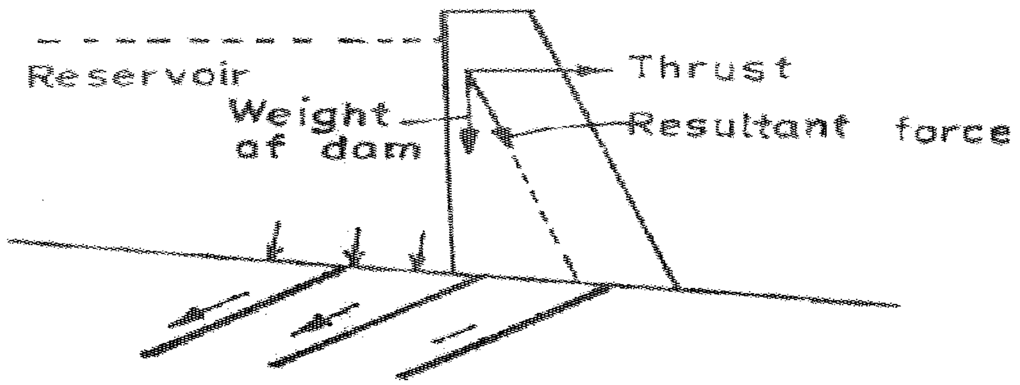


Fig. 18.9 Dam over gently inclined beds in upstream direction

In this case, rocks are best positioned to take the loads of dam because the resultant force and the bedding planes are not in the same direction. No uplift force on the dam and percolated water is returned to the upstream side only, so this is doubly advantageous.

b. Steep beds:

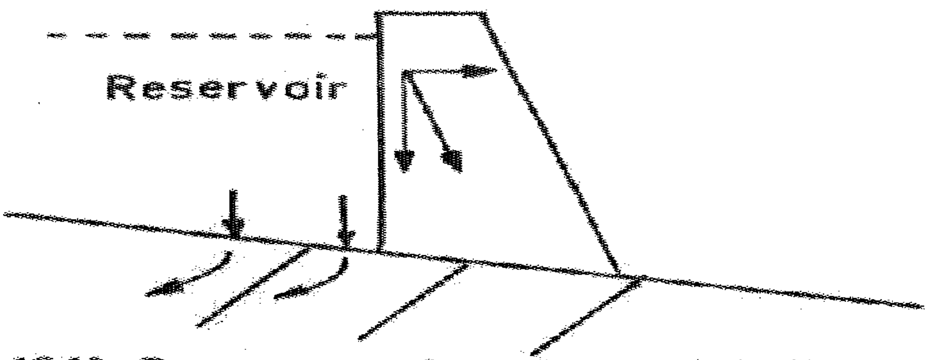


Fig. 18.10 Dam over steeply upstream side inclined beds

This situation is not bad but not that competent to take up the dam loads as compared to gently inclined beds. This may not cause uplift force on the dam and percolated water is returned to the upstream side only.

III. Beds Dipping towards Downstream

c. Gently Inclined beds:

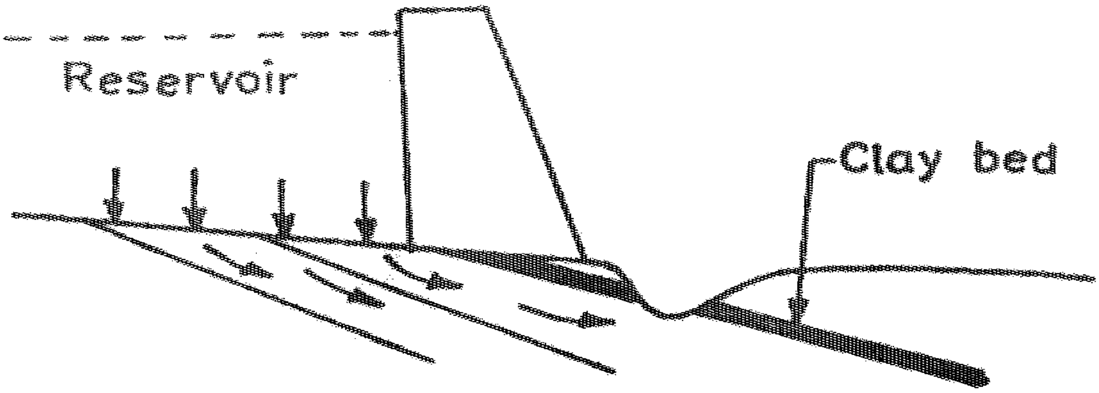


Fig. 18.11 Dam over downstream side inclined beds

It is disadvantageous, because the resultant force and the bedding planes are in the same direction. Percolated water to down stream side cause uplift force on the dam and percolated water goes out and cause significant water loss.

d. Steep beds: This situation is similar to the above situation and further dangerous because the resultant force and the bedding planes are almost parallel.

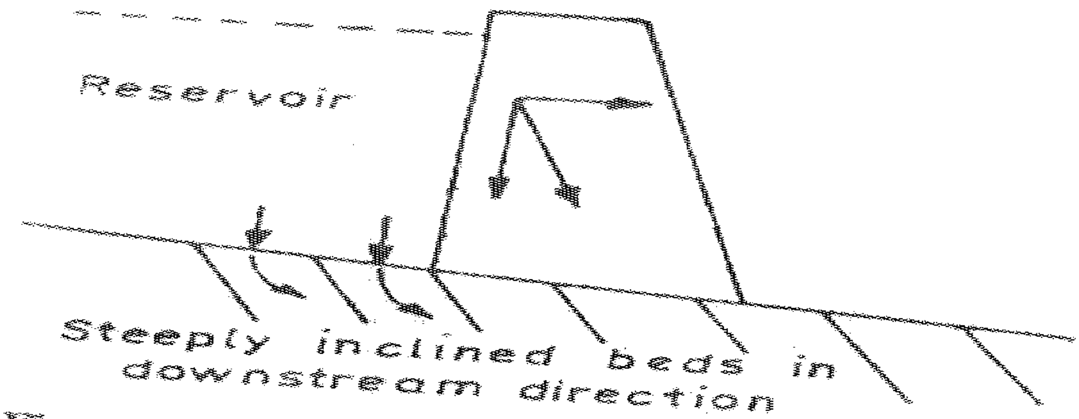


Fig. 18.12 Dam over steeply inclined beds in downstream side

IV. Beds dipping vertically

e. Dam Over Vertical Beds:

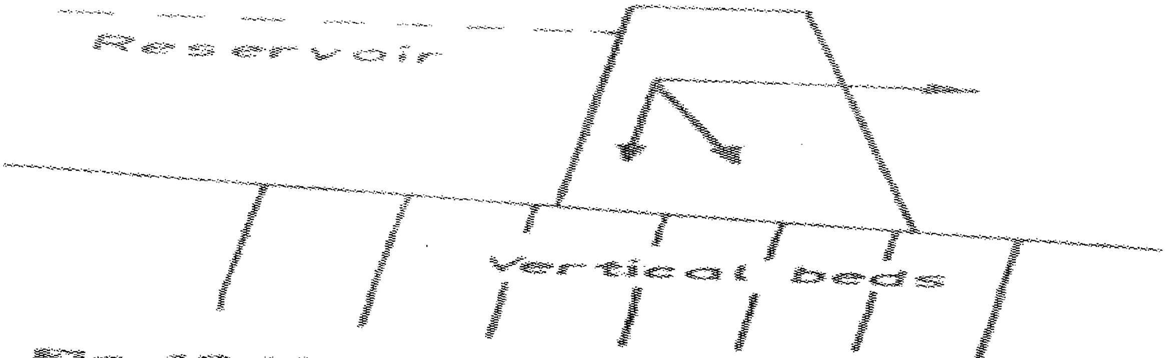


Fig. 18.13 Dam over vertical beds

Occurrence of this situation is rare. It will not pose problems of uplift force or leakage below the dam. However, it shall not have any advantage in terms of competence of rocks.

V. Beds which are Folded

Dam Over Folded Beds: Folding of beds, are generally less dangerous than the faulting, unless the folds are of a complex nature. The folded rocks are not only under strain but also physically fractured along the crests. Hence grouting and other precautions may have to be taken, depending upon the context, to improve the stability and competence of rocks at the site.

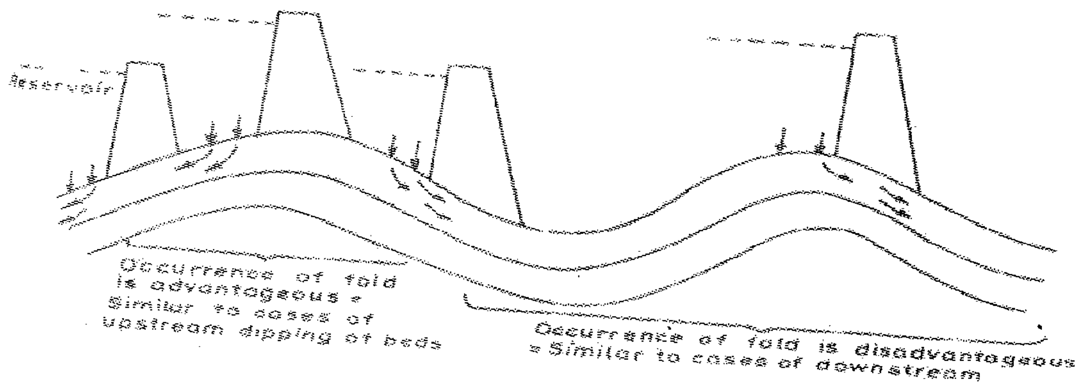


Fig. 18.14 Dam over folded beds

VI. Beds which are Faulted

Dam over Faulted Beds: Occurrence of faulting at the dam site is most undesirable. If the faults are active, under no circumstances, dam construction can be taken up there. This is due to relative movement of bed and also possible occurrence of an earthquake.

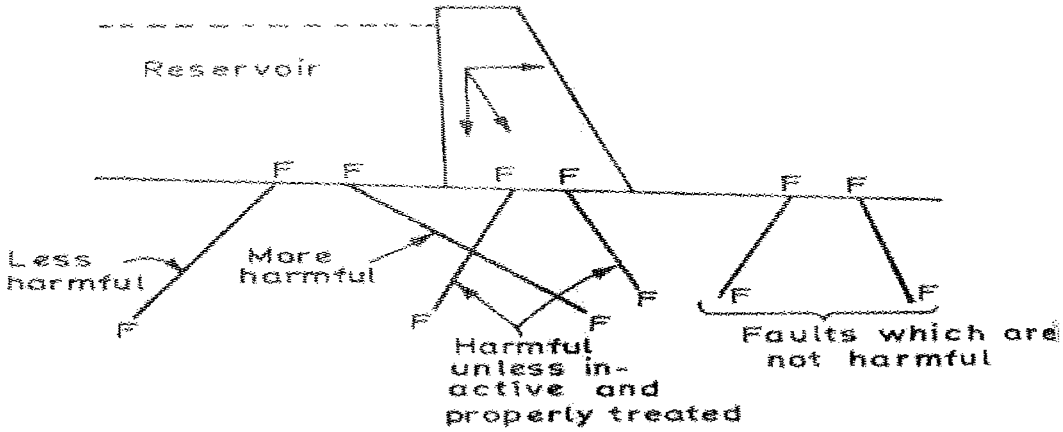


Fig. 18.15 Dam over faulted beds

1. If the faults occur in the downstream side, they will not be much harmful directly.

2. If the faults occur in the upstream side, the downstream dipping faults are dangerous because they have all the disadvantages of a case with bedding planes of such attitude (i.e., risk of uplift pressure, heavy leakage water), but if the faults dip in the upstream side they need to be sealed to avoid possible leakage.

VII. Beds Which have Joints

Joints are nothing but gaps of different magnitude that are common in rocks. They

contribute to the physical weakness of the rock and also more porous and permeability. These physical features are undesirable for the dam construction. Hence, by adopting grouting technique, these weaknesses can be avoided.

VIII. Cases where beds lie parallel to the length of the valley

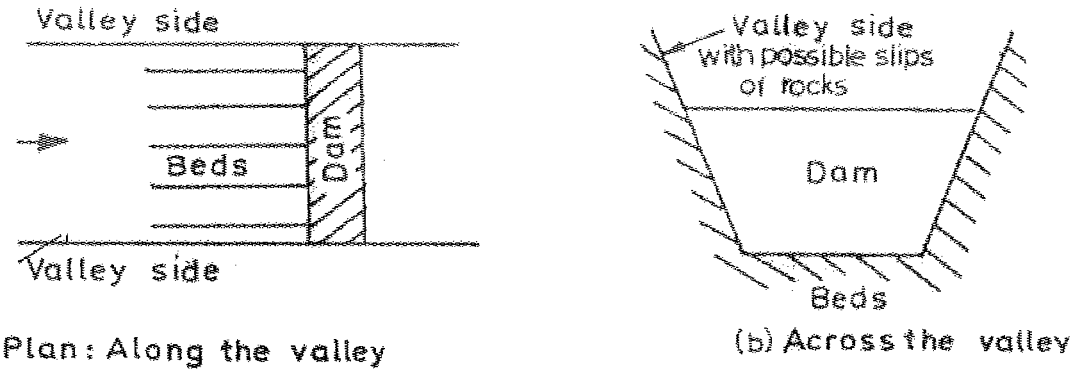


Fig. 18.16 Dam over beds striking parallel to valley

This is the case where the dam is aligned across the strike, i.e., in the dip direction of the beds. In this case the danger will almost always be present as the slope of valley sides are very steep at the dam sites and are very likely to be steeper than the dip of rocks and causes instability at the site and slipping of rocks at one side

Stages/Exploratory investigations for site location of dam: The selection of a site for dam construction is made in various stages.

Stage 1 (Preliminary stage) : All the available information in terms of topographic maps, geological maps, seismic information is summarized to have a preliminary understanding of the area.

Detailed geological mapping by incorporating the rock formation details, boundaries of formations, strike and dip of the beds, joints, faults, folds etc.... is to be prepared.

The field geological map is integrated with available aerial photos and satellite imageries to produce a composite map. Aerial photo interpretation provides information like litho logical variations of the formations; geological structures, landslide areas, drainage patterns and structural control of drainage etc....

On the other hand, satellite data provide a regional picture on various features related to Geology, Geomorphology and Physiography of the area under consideration.

Geophysical investigations including seismic and electrical resistivity surveys are undertaken to obtain information both laterally and vertically (depth).Drilling in vertical and inclined directions, is undertaken. Drill hole data enable structural variations in the formations to depth. Plate bearing load tests, water pressure tests etc in bore holes are also undertaken.

Groundwater study and preparation of ground water contour maps are important in preliminary investigation. Seepage including springs and the source of seepage water, condition of seepage water, elevation at which the seepage is present are to be recorded.

Stage 2 (Detailed investigation) : once all the field data is obtained from the above approaches, locations are identified for samples to be collected for laboratory investigations. Lab investigations include assessment of properties like UNCONFINED COMPRESSIVE STRENGTH (UCS); UNIAXIAL TENSILE STRENGTH; SHEAR STRENGTH; ELASTIC MODULI or MODULUS OF ELASTICITY (E); PERMEABILITY; EXTENT OF FRACTURING on the basis of ROCK QUALITY DESIGNATION (RQD).

All the data on integration will provide the thickness of overburden, depth to water table, areas of potential seepage, rock strengths and enable the delineation of weak zones.

Table depicts the range of values for various rock formations for UCS & ME

ROCK	**UNCONFINED COMPRESSIVE STRENGTH**				**Modulus of Elasticity**	
	UCS (kN/m^2)		UCS (MPa)		kN/m^2 (x10^6)	
QUARTZITE	200000	350000	200	350	8.28	44.06
GRANITE	40000	290000	40	290	10.35	82.11
BASALTS	180000	275000	180	275	40.71	85.56
GNEISS	151000	248000	151	248	24.15	104.19
SLATE	95000	250000	95	250		
MARBLE	48000	230000	48	230		
SANDSTONE	10000	23000	10	230	4.14	55.20
SCHISTS	7500	139000	7.5	139		
SHALES	6500	200000	6.5	200	2.07	68.31
LIMESTONE	5000	200000	5	200	2.76	97.29

The rock formations RATING are classified as RQD (%) to access the suitability:

Strength of the rock	**RQD (%)**	
Very poor	0	25
Poor	25	50
Fair	50	75
Good	75	90
Excellent	90	100

NOTE: NO SUPPORTS ARE NEEDED FOR FORMATIONS WITH RQD VALUES EXCEEDING 75.

ROCK QUALITY INDEX SYSTEM (Q – SYSTEM): rock mass rating on the basis of Q value for TUNNEL SUPPORT REQUIREMENT is as follows:

QUALITY	**Q VALUE**	
Excellent	400	1000
Extremely good	100	400
Very good	40	100

Good	10	40
Fair	4	10
Poor	1	4

DAM FAILURES OF THE PAST:

1. The **St. Francis Dam** was a concretegravity-arch dam, designed to create a reser
The dam was built between 1924 and 1926 under the supervision of William Mulhollan

The dam Height is 195 feet (59 m)& its **length is** 608 feet (185 m). The dam was constructed on the foundation of Schists and conglomerates and in turn, separated by a distinct fault. In addition, conglomerates also had veins of gypsum, a soluble mineral and hence both Schists and conglomerates are unsuitable to serve as a foundation to such a dam.

Several temperature and contraction cracks appeared in the dam when the reservoir had reached full capacity. Enormous leakage of stored water occurred through the conglomerate and the dam failed by sliding in 1928 resulting more than killing of 450 people.

Huge concrete block from the west abutment of the dam . The block is approximately 63 feet long, 30 feet high, and 54 feet wide. It was concluded that the disaster was primarily caused by the landslide on which the eastern abutment of the dam was built.

2. **Hales Bar Dam** was a hydroelectric dam located on the Tennessee River in Marion Country, Tennessee, USA. **The Hales Bar Dam** was constructed on the foundation of cavernous limestones. Such rocks are naturally weak both physically and chemically. To improve the site conditions and to reduce the seepage, the large openings were filled up by using more than 3000 tons of cement and 1100 barrels of asphalt. The height of the dam is 113 feet with a length of 2315 feet

The dam was planned to complete in 1909, but numerous difficulties brought by the soft bedrock ie limestone upon which the dam was built.

Leaks began to appear almost immediately after completion. However. in 1919, engineers attempted to minimize the leakage by pumping hot asphalt into the dam's foundation. This was temporarily successful, but by 1931, a study leaking at a rate of 1,000 cubic feet per second was noticed .

In the late 1950s, however, the water below Hales Bar Dam, was again leaking, this time at an alarming 2,000 cubic feet per second. **Dye tests** carried out in 1960 suggested that many of the leakage channels had interconnected, increasing the possibility of a future dam failure.

GEO HAZARDS : Geological hazards such as Earthquakes; volcanoes ; landslides etc.. pose a threat to the earth's stability. All these geological hazards cause considerable destruction in many ways.

During earthquake, the ground motion results in damaging buildings, dams, dislocating the roads and railway tracks; alter the course of surface water and groundwater flow etc..

Volcanic activity brings devastation on large scale due to emission of a number of gases.. Thick forests are denuded, vast areas are buried under thick volcanic debris.

Land slides are common phenomena during earthquakes. Huge flow of pyroclastic materials mix with water flows and cause damage to whatever lies in its path.

Thus, earthquakes, volcanic activity and land slides are all inter-related.

1. Earthquakes& earthquake hazards : The earth's crust is broken into 13 major plates which are in constant movement (1 to 2 cm / year on average) due to the **convection currents** in the interior of the earth. These plates are called as Tectonic Plates .

The pate boundaries move away from each other at some places while they converge and collide against each other at some places.

An earthquake is a sudden motion of the ground. In the Earth's crust, at different places , stresses accumulate causing slow and continuous deformation of rocks. As the stress exceed its elastic limit, the rocks break . Due to this sudden breakage, the strain energy is released in the form of shock waves.

The focus is the place where this slippage has initially taken place. Vertically above the focus, the location on the ground surface is known as epicenter of the earth quake.

Recording of the shock waves is done with the help of an instrument known as Seismograph. The record (chart) is known as a seismogram. These records for an earthquakes are useful in locating the epicenter of the earthquake and also to define the size of the earthquake.

The size of an earthquake is defined by its **intensity and magnitude**.

The intensity at a place depends on several factors such as distance from the epicenter, depth of focus, geological formations and the type of a civil structure.

The magnitude of an earthquake does not vary from place to place. Magnitude is a function of the energy released in an earthquake and is common ly expresses as Richter's magnitude . Richter's scale has magnitude numbers upto 10 but the maximum known magnitude is around 9.6 only.

In civil engineering practice, earthquake resistant designs have been needed for all civil structures.

Earthquake Hazards:

- Destruction of buildings eg: Bhuj earthquake (7.5) on 26-01-2001
- Dislocation of transportation routes (highways, bridges, railway tracks).

Eg: (1) California earthquake of 1994, caused subsidence and landslides.

(2) Alaska earthquake (8.7) on 27-03-1964 causing the displacement of a road bridge.

- Generation of Tsunamis for eg: Mexico, Chile , Indonesia (Tsunami means the rapid displacement on the sea floor during the earthquake. These waves travel several thousands of kilometers.
- Power lines breakdown and cause for fires

2. Volcanic and volcanic hazards: The earth's crust is highly fractured and these fractures extending to certain depths and facilitate migration of magma upwards .The rate of travel of magma depends on its composition (ie silica rich magma) granitic magma ; Basaltic magma (Fe - Mg rich with deficiency of silica).
The molten rock material emerges on to the surface as Lava. Volcanic activity involves eruptions with ejection of lava along with several volcanic gases.

Volcanic Hazards: Volcanic eruptions are hazardous and occur in many forms. The details are as follows:

<u>Volcanic gases:</u> When a volcano erupts, gases (water vapour; CO_2; SO_2; HCl; HF;
CO; H_2S) spreads into the atmosphere.

SO_2 contributes acid rain and CO_2 causes depletion of Ozone layer. Fluoride and Chloride gases contaminate water and may also cause skin irritation.

<u>Lava flows</u>: Lava flows, being hot, are very disastrous. Volcanic flows vary in their temperature between 200°C and 1000°C causing extensive burning of all the material they encounter. The volcanic flows follow stream valleys resulting floods in case of snow or ice terrains.

<u>Volcanic Fragments / ash</u> is also called as TEPHRA. If the fragments are < 2 mm, it will be called as VOLCANIC ASH whereas the large fragments are known as LAPILLI.

The volcanic ash spreads as a cloud covering enormous areas following the wind direction. The fine particles sometimes gets electrically charged causing for lightning. Volcanic ash causes breathing problems.

Lahars: Volcanic material mixed with water forms a slurry, similar to wet concrete mix. Lahars containing around 80% of the volcanic materials and destroy bridges and buildings.

Ground Subsidence: Movement of material vertically down is known as subsidence (or) Ground subsidence involves vertical collapse of ground. Sinking of the ground takes place due to underground presence of open spaces. Subsidence can be slow or relatively fast depending upon the type. Subsidence can be caused by natural or through human activities. Carbonate dissolution in the subsurface; underground mining; ground water withdrawal etc are some of the examples for subsidence.

Carbonate dissolution in the subsurface: This is common to limestone terrains. If the ground water is slightly acidic, it reacts with $CaCO_3$. In this reaction, the bicarbonate formed is soluble and is carried away by the underground circulating water.

Cavities or caverns are common in limestone formations. In the caves, the evidences of solution and the enrichment of carbonate ions in water can be seen from the formation of stalactites (hanging carbonate precipitate) from the leaking water on the cave roofs and also the growth of these deposits from the leaked water falling on the floor of the cave (stalagmites).

Underground mining: in coalmines, the subsidence of the ground is common due to collapse of the roof of the mine. During the mining, inadequate supports or excessive mining of coal results the roof collapse. In addition, underground fires taking place in some coal fields due ground subsidence. Eg: Jharia coal fields.

Groundwater withdrawal in the subsurface: Excessive withdrawal of groundwater from the subsurface results in subsidence. This process is known as hydro-compaction, usually which takes place by dewatering from the geological formations.

In oil and gas fields, withdrawal of the fluids (crude oil) also results in subsidence.

ARCH DAM in India(Idukki Dam): The 'Idukki Dam' - Asia's biggest Arch Dam of 555 feet height proudly standing between the two mountains - 'Kuravanmala' (839 meters) and 'Kurathimala' (925 meters) in Idukki district in Kerala. . This prestigeous project power House is located at Moolamattom which is about 43 kms away from Idukki.

The Idukki Dam was commissioned in 1976. This is India's first & only Arch Dam. This is also the second highest concrete dam in India. It has a thickness of 19.81 m, at the deepest foundation & 7.62 m at top.

The shape and the quality of rock at the deep gorge where this dam was built was immensely suitable to adopt the arch shape of the dam. The double curvature arch shape has resulted in an saving in concrete volume by 60 % as compared to a gravity dam of this height.

Reservoir

Principal sources of natural recharge include precipitation, stream flows, lakes etc whereas artificial recharge include excess irrigation water, seepage from canals. Reservoirs are the results of human attempts to make effective use of the run-off water which is otherwise going waste i.e., flowing into the sea. However, the reservoir basin should be of adequate water capacity to hold a large and desirable quantity of water to derive optimum benefit.

Geological investigations are carried out in advance to study the suitability of the site to serve as the reservoir.In addition, non- geological aspects such as

- Water tightness of the reservoir site
- The life of the reservoir (rate of silting)
- The capacity of the reservoir
- The area covered by the reservoir
- The effect of evaporation
- Possible submerge of economic minerals
- Submerge of fertile land, forests.
- Submerge of places of interest like temples and historical monuments.

Considerations for successful reservoir: In general, a reservoir can be claimed to be successful if it is **watertight** (doesn't suffer from any serious leakage of water) and if it has avery low rate of silting (long life of reservoir) in the reservoir basin. Of course, the reservoirs capacity is very important and it depends on the existing topography and the proposed top water level (TWL) of the reservoir.

(A) **Water- tightness and influencing factors:** As a consequence of weathering (due to natural process), the surface is covered by loose and below it lies the fractured rock and massive rock occurs further below.When a river flows over such loose soil or fractured ground, it is natural that some river water percolates into underground through cracks and may even cause for leakages. .

Before the construction of a reservoir, priority for leakage shall be considered as less or limited to some extent. When a dam is constructed, the accumulated water occupy in large quantities in a reservoir which cover a very large area. Due to the considerable height of the water in the reservoir, significant hydrostatic pressure develops which will make the leakage more effective on the sides and the floor of the reservoir through the cracks. .

Buried river channels which are more frequent in glaciated regions are a serious source of leakage when they occur at the reservoir site.Eg: A buried channel noticed in Tapoban dam site of river Dhauli Ganga which is a tributary of the river Alaknanda (U.P)

Water tightness of a reservoir basin is very much influenced by the kind of rocks that occur at the reservoir site. If the rocks are porous and permeable (i.e., aquifers) they will cause the leakage of water and hence such rocks are undesirable at the reservoir site.

The Influence of commonly occuring rock types at the reservoir site play also a majorrole:

Granite: will not cause leakage unless the presence of joints/faults.

Basalts: Not desirable because of presence of vesicles, cracks, fractures, joints etc... except if it is compact in nature .

Shales: shall not cause leakage due to fine grained and non permeable if compact

Sandstone: well cemented and compact sandstones will naturally be less porous and less permeable and hence cause less leakage.

Limestone:Undesirable but not so always. Compact limestone have negligible porosity may be suitable.

Conglomerate and Breccia cause leakage at the reservoir site.

Gneiss: will not cause.

Schists: Cause leakages due to the presence of soft and cleavage bearing minerals.

Quartzite: will not cause.

Marble: though compact not advisable by virtue of $CaCO_3$composition.

Slate: Cause leakage due to cleavages.

Influence of Geological structuressuch as folds, faults, joints, fractures have a significant influence in increasing the leakage through the rocks at the reservoir. Among the different structures, the bedding planes and fault planes are also represent planes of weakness and provide scope for leakage. Of course this depends on their attitude i.e., their Strike and Dip.

(B) **Reservoir Silting (Life of Reservoir):** The streams flowing through the catchment area into the reservoir carry sediments and in turn the sediments deposit in the reservoir. Silting of a reservoir is harmful and can cause the failure of the reservoir and the quantity of water stored gets reduced. Ofcourse, the life of the reservoir is based on the siltation rate.

If the rate of silting is very low, the life of the reservoir will be long and useful for a long period and proves worthy. The total volume of the silt likely to be deposited during the designed period of life of the reservoir /dam is therefore estimated and approximately that much volume is left unused to allow for silting and is known as **dead storage**. The remainder is known as **effective storage.** The dead storage is generally > ¼ of the total capacity.

For eg: Total capacity of a reservoir is estimated as 30 million cubic mts.

Estimated dead storage is 6 million cubic mts.

. Estimated average volume of sediment deposition is 0.15 m cu mts/year

Estimated dead storage in years is 6 / 0.15 = 40 years

Total storage of silt occupied in 30 / 0.15 = 200 years

Hence, after 200 years, the reservoir simply consists of **silt only** and **no water.**

UNIT – VI TUNNELS

Terminology

Tunnel: An underground passage for vehicles or pedestrians, especially one which is created by digging into earth.

Axis: The lengthwise course of a tunnel, especially along the center line.

Cross section : The shape of a tunnel for eg: horseshoe, round or square.

Excavation: The process of digging or the hole which results.

Muck: Debris removed during excavation.

Grouting: Unstable rock and soil is strengthened by the injection of chemicals, cementious materials .

Lining: Materials used to finish the inside surface of the tunnel.

Overburden : The soil and rock supported by the roof of a tunnel.

Portal: The open end of a tunnel. Usually includes a wall to retain the soil around the opening.

Adit: Main entrance location of a tunnel

Profile: A side view of the tunnel.

Shaft: A vertical, underground passage from the top to the bottom where there is initially no access to the bottom.

Tunnel Boring Machine (TBM): A tunneling machine which has cutting teeth at its front. It creates the tunnel opening while passing the waste material through the rear.

Ventilation: Circulation of fresh air is called as ventilation.

Tunnels are underground passages through hills or mountains used for several operations. Tunnels are made by excavation of rocks below the surface or through the hills.

Like other engineering structures, tunnels too need favourable geological conditions at their sites for achieving success. In case of tunnels also, success means safety, stability and economy.

To achieve these objectives, careful geological examinations should be made with reference to the rock types occurring at the site (lithology of rock-formations), structures associated with them and the prevailing ground water conditions.

The construction of underground tunnels, shafts and passageways are ofcourse essential but these are dangerous activities. Working under reduced light conditions, limited access; the exposure to air contaminants and the hazards of fire and explosion, underground construction workers face many dangers.

GEOTECHNICAL INVESTIGATIONS:A tunnel project must start with a comprehensive investigation of ground conditions by collecting samples from boreholes and by other geophysical techniques. Involvement of machinery and methods for excavation and ground support, which will reduce the risk of encountering unforeseen ground conditions.

PURPOSES OF TUNNELLING: Tunnels are constructed for several operations:

- **In mining practice**: Adits and shafts for reaching the work spots and for the transport of workers and materials.
- **In certain mines:** tunnels are made to extract coal from coal seams
- **In hydroelectric projects**:Diversion tunnels for channel diversion (by diverting the normal flow of river water through the tunnels) and for power generation.
- **For water supply and sewage disposal:** For supply of drinking water or sewage disposal purposes, tunnels are made.
- **Transportation**: to lay roads or railway tracks to regularize the traffic and transportation of goods.
- **For laying cables and service lines:** These are utility tunnels for laying cables and for transport of oil/gas through pipelines.
- **To reduce the distance:** To reduce the distance between places of interest across natural obstacles like hills, to save time and to provide conveyance.

  Eg (1) In Bihar, between Hazaribagh and Gaya the eastern railway passes through a number of tunnels across the hills of the Chota Nagapur Plateau.

  Eg (2) A number of tunnels of 1 km in length or less were driven in the Deccan Traps between Bombay and Pune railway line.

Eg (3) In Jammu and Kashmir, 2 parallel tunnels of 2440 mts long were made between Jammu and Srinagar in the Pir Panjal mountain range.

Eg (4):the undersea tunnels made between France and England and between some islands of Japan.

CLASSIFICATION OF TUNNELS:

Depending on the nature & competency of the ground, tunnels are classified as:

Hard rock tunnels: The tunnel alignment is essentially through competent rock mass with little or no ground water seepage.

Soft rock tunnels: The tunnel alignment is through unconsolidated or highly weathered material which always encounter the groundwater problems.

EFFECTS OF TUNNELLING: When tunnels are made through weak or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining may be in the form of steel structures or concrete.

- Due to heavy and repeated blasting during excavation of a tunnel, numerous cracks and fractures develop which reduces the compactness in rocks.In addition, rock become loose/more fractured which allow water movement .
- Lining of the tunnel helps in checking the leakage of groundwater into the tunnel.
- Fault zones and shear zones are naturally weak and tunneling through them further deteriorates and cause stability problem.
- Fall of rocks takes place even in hard rocks like granite though devoid of bedding or foliation and this process is known as **Popping.**
- Roof may collapse due to stress and strain of the region due to overburden.
- Poisonous gases encountered during the excavation of tunnels, sometimes.

ROAD TUNNELS IN INDIA:

Tunnel	Length	State	Notes
Rohtang	8 820 m	HP	Under the 3978 above msl high Rohtang pass on Manali - Leh road
Banihal	2 576 m	JK	Jammu - Kashmir road. 2209 m above sea level
Jawarhar	2 500 m	JK	Srinagar - Jammu
Kamshet-I	1 843 m	MH	Mumbai - Pune Expressway.
Bhatan	1 658 m	MH	Mumbai - Pune Expressway
Gokhale Nagar	1 000 m	MH	

Khambatki - Ghat	890 m	MH	
Madap	646 m	MH	Mumbai - Pune Expressway
Kamshet-II	359 m	MH	Mumbai - Pune Expressway
Khandala	330 m	MH	Mumbai - Pune Expressway.
Aodoshi	? m	MH	Mumbai - Pune Expressway. Only for Mumbai bound traffic

LINING OF TUNNELS: When tunnels are made through weak or loose or unconsolidated formations, they are provided with suitable lining for safety and stability.Lining may be in the form of steel structures or concrete.

The main purposes of lining are to resist the pressures from the surroundings (from the roof or the sides or the floor) and to protect the shape of the tunnel. Lining also helps in the leakage of ground water into the tunnel .Thus lining is a an effective remedial measure to overcome the various drawbacks resulting from underground tunneling either geologically or non-geologically.

Lining provides a regular shape to the tunnel as the excessive excavated portions (ie over break) are filled by concrete. Lining being a very expensive treatment, needs to be provided only at such places where the rocks are not capable of supporting themselves,., where the rocks are weak and likely to collapse.

Lining is also provided in such places where the seepage of water into the tunnel occurs and creates problems. The zones of faulting or shearing also need suitable lining to impart strength to them. Strong and complete lining is required in hydropower tunnels which carry water under great pressure and even minor leakages can prove hazardous.

GEOLOGICAL CONSIDERATIONS: Geological considerations of tunneling depend on various geological factors prevailing at the site. The geological considerations in a civil engineering project (ie tunneling) include

Lithology of rock formations;

Geological Structures and

Groundwater conditions.

1.LITHOLOGY OF ROCK FORMATIONS : Massive **Igneous rocks** (ie plutonic and hypabyssal rocks) are in general compact and competent and no lining is required for the tunnels designed.Volcanic igneous rocks being often vesicular, porous and permeable posses a threat of water seepage in the tunnel. However, sometimes, the vesicular character is also competent and suitable for tunneling.

Eg: 20 tunnels were excavatedfor Bombay–Delhi railway line through amygdaloidal / vesicular basalts.

Sedimentary rocks are less competent. However, sandstones with siliceous matrix may be considered .If the sandstones have carbonate or iron oxide as cementing material (poorly cemented), the tunnel lining needs reinforcement otherwise they are undesirable.

Eg: In the Himalayan Ramganga diversion tunnel, a poorly cemented sandstone formation, had caused a roof fall.

Limestones may expect seepage problems.Among limestones, dolomitic limestones are harder and more durable. On the other hand, calcareous limestones or porous limestones are naturally weaker, softer and are unsuitable for tunneling by virtue of their tendency to corrode.Shales are the lest competent because of the clay content. The presence of Clay layers are troublesome as they have low strength.

Among the **metamorphic rocks**, Quartzites and gneisses are massive and competent. Phyllites and Schists are problematic due to the presence of foliation and presence of susceptible minerals like mica and clay. Depending the orientation of cleavage of minerals in case of slates may be considered.Marbles are reasonably competent by virtue of their high compactness and granulose structure.. But their susceptibility to corrosion and softness necessitates lining.

GEOLOGICAL CONSIDERATIONS FOR EFFECTIVE TUNNELLING

Importance of Rock Types

SUITABILITY OF IGNEOUS ROCKS: Massive igneous rocks, i.e., the plutonic and hypabyssal varieties, are very competent butdifficult to work. They do not need any lining or any special maintenance. This is sobecause they are very strong, tough, hard, rigid, durable, impervious and, after tunneling,do not succumb to collapse, or to any other deformation.

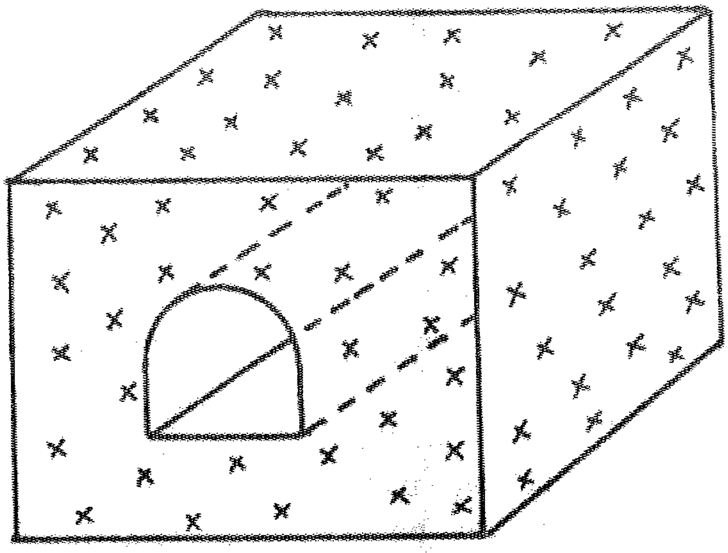


Fig. 20.1 Tunnel in igneous rocks

SUITABILITY OF SEDIMENTARY ROCKS: Thick bedded, well-cemented and siliceous or ferruginous sandstones are morecompetent and better suited for tunneling. They will be strong, easily workable and,moreover, do not require any lining. Thus they possess all the desirable qualities fortunneling, provided they are not affected adversely by any geological structures andground water conditions.

Poorly cemented or argillaceous sandstones, however, are weakand undesirable, particularly if they get saturated with water or are thin bedded.Shales, by virtue of their inherent weakness and lamination, may get badly shatteredduring blasting. Mudstones are weaker than shales as they are less compacted.

Among limestones, dolomitic limestones are harder and more durable. They are betterthan other varieties. On the other hand, calcareous limestones or porous limestones arenaturally weaker and softer.Conglomerates need not be considered seriously due to the presence of pebbles and unconsolidation.

SUITABILITY OF METAMORPHICROCKS: Metamorphic rocks such as gneisses are nearly similar to granites in terms of their competence,durability and workability. Schists, Phyllites, etc., which are highly foliated and generallysoft, are easily workable but necessarily require good lining.

Quartzites are very hard and hence very difficult to work. Marbles are reasonablycompetent by virtue of their high compactness and granulose structure. Slates are rathersoft and possess slaty cleavage. Hence they are weak and require lining.

(1) GEOLOGICAL STRUCTURES :

Strike and Dip orientation; Joints, Faults, Folds etc are the most common structural features associated with rocks.

If the tunnel alignment coincides with the strike of the formations, is acceptable if the formations are competent but in the case of less competent formations, the tunnel alignment should be a short span.

(A) Joints at the tunnel site: Closely spaced joints in all kinds of rocks are harmful (eg Koyna third stage tail tunnel has been excavated through a closely jointed basalt causing roof fall with heavy copious leakage of water).Joints which strike parallel to the tunnel axis for long distances are undesirable whereas the joints which are perpendicular to the tunnel axis have a limited effect.

In sedimentary rocks, the presence of joints may be due to folding (occur along crests and troughs) or faulting is undesirable.

In metamorphic rocks, such as granite gneisses and quartzites are competent even if the joints present due to their competent nature. Schists and Slates with joints will become very incompetent and require lining.

(B) Tunnels in Faulted Strata: Faults are harmful and undesirable because of the following problems:

Fault zones are places where the displacement of rocks occur and lead to discontinuity in the tunnel alignment. The fault zones are places of intense fracturing which means physical weakness in rock masses.Fault zones allow percolation of groundwater which may cause for collapse of walls. Eg: Koyna (Maharashtra state) third stage tunnel collapsed about 15 mts along a fault zone.

Fault zones are normally avoided along tunnel alignments. However, if they cannot be avoided, the fault zone has to be extensively treated with concrete grout and a strong lining has to be provided.

Problems are severe if the tunnel alignment coincides with the strike of the fault. If the tunnel is located in the foot wall of a fault, the roof portion of the tunnel becomes instability and needs reinforcement. In case of Hanging wall, less effect can be observed.

(C) Tunnels in Folded Strata: Folded rocks are always under considerable strain.When excavation for tunnels are made in folded rocks, such rocks get the opportunity to release the strain (stored energy). Such energy cause the rock falls or bulging. In folded regions, the tunnel alignment may be advisable to have the tunnel located on the limbs than at the core if possible.

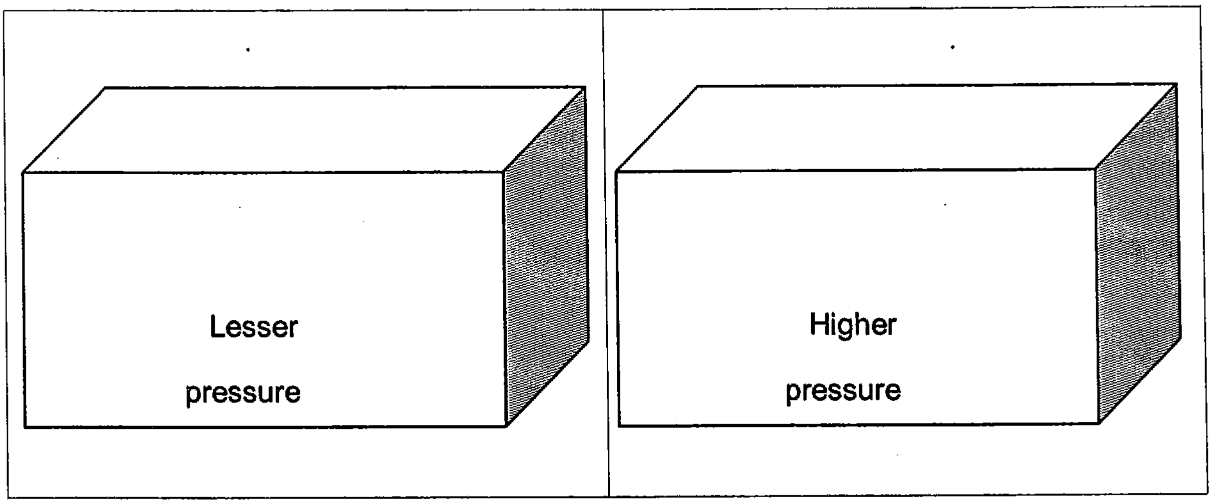
Tunnel alignment parallel to the axis of a fold: This is desirable when tunneling along limbs is considered. Rock masses may be in a highly fractured condition along crests, hence there may be frequent fall of rocks from the roof. Tunnels along troughs encounter harder formations and difficult to excavate. If bedding planes are inclined, groundwater percolates and these aquifers are punctured during the process of tunneling.

Tunnel alignment perpendicular to the axis of a fold: This is undesirable because different rock formations are encountered along the length of the tunnel due to heterogeneity in physical properties of rock.

In anticlinal fold, the central region will be under lesser pressure when compared to synclinal fold where the central region will be under higher pressure in addition to the occurrence of ground water.

However, anticlinal fold is to be considered for tunneling with proper precautions.

TUNNELS PERPENDICULAR TO THE AXIS OF FOLD



(2) GROUNDWATER CONDITIONS: Ground water problem in the tunneling is the most serious one. If ground water encountered in case of tunneling, the entire water is to be pumped out to keep the working area dry and adds the expenditure on tunneling project.

If the water table lies below the level of the tunnel, no severe ground water problem can be anticipated. But if the tunnel lies below the position of the water table , then the ground water problem is inevitable. .

TUNNEL SUPPORTS : Supports are used for keeping the tunnel walls and the roof in safety condition. Several support alternatives are available for use in tunnels. Following are the types of supports:

Shotcrete : Shotcrete is mortar or concrete pneumatically sprayed at high velocity through a hose. The process can be a dry process (Guniting) or a wet process.

Rock Bolts: These are steel bolts designed for holding weak formations together. The bolts are driven into the formations without causing any disturbance. These are used in tunneling for anchoring the tunnel walls to sold rock.

Wire mesh; Concrete lining; Pre-stressed anchor cables; Steel ribs etc are also used wherever is necessary.

Some of these types are used in combination also.

OVERBREAK: Excavations through hard rocks involves the removal of some of the rocks outside the proposed perimeter of the tunnel.

The quantity of rock removed, in excess of what is required by the perimeter of the proposed tunnel, is known as the over break.

The geological factors which govern the amount of overbreak are:

The nature of the rocks

The orientation and spacing of joints or weak zones

The orientation of the bedding planes in case sedimentary rocks.

In general, tunnels which pass through a single homogeneous formation without structural defects produce little overbreak, whereas tunnels which pass through a variety of rocks with structural defects (like fault zones) have more overbreak.

The factor of overbreak is important because it adds to the cost of tunneling, particularly if lining is required. Hence, it is desirable that over break should be as minimum as possible.

Bumping ground	Rock displacement and dislodging in tunneling rocks
Circular shape tunnel	Is adopted in case of diversion of water at dam site
Discharge tunnels	Tunnels are those which are meant ***for conveying water from one point to another*** under gravity force.
Diversion tunnels	By diverting the normal flow of river water through the tunnels dug along the valley sides
Fan cut blasting means	To get more face for the excavation of rocks
Hokoriku railway tunnel in Japan	Is 13.87 km through sandstones and granites.
Horse shoe shape tunnel;	Is adopted for old tunnel excavations
Joints oblique or perpendicular to the tunnel axis	Are obviously have a limited effect
Joints which are parallel to the tunnel axis	Are undesirable in all kinds of rocks.
OVER BREAK	The qty of rock broken and removed in excess of what is required by the perimeter of the proposed tunnel.
Parallel hole cut blasting means	Blast holes are placed parallel to each other with a RELIEF HOLE of a larger dimension

Popping effect in tunneling	It refers to the phenomenon of fall of rocks which takes place in hard rocks like granite devoid of bedding or foliation.
Pressure tunnels	Tunnels are those which are used to allow water to pass through them under force. ***Used for power generation***
Purpose of lining	Lining refers to the support for the tunnel.
Rock Bursts means	These occur at great depths with enormous overburden pressure
Smooth blasting means	Small holes are placed along the circumference of blasting area
Suitability of shales	Faster progress but proper lining is necessary
Suitability of gneisses & quartzites	Good in all aspects for tunneling
Suitability of Limestone & dolomitic limestones	Durable for tunneling purpose
Suitability of Mudstones	Weaker than shales and undesirable for tunneling.
Suitability of schists & Phyllites	In competent but require lining for tunneling
Suitability of Conglomerates for tunneling	Undesirable rocks
Suitability of igneous rocks	Very competent and lining is required
Suitability of well-cemented siliceous sandstone	Better suited for tunneling
RQD means	Rock Quality Designation means the ratio of cumulative length of rock pieces expressed as a percentage of total length of the rock
RSR	RSR means the rating of the quality of a rock for tunnel support recommendations.