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## HIGHER SECONDARY (+2)

# GEOLOGY

## (PART-II)

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# FOREWORD

The Odisha State Bureau of Textbook Preparation and Production has made a pioneering effort in publishing this textbook in Geology which is expected to meet the requirement of students in the subject. The Bureau has utilised the best talents available within the State in preparation of this Text.

The book is meant for the second year students of the +2 course. The first edition of the book was authored by Prof. Satyananda Acharya, Mr. Anil Kumar Paul, Mr. Premananda Ray, Prof. Hrushikesh Sahoo, Prof. Rabindra Nath Hota and reviewed by Prof. Satyananda Acharya. The book has been rewritten by Prof. Ghanashyam Lenka, Prof. Hrushikesh Sahoo, Prof. Rabindra Nath Hota, Prof. Shreerup Goswami, Dr. Sudhir Kumar Dash, Dr. Naba Kishore Sahoo and Dr. Manoj Kumar Pattanaik according to the latest revised syllabus of the Council of Higher Secondary Education, Odisha and gives a complete coverage of the subject matter.

I have every hope that the teachers and the students of Geology will find this book useful and fruitful. Constructive suggestions for the improvement of this book shall be highly appreciated.

**Umakanta Tripathy**
*Director*
**Odisha State Bureau of Textbook Preparation and Production**
Pustak Bhavan, Bhubaneswar

# PREFACE TO SECOND EDITION

Consequent upon changes in Higher Secondary syllabus, the course contents of the Bureau's Higher Secondary (+2) Geology Part – II has been modified with addition of Mineral deposits of Odisha in Economic Geology, Geological considerations of tunnel and Engineering properties of rocks in Engineering Geology and recasting of Stratigraphy and Structural Geology chapters. In addition, the existing course contents of some sections have been elaborated for better understanding by the students.

The Board of Writers hope that the Book of the Second Edition will cater to the need of the students of Geology of Odisha in general and Higher Secondary students in particular. Suggestions for further modification are invited from the readers for betterment of the Book.

**BOARD OF WRITERS**

# PREFACE TO FIRST EDITION

Geology is the science of the earth. It includes different aspects of the earth like its origin, age, and study of its materials. Study of the subject teaches us as to why earthquakes occur or why and how mountains form, what are fossils and economic minerals. Research in different directions takes the workers to enunciate the laws of the nature from its evolution up to the present stage.

It is, thus, a fascinating study and takes the students outside the class rooms to examine a river or spring, a bending of rock (folds) or its displacement resulting in a fault. It evolves as a natural science and a good part of the subject is learnt outside the four-walls; this is known as fieldwork. It has its laboratory wing as well.

The present textbook has been written by a group of teacher-geologists who are very experienced and are selected by the Bureau of Text Book Preparation and Production, Odisha based on the courses of studies for, Higher Secondary (+2) classes. Being a natural science, the subject is vast and they were almost forced to concisely write the parts given to them. Attempts have been made to bring the style of the language uniform and simple. Line diagrams are drawn and photographs are also added. More photographs will be planned for the reprint.

Sometimes a student may feel that more than the approved course materials have been pushed into the book. This has been done to improve their concept on those topics.

In spite of honest efforts, the authors might have failed at places and experts will please point them for a better reprint. These innovative feedbacks are needed for the quality betterment of the book which is desirable as it leads to a similar improvement of our students.

The Odisha State Bureau of Text Book Preparation and Production has conceived to print the book and constant support for completion of the book has been made. The authors are thankful to the members of the staff of the Bureau for their full co-operation.

Explicitly the scope of each sub-discipline id delimited by the syllabus provided in different sub-sections prescribed for +2 Second year course. As a matter of fact, the actual scope of each write up in particular, is confined to the very basics and preliminaries of the sub-disciplines.

We hope this book will attract students to choose geology as their professional subject in future. Study of this subject is fascinating and invigorating.

**Prof. S. Acharya**
**Reviewer**

# CONTENTS

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# CHAPTER - 1

# IGNEOUS PETROLOGY



## 1.1. DEFINITION

Petrology is the science of rocks. It is derived from two Greek words i.e. „Petra" - means rock and „Logus" – means science or discourse. Rock is the fundamental unit of the earth"s crust. They are defined as the aggregate of minerals or minerals and glass. They constitute the materials of the earth"s crust. The petrology is the branch of science that deals with the study of occurrence, description and origin of the rocks. The descriptive part is petrography and the origin of rocks is petrogenesis. In petrography, the modes of occurrence; the texture and structure, the chemistry and the mineral compositions are described. In this case the megascopic and microscopic descriptions of the rocks are done.

Before solidification, the earth passed through a molten stage and the first formed rocks must have been derived from a molten melt known as magma. By partial or complete melting of rocks in the lower crust or in the upper mantle, magma or a molten melt is also produced. These melts are primary in nature and the rocks formed from such melts by crystallisation are considered as primary or *igneous* rocks.

Once formed, primary rocks are affected by weathering triggered by agents. The disintegrated loose materials are eroded and transported by the agents and are ultimately deposited elsewhere, especially in the depressions (sea or ocean). The soluble materials are also precipitated out after their saturation limit. The rocks, thus, produced are bounded and solidified by the cementing material and form parts of the crust. The process of formation of this kind of rocks has been taking place throughout the geologic time after the formation of the lithosphere, hydrosphere and the atmosphere. As they are formed later than the primary rocks and in many instances are composed of new and secondary minerals, they are termed as secondary rocks. They are of different types. (i) Sedimentary (rocks formed from the sediments), (ii) Chemical (formed by chemical precipitation) and (iii) Organic (formed by precipitates due to organic activity). Chemical and organic secondary rocks are also termed as biochemical precipitates.

Both the Primary and Secondary rocks are affected by the earth movements by which they go down to lower depths of the earth‟s crust much beneath the zones of cementation and weathering. Here, they are subjected to different temperature and pressure conditions than that existed at the time of origin of these rocks. Due to this higher temperature and pressure conditions, the minerals of the rocks are recrystallised and chemically reconstituted because of the new environment of pressure and temperature conditions. These rocks are structurally re-arranged as most of the original characters are partly or completely obliterated. New characters are imposed upon them and some new minerals are formed. They are termed as metamorphic rocks.

All the rocks of the earth‟s crust are, thus, classified broadly into three divisions according to their mode of formation. The primary or igneous rocks are characterized by crystalline minerals or glass with interlocking texture. These are massive, commonly unstratified and unfossiliferrous. They show the characters of rocks that are solidified from the volcanic lava or liquid melt.

The secondary rocks are composed of clastic grains and / or chemical precipitates. The loose materials are bound together by cementing materials. They are commonly bedded with certain structures like parallel bedding, current bedding, ripple marks and many others. They are fossiliferous, if formed during or after the Cambrian period.

The metamorphic rocks are characterised by certain characters which are inherited from the parent sedimentary or igneous rocks. They consist of interlocking crystals which are recrystallised due to high temperature and pressure. During recrystallisation, they show some sort of planar structures formed by the preferred direction of orientation (by pressure) of new minerals. The organic matter is first spotted and later gets crystallized at high temperature. Most of the original characters are obliterated.

## 1.2. COMPOSITION AND CONSTITUTION OF THE LITHOSPHERE

The lithosphere consists of a thin layer of rocky crust and is composed of the above three kinds of rocks. Rocks are aggregates of minerals, mainly the rock forming minerals like silicates, oxides, carbonates, sulphides, sulphates, phosphates and others. The important silicates are feldspars, micas, pyroxenes, amphiboles, olivines, chlorite, serpentine, epidote, andalusite, kyanite, sillimanite, cordierite, staurolite etc. The oxides are mainly quartz, hematite, magnetite, ilmenite etc. Other important minerals are calcite, dolomite, apatite, pyrite, gypsum, barite and halite. Chemically, the crust is mainly composed of elements like oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium, titanium, phosphorous, manganese, sulphur and barium which together constitute more than 99.5% of the earth‟s crust.

## 1.3. IGNEOUS ROCKS

Igneous rocks are those which are derived from the molten rock material - the magma. The original primitive liquid which solidified to form the earth‟s crust is the primary magma. Besides, the rock materials of the lower crust or the upper mantle are partially or completely melted from time to time to give rise to the magma. These are also considered as primary magmas. Secondary magmas are derived from the primary magmas. Lavas that are erupted through the volcanic vents mostly represent the magma excepting some volatiles. Though almost all the elements are present in the igneous rocks, yet only a few elements like O, Si, Al, Fe, Ca, Na, K, Mg, Ti, P, H and Mn constitute nearly 99.5% of the mass. Among these, oxygen and silicon are the most abundant elements. For this reason, the silicates, silica and a few other oxides are the chief constituents of igneous rocks.

## 1.4. CLASSIFICATION OF IGNEOUS ROCKS

Igneous rocks show great diversity in their characters. They show much variation in their texture, structure, chemical and mineralogical compositions and association with each other. For this reason, their classification poses a problem. They are classified in a number of ways. For simplicity and field identification, a classification based on mineral composition is suitable. However, a genetic classification based on the modes of origin is always the best. Many authors tried to classify them and have given their modes of classification. Cross, Iddings, Pirsson and Washington (CIPW) devised a scheme of classification based on the chemical composition and formation of minerals (normative minerals). This is known as CIPW classification.

The igneous rocks occur chiefly in two modes. They are erupted through volcanic vents and fissures through which molten material, the lava flows out from beneath the earth‟s surface. They erupt in two different ways. One is cone and crater type of volcanic vents in which the lava erupts through a circular pit known as crater, forming lava cones. In the other case, the lava erupts through large fractures known as fissures. After the lava erupts, it immediately solidifies forming “volcanic rocks”. These are fine-grained or glassy due to sudden cooling under low pressure. They show flow forms and other characters of the volcanic rocks. When the magma does not get any fracture or fissure to come out to the earth‟s surface, it makes its own way within the crust and at times intrudes forcefully, slowly cools down and ultimately gets solidified under great pressure. Because of slow cooling, the rocks are coarse-grained. They occur at great depths of the crust and hence are deep-seated igneous rocks. These are called "plutonic igneous rocks". Sometimes, the magma comes nearer to the earth"s surface through fractures, but does not get any path to come to the surface and intrudes forcefully. Magma cools down and form near-seated intrusive bodies under low to moderate pressure conditions. Under these conditions, magma solidifies to give rise to medium-grained "hypabyssal igneous rocks".

Thus, based on the depth of cooling (either at depth or at the surface) the igneous rocks are classified into three categories viz. *plutonic, hypabyssal* and *volcanic* which are coarse-grained, medium-grained and fine-grained respectively.

Tyrrell attempted a simpler mode of classification suitable for the students, teachers and field geologists. He arranged the igneous rocks in a tabular form basing on the mode of formation and silica percentage, which is popularly known as Tyrrell"s tabular classification (Table 1.1)

## 1.5. FORMS OF IGNEOUS ROCKS

The magma solidifies to give rise to the igneous rocks. The examples are the lavas that erupt on the surface forming lava flows and are known as extrusive forms. The other igneous rocks intrude into the crust. They are intrusive or injected rocks. Their shapes are mostly controlled by the structures of the country rocks into which they intrude at a great force. Two main types of country rocks can be distinguished, one in which the rocks are nearly horizontal to sub-horizontal almost unaffected by folding; the other where the rocks are affected by folding and faulting.

Another factor which controls the shape of the igneous bodies is their behaviour with respect to the bedding planes of the country rocks. When the intrusive body remains parallel to the bedding plane, they are termed as *concordant* forms of igneous rocks. On the other hand, when the intrusive bodies

Table 1.1. Simplified classification of igneous rocks

<table>
<tr><th colspan="2"></th><th colspan="3">OVERSATURATED</th><th colspan="3">SATURATED</th><th colspan="3">UNDERSATURATED</th></tr>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">I<br>Quartz</th><th colspan="2">II<br>QUARTZ + FELDSPAR</th><th colspan="3">III<br>FELDSPAR</th><th rowspan="2">IV<br>FELDSPARS<br>+<br>FELDSPATHOIDS</th><th rowspan="2">V<br>FELDSPATHOIDS</th><th rowspan="2">VI<br>MAFIC<br>MINERALS<br>PREDOMINANT</th></tr>
<tr><th>Orthoclase Predominant</th><th>Plagioclase Predominant</th><th>Alkali-feldspar (Or, Ab) Predominant</th><th>Soda-lime plagioclase predominant</th><th>Lime-soda plagioclase predominant</th></tr>
<tr><td rowspan="3">PLUTONIC</td><td>Felsic</td><td>Igneous quartz veins (Arizonite, Silexite)</td><td>Granite</td><td>Granodiorite (Tonalite)</td><td>Syenite</td><td>Diorite</td><td>Anorthosite</td><td>Nepheline-syenite</td><td>X</td><td>X</td></tr>
<tr><td>Mafelsic</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>Gabbro</td><td>Theralite and Teschenite</td><td>Ijolite</td><td>X</td></tr>
<tr><td>Mafic</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>Peridotite<br>Picrite</td></tr>
<tr><td rowspan="5" colspan="2">HYPABYSSAL</td><td></td><td colspan="7">← Aplites →</td><td></td></tr>
<tr><td></td><td colspan="8">← Porphyries →</td></tr>
<tr><td></td><td></td><td colspan="7">← Lamprophyres →</td></tr>
<tr><td></td><td>Granophyre<br>Felsite</td><td></td><td></td><td></td><td>Dolerite</td><td>Tinguaite</td><td></td><td></td></tr>
<tr><td></td><td colspan="5">← Pitchstone →</td><td>Tachylyte</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3" colspan="2">VOLCANIC</td><td></td><td>Rhyolite</td><td>Dacite</td><td>Trachyte</td><td>Andesite</td><td>Basalt</td><td>Phonolite</td><td>Leucitophyre</td><td>Olivine-rich basalts</td></tr>
<tr><td></td><td colspan="5">← Pitchstone →</td><td>Tachylyte</td><td></td><td>Nepheline-basalt<br>Leucite-basalt</td><td>Limburgite</td></tr>
<tr><td></td><td colspan="2">← Obsidian →</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Average silica percentage</td><td>90</td><td>72</td><td>66</td><td>59</td><td>57</td><td>48</td><td>45.5</td><td>43</td><td>41</td></tr>
</table>

cut across the bedding plane and are transgressive in nature, they are termed as *discordant* forms.

### 1.5.1. Concordant forms

**(i) Sill:** This is a sheet like body (Fig. 1.1) parallel to the bedding plane and, thus, is concordant in nature. The thickness varies from a few centimeters to even hundreds of meters and extends even for tens of kilometers in length resulting in lenticular forms. They are near-seated or hypabyssal intrusive bodies. They occur in groups and may be fed by transgressive *dikes (dykes).*

The best example of sills is that of Karroo dolerites of South Africa. In India, sills are found in Deccan plateau, Rajahmundry area and in the Himalayan region. Satpura sill is one such good example. In Odisha, sills are found in Keonjhar and Mayurbhanj districts. Amjori sill in Similipal area is a good example.

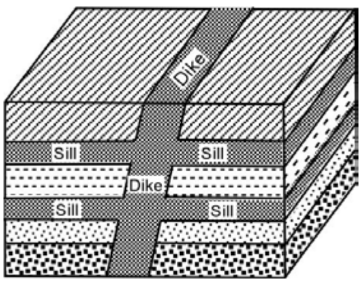


**Fig. 1.1: Sill and dike**

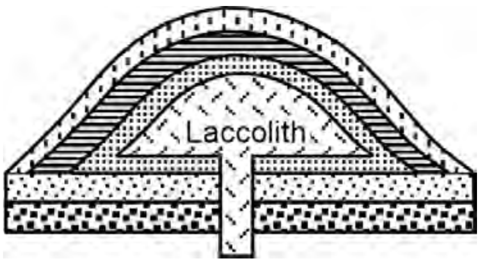


**Fig. 1.2: Laccolith**

**(ii) Laccolith:** It is a concordant igneous intrusive body. When the magma is more viscous, it cannot spread very far and pushes the country rocks upward, uplifts them, thus, forming a bun-shaped or inverted bowl shaped (Fig. 1.2) mass of magmatic rock. Commonly, the base is flat and the roof is dome shaped.

*Laccoliths* are fed by sills or may be fed by slender pipe or conduit. In India, Mt. Girnar complex is a good example of laccolith.

**(iii) Lopolith:** These are bowl-shaped or basin-shaped concordant intrusive bodies with flat top and a sunken or saucer like base (Fig. 1.3). They are lenticular and are enormously large in dimension. The thickness is much small in comparison to the diameter.

The great Bushveld complex of South Africa and Sudbury complex of Canada are good examples of Lopoliths. Sittampundi complex of South India is of this type.

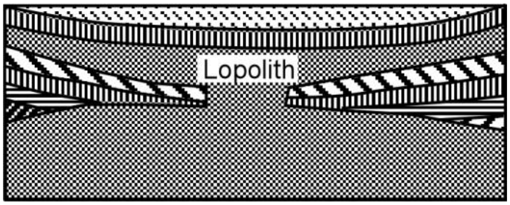


**Fig. 1.3: Lopolith**

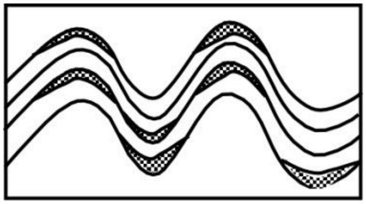

**Fig. 1.4: Phaccolith**

**(iv) Phaccolith:** These are concordant igneous intrusives in folded regions. In the folds, the antiformal and synformal hinges are the weaker zones. Magmatic intrusion takes place commonly in these regions and form lens-shaped intrusive bodies (Fig. 1.4). Phaccolithic intrusions are found in Rajsthan.

### 1.5.2. Discordant Forms

**(i) Dike:** Dikes are hypabyssal type of discordant intrusions which cut across the bedding or foliation planes (Fig. 1.1). They intrude into the country rocks forcefully along fissures, fractures, cracks, joints, faults. Thickness varies from a few centimeters to hundreds of meters and in length varies from few metres to tens of kilometres. The basic magma being more mobile shows this type of form. In most cases, they occur in groups and are known as *dike* swarms. Sometimes, they show ring like forms known as *ring dikes.*

Dikes exist plentily throughout the globe. In India, they occur in almost all the states and are numerous in Deccan trap area. In Odisha, dikes occur in large numbers in Iron Ore Supergroup of rocks and Singhbhum granite in Keonjhar, Mayurbhanj districts and at many other places.

**(ii) Batholith:** Batholiths are the largest magmatic bodies known. Some batholiths cover over thousands of square kilometers area on the surface and are assumed to be of at least 10 kilometres depth (the volume is imaginable). Some of them extend to still greater depth. Commonly, they show low transgressive relationship with the country rocks (Fig. 1.5) and occur in orogenic belts. In parts of the roof of the batholiths, masses of older country rocks project downward which are termed as roof pendants. Smaller sized batholiths, with less than 100 square kilometres surface area, are known as *stocks* (S), if irregular in shape and *bosses* (B) if circular. Origin and emplacement of batholiths are usually difficult to explain. Batholiths are commonly of granite or granodiorite in composition. Singhbhum granite, Bundelkhand granite, Mt. Abu granite and many others are examples of batholith.

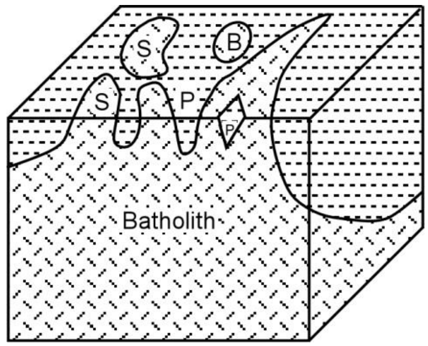


**Fig. 1.5: Batholith, stock (S) and boss (B)**

## 1.6. TEXTURE AND STRUCTURE OF IGNEOUS ROCKS

Texture is defined as the intimate mutual relationship between the minerals or minerals and glassy matter in a rock. Structure of the igneous rocks includes certain large scale features. Some small scale features formed due to juxtaposition of textural aggregates are called *microstructures.* Textures and microstructures are best studied under microscopes. Magma crystallises giving rise to minerals or glass. The style of cooling of the magma is responsible for the formation of different textures and microstructures. For this reason, the textures and microstructures speak on the cooling history of the magma. That is why, the study of textures and structures are important in magma genesis.

### 1.6.1. Texture of Igneous Rocks

Texture is studied in four different ways: (1) the degree of crystallization or crystallinity (2) the size of crystals or *granularity,* (3) the shape of the crystals and (4) the mutual relationship between crystals or crystals and glassy matter.

**(i) Crystallinity:** Cooling of magma forms crystals or crystals and glass. A rock is said to be *holocrystalline* when it consists entirely of crystals; *holohyalline* when consists entirely of glass and *meso-, hypo- or hemicrystalline* when consists of both crystals and glass. Plutonic rocks form by slow cooling, hence are *holocrystalline.* Some hypabyssal and some volcanic rocks are *mesocrystalline.* Holohyalline texture is seen in case of sudden cooling of lavas, especially at the upper and lower surfaces of the lava flows and at the bases and sides of sills and dikes. Slow cooling and low viscosity of the magma favour the formation of crystals. In some sills and dikes of basaltic magma, the sides are *glassy,* the intermediate part is *mesocrystalline* and the central part is *holocrystalline.* Even in the natural glasses, beginning of crystallisation takes place in form of *crystallites* and *microlites* with little heat and pressure. Solutions tend to favour the formation of fibrous *cryptocystalline* matter. This transformation of glass to crystalline material is known as *devitrification* and the resulting texture is called *felsitic* texture.

**(ii) Granularity:** The size of the crystals in igneous rocks varies greatly from submicroscopic as in case of some obsidians or tachylytes to even very large crystals weighing some tons as in pegmatites. It depends upon the rate of cooling and viscosity of the magma. If the crystals are visible and identifiable in the naked eye or with the help of a pocket lens, then the rock is said to be *phaneric* or *phanerocrystalline.* On the other hand, if the individual crystals are not identifiable then rock is *aphanitic.* The *aphanitic* rocks may be *merocrystalline, microcrystalline* or *cryptocrystalline.* The *phaneric* rocks are further divided into coarse-, medium- and fine-grained with average diameters of the grains more than 5 mm, 5-1 mm and less than 1 mm respectively.

**(iii) Shape of the Crystals:** The *shape* of the crystals depends upon the development of faces and forms. When the faces are perfectly developed, it is said to be *euhedral,* if imperfectly or partly developed it is *subhedral* and when faces are absent or underdeveloped, the shape is *anhedral.* Commonly, early formed minerals tend to be euhedral because of free growth and availability of material and the later formed minerals become anhedral due to space constraint. In the intermediate stage *subhedral* minerals are formed.

The minerals may be equidimensional that is equally developed in all the three directions; tabular, when developed in two directions and prismatic when well developed in one direction. Other minerals are said to be irregular in habit.

**(iv) Mutual Relationship:** Mutual relationship of the crystals along with shape is termed as the *fabric* or *pattern* of the igneous rocks. The relationship is of four types: (i) *equigranular,* (ii) *inequigranular,* (iii) *directive* and (iv) *intergrowth*.
When the individual minerals are almost of equal size, the texture is *equigranular*. If the rock is holocrystalline, coarse-grained with euhedral crystals, the texture is *panidiomorphic* as in case of some lamprophyres, equigranular texture with

subhedral crystals, is known as *hypidiomorphic* or granitic, (Fig. 1.6) where as predominance of anhedral crystals make the fabric *allotriomorphic*. In holocrystalline rock with medium size equigranular grains, the texture is *microgranitic*. Similar kind of texture in case of microcrystalline or cryptocrystalline rocks is known as *felsitic*. Most volcanic and hypabyssal rocks and in case of a few plutonic rocks the size of minerals vary in such a manner that inequality in grain size is well marked. This type of texture is termed as *inequigranular*. Two important types of inequigranular texture are well marked. In one case, large grains or *phenocrysts* are surrounded by fine grained crystals or glass, known as *groundmass*. This type of texture is known as *porphyritic* (Fig. 1.7), which is characteristic of basalt and other volcanic and a few hypabyssal rocks. The reverse of the porphyritic texture is *poikilitic* in which smaller crystals are enclosed within larger grains or *phenocrysts*. A special type of poikilitic texture is known as *ophitic* texture (Fig. 1.8), in which tiny crystals or laths of plagioclases are enclosed within big plates of augite or clinopyroxene. This type of texture is characteristic of dolerites. When the enclosure is partial, the texture is termed as *subophitic*. Two other types of inequigranular textures are *intergranular* and *intersertal*; in which cases the triangular spaces between laths of plagioclases are filled in by tiny granular minerals or glass respectively.

**Fig. 1.6: Hypidiomorphic texture**

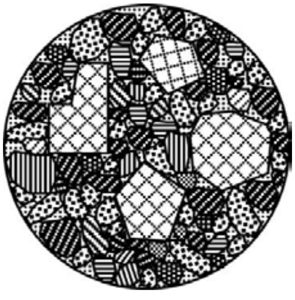

**Fig. 1.7: Porphyritic texture**

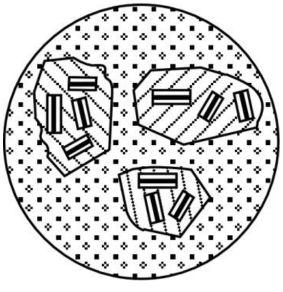

**Fig. 1.8: Ophitic texture**

During flowage of the magma, *crystallites, microlites* or the crystals are oriented parallel to the flow direction. In some volcanic rocks, especially trachytes, feldspar laths are oriented parallel to the flow direction and the resulting texture is known as *trachytic.* In some syenites, large crystals of feldspar and mica show preferred orientation, giving rise to *trachytoid* texture.

Certain minerals crystallise simultaneously during cooling of the magma giving rise to intergrowth type of relationship known as *intergrowth* texture. The intergrowth between quartz and orthoclase is known as *graphic* texture, which is characteristic of some granites and pegmatites. Imperfectly developed graphic texture is known as granophyric which is characteristic of granophyres. The intergrowth between orthoclase or microcline with albite or oligoclase gives rise to *perthitic* texture which again has different types in detail.

### 1.6.2. Structures of Igneous Rocks

Structure of igneous rocks includes large scale features megascopically visible as well as small scale structures produced due to juxtaposition of some textural aggregates.

**(i) Large scale structures:** When the lava erupts to the surface, the gases and volatiles present in the lava escape through *cavities, vesicles* and *bubbles* giving rise to *vesicular* structure. *Pumice* is produced at the extreme stage of vesiculation. Later on, the vesicles are filled in with secondary minerals known as *amygdules.* Lava rocks with amygdules form *amygdaloidal* structure. More viscous lava does not spread very far and is heaped up around the orifice. Its surface is covered with rough, angular clinkers. This type of lava is termed as *blocky lava.* In some cases, lava solidifies with a smooth surface and may form low domes. This type of lava is termed as *ropy lava.* A peculiar type of structure is produced in more mobile basaltic lava when it comes in contact with sea water, ice-sheets or water logged sediments. The consolidated rock show pillow like forms with smooth surfaces known as *pillow* structure. During flow, certain *layering* feature is formed due to parallel alignment of crystallites, microlites and cryptocrystalline materials, besides, variation in composition, giving rise to layering. The resulting structure is known as *flow* structure.

In case of most of the igneous rocks, the cooling of the mass brings about the development of a few sets of vertical joints. Here the cooling first starts around some centres. Tension due to shrinkage of lava between two adjacent centres of cooling results the development of interconnected vertical joints, dividing the entire rock mass into numerous vertical columns which may be square, rectangular, rhombic, trigonal or hexagonal in outline. Close spaced jointing gives rise to sheet structure. In case of some plutonic rocks, especially granites, three sets of perpendicular joints are seen of which one is horizontal and other two vertical. This is known as mural jointing.

**(ii) Small scale structures:** During crystallisation, reaction between the early formed crystals or foreign materials and the magma also takes place. If the reaction is incomplete, a rim of new mineral is formed around the first one forming *reaction rim. Corona* is one such type of reaction rim in which olivine is surrounded by a rim of pyroxene. *Zoning* in plagioclase is a similar feature. In some plutonic rocks, ball-like segregations with concentric shells of varying mineral composition occur. These are known as *orbicular* structure and are seen in some diorites and granites. In some acid volcanic rocks, fibrous minerals develop from a common centre with *radiating* needles which is known as *spherulitic* structure. Some glassy volcanic rocks develop concentric cracks after cooling. These are known as *perlitic* cracks produced by contraction during cooling.

## 1.7. PETROGRAPHY

Petrography is the megascopic and microscopic description of the rocks. The texture, mineralogy and mode of occurrence of some igneous rocks are described below:

### 1.7.1. Granite

**(i) Introduction:** Granite is a leucocratic, coarse-grained plutonic igneous rock. It is the most abundant of all plutonic rocks on the earth surface and commonly occurs in form of batholiths, stocks or bosses.

**(ii) Texture:** Most of the granites are coarse-grained, subhedral and show hypidiomorphic or granitic texture. There are also granites with porphyritic texture. At times, the rock shows graphic intergrowth of quartz and feldspar.

**(iii) Mineralogy:** The essential minerals of granite are feldspars and quartz. Orthoclase, microcline, albite and oligoclase are the common feldspars. The accessory minerals are muscovite, biotite, hornblende and rarely apatite, zircon, sphene and magnetite.

Granodiorite is a granitoid rock where alkali feldspar is subordinate to plagioclase and there is appreciable quantity of mafic minerals like biotite, hornblende and pyroxene.

**(iv) Mode of occurrence:** Granites occur exclusively as intrusive bodies and may occur in almost in any form like dykes, sills, plugs and bosses. The largest masses of granites are, however, batholiths.

**(v) Example:** In India granite and granitoid rocks are very common. They occur mostly in Precambrian belts as core-batholiths in the Himalayas. Singhbhum granite of Jharkhand and Odisha is a huge body of batholithic dimension with several varieties. The other important granites are Bundelkhand granite, Mount

Abu granite, Chittradurga granite and Erinpura granite. In Odisha, besides Singhbhum granite, other granite bodies are Mayurbhanj granite, Nilgiri granite, Bonai granite, Kuilapal granite etc.

### 1.7.2. Pegmatite

**(i) Introduction:** Pegmatite is a hollocrystalline, very coarse-grained acid igneous rock. Some of the constituent minerals are so large that they may weigh up to hundreds of kilograms and extend up to a few metres in length. The rock is supposed to be a residual hydrothermal product derived from a magma.

**(ii) Texture:** Texturally, the minerals are very large in size and interlocked. Such coarse-grained texture is called pegmatitic or pegmatoid. Graphic texture is also often seen.

**(iii) Mineralogy:** Most of the acid pegmatites are similar to granite chemically and mineralogically. A few are syenitic and dioritic in composition. Quartz, microcline, albite, oligoclase with or without muscovite, biotite and hornblende are the chief minerals. Other minerals are ilmenite, tourmaline, columbite, tantalite, garnet, topaz, beryl, apatite, epidote, zircon, corundum etc. Many of them like garnet, beryl, corundum occur as very large crystals.

**(iv) Mode of occurrence:** The peculiar grain size and mineral composition suggests that pegmatites are formed as products of solidification of final magmatic residue which are especially rich in volatile constituents. These are mainly aqueous in character and are concentrated with rarer and more volatile constituents. These are injected into solidified and cracked margins of plutonic mass and into the surrounding country rocks. In this way, pegmatites occur as veins, sheets, dykes or in the form of lensoidal bodies.

**(v) Example:** In India, pegmatites occur abundantly in the Peninsula. The Bihar, Rajsthan and Nellor mica belts are three major mica bearing pegmatite belts of

India. In Odisha, pegmatites occur in granitic terrains and in the Eastern Ghats Supergroup of rocks.

### 1.7.3. Syenite

**(i) Introduction:** These are leucocratic plutonic igneous rocks.

**(ii) Texture:** Syenites are holocrystalline, coarse-grained and show hypidiomorphic or granitoid texture. In some varities perthitic texture is also seen.

**(iii) Mineralogy:** Alkali feldspar, particularly potash-feldspars are the essential mineral of syenite. When quartz percentage decreases to less than 12%, granite grades to syenite. Similarly, when alkali feldspars decrease and plagioclases increase syenite grades to diorite or gabbro. Orthoclase, microcline, anorthoclase are the chief constituents of syenite with albite and oligoclase in subordinate amounts. The accessory minerals are biotite and hornblende.

**(iv) Mode of occurrence:** Syenites occur as veins, apophyses, dykes and as differentiated products of granites, diorites, alkaline and basic igneous rocks.

**(v) Examples:** Syenites occur in Bastar, Chhatishgarh and Mount Girnar in Rajsthan and as minor differentiated bodies at many places in India. With less silica, it is regarded as nepheline syenite (Koraput of Odisha and Kishangarh of Rajsthan).

### 1.7.4. Diorite

**(i) Introduction:** It is leucocratic to mesocratic plutonic igneous rock and is the plutonic equivalent of andesite. It belongs to intermediate silica saturated group.

**(ii) Texture:** A typical diorite is holocrystalline, coarse-grained igneous rock having hypidiomorphic or granitoid texture. Rarely it exhibits poikilitic texture where large hornblende crystals enclose numerous laths of plagioclase. Some diorites show orbicular structure.

**(iii) Mineralogy:** The essential minerals of diorite are plagioclase of andesinic composition, microcline and hornblende. When the potash-feldspar and quartz percentages decrease and plagioclase and amphibole percentage increase, granites grade to diorites. Similarly, syenite grades to diorite. The accessory minerals of diorite are quartz, orthoclase, biotite, pyroxene (clino pyroxene), apatite, zircon, garnet etc.

**(iv) Mode of occurrence:** Diorite occurs as differentiate product of granite-granodiorite batholiths. It also occurs as marginal bodies associated with syenite, gabbro etc.

**(v) Examples:** In India diorite is found associated with Singhbhum granite and also occurs in Girnar Mountain, Gujrat in association with Deccan lavas. In Odisha, diorite occurs as differentiated bodies in association with Singhbhum granite.

### 1.7.5. Gabbro

**(i) Introduction:** Gabbro is a dark coloured or melanocratic plutonic igneous rock. It is the plutonic equivalent of basalt.

**(ii) Texture:** It is holocrystalline, coarse-grained and shows hypidiomorphic texture.

**(iii) Mineralogy:** The essential mineras of gabbro are plagioclase of labradoritic composition and clinopyroxene like diopside, augite and pigeonite. Orthopyroxene, olivine and opaque ores are common accessories. Other possible accessories are biotite, garnet, apatite, rutile, zircon and spinel.

**(iv) Mode of occurrence:** Gabbro occurs as minor intrusive bodies like laccolith, lopolith and lensoidal form.

**(v) Examples:** In India, gabbro occurs associated with other basic and ultrabasic rocks. In Sittampundi igneous complex of Tamilnadu gabbro is found to be associated with anorthosite and norite. In Odisha, it occurs in Similipal, Baula - Nausahi, Sukinda, Koraput and many other places.

### 1.7.6. Peridotite

**(i) Introduction:** Peridotite is the most widespread member of the ultrabasic group of igneous rocks. It is dark coloured (melanocratic) and plutonic in origin.

**(ii) Texture:** Peridotite is holocrystalline, coarse-grained and shows hypidiomorphic or granitic texture.

**(iii) Mineralogy:** The essential minerals are olivine, ortho- and clino-pyroxenes. The accessory minerals are hornblende, biotite, garnet and opaque minerals. Olivine and/or ortho-pyroxenes alter to serpentine which is invariably present in this rock.

**(iv) Mode of occurrence:** Peridotite is found either as a layered body occurring as the bottom member of many layered complexes in association with gabbro, anorthosite and norite (Bushveld, South Africa and Sittampundi, India). It also occurs as minor intrusive bodies like laccoliths, lopoliths and lensoidal bodies.

**(v) Examples:** In India, peridotites occur in Precambrian terrains and in the Himalayas. In Odisha, it occurs in Similipal, Sukinda, Baula-Nausahi and along the periphery of the Iron Ore Supergroup.

Chromite ore bodies are associated with peridotite. Diamond bearing peridotites are known as kimberlites.

### 1.7.8. Dolerite

**(i) Introduction:** It is a mesocratic, medium-grained igneous rock and is the hypabyssal equivalent of gabbro and basalt. It is commonly saturated with silica.

**(ii) Texture:** Dolerite shows a number of textures but the characteristic texture is ophitic or subophitic. Other common textures are porphyritic, poikilitic, intergranular, equigranular and microgranitic.

**(iii) Mineralogy:** Mineralogy of the dolerite is similar to gabbros and basalts. The essential minerals are plagioclase of labradoritic composition and clinopyroxenes like augite, diopside or pigeonite. Common accessories are orthopyroxenes, olivine and opaque ore minerals. Hornblende and quartz may occur as minor accessory minerals.

**(iv) Mode of occurrence:** Dolerite occurs as differentiated product in the form of laccolith, lopolith and phacolith. The most common occurrence is in form of dykes and sills.

**(v) Examples:** Dolerite is a very common rock throughout the globe. In India, profuse dolerite dykes are found cutting the rocks of Archean, proterozoic and Gondwana age. In Odisha, it is found in Mayurbhanj and Keonjhar districts as Newer Dolerite that occurs as dikes and sills in Iron Ore Supergroup of rocks and Singbhum granite. In Cuttack, Dhenkanal, Angul, Sundergarh and Koraput districts it is found as minor intrusive into rocks of different ages.

### 1.7.8. Basalt

**(i) Introduction:** It is the most widespread volcanic rock, dark coloured (melanocratic) and volcanic equivalent of gabbro and dolerite.

**(ii) Texture:** Texturally basalt is fine-grained, holocrystalline, hemicrystalline or holohyaline rock. Mostly it exhibits porphyritic texture (glomeroporphyritic) with phenocrysts of pyroxene, olivine and plagioclase in a fine-grained matrix of glass or a mixture of glass, plagioclase, pyroxene and iron oxides. Some basalts also show poikilitic, ophitic, subophitic, intergranular, intersertal type of textures.

Externally many basalts exhibit vesicular structure where vesicles are often filled up by several secondary minerals like cryptocrystalline silica, epidote, zeolite etc forming amygdaloidal basalt. The other structures include flow structure, ropy and columnar structure.

**(iii) Mineralogy:** Mineralogically, it is similar to gabbro and dolerite and consists of plagioclase (labradorite laths) and clino-pyroxenes as essential minerals. Olivine, ortho-pyroxene and opaque ore minerals are common accessories. At times, quartz and hornblende occur as accessory minerals.

**(iv) Mode of occurrence:** Being an extrusive rock, the basalt occurs as lava flows.

**(v) Examples:** In India, the Deccan traps are the best examples in addition to Rajmahal traps, pillow lavas of Karnataka, Cuddapah traps. In Odisha, Dhanjori lavas of Similipal and Keonjhar, Jagannathpur lava of Keonjhar and Sundergarh district are examples of basalt flows.

## 1.8. SAMPLE QUESTIONS

### 1.8.1. Long answer type questions

(i) Describe different intrusive forms of igneous rocks.

(ii) How can you distinguish among igneous, sedimentary and metamorphic rocks?

(iii) What is texture? Briefly describe different textures of igneous rocks.

(iv) Give the texture and mineralogy of the following:

(a) Dolerite (b) Peridotite (c) Granite (d) Basalt

### 1.8.2. Short type questions

**(A) Write short notes within 3 to 5 sentences.**

| | | | | | |
|---|---|---|---|---|---|
| (i) | Sill | (vii) | Dyke | (xiii) | Laccolith |
| (ii) | Lopolith | (viii) | Batholith | (xiv) | Granite |
| (iii) | Porphyritic texture | (ix) | Poikilitic texture | (xv) | Diorite |
| (iv) | Hypidiomorphic texture | (x) | Ophitic texture | (xvi) | Syenite |
| (v) | Graphic texture | (xi) | Pegmatite | | |
| (vi) | Dolerite | (xii) | Basalt | | |

**(B) Distinguish between the following pairs.**

| | | | |
|---|---|---|---|
| (i) | Sill and dyke | (v) | Porphyritic texture and poikilitic textures |
| (ii) | Laccolith and lopolith | (vi) | Poikilitic and ophitic textures |
| (iii) | Stock and boss | (vi) | Gabbro and dolerite |
| (iv) | Diorite and syenite | (viii) | Plutonic rock and hypabysal rock |

**(C) Answer the following within one sentence.**

(i) Name the igneous rock that essentially consists of quartz and feldspars.

(ii) Name the igneous intrusive form that is concordant and inverted bowl shaped.

(iii) Name two important concordant igneous intrusive forms.

(iv) Name the largest igneous intrusive form.

(v) Name the essential minerals of dolerite.

(vi) What is porphyritic texture?

(vii) Define graphic texture.

(viii) What is ophitic texture?

**Answer:**

(i) Granite

(ii) Laccolith

(iii) Sill, Laccolith, Lopolith, Phaccolith - any two

(iv) Batholith

(v) Plagioclase (or labradorite) and clinopyroxene (or augite)

(vi) Where the larger grains or phenocrysts are surrounded by smaller grains.

(vii) The texture formed due to intergrowth of quartz and orthoclase (or alkali feldspar).

(viiii) Where laths of plagioclase are enclosed in big plates of augite (or clino pyroxene).

### 1.8.3. Multiple choice type questions

**(A) Choose the correct answer from the given choices**

(i) The rock formed by the solidification of lava erupted from a valcano is known as:

(a) Plutonic rock (b) Volcanic rock
(c) Hypabyssal rock (d) Sedimentary rock

(ii) The inverted bowl shaped mass formed by igneous intrusion is known as:

(a) Phacolith (b) Laccolith
(c) Lopolith (d) Batholith

(iii) The saucer shaped mass formed by the igneous intrusion is known as:

(a) Phacolith (b) Laccolith
(c) Lopolith (d) Batholith

(iv) Out of the following, which is not a concordant intrusive form?

(a) Sill (b) Dike
(c) Laccolith (d) Lopolith

(v) Which of the following igneous rocks are extrusive in nature?

(a) Gabbro (b) Dolerite
(c) Basalt (d) Peridotite

(vi) The texture formed due to larger grains (phenocryst) surrounded by smaller grains is termed as :

(a) Panidiomorphic (b) Poikilitic
(c) Porphyritic (d) Ophitic

(vii) The texture formed due to small crystals being enclosed within big crystals is known as:

(a) Hypidiomorhpic (b) Poikilitic
(c) Porphyritic (d) Allotriomorphic

(viii) The texture formed due to intergrowth of quartz and orthoclase is known as:

(a) Hypidiomorphic (b) Allotriomorphic
(c) Graphic (d) Glommeroporplyritc

(ix) Quartz and feldspars are the essential-minerals of:

(a) Basalt (b) Granite

(c) Syenite (d) Dolerite

(x) Out of the following which pair is similar in chemical and mineralogical composition?

(a) Granite and Syenite (b) Dolerite and Basalt

(c) Dolerite and Diorite (d) Gabbro and Granite

**Answers:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (i) | Volcanic rock | (ii) | Laccolith | (iii) | Lopolith | (iv) | Dike |
| (v) | Basalt | (vi) | Porphyritic | (vii) | Poikilitic | (viii) | Graphic |
| (ix) | Granite | (x) | Dolerite and basalt | | | | |

**(B) Correct the sentences, if they are incorrect without changing the word / words underlined.**

(i) Igneous rocks are formed by metamorphism of deep seated rocks.

(ii) Dyke is a concordant igneous intrusive.

(iii) Laccolith is a saucer shaped intrusive body.

(iv) In case of porphyritic texture, smaller grains are enclosed within larger crystals.

(v) Diorite is a volcanic igneous rock.

(vi) Olivine and pyroxenes are essential minerals of dolerite.

**Answers:**

(i) by solidification of magma

(ii) discordant igneous intrusive

(iii) inverted bowl (or bun) shaped intrusive body

(iv) larger grains or phenocrysts are surrounded by smaller grains.

(v) is a plutonic or coarse grained igneous rock.

(vi) Plagioclase and pyroxenes

**(C) Fill in the blanks with appropriate word/ words.**

(i) The thin tabular concordant intrusive form is known as ____________.

(ii) The inverted bowl shaped concordant intrusive form is known as ______.

(iii) Lopolith is a large concordant intrusive body which is _________ shaped .

(iv) The largest of all igneous intrusive form is known as _______________.

(v) The igneous texture formed by holocrystalline, equigranular grains with subhedral shape is known as _______________ texture.

(vi) In case of poikilitic texture _________ grains are enclosed in ________ grains.

(vii) The volcanic equivalent of dolerite is _____________.

(viii) Graphic texture is formed due to intergrowth of ________ and __________.

(ix) The essential minerals of granite are __________ and ________________ .

(x) ______________ and ________________ are essential minerals of gabbro.

(xi) The Deccan volcanics are the best examples of ____________ type of eruption.

**Answers:**

(i) Sill

(ii) Laccolith

(iii) Saucer

(iv) Batholiths

(v) Hypidiomorphic

(vi) Smaller grains, larger

(vii) Basalt

(viii) Quartz and alkali-feldspar or orthoclase

(ix) Quartz and feldspars

(x) Plagioclase and clinopyroxenes

(xi) Fissure type

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# CHAPTER - 2

# SEDIMENTARY PETROLOGY

## 2.1. INTRODUCTION

*Sediment* is defined as the matter that settles to the bottom. It may range in size from a few meters to few microns in diameter. *Sedimentation* is the process of sediment accumulation and is primarily applied to the settling of solid particles in a fluid medium. Rock composed of sediments is known as *sedimentary rock*. *Sedimentary petrology* deals with the sedimentary deposits and their ancient equivalents i.e. sedimentary rocks. *Sedimentary petrography* is the description of sedimentary rocks. Wadell has suggested the term *sedimentology* for the science of sedimentary deposits. In general, sedimentology and sedimentary petrology are synonymous. *Sedimentary deposit* is the body of solid materials accumulated at or near the surface of the earth under low temperature and pressure condition. Fragmental materials expelled from volcanoes and particles deposited on the deep-sea floor, which accumulate at elevated temperature and pressure conditions respectively, are exceptions. Though the science of sedimentology is of recent origin, man‟s knowledge of the sediments can be traced back to prehistoric times. Primitive man had fair idea about the nature and manner of occurrence of flint, from which he made knives, spear and arrow points; something about the clays from which he made pottery and something about the ochers, which he used for colouration.

The volume the sedimentary rocks and their metamorphic equivalents i.e. metasedimentary rocks are estimated to constitute only 5 percent of the lithosphere where as the igneous rocks form 95 percent. On the other hand, the area of exposure of the sediments is 75 percent of the total land area in comparison to igneous rocks that crop out over only 25 percent of the total land area. It is evident that sediments form a thin superficial layer of about 2.2 km in average thickness.

## 2.2. FORMATION OF SEDIMENTARY ROCKS

### 2.2.1. Formation of sediments

All the exposed rocks tend to break up into coarse to fine particles under the influence of different weathering processes. The breaking down is accomplished by disintegration and decomposition processes. In disintegration processes, the rocks break by the disruptive effects of changes of temperature, frost action, abrasion by ice, water or air carrying sand without undergoing chemical change. In decomposition processes, the minerals constituting the rocks undergo chemical change as a result of which the soluble products are carried away by water and chemically simpler and durable residue is left in place. Disintegration and decomposition usually occur together but one process is generally dominant at a time. Disintegration mainly occurs in the drier, elevated and colder regions in contrast to decomposition, which is more active in moist, low-lying and temperate areas of the earth‟s surface. The final product of these changes is a mantle of broken and decomposed material of varying composition and thickness known as *regolith* and soluble materials. The regolith may accumulate in place for a long period or may be swept away rapidly by transporting agencies.

The soluble materials generally find their way to the river and are carried to lake, sea or ocean adding to the dissolved salts of these water bodies. In rare occasions, due to evaporation, the materials in solution may be precipitated and deposited before reaching the final destination. In case of arid environment the accumulated salts may form valuable saline deposits. In humid climatic areas the precipitated materials are dissolved in rainwater and are transported downstream.

The insoluble products and the unaltered minerals may remain in place forming a part of the regolith, but ultimately they are carried by different transporting agencies to suitable depositional sites. In some cases, the altered products may accumulate in place forming residual deposit.

### 2.2.2. Transportation of sediments

The agents of transportation are glaciers, wind, rivers and ocean waves and currents. The glaciers carry the broken rock materials on their surface, frozen within the body of the ice or dragged beneath it. The thickness and clast size of the Talchir boulder bed that forms the basal unit of the Lower Gondwana rocks amply testify the transporting power of glaciers during Permo-Carboniferous period. The wind is the most effective agent of transportation of fine-grained materials in arid and semi-arid regions. The loess of China is believed to be an extensive deposit of wind-blown dust derived from the Asian deserts. The dunes of deserts and sandy shores also testify the transporting capacity of the wind. Rivers carry materials in solution, suspension and traction. A part of the soluble products of the weathering, that percolates to subsurface and mixes with groundwater, after traveling for a shorter or longer period and distance may find its way to river and carried to the sea. The finer insoluble materials like clay and sand, after many halts along the stream course, are finally discharged into the sea. The coarser materials, which the water current of river cannot lift, are transported rolling as bed material. These are deposited at suitable places in the river course. During periodic floods, when the water velocity increases appreciably, the halted materials are transported in downstream direction. The waves and currents of the sea shift the materials supplied by the rivers. The rocks exposed along the coast may break down by the dashing waves and are carried into the sea.

### 2.2.3. Deposition of sediments

Deposition may be either mechanical or chemical depending on the nature of materials it affects. The insoluble and mechanically transported materials are deposited by mechanical processes like change of the velocity of the transporting agency while the substances carried in solution are deposited by changes of the chemical parameters like pH, Eh etc.

The materials carried mechanically by water, wind or ice are deposited when the transporting medium is overloaded, the velocity decreases or the chemical and/or physical parameters of the medium change. Extensive deposits of sand, silt and clay are deposited in lower parts of river course and at the place where river debouches into the sea (delta). Deposition is effected by decrease of the river velocity as well as by admixture of salt water that promotes flocculation favouring the deposition of suspended materials.

The materials in solution may be deposited by precipitation, evaporation or by the action of organisms. If the water containing dissolved substance (AB) comes in contact with another substance (CD), chemical reaction (AB + CD = AC + BD) may take place leading to the precipitation of the dissolved substance. In the process of evaporation, the solvent evaporates as a result of which the solution becomes supersaturated with the solute and deposition takes place. Preparation of common salt ($NaCl$) from seawater in Ganjam district of Odisha is an example of deposition by evaporation. Large volume of dissolved materials derived from rock decomposition reaches the sea. A part of it is precipitated and deposited by organisms directly. Some of the Precambrian iron ore deposits are thought to have been deposited by iron precipitating bacteria. Many organisms extract the calcium and magnesium salts from the seawater to build their shells and skeletons. After death of these organisms, the hard parts accumulate to form extensive deposits.

### 2.2.4. Conversion of sediments to sedimentary rocks

Lithification is a complex process by which loose sediments are converted to compact and indurated sedimentary rocks. It includes diagenesis, authigenesis, compaction and cementation.

Diagenesis primarily refers to the reactions, which take place between sediment-sediment and sediment-interstitial fluids. These reactions result in postdepositional recrystallisation, replacement, overgrowth, segregation of mineral materials and production of intrastratal solution. Diagenetic changes are achieved by processes of chemical reorganization like solution, precipitation, crystallization, recrystallization, oxidation, reduction etc. Diagenetic differentiation is the redistribution of materials within sediment leading to segregation of the minor constituents into nodules, concretions etc. Intrastratal solution plays an important role in all diagenetic changes.

Authigenesis or diagenetic reorganization is the result of reaction between sediments of both detrital and chemical in origin, leading to the formation of certain new minerals or the enlargement or outgrowth of minerals already present. The new minerals thus formed are the authigenic minerals. Common authigenic minerals are quartz, chalcedony, calcite, dolomite, siderite, albite, orthoclase, illite, sericite, chlorite, rutile, anatase, brookite, gypsum, anhydrite, barite, marcasite, pyrite, tourmaline, zircon etc.

Compaction is the reduction of pore space and expulsion of interstitial fluids resulting in rearrangements of grains under pressure. Compaction is greatest and most important in case of fine-grained sediments like shale. Compaction results in the reduction of porosity.

Cementation is the process of precipitation of mineral matter in the pores or voids of clastic sediments as a result of which the loose sediments are bounded to become indurated rock. It is the principal means by which sandstones and conglomerates become lithified. The cements of medium- and coarse-grained clastic sediments are important constituent of such rocks. If the voids are completely filled, the cement constitutes about one-fourth to one-third of the whole rock. Common cements are siliceous (quartz), calcareous (calcite) and ferruginous (various forms of iron oxide) in composition. In case of some detrital rocks like conglomerates and sandstones, the intergranular spaces are filled with finer detrital material, which is known as matrix. In contrast to cement, which is chemically precipitated material, matrix is the finer detrital material entrapped in the pore spaces. In case of conglomerates, sand (arenaceous) forms the matrix, while in sandstones, silt and clay (argillaceous) constitute the matrix. In case of many sandstones associated with coal seams, finely divided plant debris (carbonaceous) constitutes the matrix.

## 2.3. TEXTURE OF SEDIMENTARY ROCKS

In case of clastic sedimentary rocks, texture includes size, shape, roundness and arrangement of individual grains (fabric) of a rock.

### 2.3.1. Size

As discussed above the sediments are produced by weathering processes as a result of which fragments more than meters in diameter to grains of micron size are produced. During transportation, collision between grains results in further breaking down of the grains. Thus, the grain sizes of sedimentary rocks vary within wider limits. If for example a scale of from 1000 to 1 mm with intervals of 1 mm is taken, many classes in the upper part of the scale remain unrepresented while many grains ranging from 1 to 0.0001 group together within the interval 1- 0 mm. To overcome these difficulties and to accommodate all the possible sizes, Krumbain proposed a logarithm scale in which the grain size is expressed as „phi (Φ)‟, which is the negative logarithm of the particle diameter in millimeters to the base 2.

$$\Phi = -\log_2 d \quad \text{and} \quad d = 2^{-\Phi}$$

Udden proposed some descriptive terms for sediments of specific size limits. The Udden-Wentworth size classes of sedimentary particles are given in Table 2.1.

### 2.3.2. Sorting

Sorting refers to the size range of the clastic grains constituting a sedimentary rock. The rock is said to be poorly sorted if the size range is large as in case of conglomerates and breccias. The sorting is said to be well when the size range is narrow as in case of sandstones and siltstones. Terms like *very well sorted*, *well sorted*, *moderately well sorted*, *moderately sorted*, *poorly sorted*, *very poorly sorted* and *extremely poorly sorted* are used to describe the degree of sorting.

### 2.3.3. Shape

In the process of transportation, the clastic particles are abraded with rounding of corners and tend to acquire an equidimensional shape. The limiting shape is a sphere, which is taken as reference in defining the shape of a grain. The shape (sphericity) of a grain is defined as the ratio of the surface area of a sphere (s) of the same volume as the grain under examination and the actual surface area of the grain (S).

$$\text{Sphericity } (\Psi) = s/S$$

For a sphere, the sphericity has the value of 1.0 and for all other shapes the sphericity is less than 1.0. Due to the difficulty of measuring the surface area of an irregular solid, the sphericity is approximated by

$$\text{Sphericity } (\Psi) = d_n/D_s$$

where $d_n$ = the diameter of a sphere of the same volume as the object

$D_s$ = the diameter of a circumscribing sphere

**Table 2.1. Udden-Wentworth size classes of sedimentary particles**

<table>
<tr><th>Sieve mesh number (ASTM)</th><th>Phi (Φ)</th><th>Millimeter</th><th colspan="3">Class</th></tr>
<tr><td></td><td>-12.00</td><td>4096.00</td><td colspan="3" rowspan="3">Boulder<br>(< - 12 to - 8 Φ)</td></tr>
<tr><td></td><td>-10.00</td><td>1024.00</td></tr>
<tr><td></td><td>- 8.00</td><td>256.00</td></tr>
<tr><td></td><td>- 7.00</td><td>128.00</td><td>Large</td><td rowspan="2">Cobble<br>(- 8 to - 6 Φ)</td><td rowspan="6">GRAVEL</td></tr>
<tr><td></td><td>- 6.00</td><td>64.00</td><td>Small</td></tr>
<tr><td></td><td>- 4.00</td><td>16.00</td><td>Very coarse</td><td rowspan="4">Pebble<br>(- 6 to – 2 Φ)</td></tr>
<tr><td>3</td><td>-3.00</td><td>8.00</td><td>Coarse</td></tr>
<tr><td>3.5</td><td>-2.50</td><td>5.66</td><td>Medium</td></tr>
<tr><td>5</td><td>-2.00</td><td>4.00</td><td>Fine</td></tr>
<tr><td>6</td><td>-1.75</td><td>3.36</td><td colspan="3" rowspan="4">Granule<br>(- 2 to - 1 Φ)</td></tr>
<tr><td>7</td><td>-1.50</td><td>2.83</td></tr>
<tr><td>8</td><td>-1.25</td><td>2.38</td></tr>
<tr><td>10</td><td>-1.00</td><td>2.00</td></tr>
<tr><td>12</td><td>-0.75</td><td>1.68</td><td rowspan="4">Very coarse</td><td colspan="2" rowspan="12">S<br>A<br>N</td></tr>
<tr><td>14</td><td>-0.50</td><td>1.41</td></tr>
<tr><td>16</td><td>-0.25</td><td>1.19</td></tr>
<tr><td>18</td><td>0.00</td><td>1.00</td></tr>
<tr><td>20</td><td>0.25</td><td>0.84</td><td rowspan="4">Coarse</td></tr>
<tr><td>25</td><td>0.50</td><td>0.71</td></tr>
<tr><td>30</td><td>0.75</td><td>0.59</td></tr>
<tr><td>35</td><td>1.00</td><td>0.50</td></tr>
<tr><td>40</td><td>1.25</td><td>0.42</td><td rowspan="4">Medium</td></tr>
<tr><td>45</td><td>1.50</td><td>0.35</td></tr>
<tr><td>50</td><td>1.75</td><td>0.30</td></tr>
<tr><td>60</td><td>2.00</td><td>0.25</td></tr>
</table>

| | | | | |
|---|---|---|---|---|
| 70 | 2.25 | 0.21 | Fine | D (- 1 to 4 Φ) |
| 80 | 2.50 | 0.177 | | |
| 100 | 2.75 | 0.149 | | |
| 120 | 3.00 | 0.125 | | |
| 140 | 3.25 | 0.105 | Very fine | |
| 170 | 3.50 | 0.088 | | |
| 200 | 3.75 | 0.074 | | |
| 230 | 4.00 | 0.063 | | |
| 270 | 4.25 | 0.053 | Coarse | S I L T (4 to 8 Φ) |
| 325 | 4.50 | 0.044 | | |
| | 4.75 | 0.037 | | |
| | 5.00 | 0.031 | | |
| | 5.25 | 0.026 | Medium | |
| | 5.50 | 0.022 | | |
| | 5.75 | 0.019 | | |
| | 6.00 | 0.015 | | |
| | 6.25 | 0.013 | Fine | |
| | 6.50 | 0.011 | | |
| | 6.75 | 0.009 | | |
| | 7.00 | 0.008 | | |
| | 7.25 | 0.007 | Very fine | |
| | 7.50 | 0.006 | | |
| | 7.75 | 0.005 | | |
| | 8.00 | 0.004 | | |
| | 9.00 | 0.002 | Coarse | CLAY (< 8 Φ) |
| | 10.00 | 0.001 | Medium | |
| | < 10.00 | < 0.001 | Fine | |

The shapes of grains can also be expressed by the ratio of the length (a), breadth (b) and thickness (c) as proposed by Zingg. Zingg‟s shape classes are given in Table 2.2.

**Table 2.2. Zingg's shape classes**

| Class | b/a | c/b | Shape | Class | b/a | c/b | Shape |
|---|---|---|---|---|---|---|---|
| 1. | > ⅔ | < ⅔ | Tabular or discoidal | 3. | < ⅔ | < ⅔ | Triaxial or bladed |
| 2. | > ⅔ | > ⅔ | Equant or spherical | 4. | < ⅔ | > ⅔ | Prolate or rod-shaped |

### 2.3.4. Roundness

Roundness is the measure of sharpness of the edges and corners of the clastic grains. It is defined as the ratio of the average radius of curvature of the corners to the radius of curvature of the largest inscribed sphere. In actual practice these parameters are difficult to measure. The three-dimensional grain can be projected on two-dimension (Fig.2.1) and the roundness is determined by calculating the average radius of curvature of the corners ($r_i$) of the grain in projection and the radius of the largest inscribed circle (R) by the following formula:

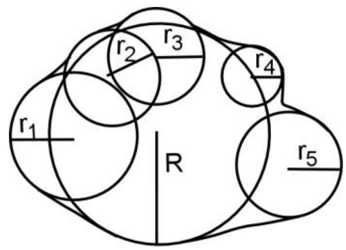


**Fig.2.1. Roundness measurement**

$$\text{Roundness } (\rho) = [(\sum r_i)/N]/R$$

On the basis of roundness values, Pettijohn has defined five roundness grades for the clastic grains. These are given in Table 2.3.

### 2.3.5. Fabric

The fabric of a clastic sedimentary rock refers to the homogeneity or otherwise of the orientation of long axes of constituent grains, particularly in case

**Table 2.3. Pettijohn's roundness grades**

| Roundness | Grade | Roundness | Grade | Roundness | Grade |
|---|---|---|---|---|---|
| 0.00 – 0.15 | Angular | 0.25 – 0.40 | Subrounded | 0.60 – 1.00 | Well-rounded |
| 0.15 – 0.25 | Subangular | 0.40 – 0.60 | Rounded | --------- | ---------- |

of coarse-grained rocks like conglomerates. If the long axes show some degree of preferred alignment, the fabric is termed as anisotropic (Fig.2.2). On the other hand, if the long axes are randomly oriented, the fabric is termed as isotropic (Fig.2.3). In the former case, the preferred arrangement may be in response to hydrodynamic condition of the transporting medium and can be used as an important clue to decipher the palaeocurrent direction.

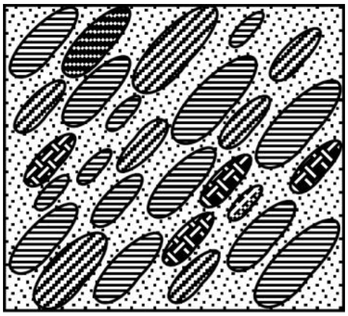

Fig.2.2. Anisotropic fabric

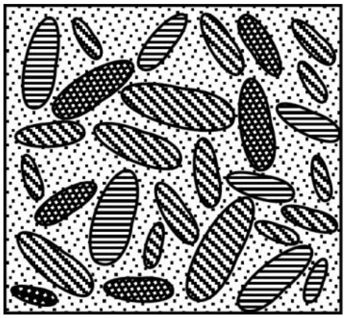

Fig.2.3. Isotropic fabric

Texture also describes the interrelationship between the grains, which constitute the rock. Following textural terms are in common use.

### 2.3.6. Clastic texture

The clastic sediments are primarily detrital in nature and lie in tangential contact with each other with intergranular pore spaces. When converted to rock, matrix and/or cement fill the intergranular pore spaces partially or completely. The collection of grains, matrix and/or cement constitutes the clastic texture.

### 2.3.7. Nonclastic texture

Sediments precipitated from solution by chemical processes show interlocking arrangement of their grains without intergranular pore spaces. This type of texture is known as nonclastic texture.

### 2.3.8. Organic texture

This type of texture is seen in rocks formed by accumulation of organic debris like shells, bones etc, which are well preserved and bounded by finely divided organic matter.

## 2.4. STRUCTURE OF SEDIMENTARY ROCKS

The sedimentary structures are large-scale features better observed in the outcrop than in hand specimen and in thin sections. The structures can be classified into three groups viz. mechanical or primary, chemical or secondary and organic or biogenic.

### 2.4.1. Mechanical or primary structures

Mechanical or primary structures are dependent on the rate of sedimentation and current of the medium. Planar bedding structures (beds, laminations, ripple marks, cross lamination, cross bedding, graded bedding), sole marks (flute and tool marks, groove casts, load casts and rain prints), deformed and disrupted bedding (soft sediment folding, boudinage, brecciations, mud crack casts, armored mud balls and clay galls), sedimentary sills and dykes belong to this category. Some of the important primary structures are described below.

**(i) Bedding/ Lamination:** The smallest sedimentation unit is the bed, which was deposited under essentially constant physical conditions. Since the current flow varies in magnitude and direction from time to time, the sediment carrying capacity of the medium also changes accordingly. The prevailing current of a particular mean velocity deposits sediments of some particular size range. When the current velocity changes appreciably, a new set of conditions is established as a result of which sediments of differing grain size are deposited, which are different from the underlying sediments in composition and colour. The top and bottom of beds are demarcated on the basis of changes in size, colour and structure of sediments. A bed may be thick or thin depending on the persistency of the current system and supply of the sediments. The terminologies used to designate stratified beds are given in Table 2.4. When the bed thickness is less than 1 cm it is termed as lamination. The varves deposited by glacial melt water are good examples of laminations. Laminations are most characteristic of fine-grained sediments like siltstones and shales

**Table 2.4. Terminology for stratification thickness**

| Thickness | Term | Thickness | Term |
|---|---|---|---|
| > 1 m | Very thick bed | 3 cm – 1 cm | Very thin bed |
| 1 m – 30 cm | Thick bed | 1 cm – 3 mm | Thick lamination |
| 30 cm – 10 cm | Medium bed | < 3 mm | Thin lamination |
| 10 cm – 3 cm | Thin bed | | |

**(ii) Ripple mark:** Ripple marks are regularly spaced undulations on a sand surface or on a bedding plane of sandstone or coarse-grained siltstone. Their wavelength is usually less than 50 cm and amplitude about 3 cm. Bed undulations exceeding these dimensions are termed as dunes or sand waves. Ripples show wide variety of shapes each of which are related to a particular sedimentary processes and hence are used as criteria in interpretation of deposition conditions. Generally the ripples are of two types. The symmetric or wave ripples (Fig. 2.4) are formed due to wave action in the bottom of standing water bodies. These are characterised by upward pointed crests and rounded troughs. These are used to determine the top and bottom of beds in case of isoclinally folded or overturned strata. The asymmetric or current ripples (Fig. 2.5) are produced due to current action and have a gentle stoss or up-current slope and a steep lee or down current slope. These are used for deduction of palaeocurrent direction.

**(iii) Cross lamination:** Cross lamination is a type of internal lamination, which is produced due to migration of ripples. It can be seen both on bedding planes as well as on vertical sections.

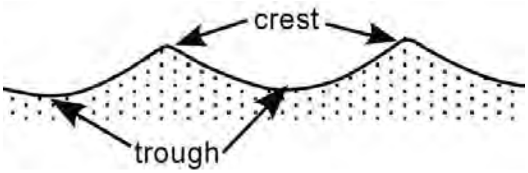


**Fig. 2.4. Cross section of symmetric ripple**

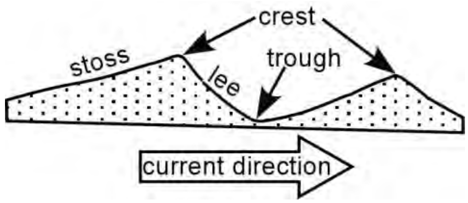


**Fig. 2.5. Cross section of asymmetric ripple**

Ripple and cross lamination are principal features of sand grade sediments and may be seen in coarse silts as well. They are most common in fine to medium grained sand and are rare in material coarser than coarse-grained sand.

**(iv) Cross bedding:** Cross bedding is produced due to migration of a mega ripple or a sand wave. There are two types of cross beddings. One is a simple tabular set with foresets approximately planes (Fig.2.6). The other is a trough shaped set of cross strata, which are usually curved surfaces (Fig.2.7). The traces of the foresets of tabular cross bedding are straight lines whereas in the second case they are curved. The dip direction of foresets in case of tabular cross bedding and the bisertix of concavity in case of trough cross bedding indicate the down-current direction. Cross beddings are one of the most widely used palaeocurrent indicators. In case of cross beddings, the thickness of foreset layers are greater than 1 cm while the thickness of foreset layers are less than 1 cm in case of cross laminations.

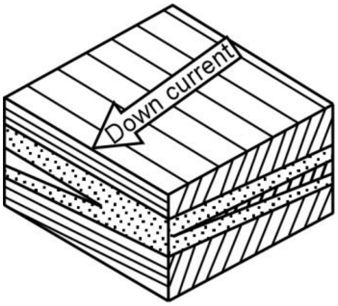


**Fig. 2.6. Tabular cross-bedding**

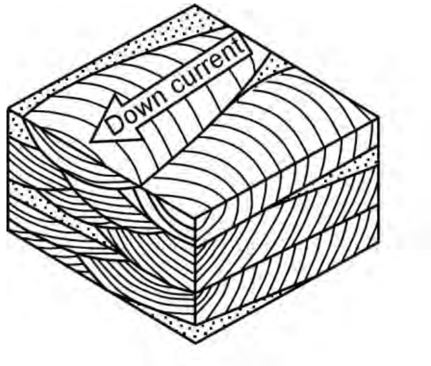


**Fig. 2.7. Trough cross-bedding**

**(v) Hummocky cross stratification:** Hummocky cross stratifications consist of broadly undulating sets of gentle slopping laminae made of fine sand and coarse silt (Fig.2.8). Dip directions of the individual sets show much variation and cannot be used to deduce palaeoflow direction. Hummocky cross stratifications are characteristic of marine shelf environment and are possibly formed by large storm waves.

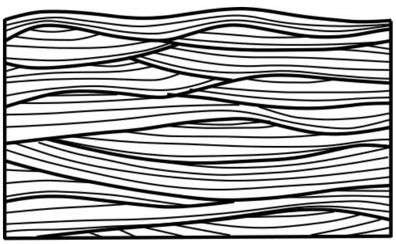

**Fig. 2.8. Hummocky cross stratification**

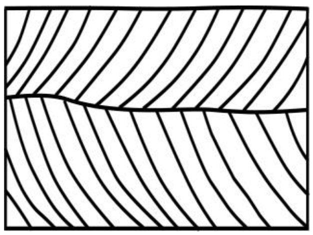

**Fig. 2.9. Herring-bone cross stratification**

**(vi) Herring-bone cross stratification:** Herring-bone cross stratification is an example of bimodal and bipolar cross stratification in which two sets dip in exactly opposite directions (Fig.2.9). Oscillate currents occurring in the same place at different times gives rise to this type of cross stratification. The rate of sedimentation should be high enough to preserve the cross stratification. This type of stratification is typical of tidal environment.

**(vii) Graded bedding:** Graded beds are sedimentation units characterised by decrease in grain size from the base to the top of the unit. Two types of graded beds are commonly seen. In one type, there is gradual gradation of particle size from the base to top, without any fines in the lowest part of the graded bed (Fig.2.10). Waning current produces this type of graded bedding. In the second type, there is overall decrease of grain size from base to top, but the fines are distributed throughout the bed (Fig.2.11). This type of graded bed is characteristic of deposition from turbidity current. Graded bedding is useful in determination of top and bottom of beds and the order of superposition in isoclinally folded and overturned strata.

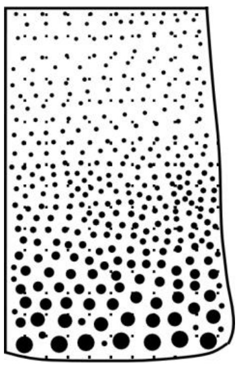

**Fig. 2.10. Graded bedding produced by waning current**

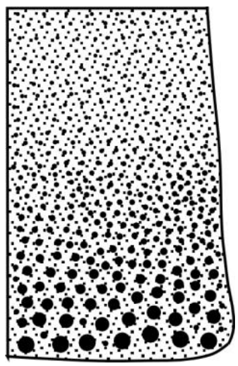

**Fig. 2.11. Graded bedding produced by turbidity current**

**(viii) Sole marks:** Sole marks are bedding plane features present in the undersurface of some sandstone beds overlying shales. These are raised structures formed by the filling of depressions produced by current action on the mud surface. Flute casts, groove casts and tool marks are some of the important sole marks.

During flow of water, a swarm of eddies develops and rub the mud surface resulting in the formation of scours. Infilling of these scours by the sandstone deposited on the mud surface give rise to protruding features, which are known as flute casts. The flute casts commonly occur in groups.

At times, furrows are carved on the mud surface by dragging of objects like mud chips, shells, rock fragments etc by the water current. Infilling of these furrows by sands deposited above mud form groove casts, which appear as rectilinear, rounded to sharp crested features on the base of the overlying sandstone bed.

Scars are produced when objects like mud chips, shells, rock fragments etc. impinge over the mud surface. These scars are filled by sands deposited on the mud surface and are found to be preserved as small elevations on the underside of the overlying sandstone. These features are known as tool marks.

When sand is deposited over unconsolidated mud, differential sinking of the heavy sand layer into softer mud substratum results in the formation of irregular bulbous features in the base of sandstone bed. These structures are known as load casts.

**(ix) Mud crack cast:** Mud cracks develop in cohesive materials like mud as a result of drying and shrinkage giving rise to polygonal cracks. When such a surface is buried by sand, the cracks are filled with sand and become welded to the overlying sandstone bed. After removal of the underlying mudstone/ shale, polygonal ridges appear on the sole of the sandstone.

**(x) Rain print:** Rain prints are minor and rare structures preserved in similar fashion as mud crack casts. Each print is a shallow depression surrounded by a low ridge. In case of slanting rainfall, the elevation on the lee-side is higher than that on the windward side.

**(xi) Armored mud balls:** Armored mud balls are subspherical clay balls covered by fine gravels. The size of the mud balls varies within wide limits, but those within 5-10 cm diameter are generally more common. The mud balls are formed by dislodge of clay chunks from riverbank, which by rolling downstream attain spherical shape and collect gravels on the surface. These structures are sparse in occurrence.

### 2.4.2. Chemical or secondary structures

Chemical or secondary structures are produced by chemical action simultaneously with sedimentation or soon thereafter. Structures like nodule, spherulite, rosettes, concretions, veins, geodes, septaria, cone-in-cone, stylolite, corrosion zone, vug, oolicast, etc. belong to this category. Some of the important chemical structures are described below.

**(i) Nodule:** Nodules are irregular tuberous bodies of chert and flint produced due to post-depositional replacement of host rocks by silica. These are devoid of internal structure and commonly arranged parallel to the bedding.

**(ii) Spherulite:** These are small spherical bodies produced by precipitation from colloidal gel state and are arranged radially about a center. The smaller spherulites are made up of chalcedony silica, carbonate, apatite or aragonite, while larger ones are carbonate concretions.

**(iii) Rosette:** These are formed by successive addition of barite, marcasite or pyrite with symmetrical growth. Marcasite rosette is formed in fresh water acidic environment while pyrite rosette is indicative of neutral or alkaline marine environment.

**(iv) Concretion:** The concretions are spheroidal or disc-shaped bodies with concentric structure. They vary in size from small pellet to large spheroidal bodies of more than a meter in diameter. They are commonly composed of silica, calcite or iron oxide. Some of the concretions, particularly those composed of iron oxide are hollow with a central cavity and outer limonitic layer.

**(v) Geode:** Geodes are characterized by subspherical shape, hollow interior, outer chalcedonic silica layer, inner drusy lining of inward pointing crystals. They are generally found in some limestone beds. A cross section of a geode is shown in Fig.2.12.

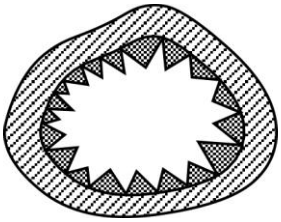

**Fig.2.12. Geode**

**Fig.2.13. Septaria**

**(vi) Septaria:** Septaria are large nodules characterized by a series of radial cracks which widen towards the center. A network of cracks concentric with the margin intersects the radial cracks (Fig.2.13). The cracks are generally filled with crystalline calcite. Formation of septarian nodules is initiated with the formation of a nodule of aluminous gel, hardening of the exterior, dehydration of interior, formation of shrinkage cracks followed by partial or complete filling of the cracks with precipitated calcite.

**(vii) Cone-in-cone:** Cone-in-cone is a minor structure seen in case of some shales. These are 1-15 cm thick and consist of a number of right circular cones (Fig.2.14), which are in inverted position with the cone axis normal to the bedding. The sides of the cone are generally ribbed or grooved and are marked by depressions and ridges.

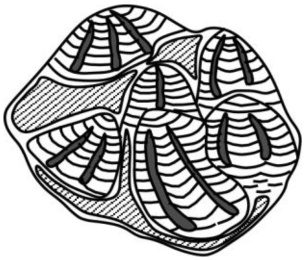

**Fig.2.14. Cone-in-cone**

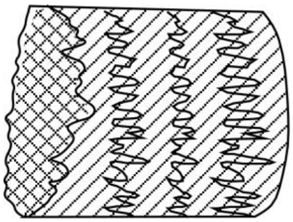

**Fig.2.15. Stylolite**

**(viii) Stylolite:** A stylolite consists of teeth like projections of one side, which fit into the sockets of exactly similar dimension on the other side. In cross section, the stylolite surface resembles the suture (Fig.2.15). The relief on a stylolite surface varies from less than a millimeter to more than two decimeters. The stylolites of some sandstones contain a parting of coaly matter, while those of quartzites are indicated by iron oxide. Commonly, the stylolites are parallel to the bedding but in a few cases they are inclined at high angles to bedding planes. Though stylolits occur in many types of rocks, they are most abundant in carbonate rocks like limestone, dolomite and marble.

**(ix) Corrosion surface:** Corrosion surfaces are weathered bedding surfaces of carbonate rocks formed by termination of deposition of lime and removal of some of the previously deposited materials. Such a surface is characterized by minor irregularities and concentration of insoluble materials like quartz grains and phosphatic shells.

**(x) Vug:** Vugs are openings formed by the action of subsurface water. These are most common in carbonate rocks. In many instances they are partially filled by precipitated mineral matter.

**(xi) Oolicast:** Oolicasts are small subspherical openings formed by selective solution of oolites in preference to matrix in case of oolitic limestone. These structures enhance the porosity significantly facilitating the movement of fluids.

### 2.4.3. Organic or biogenic structures

These structures are directly or indirectly produced by organisms. Organic structures include petrification, casts and mold, tracks and trails, burrows and borings, fecal pellets, coprolites and stromatolites.

**(i) Petrification:** Under suitable conditions the remains of organisms are fossilized within sedimentary rock beds. In many instances hard parts like bones, teeth and shells are replaced by iron oxide, silica, carbonate etc. The replacement takes place very slowly and in the process both internal and external structures of the organism are found to be well preserved. In many instances, cavities are formed by removal of the original object in form of solution. These are known as moulds. The moulds show the outer form and ornamentation of the original organism. When it is filled with silica, iron oxide etc, it is termed as cast. A cast preserves the form and ornamentation but does not retain the internal structures of the replaced object.

**(ii) Tracks and trails:** Continuous grooves or furrows formed on the sediment surface by locomotion of organisms are known as trails. Common trail patterns are: gentle curving, irregular meandering, zigzag meandering, meandering with highly attenuated loops, spiral and honeycomb network.

**(iii) Burrows and borings:** Burrows are excavations filled with sediments by active or passive filling after it is abandoned. Horizontal and nearly horizontal burrows are known as tunnels where as vertical or nearly vertical burrows are known as shafts. Borings, on the other hand, are excavations in consolidated materials such as lithified sediment, shell or bone.

**(iv) Faecal pellets:** These are excreta of invertebrates present in modern marine deposits as well as in some sedimentary rocks. They are rod shaped or ovoid with either longitudinal or transverse sculpturing or both. Simple ovoid forms with about one millimeter size are more common. The pellets are generally transformed into glauconite, replaced by pyrite or may serve as centers for accumulation of phosphate.

**(v) Coprolites:** These are large sized phosphatic faecal pellets characterized by dark colour, ovoid to elongate in form and the surface may be marked by annular convolutions. Longitudinal striae and grooves are occasionally present.

**(vi) Stromatolites:** The stromatolites or commonly known algal stromatolites are laminated structures composed of particulate sand-, silt- and clay-sized sediments, which have been formed by trapping and binding by algal mats. The structures of stromatolites vary from flat lamination to small mound like forms of varying size.

## 2.5. DESCRIPTION OF COMMON SEDIMENTARY ROCKS

### 2.5.1. Conglomerate

**(i) Texture:** Very coarse grained, greater than 4 mm in diameter (cobbles, pebbles and boulders). The clasts are commonly of high sphericity (equant or spherical), subrounded to well rounded.

**(ii) Structure:** Generally massive, without any internal stratification as in case of glacial and alluvial fan deposits. Fluvial conglomerates may show internal stratification like current and graded beddings.

**(iii) Mineralogy:** Two types of conglomerates have been recognized viz. polymictic composed of quartz, jasper, chert and rock fragments of variable composition and oligomictic when composed of clasts of same composition like quartz, jasper or quartzite.

**(iv) Matrix and cement:** The matrix is commonly arenaceous (sandy). In case of glacial conglomerates, matrix is composed of argillaceous (mud) materials. Dominant cements are siliceous and ferruginous materials. The clast: matrix ratio is variable, high in case of fluvial conglomerates and low in case of glacial conglomerates.

**(v) Examples:** Conglomerates commonly occur above the surface of unconformity. The Quartz Pebble Conglomerate, Talchir Boulder Bed, Vindhyan conglomerates are some of the well-known Indian examples. Common variants are:

(i) Oligomictic conglomerates: Pebbles are of same composition.

(ii) Polymictic conglomerate: Pebbles are of different composition.

(iii) Intraformational conglomerate: Composed of mud or shale-pebbles intraclasts derived from sedimentary rocks within the basin.

(iv) Tillite: High matrix conglomerates with striated and pentagonal boulders of glacial origin.

(v) Tilloid: Haphazard assemblage of nonglacial boulders in muddy matrix.

(vi) Conglomeratic argillite: Laminated argillites with ice rafted pebbles.

**(vi) Properties and uses:** Coarse-grained and compositional heterogeneity make these rocks good aquifers and poor building materials. Well-cemented, hard and compact conglomerates may be used as building stones. The Vindhyan conglomerates are diamondiferous.

### 2.5.2. Breccia

**(i) Texture:** Very coarse grained, 4 - 64 mm in diameter (pebbles). The clasts are commonly of low sphericity and angular.

**(ii) Structure:** Generally massive, without any internal stratification.

**(iii) Mineralogy:** The composition of clasts depends on the nature of origin. The volcanic breccias are made up of pyroclasts of volcanic eruption and as such the clasts may be of same composition. On the other hand, the fault- and collapse-breccias as well as tillites of glacial origin show much wide variation of clast composition depending on the rocks involved. Like conglomerates, the breccias may be termed as oligomictic and polymictic depending on clast composition.

**(iv) Matrix and cement:** The matrix is commonly arenaceous (sandy). In case of glacial tillites, matrix is composed of argillaceous (mud) materials. Dominant cements are siliceous and ferruginous materials. The clast: matrix ratio is variable.

**(v) Examples:** Depending on the mode of origin, different types of breccias occur in different regions. Tectonic breccias are seen in case of tectonically disturbed regions like the Himalayas. Tillites of glacial origin are seen in ancient and present glaciated areas. Some of the boulder beds occurring at the base of Lower Gondwana rocks are breccias, where the clasts are not reworked by fluvial action. Common variants are:

(a) Volcanic breccia: Composed of pyroclastic materials of volcanic origin.

(b) Cataclastic breccia: Produced by tectonic activities like folding, faulting, slumping etc.

(c) Impact breccia: Produced by meteoric impact.

**(vi) Properties and uses:** Coarse-grained polymictic breccias are good aquifers and poor building materials. Well-cemented, hard and compact breccias may be used as building stones.

### 2.5.3. Sandstone

**(i) Texture:** Coarse to fine grained, 2 – 0.063 mm in diameter. The clasts are commonly of medium to low sphericity and subrounded to angular. Angular sand of 1 to 0.5 mm diameter is termed as grit.

**(ii) Structure:** Massive, ripple mark, graded bedding, tabular and trough cross-bedding, cross- and parallel-lamination.

**(iii) Mineralogy:** The composition of the sandstones is expressed in terms quartz, feldspar and rock fragments. Depending upon the dominance of these three constituents the sandstones are termed as orthoquartzite, arkose and lithic-sandstone respectively.

**(iv) Matrix and cement:** Silt and clay (argillaceous) are the common matrix. The matrix of sandstones associated with coal seam may be carbonaceous. Dominant cements are siliceous and ferruginous materials. The clast:matrix ratio is variable. Sandstones are divided into two broad groups depending on the percentage of matrix and cement viz. arenites (<15% matrix) and wackes (>15% matrix).

**(v) Examples:** Among the sedimentary rocks, sandstones are very common and make up 14 - 40% in volume of the total sedimentary rocks. They are formed in most of the sedimentary environments and are common in stratigraphic record.

Common variant are:

(a) Calcareous sandstone: Sandstone with $CaCO_3$ cement.

(b) Ferruginous sandstone: Sandstone with ferruginous cement.

(c) Arenite: Sandstone with less than 15% matrix.

(d) Wacke: Sandstone with more than 15% matrix.

(e) Arkose: Sandstone with more than 25% feldspar.

(f) Orthoquartzite: Sandstone with more than 95% quartz.

(g) Flagstone: Micaceous sandstone.

**(vi) Properties and uses:** Due to high porosity and permeability sandstones form good aquifers for ground water and reservoir rocks for storage of oil and gas. Hard and indurated sandstones are good building materials. The temple of Lord Jagannath at Puri and temples of Lord Shiva at Bhubaneswar are made up of Athgarh sandstones. The Agra fort, Red fort and many other monumental works of Mogul period were constructed with Vindhyan sandstones.

### 2.5.4. Shale

**(i) Texture:** Shales are fine- to very fine-grained and compact. Grains are of silt and clay grade materials of less than 0.063 mm in diameter. Measurement of sphericity and roundness needs high precision instruments. Variously coloured in shades of white, red, yellow, gray, green, khaki, brown and black. Commonly give off earthy smell when wet.

**(ii) Structure:** Massive, parallel and cross-laminated, fissile. They often contain fossils of flora and fauna.

**(iii) Mineralogy:** Shales are made up of silt and clay sizes grains of quartz, feldspar and various clay minerals like montmorillonite, kaolinite, chlorite, halloysite, pyrophyllite etc. Relative proportions of these minerals vary depending on environmental conditions and physico-chemical parameters of weathering. In addition, shales may also have siliceous, calcareous, ferruginous and glauconitic materials.

**(iv) Matrix and cement:** Shales are commonly formed by compaction and not by cementation. It is very difficult to distinguish between grain and matrix.

**(v) Examples:** Among the sedimentary rocks, shales are very abundant and constitute 39 – 59% of the volume of the sedimentary rocks. They are formed in many sedimentary environments and are common in stratigraphic record. Common variants are

(a) Calcareous shales which grade into marl, argillaceous limestone and limestone with increase of $CaCO_3$ proportion.

(b) Carbonaceous shales are black in colour due to the presence of high proportion of organic matter.

(c) Alum shales are grey or black shales associated with pyrite.

(d) Siliceous shales are rich in sand.

(e) Oil shale is carbonaceous shale that yields oil on distillation.

(f) Mudstones are similar to shale but lack fissility.

**(vi) Properties and uses:** Shales are extremely fine-grained and highly porous (porosity 40 – 60%) but impermeable. More water can be stored within shale beds due to surface tension effect but cannot be transmitted effectively. Low permeability makes them aquiclude. They are also unsuitable for engineering construction. However, on disintegration they yield good soil profiles, which are of paramount importance from agriculture viewpoint. In addition, they form good cap rocks for oil and gas deposits and are used in manufacture of cement.

### 2.5.5. Limestone

Limestones are typical nonclastic rocks formed either by chemical precipitation of $CaCO_3$ or due to accumulation of hard parts of organisms. However, some limestones are of clastic origin formed by erosion of pre-existing carbonate deposits, transportation to the basin of deposition and accumulation like any other clastic sedimentary rock.

**(i) Texture:** In hand specimen, limestones show different colours like white, gray, buff, cream, pink, yellow, black etc. Those formed by precipitation from solution are extremely fine grained, while those made up of skeletal parts of organisms are fine to coarse-grained. The limestones of Cretaceous formation of Trichinopolly, for example, have gigantic fossils of ammonoids and nautiloides of a few decimeter in diameter.

**(ii) Structure:** Many of the limestone beds are massive without any internal structure. Those formed by erosion of pre-existing carbonate deposits show colour banding, ripple lamination and similar current generated structures. They also show diversified chemical structures like nodular, concretionary, pisolitic, oolitic, stalactitic etc. Stylolites are commonly seen in some limestones.

**(iii) Mineralogy:** Limestones are dominantly composed of carbonate minerals like calcite and dolomite. Shell fragments and complete fossils are seen in many cases.

**(iv) Matrix and cement:** Matrix and cement are seen in case of clastic limestones only in which intraclasts (reworked fragments of pre-existing carbonate deposits), fossils, oolites and pellets constitute the clasts and micrite (microcrystalline calcite) and sparite (calcite crystals deposited within pore-spaces) form the binding materials.

**(v) Examples:** Among the sedimentary rocks, limestones constitute 5 – 29% of the volume of the sedimentary rocks. Common variants are:

(a) Lithographic limestone: Fine-grained, homogeneous, massive and compact variety of limestone.

(b) Magnesian limestone: When limestone comes in contact with magnesium-bearing water, the calcium content of limestone is partially replaced by magnesium resulting in the formation of dolomite. The process is known as dolomitization.

(c) Marl: It is an impure limestone containing high proportion of clay.

(d) Siliceous limestone: It is an impure limestone containing silica (commonly in form of quartz).

(e) Chalk: It is a soft, white and very fine-grained calcareous deposit formed out of *Globigerina* ooze.

(f) Stalactites, stalagmites and dripstones: These are calcareous deposits formed in caves. When surface water with dissolved $CaCO_3$ trickles down through fractures in the roof of a cave, it evaporates there leaving a residue of $CaCO_3$. As the process continues, slender column-like deposit grows from the roof, which is known as stalactite. When the rate of percolation of $CaCO_3$ containing water is more, a part of it falls down to the floor of the cave. With continuance of the process, a stout and slender cone like body grows from the floor towards the roof, which is known as stalagmite. If the growth of both stalactite and stalagmite continue, both may join together producing a pillar like structure known as dripstone.

(g) Travertine (calc sinter): This is the carbonate deposit formed by evaporation of $CaCO_3$ saturated water oozing out from hot springs.

(h) Kankar: This is the nodular or concretionary form of $CaCO_3$ formed by the evaporation of subsoil water drawn to the surface by capillary action.

**(vi) Properties and uses:** Limestones are most unpredictable rocks in terms of porosity and permeability because they can be easily corroded by acidified water.

Some limestone beds, which appear massive and compact externally, may have solution cavities and channels inside. Due to highly variable porosity and permeability, they can be the best aquifers for groundwater and reservoir rocks for storage of oil and gas. Hard and indurated limestones are good building materials.

## 2.6. Sample questions (Sedimentary petrology)

### . 2.6.1. Long answer type questions

(i) Give an account of the formation of sedimentary rocks.

(ii) Describe different types of mechanical structures of sedimentary rocks with neat sketches.

(iii) Give an account of the chemical structures of sedimentary rocks with neat sketches.

### 2.6.2. Describe the texture, structure, mineralogy and use of following sedimentary rocks

(i) Conglomerate (ii) Breccia (iii) Sandstone (iv) Shale (v) Limestone

### 2.6.3. Distinguish between the following pairs

(i) Tabular cross bedding and trough cross bedding

(ii) Wave ripple and current ripple

(iii) Roundness and sphericity

(iv) Hummocky cross stratification and herring-bone cross stratification

(v) Nodule and spherulite

(vi) Rosette and concretion

(vii) Geode and septaria

(viii) Burrows and borings

(ix) Faecal pellets and coprolites

### 2.6.4. Write short notes in about five sentences

| | | | | | |
|---|---|---|---|---|---|
| (i) | Lithification | (vi) | Sphericity | (xi) | Cross bedding |
| (ii) | Sorting | (vii) | Ripple mark | (xii) | Stylolite |
| (iii) | Bedding | (viii) | Mud crack | (xiii) | $\Phi$ - scale |
| (iv) | Sole marks | (ix) | Fabric | (xiv) | Size of sediments |
| (v) | Cementation | (x) | Roundness | (xv) | Graded bedding |

### 2.6. 5. Fill in the blanks with appropriate word/ words

(i) The primitive men were using ochers for __________.

(ii) The area of exposure of sedimentary rocks is ______ than the igneous rocks.

(iii) Rocks are converted into sediments by __________ process.

(iv) The process of conversion of sediments to sedimentary rock is known as_________.

(v) New minerals formed during lithification of sediments are known as__________ minerals.

(vi) Sediments of mean diameter more than 256 mm are known as _________.

(vii) The size range of sand is __________ to ___________ mm.

(viii) Sediments of roundness less than 0.15 are __________

(ix) Symmetric ripples are produced by _____________.

(x) Cross beddings are useful in determination of _______________.

**Answers**

| | | | | | |
|---|---|---|---|---|---|
| (i) | Coloration | (v) | Authigenic | (ix) | Wave action |
| (ii) | More | (vi) | Boulder | (x) | Palaeocurrent direction |
| (iii) | Weathering | (vii) | 2-0.0625 mm | | |
| (iv) | Lithification | (viii) | Angular | | |

### 2.6.6. Choose the correct answer

(i) Logarithmic scale for size of sediment was proposed by:

(a) Krumbain (c) Auden

(b) Pettijohn (d) Wentworth

(ii) Granule has size range of:

(a) 8 – 4 mm (c) 2 – 0.5 mm

(b) 4 – 2 mm (d) < 0.25 mm

(iii) Sediments of size < 0.004 mm are known as:

(a) Pebble (c) Clay

(b) Sand (d) Silt

(iv) Sediments of roundness more than 0.60 are known as:

(a) Well rounded (c) Angular

(b) Subrounded (d) Subangular

(v) Bimodal and bipolar cross stratification is characteristic of:

(a) Hummocky cross stratification (c) Asymmetric or current ripples

(b) Herring-bone cross stratification (d) Tabular cross bedding

(vi) Texture of sandstone is:

(a) Rudaceous (c) Argilaceous

(b) Arenaceous (d) Calcareous

(vii) Oligomictic conglomerates made of:

(a) Quartz and feldspar pebbles (c) Pebbles are of different composition

(b) Pentagonal boulders (d) Pebbles are of same composition

(viii) Angular sand of 1 to 0.5 mm diameter is termed as:

(a) Cobble (c) Gravel

(b) Grit (d) Coarse sand

(ix) Arenites are sandstone with:

(a) Less than 15% matrix (c) $CaCO_3$ cement

(b) More than 15% matrix (d) Ferruginous cement

(x) Orthoquartzites are sandstones with:

(a) More than 95% feldspar
(b) Less than 95% quartz
(c) More than 95% quartz
(d) More than 95% rock fragment

**Answers**

(i) Krumbain
(ii) 4 – 2 mm
(iii) Clay
(iv) Well rounded
(v) Herring-bone cross stratification
(vi) Arenaceous
(vii) Pebbles are of same composition
(viii) Grit
(ix) Less than 15% matrix
(x) More than 95% quartz

************

# CHAPTER – 3

# METAMORPHIC PETROLOGY

## 3.1. DEFINITION OF METAMORPHISM

Metamorphism refers to mineralogical recrystallisation, chemical reconstitution and structural re-arrangement of the solid rocks due to newly imposed physico-chemical conditions which are different from those that existed at the time of origin of the said rocks below the zones of cementation and weathering.

At normal surface temperature and pressure conditions, the surface rocks change over which is included under weathering. Similarly, loose secondary rocks are hardened by cementation under similar conditions. All these changes take place above the zones of cementation and weathering. However, at certain depths with a little rise of temperature and pressure conditions, some changes take place within the sedimentary rocks without obliterating sedimentary characters. These changes are termed as diagenetic changes and the phenomenon is *diagenesis.*

The primary or secondary or pre-existing rocks may go down the interior of the earth where temperature and pressure conditions are more. Even the continued sedimentation in geosynclines increases the depth of the basin and the rocks at the floor are subjected to higher temperature and pressure conditions. Under these conditions, the mineralogy of the above rocks may change by recrystallisation and chemical reconstitution. Some new minerals are formed by reactions. The texture and structure of the above rocks are obliterated leading to structural rearrangement. This comes under the domain of metamorphism.

Hence, all those chemical, mineralogical and structural changes which take place beneath the zones of cementation and weathering are included under metamorphism. All these changes take place in the solid state. At much higher temperature and pressure conditions, *anatexis* takes place where rocks of granitic composition partially fuse to give *anatectic* melt.

## 3.2. AGENTS OF METAMORPHISM

Metamorphism is effected mainly by temperature, pressure and chemically active fluids which are known as the agents of metamorphism.

### 3.2.1. Temperature

The upward flow of heat emanated from the mantle varies from place to place and is known as the geothermal gradient. Most metamorphic reactions take place due to rise of temperature caused by the geothermal gradient, depth of burial or by intrusion of magma. Other heat sources are chemical and radiogenic sources. In case of injection of magma, the country rocks are subjected to temperature of the order of 800°C - 1000°C near the contact of the magmatic body and decreases outward. Temperature also rises due to increase of depth of burial. In places of higher geothermal gradient, the temperature at greater depth of burial increases up to 700°C to 750°C at which anatexis takes place. The minimum temperature at which metamorphism begins is about 150°C.

### 3.2.2. Pressure

With rise of depth, the pressure also increases, which is known as uniform pressure or hydrostatic pressure. This pressure is due to load of overlying rocks. Besides, other pressure variables such as water pressure ($P_{H_2O}$), Oxygen pressure ($P_{O_2}$), Carbondioxide pressure ($P_{CO_2}$) and pressure due to other volatiles also play a dominant role. These are otherwise known as fluid pressure ($P_f$) which affects the rocks undergoing metamorphism. The pressure - temperature variable with respect to depth is shown in (Fig. 3.1). The other type of pressure, known as directed pressure or stress, is dominant in the regions, where mountain-building forces are in play. This pressure or stress is due to tectonic forces. It is predominant at or near the surface of the earth and acts in any direction, i.e. upwards, downwards or sidewards. With increasing depth, this pressure becomes less and finally diminishes.

### 3.2.3. Chemically active fluid

Rocks often contain chemically active fluids like water, oxygen, carbon dioxide and other volatiles present in the intergranular pore spaces. These fluids actively take part in reactions leading to transformation of minerals during metamorphism.

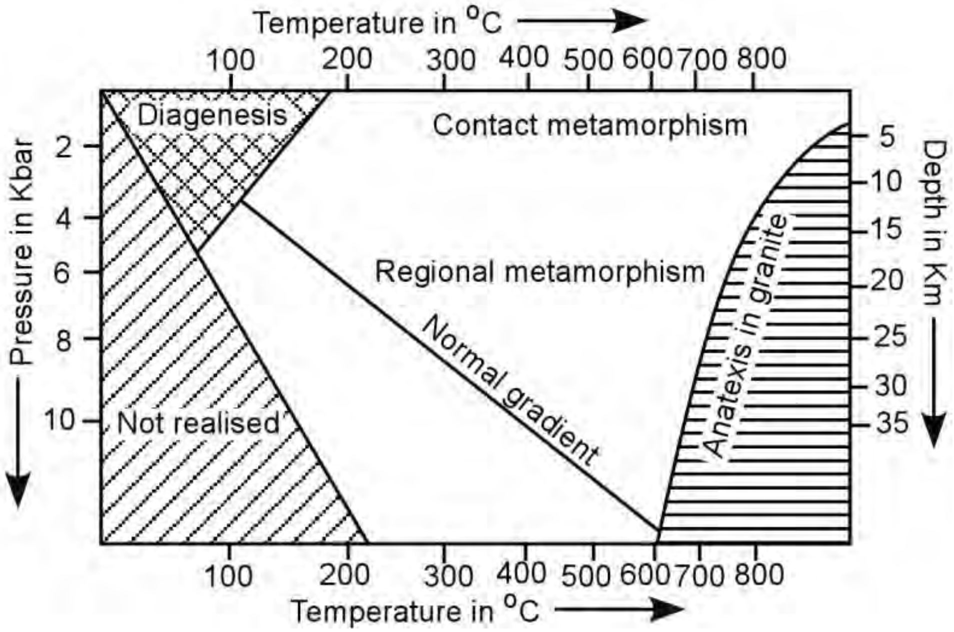


**Fig.3.1: Temperature – pressure domains of metamorphism**

## 3.3. KINDS OF METAMORPHISM

A number of kinds of metamorphism have been described by different authors. Most of these are either ambiguous or are not based on petrogenesis perfectly. Large scale metamorphism of regional scale takes place in orogenic belts and along mid-oceanic ridges. In addition, metamorphism of lesser extent is seen along the transform faults and within the contact aureoles surrounding igneous intrusions. The important types of metamorphism are described below:

### 3.3.1. Regional metamorphism

Regional metamorphism develops in the orogenic belts. This type of metamorphism takes place on a regional scale throughout the continents within orogenic belts where the geosynclinal pile of sediments are subjected to rise of temperature and pressure due to the load of superincumbent sediments. Rise of temperature is also influenced by magmatic activity. Regional metamorphism is a long process with multiphase recrystallisation and deformation. The belt is commonly hundreds or thousands of kilometres in length and tens or hundreds of kilometres in width. This metamorphism is often associated with magmatic activity and marked by volcanism and intrusion of mafic, ultramafic, basic igneous rocks and granites.

### 3.3.2. Ocean floor metamorphism

Metamorphism is widespread in the deep ocean basins, especially along mid-oceanic ridges and like regional metamorphism, extends over large areas. Mostly, the rocks affected are basic and ultrabasic in composition.

*Burial metamorphism* proposed by Coombs forms a part of both regional and ocean floor metamorphism.

### 3.3.3. Contact metamorphism

This type of metamorphism is of local nature and occurs relatively at shallow depth, late in orogenic phase. It is characterised by low pressure and variable temperature ranging from 300 - 800°C. Recrystallisation of rocks takes place in the contact aureole around intrusive igneous bodies. It is also termed as *thermal metamorphism*.

### 3.3.4. Pyrometamorphism

It is seen in xenoliths associated with volcanic rocks or in the walls of some intrusives. Partially fused rocks and occurrence of high temperature minerals like sanidine, mullite, tridymite etc. indicate a very high temperature condition.

### 3.3.5. Cataclastic metamorphism

Cataclasis means crushing and grinding of rocks. This usually takes place due to movement along faults and shear zones. Metamorphism is characterised by low temperature and incipient recrystallisation. The resultant rocks are incoherent crush-breccias near the surface and coherent cataclasites and mylonites at greater depth.

### 3.3.6. Hydrothermal metamorphism

It is also termed as metasomatic metamorphism. Under the influence of high temperature fluid phase, a number of metamorphic reactions take place leading to reconstitution and recrystallisation of minerals. In certain areas, it is widespread.

### 3.3.7. Retrogressive metamorphism

With lowering of temperature and pressure conditions, high temperature and high grade metamorphic minerals are changed over to low temperature mineral assemblages which are stable at the changed conditions. This type of metamorphism is also known as diapthoresis.

## 3.4. TEXTURE AND STRUCTURE OF METAMORPHIC ROCKS

During metamorphism, the rocks undergo textural and structural adjustments besides recrystallisation and reconstitution. New mineral assemblages develop with a new fabric. However, some fabrics of the pre-existing rocks survive complete obliteration. These are fabric relics or palimpsest structures inherited from the parent rocks.

### 3.4.1. Inherited texture and structure

Bedding, the most important sedimentary structure is commonly inherited and is observed in most metamorphic rocks. Besides, graded bedding, current bedding, ripple marks and some primary sedimentary structures survive. In case of coarse-grained sedimentary rocks, the outlines of individual grains or pebbles survive in metamorphosed conglomerates. In low grade metamorphic rocks, even outlines of fossils remain intact and are recognizable.

Some typical magmatic textures like porphyritic, poikilitic and ophitic often withstand obliteration and are recognised in low to moderate grade of metamorphosed igneous rocks. Amygdaloidal structure often remains as relic fabric. A few textures and structures like schistosity, gneissosity, inclusions, porphyroblasts are inherited from the parent rock to the newly developed metamorphic rocks.

### 3.4.2. Newly developed fabric

The new fabric of metamorphic rocks is developed in two ways – one formed by mechanical strain and rupture and the other by chemical reconstitution with the growth of new minerals in the solid state. The first type of fabric is termed as *cataclastic,* characteristic of cataclastic rocks, and the later is *crystalloblastic.*

*Crystalloblastic* fabric is developed due to simultaneous growth of all the component crystals in a solid state. During this growth, some crystals tend to develop their faces perfectly and the rock with such crystals are said to show *idioblastic* fabric. Some minerals grow to large size giving rise to *porphyroblastic* texture. *Porphyroblasts* may enclose numerous small crystals of other minerals, resulting in the formation of *poikiloblastic texture.* Due to simultaneous growth in the solid state, most of the grains are irregular in outline; such type of fabric is termed as *xenoblastic.* When almost all the grains of *xenoblasts* are of equal size the texture is *granoblastic.* Micaceous platy and flaky minerals give rise to lepidoblasitc and fibrous minerals form *nematoblastic* texture. One of the important textures of the deformed schists and gneisses is the preferred orientation of the minerals known as *tectonitic* fabric.

From the above discussion, it is inferred that the word "blast" plays an important role for knowing above two major types of textures. When it is used as prefix, it indicates palimset or inherited texture and when it is used as suffix, it indicates crystalloblastic or newly developed texture.

Megascopic and microscopic structures of the metamorphic rocks are described below:

**3.4.3. Cataclastic:** This type of structure is formed by mechanical strain, rupture, crushing and pulverisation. Finally, the grains are completely powdered. This type of structure is shown by *crush breccia, cataclasites* and *mylonites.*

**3.4.4. Maculose:** During recrystallisation, the components with higher percentage give rise to large grains owing to their power of crystallization. Outline of large grains or spotting of the carbonaceous matter occurs due to incipient recrystallisation. This type of structure is seen in low grade contact metamorphic rocks.

**3.4.5. Schistose:** As recrystallization proceeds, micaceous minerals with flaky, platy, lamellar, tabular and minerals with prismatic habit are oriented in a particular direction with the development of a perfect planar structure. The resulting structure (Fig. 3.2) is known as schistose which is seen in metamorphic rocks of regional metamorphic belts as well as in ocean floors.

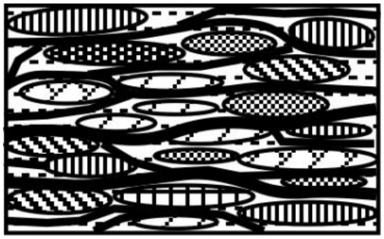

**Fig.3.2: Schistose structure**

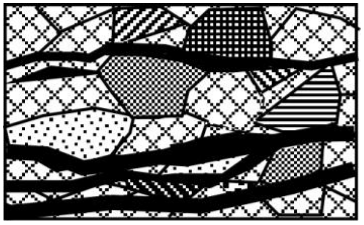

**Fig.3.3: Gneissose structure**

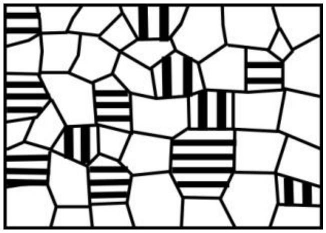

**Fig.3.4: Granulose structure**

**3.4.6. Gneissose:** Alternation of schistose and granulose bands gives rise to gneissose structure (Fig. 3.3) which is characteristic of quartzo-feldspathic rocks. At higher temperature, the parallel nature of the schistocity is disturbed, flaky minerals break down and the *schistose* structure passes over to the gneissose structure in medium and high temperature of metamorphism.

**3.4.7. Granulose:** Predominance of equidimensional grains like quartz, feldspar, garnet, pyroxene etc. gives rise to granulose structure (Fig.3.4). These minerals recrystallise at very high temperature at which the flaky and platy minerals completely break down and are eliminated. This type of structure is characteristic of metamorphic rocks like granulite, charnockite and khondalite.

## 3.5. TYPES AND DETERMINATION OF PROTOLITH

Protoliths are original rock materials which undergo metamorphism. The chemical composition of the prtolith, is however, a significant factor controlling the mineralogical composition of the product rock. Generally they are of six types:

**(i) Pelitic (shale, mudstone)**

(a) Quartzo-feldspathic (sandstone, rhyolite, granite, chert)

(b) Calcareous (limestone, dolomite, marls)

(c) Basic (basalt, andesite, gabbro, diorite)

(d) Magnesian (peridotite, serpentine)

(e) Ferruginous (ironstone, umbers)

**(ii) Pelitic protoliths** = Rocks enriched in clay minerals

(a) High $Al_2O_3$, $K_2O$, lesser amounts Ca

(b) Micas favoured because of $Al_2O_3$ content

(c) Also aluminosilicates: $Al_2SiO_5$ - sillimanite, andalusite, kyanite.

(d) Kyanite: Highest density (smallest volume) forms at higher pressures.

(e) Andalusite: Lowest density, largest volume, forms at low pressures.

(f) Sillimanite: Intermediate density, volume; forms at moderate T, P.

(g) Alumino-silicate triple point = 5.5 kb at 600oC

(h) Wet granite solidus: Shows where anatexis occurs in sillimanite zone.

(i) Staurolite ($2Al_2O_5$ $Fe(OH)_2$) = Common metamorphic mineral

(j) Need an Al and Fe-rich protolith -- This restricts occurrence

**(iii) Quartzo-feldspathic protoliths (Psammitic)**: High $SiO_2$, low Fe and Mg

(a) Quartz-rich sandstones with varying % feldspars ("arkose")

(b) Felsic igneous rocks (rhyolites, tuffs, granites)

(c) If protolith >50% quartz then probably a sandstone or chert.

(d) Gneiss: Fine-grained at low grade, coarser with increasing grade.

(e) Felsic tuffs, granite hard to tell from arkose when highly metamorphosed.

**(iv) Calcareous Protoliths**: High CaO, $CO_2$

(a) Limestones and dolomite form marbles

(b) Impure limestones (with clay, silt) form Calc-silicates:

(c) [tremolite, diopside, wollastonite, forsterite, epidote, et cetera]

**(v) Basic Protoliths**: Low $SiO_2$ moderate CaO, MgO, FeO

(a) Basalts, andesites, gabbros - mafic igneous rocks.

(b) Some shale-limestone mixtures.

(c) Minerals depend on grade: chlorite, actinolite, hornblende, plagioclase, epidote, garnet.

**(vi) Magnesian Protoliths**: Very low $SiO_2$, high MgO

(a) Peridotites >> serpentine, magnesite.

(b) Serpentine (low T) >> antigorite (high T serpentine), olivine.

**(vii) Ferruginous Protoliths**: High $Fe_2O_3$

(a) Ironstones = Precambrian iron formations (Fe-rich cherts).

(b) Umbers = Fe-rich cherts, shales associated with Mid Oceanic Ridge.

## 3.6. PETROGRAPHY

The textural, structural and mineralogic characters of certain important metamorphic rocks are described below:

### 3.6.1. Gneiss

**(i) Texture & Structure:** This is a coarse grained irregularly banded metamorphic rock with gneissose structure in which a gross banded character develops. It shows xenoblastic and porphyroblastic textures. It is the product of high grade regional metamorphism and also occurs in the innermost part in case of contact metamorphic rocks.

**(ii) Mineralogy:** The constituent minerals are equidimensional grains like quartz, feldspar, garnet. Micaceous minerals are either absent or present in subordinate amount. Because of high temperature and pressure of metamorphism, the minerals become ellipsoidal and are oriented in a particular direction, thus, forming an ill defined planar structure.

**(iii) Indian Occurrence:** In India, gneisses are found in all Precambrian terraines. In Odisha, quartzofeldspathic gneisses are abundant in the Eastern Ghats Supergroup of rocks. Most of the granites are gneissose in nature.

### 3.6.2. Schist

**(i) Texture & Structure:** The metamorphic rocks with perfect planar structure are known as schists. The micaceous minerals with platy, flaky and prismatic habits are arranged to show schistose structure as in case of mica-schist, chlorite schist etc. The textures exhibited by these rocks are lepidoblastic, porphyroblastic, idioblastic, xenoblastic, poikiloblstic etc. Schists are the products of low to moderate grade of metamorphism. They occur in almost all regional and contact metamorphic terrains.

**(ii) Mineralogy:** Muscovite, biotite, chlorites, amphiboles, epidote, staurolite, serpentine, kyanite, sillimanite etc. predominate. Equidimensional minerals like quartz, feldspars, garnent may be present.

**(iii) Indian Occurrence:** In India, schists are abundant in all the Precambrian metamorphic belts.

In Odisha, schists are found in Sundargarh, Mayurbhanj district and many other areas, even in rocks of the Eastern Ghats where higher grade of regional metamorphism in exhibited.

### 3.6.3. Quartzite

**(i) Texture & Structure:** It is a metamorphic rock with granoblastic and xenoblastic textures. The structure is commonly granulose.

**(ii) Mineralogy:** Quartz is the most abundant mineral, Feldspars, kyanite, sillimanite, occasional micas and other ferruginous minerals may be present in minor quantities.

It is the product of contact or regional metamorphism of sandstones where the constituent minerals are recrystallised with the complete obliteration of the clastic nature. Often igneous quartz veins are recrystallised to give rise to quartzites.

**(iii) Indian Occurrence:** In India, these rocks are found in Precambrian terraines like Dharwars, Eastern Ghats, Central India, Rajasthan and many other areas.

In Odisha, it occurs in the Eastern Ghats Supergroup, Iron Ore Supergroup and Gangpur Group of rocks.

### 3.6.4. Marble

**(i) Texture and Structure:** This is a metamorphic rock with granoblastic texture. The structure is granulose. In some cases, sachharoidal texture is also seen.

**(ii) Mineralogy:** Commonly limestones are metamorphosed to marble. Calcite and / or dolomite are the chief minerals. The impurities of the limestone react with calcium carbonate to give rise to some calc-silicate minerals. Marbles are the products of low to high grade regional or contact metamorphism of calcareous sediments.

**(iii) Indian Occurrence:** In India, marble occurs largely in the Aravallies of Rajasthan, in Sausar Group in M.P. and in Chhatishgarh region.

In Odisha, marble occurs in the Gangpur Group of rocks in Sundargarh district.

### 3.6.5. Khondalites

**(i) Texture & Structure:** These are high grade metamorphic rocks with gneissose or schistose structure. The texture is commonly crystalloblastic, xenoblastic or granoblastic.

**(ii) Mineralogy:** The chief minerals are quartz, feldspars, garnet, sillimanite with minor amounts of graphite and some manganese-silicates. These minerals usually show some preferred degree of orientation. For this, the rock is termed as quartzofeldspathic granetiferrous-sillimanite-schist or gneiss.

**(iii) Indian Occurrence:** These are the products of high grade regional metamorphism. Khondalites occur in South and Eastern India. It is the typical metamorphic rock of the Eastern Ghats Supergroup of rocks in India and Odisha as well.

## 3.6. SAMPLE QUESTIONS

### 3.6.1. Long answer type questions

(i) Briefly describe different agents of metamorphism.

(ii) Describe different kinds of metamorphism.

(iii) Give a brief account of texture and structure of metamorphic rocks

(iv) Write notes on:

(a) Gneiss (b) Schist (c) Marble (d) Khondalite

### 3.6.2. Short type questions

(i) Write short notes within 3 to 5 sentences.

(a) Agents of metamorphism (b) Schist

(c) Contact metamorphism (d) Gneiss

(ii) Distinguish between the following pairs. (Answer should be within 3 to 5 sentences.)

(a) Quartzite and Marble

(b) Sehist and Gneiss

(c) Contact metamorphism and Regional metamorphism

**3.6.3. Answer the following questions within one short sentence**

(a) Name two agents of metamorphism

(b) Name two important metamorphic structures

(c) What is palimpsest texture?

(d) Name the rock that is formed by metamorphism of limestone

**Answers:**

(a) Temperature and pressure

(b) Schistose, Gneissose, Granulose, Maculose, Cataclastic - any two

(c) Texture inherited from the parent rocks

(d) Marble

**3.6.4. Objective type questions**

**(i)** Out of the following which is a metamorphic rock?

(a) Breccia (b) Khondalite

(c) Diorite (d) Pegmatite

**Answer:** Khondalite

**(ii) Correct the sentences, if they are incorrect without changing the word / words underlined.**

(a) Schistosity is the characteristic structure of marbles.

(b) Cataclastic structure is commonly shown by igneous rocks.

(c) Quartzite is formed by metamorphism of limestone.

(d) Contact metamorphism takes place mainly due to increase of pressure.

**Answers:**

(a) Schists (or metamorphic rocks) (b) Metamorphic rocks

(c) Sandstones or vein quartz (d) increase of pressure and temperature

**(iii) Fill in the blanks by appropriate word / words.**

(a) Marble is formed by _____________ of limestone.

Answer: metamorphism

***************

# CHAPTER – 4

# ECONOMIC GEOLOGY

## 4.1. INTRODUCTION

The domain of „Economic Geology" includes minerals, metals and certain rocks which promote the progress and welfare of a nation. The value of minerals and rocks was known to human beings since „Stone age" (e.g. Palaeolithic, Mesolithic and Neolithic ages), the „Bronze age", the „Iron age", the „Atomic age" and the reigning age of the „Space Odyssey". The broad spectrum of economic materials forms the prime base that not only fortifies the nation"s exchequer (income), but also provides livelihood to the local dwellers and the peripheral settlers. Thus, the resulting benefits accruing from the core of natural economic mineral commodities keep the industrial wheel of the country ever moving forward.

The scope of economic geology pertains to the basic natural raw materials which promote the development of a country and its citizens. It enters into our modern life-style in multitudinous ways. The principal scope, however, pertains to the application of the overall geologic knowledge to the study and analysis of geo-economic bodies in respect of their (i) broad mineralogical entities, (ii) modes of occurrence (geometric forms in space), (iii) genesis (mode of formation), (iv) search and investigational methodologies and (v) various utilarian aspects.

## 4.2. CLASSIFICATION OF ECONOMIC MATERIALS

Economic materials are the natural crustal products which include (i) minerals of commercial value commonly referred to as economic minerals and (ii)

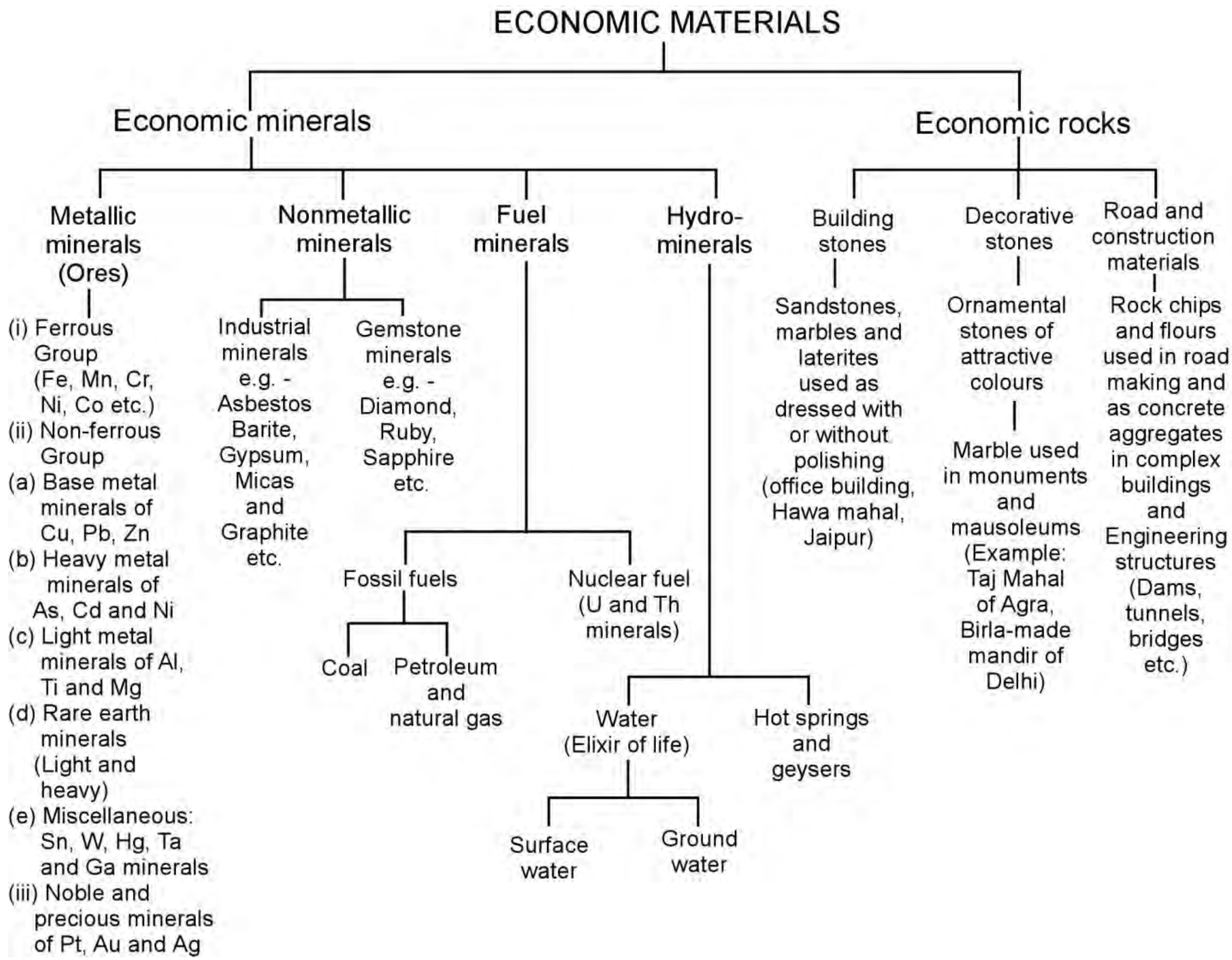


**Fig. 4.1: Schematic classification of natural economic materials**

some rocks of industrial utility. A simplified and schematic classification of the natural economic materials is presented in Fig. 4.1. The economic minerals can be broadly divided into metallic and non-metallic. The distinction between these two groups is given in Table 4.1.

## 4.3. ORE, GANGUE, TENOR AND GRADE

### 4.3.1 Introduction

About 90% of the minerals present in the crustal apron constitute the rock forming silicates and carbonates. The rest 10% comprise the quantum of economically usable minerals which amount to about 180 metallic minerals and 70 non-metallic minerals (total being 250). This statistical estimation exclusively pertains to the global perspective. However, the Indian scenario presents a numerical figure of 56 economically viable minerals comprising 38 major minerals, 15 minor minerals excluding the commodities of petroleum, natural gas and various forms of water (surface, underground and icecaps), as per the current MMRD (Mines, Minerals, Regulation and Development) Act.

### 4.3.2. Ore

**Definition:** (a) Ore may be defined as a natural aggregate that contains sufficient amount of valuable metallic components mixed with valueless gangue, that permit industrial extraction at a profit.

(b) A more expressive definition is: Ore is a natural assemblage of economically viable metallic mineral(s) and the useless non-metallic rock forming minerals called the „gangue" from which one or more metals can be extracted at profit.

**Narration:** Thus an ore is more or less a physical mixture between two parts termed as (i) useful ore mineral(s) and (ii) worthless gangue material.

Ore minerals are natural inorganic chemical compounds of metals. These occur in

**Table 4.1: Distinction between metallic and non-metallic minerals**

| Parameters | Metallic Minerals | Non-metallic Minerals |
|---|---|---|
| 1. Nature /mode of use | For extraction of metalls in blast furnace and smelters | No metal extraction involved. Used in raw form more or less in cement, refractory, abrasive andfertiliser industries |
| 2. Colour | Mostly black /steel gray; a few are brass /bronze yellow e.g. pyrite and chalcopyrite | Various shades of green, blue, yellow, pink, red and white |
| 3. Lustre | Metallic to submetallic | Non-metallic lustres e.g. resinous, vitreous, silky, pearly and admantine |
| 4. Streak | Diagnostic in some e.g. chalcopyrite (greenish black) Hematite (cherry red) | Non-diagnostic being white to colourless. |
| 5. Opacity | Mostly paque | Non-opaque; mostly translucent to transparent |
| 6. Secific gravity | High; commonly more than 5 | Commonly low; between 2.6 to 2.8 |
| 7. Magnetism | Highly to moderately magnetic i.e. para-and ferro-magnetic | Very weakly to non-magnetic (diamagentic) |
| 8. Conductivity (heat and electricity) | Invariably good conductors | Invavariably bad to non-conductors |
| 9. Malleability | Variably malleable | Invariably brittle (non-malleable) |

nature as :

(a) Native metals and alloys such as gold, silver, platinum and copper

(b) Oxides of metals like Fe, Mn, Cr, W, etc.

(c) Hydroxides of metals like Fe and Mn etc.

(d) Carbonates of a few metallic elements such as iron carbonate (siderite)

(e) Sulphides of metals like Cu, Pb and Zn etc.

(f) Complex sulphosalts of metals e.g., arsenides, antimonides

(g) Halides of metallic elements such as chlorides and fluorides

### 4.3.3. Gangue

**Definition:** Gangue may be defined as (i) the valueless non-metallic mineral matter with or without rock material that encloses and bind the ore (metallic) minerals and (ii) as the discardable components of an ore consisting of rock forming minerals and / or rock matrix which strongly binds the ore minerals into a natural aggregate.

**Narration:** The age relation between the ore mineral and gangue may be (i) ore minerals may be younger or later than gangue, (ii) both may be of same age i.e. may be contemporaneous, (iii) Gangue may be younger than ore minerals.

The gangue is invariably discarded as wasteful material. However, gangue may rarely contain nonmetallic mineral of some value. In general, gangue comprises quartz, feldspars and feromagnesian minerals.

### 4.3.4. Tenor

**Definition:** Tenor is defined as a measure of metal content in an ore. In most of the ores, it is expressed as percentage (%) of metal in the ore. However, in case of precious and noble metals and minerals of Au and Ag, tenor is expressed as ounces or dwt per ton in FPS (British) system or as grams per tonne in CGS

(Metric) system.
In case of oxide ores of Fe, Mn, Cr and Al etc. the tenor ranges between + 60% to 40% (±) of metal; in respect of sulphide ores of Cu, Pb and Zn, it is very low ranging between more than 6 % to less than 1 % at the minimum.

**Narration:** Tenor has the highest value which is the theoretical percentage of metal in an ore in its purest form. For economic consideration, tenor is taken as the lowest economic limit of metal incidence in percent at which ore remains profitable for metallurgical use.
Salient features of tenor are as follows:
(a) Tenor varies in different ores of the same metal in a country. In India, for Fe metal, the chief ores are hematite ($Fe_2O_3$) and magnetite ($Fe_3O_4$). Tenor of hematite is +59% Fe and for magnetite, it is 35% Fe.
(b) Tenor varies in the same ore from one country to another. For hematitic ore, it is +59% Fe for India whereas for Japan, it is ± 25% Fe.
(c) It varies with the state of the advanced technological know-how, by which ores of lower tenor can be worked out profitably.

**4.3.5. Grade:** As compared to tenor, grade of an ore is more or less a qualitative to semi quantitative term. It applies to both metallic and nonmetallic (industrial) economic minerals.

In ores, it shows a few more chemical constituents other than the tenor in terms of oxides, fluxes (constituents which lower the melting point in smelters) and a few harmful elements e.g. sulphur, phosphorus and some toxic elements like arsenic and lead etc.

Further the ores are arbitarily divided into size grades at mine site such as coarse (lumpy), medium to fine grained fractions. Again the ores may be principally classified into (i) metallurgical grade, (ii) refractory grade and (iii) chemical grade etc. on the bases of their fields of use.

## 4.4. ELEMENTARY IDEA ABOUT THE PROCESSES OF FORMATION OF MINERAL DEPOSITS

### 4.4.1 Introduction

Mineral deposits are formed in a variety of ways which manifest either as a single process or more often as combination of various processes. A mineral in general is composed of cationic and anionic elements which are bonded to form a stable phase under certain interplaying conditions in harmony with the established geochemical laws. These controlling physico-chemical conditions (factors) are (i) temperature - rising and falling (ii) pressure (hydrostatic and directed) (iii) pH (hydrogen ion concentration) (iv) Eh (exidation - reduction potential) (v) action of emanating mineralising solution and chemically active gases and fluids (vi) state of deposition i.e. whether ionic or colloidal. Precisely a decrease in pressure and temperature tends to lower the solubility of minerals in solution, promoting thereby their crystallization / precipitation. Of the vast number of crustal minerals, only certain minerals form the smaller bulk of economic minerals which constitute metallic minerals (ores) and non-metallic (industrial) minerals. The ancient ideas concerning ore / mineral genesis date back the early 16$^{th}$ century, when fanciful Greeko-Roman thoughts were held by a group of arm-chair dreaming philosophers like Aristotle, Pliny, Magnus, Becon and Buffons. The mid-16$^{th}$ century witnessed the advent of the golden era highlighted by the existence of ore-genetic concepts which got matured and proliferated with the passage of time, through later centuries. The doyen of this progressional trait was none other than „'Georgius Agricola" of Germany who for his most memorable treatise on ore genesis entitled as "De Re Metallica" published in mid-16$^{th}$ century, is reckoned as the "Father of both mineralogy and economic geology". The fag end of 18$^{th}$ century witnessed the emergence of two diametrically opposite ore genetic concepts of (i) The

Plutonistic school of thought championed by James Hutton, a Scottish amateur naturalist and a doctor by profession, who propounded the axiom doctrine of uniformitarianism (meaning “present is the key to the past”) in 1788. According to his concept, all minerals were the products of igenous and metamorphic processes. (ii) The neptunistic (neptune means of „god of ocean‟) school of thought advocated by A. G. Werner of Germany in 1791 and his ardent supporters who strongly believed the formation of ores in vein forms aided by precipitation of materials dissolved in saline waters. It is a syngenetic-sedimentary concept.

These two concepts afforded the basic platform which influenced and streamlined the growth of modern concepts / theories. It is imperative to mention here that these ore genetic concepts got proliferated in parallel trends in Germany, France, Britain, Scandinevian countries, Soviet Union, U.S.A. and Canada during second half of 20$^{th}$ century.

### 4.4.2 Outlines of Processes of Formation

Based on the processes of formation of mineral deposits, various genetic schemes of classification have been proposed from time to time. One such scheme proposed by A. M. Bateman in 1942 and subsequently reiterated by him in 1950, yet remains to be the standard and the most world widely followed genetic classification. It is instantly usable both in the field and laboratory by teachers, researchers, students, geo-professionals and others linked with earth sciences.

Bateman‟s genetic classification of mineral (ore) deposits is outlined as follows:

(i) Magmatic concentration
(ii) Sublimation
(iii)Contact metasomatism
(iv)Hydrothermal action

(v) Sedimentation
(vi) Evaporation
(vii) Residual concentration
(viii) Mechanical concentration
(ix) Oxidation and supergene enrichment
(x) Metamorphism

The magmatic concentration and hydrothermal processes are dealt with some what extensively at the end. Other processes are shortly noted below:

**(i) Sublimation:** It is the process of formation of minerals by volcanic, fumarolic and hot spring activities at or near the surface in low temperature and low pressure conditions. The minerals are products of sudden cooling of gaseous emanations / vapour matter. Deposits occur as small and thin encrustations around volcanic orifices and also around sites of geysers, hot springs and fumaroles. These are superficial and small sized deposits which occur on smaller scales. Indian examples of sublimate deposits are: (i) native sulphur of Barren island near Andaman island in Bay of Bengal (ii) both sulphur and borax (mineral salt of boron) of Pugavalley, Kashmir.

**(ii) Contact Metasomatism:** This is also termed as pyrometasomatism. This process is characterized by the following features:

(a) Confined to contact aureole (zone) between the intrusive rocks (mostly granitic) and invaded country rock.
(b) Invaded rock is altered around it by the combined effect of heat transfer and interchange of chemical constituents.
(c) Formation of new high temperature and high pressure minerals.
(d) The deposits are irregularly shaped and small sized.

(e) The igneous intrusives are large sized batholiths or stocks of granitic composition.

(f) Invariably associated with new silicate minerals (skarn minerals).

(g) Resulting mineral deposits are (i) non-metallic minerals such as fluorite, micas, tourmaline, topaz and graphite (ii) some metallic menrals (ores) such as iron ore, Cu, Pb and Zn ores, tin (Sn) and tungsten (W) ores. Indian example is that of tin deposits of Mundagoda, Koraput district, Odisha.

**(iii) Sedimentation:** Various weathered products from preexisting rocks are transported to the depositional sites by various geomorphic agencies such as running water, ice, air or marine wave / current actions to form transported deposits of various clastic (detrital) rocks and non-clastic rocks of chemical precipitates and organic debris formed in lake, river, desert and marine environments.

Some sedimentary clastic rock, chemical (colloidal) precipitates, bio-clastic products and biogenically precipitated chemical sediments may contain metallic and non-metallic minerals of economic importance. Examples are (i) Coloured sandstones and limestones used for building and decorative purposes, (ii) Banded colloidal precipitates such as Banded Hematite Chert (BHC), Banded Hematite Jasper (BHJ) of Precambrian age (Banded Iron Formations) of Odisha-Jharkhand-M.P. (iii) Manganese nodules in Arabian sea and Bay of Bengal (iv) Bituminous coal beds of Lower Gondwana age in Indian river basins (Talchir, Ib and Damodar valleys).

**(iv) Evaporation:** It is the process of slow vapour formation from enclosed sea water or saline lake water where by saline water becomes concentrated in salts on volume reduction. At various stage of volume reduction, the least soluble salt minerals form first and the most soluble minerals at the end. This causes precipitation of salts to form bedded deposits of common salt (NaCl), gypsum (hydrated $CaSO_4$), K-salt etc. Many marine evaporates are formed from successive volume reduction of saline water in enclosed and cut-off sea body in which the origin is explained by „bar theory". Also inland saline lakes in arid climate to produce evaporites come under this category.

**World example:** Halite (NaCl) and gypsum beds of Strassfurt, West Germany.

**Indian examples:** (i) Gypsite deposits of desert lakes, Thar Desert, Rajastan (at Jamasar and Kavas).

**(v) Residual concentration:** Rocks containing economic minerals undergo in-situ (inplace) mechanical and chemical weathering. Resultantly unstable minerals go into solution and insoluble mineral ingredients get retained in the rocks. The insoluble mineral residues so formed on being subjected to continued and recurrent operations may be quantitatively enriched in insoluble and stable minerals of economic value. These end products result in the formation of insitu laterites, bauxites and clay products of commercial value. These residual deposits are formed under suitable palaeo-climatic, geomorphic and source rock conditions

**Indian examples:** (i) High level lateritic and bauxitic flat deposits forming aprons capping the Eastern Ghats rocks in East coast bauxitic-lateritic high plateaus (ii) Similar cappings in Deccantrap bauxitic high terrains of M.P., Maharastra and Gujrat states.

**(vi) Mechanical concentration:** Some hard, durable and heavy ore minerals and a few non-metallic minerals get dislodged from the country rocks by the combined effect of differential weathering phenomena and subsequently deposited at favourable sites near and far off the location of source rocks. The heavy and resistant minerals are formed and deposited as the resultant effects of combined gravity and current actions in river water, air and sea waters (waves). By this differential action, heavy and durable mineral grains get separated from lighter fractions. The heavy mineral fractions form concentrated surfacial accumulations termed as „Placers". The placer deposits are

(a) Eluvial placers formed by gravity action at high hill slopes close to the lodes.

(b) Deluviafplacers are talus placers comprising nearly in situ coarse debris formed by short distant gravity transport.

(c) Colluvial placers or Proluvial placers formed by accumulation of heavy minerals fractions at the foot of hill slopes.

(d) Alluvial placers or Stream placers formed behind rock barriers at meander and confluence sites of tributary rivers.

(e) Aeolian placers formed by differential wind action.

(f) Beach placers formed along shore and shelf regions of the seas/oceans wave and current actions. Metallic minerals of native gold, cassiterite (tin ore) and ilmenite-rutile-zircon sands constitute the bulk of beach placers.

Example: (i) Diamondiferous conglomerate of Panna district, M.P.
(ii) Monazitic sands of Kerala coast, Odishan coast (Chhatrapur-Gopalpur), Andhra and Tamilnadu coasts.

**(vii) Oxidation and supergene enrichment:** This is a secondary genetic process which comprises two sub-processes operative under suitable chemical components and favourable Eh-pH conditions. The sub-processes are:

**(a) Oxidation:** Oxidation of primary / hypogene ores operative in an upper zone lying above the water table. Oxidation of primary, minerals/ores under favourable condition in presence of free oxygen yields oxidized ores, which comprise variously coloured oxides, hydroxides, carbonates and silicates of metals and also native metals.

**Indian examples:** (i) Malanjkhand copper deposit located in Balaghat district of Madhya Pradesh shows the development of thick oxidized and gossanic zone (> 100 meters thick).

**(b) Supergene or Secondary sulphide enrichment:** This sub-process is a function of oxidation and it operates below the water table where there is dearth of free oxygen. Some metals which descend from oxide-zone through the water table, replace the hypogene sulphides of the primary zone resulting in the formation of metallic sulphides. This secondary chemical reaction between descending mineralized waters and the unaltered hypogene (primary) sulphide ores results in formation of new secondary copper sulphides such as chalcocite, covellite and bornite (Cu and Cu-Fe sulphides) which volumetric ally replace the bottom zone of primary sulphides.

**(c) Gossan:** It is the uppermost part of the oxidized zone. It occurs in form of limonitic (hydrated iron oxide) cap rock that tops the leached zone of oxidized apron. It invariably consists of ubiquitous limonite that is characterised by cellular structures and tinted with a variety of colours indicative of Fe, Pb, Cu, Zn and Mo sulphides. Thus, gossan is the hard mantle of wasteful cap rock which unfolds many clues / inferences about the size, nature and mineral composition of the hidden underlying ore deposits. Gossan (true or insitu) is also termed as „Iron hat" that serves as a signboard to the sulphidic ores that lie beneath it.

**Indian Examples:** (i) Supergene sulphide enrichment: Cu-mines of the arcuate Singhbhum Copper belt located at Mosabani, Badia, and Rakha mining sectors show development of thinly persistent secondary sulphide (Cu-Fe-Ni) zone.
(ii) Gossan: Gossanic caps associated with the Khetri, Malanjkhandand and Agnigundla base metal sulphide deposits and Iron-hat gossanic tops associated

with the bauxite-laterite plateaus of the East Coast ranges of Odisha-Andhra Pradesh may be cited as classic examples.

**(viii) Metamorphism:** By metamorphism, earlier mineral deposits of igneous and sedimentary origin are transformed and equilibrated into new sets of rocks and minerals under the action of temperature, pressure, and chemically active fluids. It is essentially a process of solid state transformation of rocks which get both reconstituted and recrystallised in terms of mineralogy and texture / structure. The important mineral deposits so formed are grouped into (i) Metamorphic mineral deposits in which earlier deposits are changed both in mineralogy and textures / structures. (ii) Metamorphosed mineral deposits in which there only occurs new textural/structural readjustment without any mineralogical change.

**Examples:** (a) Metamorphic mineral deposit:
(i) Graphite deposits in Khondalite rocks and marbles of Eastern Ghats terrain in Odisha and Andhra Pradesh.
(ii) Kyanite deposits of Lapsoburu, located near Rajkharsuan in the Singhbhum district of Jharkhand state. It is the largest kyanite deposit in the world.
(iii) Sillimanite deposit of Sonarpahar area of Meghalaya state. It is also the largest of its kind in the world.
(b) Metamorphosed mineral deposits: The earlier minerals only get changed in texture-structure but not in mineralogy, e.g., marble from limestone.

## 4.5. MAGMATIC CONCENTRATION PROCESS

It is a primary process of magmatic differentiation by which large number and variety of economic mineral deposits are formed from cooling magma/lava of acidic, intermediate, basic and ultrabasic compositions. The mechanisms of magmatic differentiation are (i) fractional crystallization under gravitative settling and filter pressing (ii) liquid immiscibility (iii) thermal diffusion and (iv) gas streaming. Magmatic processes yield many valuable mineral deposits. Magmatic mineral deposits show the following characteristics:

(a) Genetically related to plutonic and hypabyssal igneous rock of all most all clans. Mostly, these are related to ultramafic and mafic rocks.

(b) These either constitute the whole igneous mass in which economic minerals are sparsely distributed or as discrete bodies of tabular sheets, lenses and pods.

(c) The overall mineralogy is simple comprising rather fewer number of minerals.

(d) Magmatic bodies are widely represented by a few types.

(e) Many metallic deposits ofCr, Ti-V, Ni-Cu sulphide and some nonmetallic deposit of diamond and corundum belong to magmatic class.

The magmatic mineral deposits of commercial value are formed by the following processes:

**4.5.1. Early magmatic process** which forms

**(i) Dissemination** in which minerals are formed by simple crystallization without concentration. Economic minerals are formed at the'very early stage of magmatic evolution and minerals are unevenly and sparsely distributed throughout the igneous body.

**Examples are:** (i) Diamond in kimberlite pipes and (ii) corundum in nepheline syenite rock.

**Indian example:** Diamond bearing pipe rock body in Majhgawan, Panna district, Madhya Pradesh.

**(ii) Segregation:** This is a type of magmatic crystallization of economic minerals leading to concentration of early formed heavy crystals under differential gravitative settling. By this, chromite deposits are mostly formed. Also platinum deposits are formed in ultramafic-mafic rocks. The resultant ore bodies occur in form of extensive bands and leticular bodies within ultramafic-mafic rocks.

**World example:** Layered chromite bodies of Bushveld complex, South Africa.

**Indian example:** (i) Sukinda chromite belt, Jajpur district, Odisha. (ii) Nausahi chromite deposits of Keonjhar district, Odisha.

**(iii) Early magmatic injection:** The early magmatic minerals get displaced from magmatic chamber into adjacent rocks towards the end phase of early magmatic process. **Example (World):** Magnetite deposit of Kiruna, Sweden.

It needs to be clarified that early magmatic deposits are formed at the same period as that of the enclosing host-rocks where as late magmatic ores are formed from the residual magmatic crystallization, much later than early magmatic fraction.

**4.5.2. Late magmatic process:** It operates upon the residual magma left after the separation of early magmatic concentration products. These magmatic minerals crystallize from residual basic magma at later stage of magmatic events. It is subclassified as follows:

**(i) Residual liquid segregation (accumulation):** Residual magma enriched in Fe and Ti, may trickle through the early formed crystal interstices and solidify in situ without further movement. These are invariably associated with basic (gabbro--norite) and ultrabasic rocks as bands and lenses.

**Examples:** Ti-bearing magnetite bands of Bushveld-Complex, South Africa.

**(ii) Residual liquid injection:** Residual liquid magma may be squeezed and injected towards low pressure zone into neighbouring region. It, being rich in Fe, forms mineralized dyke rock containing magnetite.

**Indian example:** Magnetite-Apatite deposit of Kashipatnam, Visakhapatna district, Andhra Pradesh.

**(iii) Immiscible liquid segregation:** Sulphides and silicate melt admixture in late magmatic stage remain as immiscible liquid droplets and will settle to the bottom of basic-ultrabasic magma chambers. On consolidation, admixture of sulphidic ores and silicate minerals showing rounded and globular shaped droplets form segregations. These are economically important carriers of valuable platiniferous base metal sulphide ores making up to 10 to 20%.

**Examples:** Pt-bearing base metal sulphides of (i) Ni-Cu deposits ofInsizwa type in South Africa. (ii) Pt-bearing base metal suphides in the breccia zone of Boula-Nausahi belt, Keonjhar dist, Odisha.

**(iv) Immiscible liquid Injection:** Above type of melt in semi-liquid state may be displaced to low pressure zone into which the segregated liquid may be squirted out in melt state with forceful intrusion along weak parts.

**World example:** Ni-Cu deposits at Sudbury, Ontario, Canada.

## 4.6. HYDROTHERMAL PROCESS

It is an important process of formation of mineral deposits of both metallic and non-metallic ores. „Hydro" means aqueous / water and „Thermal" means heat / temperature. In general, this process is distantly related to magmatic mineralization. As magma cools leading to crystallization of minerals in early and late stages, the residual liquid become enriched in $SiO_2$ and water and an aqueous solution impregnated with metal bearing constituents is formed. The temperature of hydrothermal process varies between 50 °C and 500 °C. This hydrothermal solution is commonly expelled from cooling granitic magmas at end stage. This solution becomes enriched in metal and nonmetal compounds inherited partially from magmatic source and mostly through leaching from the metal bearing country rocks through which this solution moves and paves during its migration and with falling temperature and pressure conditions to ultimately unload the metallic and non-metallic mineral constituents in favourable textural and structural locales in the enclosing country rocks. This solution is acidic to start with but becomes alkaline as the solution passes through rock openings. The required conditions for promoting hydrothermal process are (i) enough incidence of metal contents in the solution, (ii) solution must be capable of dissolving and transporting mineral materials (iii) presence of favourable precipitant lithology (carbonate rocks etc.) in pathways to promote crystallization from mineralized hydrotherm and (v) favourable chemical kinetics to cause deposition of ore in the channel ways.

The hydrothermal deposition is facilitated by chemical reaction of mineralized solution with wall rocks under favourable physical (temperature and pressure), pH and Eh conditions. With decrease of solubility on its forward movement, this solution promotes precipitation (crystallization) of minerals. The gamut of mineralization shows an orderly sequence of deposition of nonmetallic and metallic minerals termed as „paragenesis". Hydrothermal action promotes various types of wall rock alterations, which serve as lithologic controls for hydrothermal mineral types. Two broad types of hydrothermal process are:

**4.6.1. Cavity filling sub-process** in which minerals are deposited in various types of primary and secondary openings or cavities such as pore spaces, faults, joints, beds and other types of structural locales. The deposits are indicative of lower temperature of formation and characterized by crustification, fissure vein, stock work, saddle reef, ladder viens, breccia fillings, pore space filling and vesicular fillings by metallic and nonmetallic minerals. Cavity filling sub-process operates under comparatively lower temperature and pressure ranges.

**4.6.2. Metasomatic replacement sub-process** that operates under higher temperature and pressure regimes. In this, hydrothermal solution reacts with some earlier minerals, dissolves them and replaces thereby with new minerals/ores. This sub-process mostly operates under higher temperature and pressure regimes. It is a process of volume per volume replacement, in which features in earlier or replaced mineral phase are somewhat retained in the newly replaced phase. The replacement sub-process is characterized by (i) presence of remnants of earlier minerals, (ii) presence of pseudomorphs (iii) forms of resultant deposits conforming to massive, lodes (tabular) and disseminated types.

Hydrothermal minerals show a sequential order of deposition of minerals termed as paragenetic sequence in which quartz crystallizes first followed by other non-metallic minerals and then by sulphides and arsenides in the order of Fe, Zn, Cu, Pb, Au and Ag metals.

The hydrothermal deposits are classified into the following major types based on temperature and pressure (depth) of formation.

(i) Hypothermal deposits: High temperature (300-500°C) and very high pressure (great depth)

(ii) Meso-thermal deposits: Moderate temperature (200-300°C) and high pressure deposits.

(iii) Epithermal deposits: Denoted by lower temperature (50C to 200°C) and lower pressure deposits formed at shallow depths.

(iv) Telethermal deposits formed at low temperature and low pressure deposits formed at very shallow depths.

It may be noted that a great number of world sulphide deposits belong to hydrothermal category.

**World Examples:** (i) Cavity filling type: Fissure veins of gold, Mother lode, California, U.S.A.

(ii) Replacement type: (a) Rio Tinto, Spain (Europe) (Cu-ores) (b) Bisbee Cusulphide deposit, Arizona, U.S.A.

**Indian Examples:** (i) Cavity filling type: Veldurti-Ramallakota long fissure vein belt of Nellore district, Andhra Pradesh. (ii) Replacement lode deposits of

Singhbhum Cu-belt, Jharkhand and Khetri Cu-belt of Rajasthan (Jhunjhunu district).

## 4.7. IRON ORES

It is the second most abundant metal in the earth‟s crust next to aluminium. Although iron was known to man as early as 4000 B.C., its real industrial use started around 800 B.C. which is the start of the Age of Iron. In nature iron occurs in close association with other group of famous elements i.e. tin, manganese, chromium, nickel, cobalt etc. A wide variety of iron minerals are found in nature in form of oxides, carbonates, sulphides, silicates, hydroxides, phosphates etc. Iron is found as important constituent of silicate mineral groups such as olivine, pyroxene, amphibole, garnets, chlorites, chloritoids etc.

Iron is the most indispensable metal to human being. Iron and steel industries are of basic importance to a country‟s economy.

### 4.7.1. Mineralogy

More than hundred iron minerals occur in nature out of which a few are given in Table 4.2 which serve as sources of iron.

### 4.7.2. Uses

The industrial use of iron was started for the first time in 800 B.C. The uses of iron ore can be grouped as given below.

**(i) Metallurgical use:** Iron ores are basically used for extraction of iron metal which is used for manufacture of cast iron, wrought iron, steel and iron alloys. Iron in form of the metal is used both in home (starting from needle to utensils) and outside such as buildings, machineries, rails, railway wagons, automobiles, ships etc. In the blast furnace the lumpy ores are used after sizing and washing as such but the fines are used after agglomerating them in form of pellets or sinters.

By using noncoking coals now-a-days iron ores are reduced to sponge iron for use in blast furnaces.

**Table 4.2: Ore minerals of iron**

| Group | Mineral | Chemical Composition | Fe % |
|---|---|---|---|
| Native iron | Native iron | Fe | 100 |
| Oxides | Magnetite | $FeO.\ Fe_2O_3$ | 72.4 |
| | Hematite | $Fe_2O_3$ | 70.0 |
| Hydrated Oxides | Goethite | $HFeO_2$ | 62.7 |
| | Limonite | $HFeO_2 \cdot nH_2O$ | 59.0 to 63.0 |
| | Lepidochrosite | $FeO \cdot OH$ | 62.7 |
| | Turgite | $Fe_2O_3 \cdot nH_2O$ | 66.1 |
| Sulphides | Pyrite | FeS+ | 46.6 |
| | Pyrrhotite | $Fe_nS_{n+1}$ | 38.0 |
| | Marcasiste | $FeS_2$ | 46.6 |
| Carbonate | Siderite | $FeCO_3$ | 48.2 |
| Phosphates | Vivianite | Iron Phosphate with $H_2O$ and other impurities | Very low |
| Silicates | Chamosite<br>Greenalite<br>Stilpnomelane<br>Minnesotaite | Hydrated silicates of Fe, Al, Mg, etc. | Varies widely from 25 to 30% |

Iron ores are utilised for manufacture of stainless steel (Fe+Ni+Cr), ferrochrome (Fe+Cr) Ferro-silicon (Fe+Si), ferromanganese (Fe+Mn) which have utilization in various industries.

**(ii) Use in Coal washeries:** Iron ores mixed with washing fluids are used as a medium of floatation in coal washeries.

**(iii) Use in cement industries:** In the cement insustry it is used as a raw material to make up the proportion for iron.

**(iv) Use in Paint and Pigment industries:** Micaceous hematite, soft impure varieties of hematite (red ochre) and limonite (yellow ochre) are used in paint and pigment industries.

**(v) Miscellaneous use:**

(a) Sideritic ore after being calcined is used for generation of hydrogen by the steel-iron contact process.

(b) Many of the iron salts (sulphates, carbonate, citrate, phosphate etc.) are used in medicines.

(c) Pyrite is used for preparation of sulphuric acid and sulphur.

### 4.7.3. Classification of iron ore deposits of the world

On the basis of genesis, the iron ore deposits can be classified into the following types.

**(a) Igneous deposits:** These deposits are somewhat related to magmatic activities. These deposits are further subdivided into following types.

**(i) Magmatic deposits**: These deposits are formed by crystallization of iron minerals followed by either seggregation due to gravitative settling or by injection into adjacent rock bodies. e.g. Kumardhubi of Mayurbhanj district, Odisha, Adirondack, U.S.A. etc.

**(ii) Sublimates:** Such deposits are formed by reaction between volatile gases emanating from a volcanic source with the rocks in the vent. Volatiles which carry halides and sulphur can produce hematite at the vents.

**(iii) Contact metasomatic deposits:** These deposits are formed at the contact zones of the intrusive rocks with the country rocks. Magnetite and hematite deposits are sometimes formed at the contact of limestones with intermediate or basic igneous rocks.

**(iv) Hydrothermal deposits:** These deposits are formed by precipitation / deposition from hot mineralised solutions (hydrothermal solutions) rich in iron. These solutions are derived from magma at a late stage. Such deposits are either formed as cavity filling deposits or as replacement deposits

**(b) Sedimentary deposits:** Most of the workable iron ore deposits of the world belong to this category. These deposits are associated with banded iron formations (banded hematite /magnetite jasper, banded hematite / magnetite chert etc.) of Precambrian age where hematite or magnetite is inter-banded with silica. The iron minerals may be associated with siderite, pyrite, iron silicates etc. Iron ore deposits of India (Jharkhand-Odisha, Chhatisgarh, Karnataka, Goa), Brazil, U. S. A,, South Africa and Australia belong to this category.

In some cases iron ores of inferior quality are found in association with Barren Measures Formation of Damuda Group (Lower Gondwana) where the iron ore minerals are mostly limonitic and rarely sideritic.

**(c) Residual Concentration type deposits**: Basic, ultrabasic igneous rocks and iron rich metamorphic rocks due to weathering under humid-tropical climatic conditions may retain iron hydroxide, aluminium hydroxide etc. with release of silica, soda, potash etc. Such conditions may result in the formation of lateritoid iron ore deposits or surficial deposits.

**(d) Mechanical Concentration type deposits:** Rocks containing magnetite - hematite, ilmenite etc. may be subjected to mechanical disintegration by weathering and produce sands rich in these minerals. These sands on transportation by different geomorphic processes such as wind, running water, sea waves may deposit these mineral sands at favourable localities producing smaller deposits known as placer deposits.

### 4.7.4 Mode of occurrence

The mode of occurrence of principal minerals of iron varies to a great extent which is given below.

#### 4.7.4.1 Magnetite

(i) Magnetite occurs as disseminations, segregation or injection deposits in basic igneous rocks. In these rocks it occurs as massive and granular deposits.

(ii) Magnetite also occurs as black sand in placer deposits.

(iii) In some cases Magnetite occurs as metasedimentary deposits in association with quartz in granulitic terrains.

(iv) At times Magnetite is a part of the banded iron formation and occurs as bands and lenses in banded magnetite quartzite.

(v) Magnetite is sometimes developed at the contact of igneous intrusive with the host rocks rich in iron.

#### 4.7.4.2 Hematite

(i) The most important mode of occurrence of hematite is their association with banded iron formation such as banded hematite chert (BHC) and banded hematite jasper (BHJ). In these rocks hematite occurs as beds and lenticular bands either at the base of the BHC / BID or at the top as a derivative from them. The different varieties associated with such types are:

(a) Massive ore - No banding is seen.

(b) Laminated ore - Thin bands are found.

(c) Bedded or banded ore- The bandings are relatively thick.

(d) Biscuity ore - Leaching of silica from the bands makes the iron band broken in form of small thin pieces.

(e) Powdery and friable ore (blue dust). Due to leaching away of silica hematite remains in situ forming blue dust.

(f) Brecciated ore - The ore bodies are brecciated.

(g) Conga ore - Pebbles, cobbles and boulders of iron ore, after being detached from the main iron ore body, are deposited at the lower levels and later on get cemented by iron oxide or iron hydroxide.

In a typical sequence, massive ores form high level occurrences and grade downward into laminated and powdery ores. Hematite in such deposits is associated with magnetite and martite in varying proportions.

(ii) Hematite and limonite occur as lateritic weathering of ferruginous rocks.

(iii) Hematite also occurs as nodules and concretions associated with carbonaneous shale or coal seams.

(iv) Deposits formed by hematite in some cases occur as fissure filling bodies in the pre existed cavities or as replacement bodies.

**4.7.4.3. Siderite:** Siderite deposits of economic importance are usually sedimentary deposits occuring as beds and lenses. It also occurs as a replacement deposit in limestones and as a gangue mineral in metalliferous veins. It is often found as nodules and concretions in shales and as bands associated with coal seams.

### 4.7.5. Origin of iron ores

The origin of iron ores can be classified into the following:

(i) Magmatic

(ii) Sublimation

(iii) Contact metasomatism

(iv) Hydrothermal

(v) Sedimentation followed by leaching and / or enrichment

(vi) Residual concentration

(vii) Mechanical concentration

(viii) Oxidation and secondary enrichment

**(i) Magmatic concentration:** Crystallization of magnetite from basic igneous rocks followed by segregation and at times injection has produced magnetite deposits of sizeable dimension. Titaniferous and vanadiferous magnetite deposits of Kumardhubi in Mayurbhanj district of Odisha, magnetite deposits of Nuasahi, Keonjhar district of Odisha, Kiruna magnetite deposits of Sweden, Adirondock magnetite deposits of U. S. A are formed by this process.

**(ii) Sublimation:** In some cases metallic halides coming out of the volcanoes may react with water giving rise to hematite. However such occurrences are very small and are uneconomic.

**(iii) Contact metasomatism:** The emanations coming out of, an intrusive body, after coming in contact with the host rocks, may form iron ore deposits.

Basic and intermediate intrusives when intrude into the impure carbonate rocks like limestone and dolomite transfer of materials take place with formation of magnetite at the contact aureoles.

**(iv) Hydrothermal:** Hematite ore deposits are formed from hydrothermal solutions either by fissure filling (cavity filling) or metasomatic replacement processes. The hydrothermal solutions rich in iron may get deposited along pre-existing cavities of host rocks or by replacement of silica from the host rocks. Such cavities may be in form of small veins or very large sized fault zones.

Example: Veldurti - Ramallakota hematite deposit of Kurnool district, Andhra Pradesh.

**(v) Sedimentation followed by leaching and / or enrichment:** The iron ores, associated with the Precambrian banded iron formation are originated by a number of processes such as sedimentation, leaching and supergene enrichment processes. The origin can be discussed under two headings.

(a) Origin of the protores i.e. the BHJ, BHC, BHQ etc.

(b) Origin of the iron ores.

**(a) Origin of the BHJ / BHC / BHQ:** The rocks are rhythmically banded comprising of hematite (mostly) and cherty silica or jasper. In some cases instead of hematite, magnetite, siderite, pyrite, pyrrhotite, iron silicates may be present as iron minerals. The BHJ / BHC indicate typical sedimentary characters and their formation under marine conditions. The reducing conditions in the Precambrian atmosphere aided for their development. The typical rhythmicity is due to alternate wet and dry conditions. The source of iron is suggested to be partly due to submarine volcanism. The sediments were deposited in form of iron oxide-silica gels which lacked coarse clastics. Silica secreting primitive organisms might have played certain role in the deposition of silica.

The views suggested by various workers to explain the origin of banded iron formation such as BHJ, BHC etc. cannot explain the diverse character of these rocks. Moreover, there are evidences and counterevidences to explain various aspects such as source and nature of the sediments, reasons of banding, nature of the atmosphere, depositional basin etc. and a number of discrepancies are there to explain all of them.

The sedimentation process is also responsible for the formation of a variety of iron ores which are either massive or banded in character lying below the BHJ /

BHC. The formation of this iron ore could be attributed to the sedimentation process whereby only iron oxide came to the depositional basin without silica. Such iron ores at places contain lenses of jasper and chert in them. The process of formation of such iron ores can be described as synsedimentary and syngenetic.

**(b) Origin of the iron ores:** While a sedimentary origin explains the origin of BHJ, BHC etc. the process of formation of different types of iron ores such as massive, laminated, biscuity, blue dusty, shaly, lateritic and conga varieties can be the result of a leaching of silica and simultaneous / subsequent replacement by secondary iron oxides and hydroxides to varying degrees.

The silica of BHJ / BHC was dissolved and leached away by downward percolating meteoric waters. The voids of leached out silica was filled up either simultaneously or subsequently by meteoric water rich in iron oxide. Complete replacement gave rise to massive and compact ore whereas partial enrichment produced laminated ore. Leaching away of silica layer without appreciable enrichment resulted in the crumbling of the iron bands giving rise to biscuity ore. Leaching of silica from iron formations resulted in the formation of dusty ore known as blue dust. Replacement and enrichment of ferruginous shales which are associated with BHJ, give rise to shaly ore.

**(vi) Residual concentration:** Due to residual concentration process, iron rich igneous and metamorphic rocks are subjected to weathering under humid tropical climatic conditions followed by leaching away of silica, soda, potash etc. with residual enrichment of alumina, iron oxide, titania etc. Lateritic iron ore, laterite and bauxites are formed by this process.

**(vii) Mechanical concentration:** Mechanical weathering of rocks containing magnetite and hematite may get transported by various geomorphic agents such as sea waves, running water, wind etc. and deposited as placer deposits at suitable locations. However, this process is responsible in producing only minor occurrences which do not have any economic significance.

### 4.8.6. Indian distribution of iron ores

Although iron ore deposits occur in many states of India, the deposits of Odisha, Jharkhand, Chhatishgarh, Karnataka and Goa are of major economic importance.

**(i) Odisha**

In Odisha, iron ores occur in two geological set up i.e. one associated with the basic intrusives and the other associated with the BHJ / BHC. District-wise distribution in Odisha is given below.

**(a) Mayurbhanj district:** Iron ore deposits in this district were discovered by P. N. Bose in 1904. Most important localities are Gorumahisani, Badampahar, Suleipat where iron ores are associated with banded hematite / magnetite grunerite and banded hematite quartzite intruded by basic rocks. Although mining was closed for sometime after reduction in the grade of iron ores, it has again started after the boom in the iron ore market of the world.

Another very important iron ore deposit occurs in Kumardhubi area where magnetite is associated with basic igneous rocks as a product of magmatic concentration process. This ore contains 10-25% $TiO_2$ and 2-7% $V_2O_5$ Total reserve in this district is about 19 million tonnes.

**(b) Keonjhar district:** In this district, iron ores are found in the „horse-shoe' shaped belt (Bonai- Keonjhar belt) and an isolated deposit lying to the south. The iron ore mineral is mostly hematite which is associated with unmetamorphosed to slightly metamorphosed BID, shale, phyllite etc. belonging to Iron Ore Supergroup. Iron ores are mainly produced by the process of leaching of silica of the BHJ with concommitant enrichment by iron oxide at the top of the hills occupied by BHJ. The ore bodies are of massive, laminated, shaly, blue dusty, lateritic types with Fe content varying from 55 to 70%. This belt is in form of a synclinorium with axial trend in a NNE-SSW direction with closure towards south. The rocks are affected by folding, faulting etc. related to more than two phases of deformation. Important workable deposits occur at Thakuranipahar, Baraparbat, Joda east, Bolani, Barjamda, Banspani, Bhadrasahi and Malangtoli (a part). Gandhamardan iron ore deposit located at a distance of 16 kms west of Keonjhargarh is also associated with BHJ. Here the ore body extends for a strike length of 3.6 km and having average width of 650 m. There are two types of ore bodies in Gandhamardan area, one lying below the BHJ and another lying above the BHJ formed by leaching and enrichment process. Total reserve in Keonjhar district is about 3510 million tonnes.

**(c) Sundargarh district:** In Sundargarh district, iron ore deposits are located in the western part of the „horse-shoe" shaped synclinoriurm and have the same geological set up as that of the Keonjhar district. Important localities are Barsuan, Khandadhar, Rontha, Mankarnacha, Malangtoli (in part), Mitihurda, Taldih etc. Total reserve in Sundargarh district is about 1149 million tonnes.

**(d) Jajpur district:** In this district and partly in Keonjhar district, very important iron ore deposits occur in association with banded hematite quartzite in Tomka-Daitari range. In this range scattered deposits of high grade hematite occur as massive, laminated and powdery ore types. The reserve in this district is about 80 million tonnes.

**(e) Nawrangpur district:** A small deposit of iron ore occurs at Hirapur in assotiation with banded hematite quartzite. The reserve of this deposit is only 2 million tonnes,

In addition to the major iron ore deposits mentioned above, small deposits occur at Pallahara and Deogarh areas of Deogarh district. Total resources in

Odisha is 5930.2 million tones of hematitic ore and 0.20 million tones of magnetite ore.

**(ii) Jharkhand**

In Iharkhand iron ores are found in the Singhbhum district which is the northern extension of the horse - shoe shaped belt occurring in the Sundargarh - Keonjhar districts of Odisha. The geological set up is same as that of the Keonjhar and Sundargarh districts of Odisha. Important localities are Chiria, Gua, Budhaburu, Raijoriburu, Kotamatiburu, Noamundi etc. The Chiria deposit is probably the biggest single deposit in the world with an estimated reserve of about 1950 million tonnes.

Magnetite in association with apatite-magnetite rocks occur in Singhbhum thrust belt. Magnetite also occurs as a product of magmatic concentration in basic igneous rocks of Singhbhum district.

**(iii) Chhatisgarh**

Hematitic ores associated with BHJ / BHQ of Bailadila Group are found in Bastar and Durg districts. In Bastar district, iron ores are located in Bailadila belt represents two ridges with an intervening valley. The ore bodies are of massive and friable nature. In the Rowghat area of Narainpur Tehsil, the ore bodies occur in a horse - shoe shaped ridge closing to the south. In the Durg district, iron ores of high grade occur as flat bands and lenses at the top of Dhalli - Rajhara hills, Kondekasa etc. Total reserve of iron ore in Chhatisgarh is about 2186 million tones.

**(iv) Karnataka**

Large hematitic iron ore deposits of Karnataka occur in Bababudan hills of Chikmagalur district and Sandur, Hospet, Bellary of Bellary district. The most important deposit of Bababudan hill occurs at Kummangudi. A very large magnetite deposit is located at Kudremukh in Chikmagalur district. In Kamataka, hematitic and magnetitic ores occur in association with BHQ and BMQ of Bababudan, Chitradurga and Shimoga Groups.

In addition to the above two districts, economically workable deposits are also located in Bijapur, Chitradurga, North Kanara, South Kanara, Shimoga and Tumkur districts. Total reserve of iron ores in Kamataka is about 11,000 million tonnes.

**(v) Maharastra**

Many scattered deposits of hematite alongwith magnetite sometimes are associated with banded hematite quartzite and ferruginous quartzites in Chanda.and Ratnagiri districts. In Chanda district, the localities are Lohara, Pipalgaon, Asola, Dewalgaon etc. In the Ratnagiri district, the deposits are located at Vegda, Kaukali, Katta and also at Redi at Goa boarder.

**(vi) Goa**

Hematite occurs in banded hematite quartzite in a belt running in NW-SE direction for a distance of 95 km. The ores are mostly lumpy (massive) and friable varieties. Important localities are in the northern block comprising of Bicholim, Satari, Ponda, Valiem, Sahqualim, Sanguem, Sirigod, Kosti etc.

**(vii) Andhra Pradesh**

Low grade iron ores containing 35% Fe are found in the districts of Guntur, Anantapur, Cuddapah, Hyderabad, Kumool, Adilabad, Karimnagar, Nellore and Nizamabad.

**(viii) Tamil Nadu**

Iron ores occurs as banded hematite quartzite and banded magnetite quartzite in Salem and Tiruchirapalli districts. The ore bodies are formed by metomorphism of magnetite - quartz rocks and hematite - quartz rocks. However the grade is low comprising 36-41 % Fe.

### (ix) Rajasthan

A few small deposits of iron ore are found in jaipur, Jhunjhunu, Sikar, Udaipur, Alwar and Bundi districts. The ores are mostly hematitic associated with metamorphic rocks of Precambrian age.

### (x) Punjab and Haryana

Magnetitic iron ores are found in a few places in the Kangra, Normaul and Mohendragarh districts. These ores are usually used for manufacture of pig-iron.

### (xi) Uttarakhand

Several deposits of hematite of small dimensions occur near Ramgarh. Namakhan, Dechauri, Kala Dhungri etc. in Almora, Garhwal and Mirzapur districts. Here the ore bodies are mostly located with in rocks of Siwalik Group.

### (xii) West Bengal

Ore bodies which are mostly sideritic oxidised to limonite occur in Birbhum and Burdwan districts in the Raniganj coal field area. The ores are confined to iron stone shales of Barren Measures formations. Important localities are Kulti, Begunia, Sibpur etc. where Fe content averages about 41 %.

### (xiii) Jammu and Kashmir

Hematitic deposits are found mainly in Matah and Khandi areas of Kashmir where the ore bodies are associated with ferruginous chert and quartzite.

### Indian reserve and production

The total resources of hematitic iron ores in India with is about 17882 million tonnes. The total resources of magnetitic iron ores is about 10,644 million tonnes.

## 4.8. MANGANESE ORES

The word "manganese" in Greek means to purify. The metal has significance in purifying / decolourising glass and hence the name. Manganese as a metal was discovered by a Swedish Chemist J. Gahn in 1774 although man was familiar with the black manganese powder of pyrolusite since very olden times. The year l882 is a land mark in the history of manganese because in this year steel was produced with about 13% manganese. Manganese occurs in four valency states, +2, +3, +4 and +6 as a result of which a number of manganese minerals are found.

### 4.8.1 Mineralogy

Important manganese minerals that serve as ores and protores are given in Table 4.3.

### 4.8.2. Uses of manganese ores

More than 95% of manganese ore is consumed in the metallurgical industries and the rest in other industries. Different fields of uses are given below.

**(i) Metallurgical use:** Manganese ore is used for extraction of Mn metal which is used for manufacture of various alloys both ferrous and non ferrous. Manganese improves the strength, hardness, toughness and workability of the steel. It also acts as a deoxidiser and desulphuriser and helps in purifying the products. In non-ferrous alloys it is used as a deoxidizer and to improve the physical properties like strength, ductility etc. Besides, it adds non - corrosiveness to the products. Some of the ferrous alloys containing Mn are:

(a) Ferro-manganese: 74-82% Mn

(b) Iron- Manganese-Chromium alloy: 8-10% Mn

(c) Manganese-pig iron: 0.4 to 1 % Mn .

**Table 4.3: Ore minerals of manganese**

| Group | Minerals | Composition | Mn % |
|---|---|---|---|
| Oxide | Braunite | $Mn_2O_3 \cdot MnSiO_3$ | 64.3 |
| | Hausmanite | $Mn_3O_4$ | 72.5 |
| | Sitaparite | $(Mn, Fe)_2O_3$ | 44.0 |
| | Pyrolusite / Polianite | $MnO_2$ | 63.0 |
| | Manganite | $Mn_2O_3 \cdot H_2O$ | 62.4 |
| | Psilomelane | $MnO \cdot MnO_2 \cdot H_2O$ | 45.0 – 60.0 |
| | Wad | A fine earthy mixture of variable Mn-Oxide composedof pyrolusite, psilomelane etc. | Variable |
| Carbonate | Rhodochrosite | $MnCO_3$ | 47.6 |
| Silicate | Rhodonite | $MnSiO_3$ | 41.9 |
| | Bementite | $2MnSiO_3 \cdot H_2O$ | 39.1 |
| | Spessartite | $3MnO \cdot Al_2O_3 \cdot 3SiO_2$ | 33.4 |

(d) Spiegeleisen: 10-30% Mn

Some of the non-ferrous alloys containing Mn are:

(a) Manganese bronze: Mn with Cu

(b) Manganin: Mn with Cu and Ni.

(c) Alloy of Mn with Cu and Al

For the manganese ores to be used in Iron and steel industry, Mn content should be within the range of 28 to 35%, Fe 15 to 25%, $SiO_2$ 6-13% $Al_2O_3$ 5 to 8% and phosphorous 0.3% maximum. For the Ferromanganese industry the manganese ores must have 40-48% or more of Mn, 7-12% Fe, 8-12% $SiO_2$ and maximum 0.15% phosphorous.

**(ii) Chemical industries:** Pyrolusite, Psilomelane and other manganese minerals are utilized for preparation of various compounds such as manganous oxide, manganese metaphosphate, barium manganate, manganese phosphate, manganous fluoride, bromide, sulphide, acetate, glycero-phosphate, lactate, pheno-sulphonate, benzaldihide etc. These chemicals are used for various purposes such as in paints, photography, drying agent, match industry etc. .

For the use in chemical industry, the manganese ores should have minimum 80% $MnO_2$, maximum 5% $SiO_2$ and maximum 10% $Fe_2O_3$

**(iii) Battery industry:** $MnO_2$ is used as a depolariser of hydrogen in the manufacture of dry battery cells. For the use in dry cells, the mangariese ores should have minimu of 84% $MnO_2$, maximum of 3% Fe, 0.1 % Ca, 0.1 % Ni and 3% moisture.

**(iv) Glass and ceramic industry:** $MnO_2$ imparts various shades of purple, brown and chocolate colours to glass. It is also used as a decolorizer to glass and ceramics.

**(v) Fertilizer use:** In agricultural activity, manganese ores can be added as fertilizer to increase fertility. Plants like tomato, potato, rice and maize are well grown in the soil rich in maganese.

**(vi) Other use:** Manganese ores are used as a constituent of heavy media in sink and float process of ore dressing.

### 4.8.3. Classification of Indian manganese ore deposits

In 1909, L. L. Fermor classified the Indian manganese ore deposits into three types. These are:

(a) Gondite type - Metasedimentary ongm
(b) Koduritic type - Hybrid origin
(c) Lateritoid type - Residual origin

Later workers classified the Indian manganese ore deposits into following four types. These are:

**(i) Primary reef and bedded deposits:** These are syngenetic deposits associated wirh Precambrian metapelites and metapsammites including gondites, banded braunite quartzite etc. Gondite is composed of Mngarnet (spessartite) and quartz with subordinate amounts of rhodochrosite, rhodonite, and other silicates. There are associated with secondary manganese oxides like pyrolusite, psilomelane etc. Manganese deposits associated with Sausar Group (M. P. and Maharastra), Gangpur Group (Odisha), Champaner Group (Gujarat) and Aravalli Group (Rajasthan) belong to this category.

**(ii) Manganese deposits associated with khondalite:** Fermor described the deposits of this belt as kodurite after Kodur pit which is an assimilated product composed of potash feldspar, Mn-garnet and apatite. The manganese ores are associated with rocks of Eastern Ghats Supergroup composed of khondalite, garnetiferous quartzite, calc-silicate etc. The minerals include psilomelane, pyrolusite, manganite etc. Manganese deposits associated with Eastern Ghats in Odisha and Andhra Pradesh belong to this category.

**(iii) Replacement type of deposits:** These are epigenetic manganese ores confined to shales, phyllites, schists, quartzites etc and are associated with Banded Iron Formation. The ore minerals include pyrolusite, psilomelane, manganite, wad etc. The manganese ore bodies associated with Iron Ore Supergroup rocks of Keonjhar and Sundargarh district of Odisha, Sandur and Shimoga areas of Karnataka and Banswara and Udaipur areas of Rajasthan belong to this category.

**(iv) Lateritoid type deposit:** These deposits occur as cappings at and near the surface on other type of deposits. These deposits represent the residual concentration type deposits dominated by manganese and iron minerals. The upper part of the lateritoid zone is iron rich where as manganese rich zones are found next to the iron rich zones. These deposits are found in Goa, Odisha and Jharkhand.

**4.8.4. Mode of occurrence**

Manganese ore bodies are found in different modes of occurrence which are described below.

**(i) Bedded deposits:** These are sheet-like bodies of oxide ores overlying Precambrian rocks rich in Mn content like gondites and kodurites. These are conformable and tabular bodies where bands and lenses of ore bodies have variable thickness and lateral extension. These deposits contain primary oxides like braunite and silicate like spessartite, rhodonite etc along with oxidised secondary minerals like psilomelane, pyrolusite, manganite etc.

**(ii) Replacement:** Distinct lamination or banding conformable with the shales and cherty silica are found in manganese ores associated with banded iron formation of Keonjhar-Sundargarh-Singhbhum area of Odisha and Jharkhand. Sometimes the ore bodies are controlled by structures and are either conchordant or dischordant with the host rocks. The ore bodies which ore dischordant are found as veins, veinlets, pockets along joints, shear planes, tension cracks, fractures etc. These ore bodies exhibit typical replacement characters.

**(iii) Lateritoid deposits:** These deposits occur as superficially occurring ore bodies as cappings at and near the surface of other type of deposits. These deposits also occur as float ores with limited depth persistency.

### 4.8.5. Origin

Manganese ores are formed by the following modes of origin.

**(i) Metasedimentary origin:** The primary reef and bedded deposits of manganese ore bodies associated with banded braunite quartzite and gondite are formed by syn-sedimentary origin later affected by metamorphism. During metamorphism, impure portions formed silicates and the pure portions formed primary manganese minerals. The primary manganese minerals are later affected by oxidation and alteration giving rise to supergene oxides like pyrolusite, psilomelane, manganite etc.

**(ii) Residual Concentration:** By the process of residual concentration, the origina1 manganese rich rocks after weathering get richer in manganese content with removal of silica, soda, potash etc. This process gives rise to lateritoid deposits with limited depth persistency.

**(iii) Hydrothermal process:** Hydrothermal solutions either by cavity filling or metasomatic replacement have given rise to manganese deposits. However, very small deposits are formed by this process.

**(iv) Remobilisation:** The ore bodies found along discordant veins, veinlets, fracture; shear planes etc may be formed due to remobilisation of preexisting materials along structurally weak planes mentioned above.

**(v) Oxidation:** Primary oxides present in the metamorphosed manganiferous sediments undergo oxidation giving rise to supergene oxides like pyrolusite, psilomelane, manganite etc. which form the principal manganese minerals in an ore deposit.

### 4.8.6. Indian distribution

The manganese ores deposits of India are confined mostly to Precambrian rocks. Geographically the ore deposits of economic importance are located in Andhra Pradesh, Odisha, Jharkhand, Madhya Pradesh, Maharastra, Karnataka, Goa, Rajasthan and Gujarat. Total resources of manganese ores in India is about 295 million tonnes.

**(i) Andhra Pradesh:** Manganese ores are associated with kodurites in kaolinised khondalites of Eastern Ghats Supergroup. The manganese ore bodies occur as tabular bodies, lenses, pockets etc. conformable with the attitude of enclosing host rocks. Pyrolusite and psilomelane are principal minerals. The ore is of low to medium grade containing 28 to 31% Mn, 0.10 to 0.56% phosphorous, 5 to 35% iron and about 5-7% silica. Important localities are Garivadi, Garbhum, Duvuum, Devada, Chiprupalle, Kodur, Avagudam, Sadanandapuram of Srikakulum and Visakhapatnam districts. Manganese ore deposits of minor scale associated with chert and jasper in limestone are located in Adilabad district.

**(ii) Odisha:** In Odisha, manganese deposits are found in three different geological set ups as mentioned below.

**(a) Ore deposits associated with Iron Ore Supergroup:** The horse-shoe shaped belt in Keonjhar-Sundargarh districts also known as Jamda- Koira valley have both iron ore and manganese ore deposits at various places. The rocks broadly form a NNE plunging synclinorium with its closure towards south. The manganese ore bodies are mostly confined to the shales of the Upper Shale formation lying above the Banded Iron Formation of the Iron Ore Supergroup. However, Acharya (2000) reported manganese ores in the Lower Shale Formation by detailed mapping.

The manganese ores occur as thin bandings conformable with the shales of various colour or show a cross-cutting relationship with the shales. Lateritoid type deposits occurring as float ores at shallow depths are also found. The manganese ores occur as nodular, oolitic or colloform bandings. The principal minerals are pyrolusite, psilomelane and manganite with gangue minerals like quartz, kaolinite, illite etc. The ore bodies contain average $MnO_2$ content of 47.43% varying from 5.2 to 86.4%.

Important localities are Joda, Roida, Kusumdih, Orahari, Kalimati, Mahulsuka, Dubna etc. where it also occurs along fault planes.

**(b) Ore deposits associated with Gangpur Group:** These types of ore deposits are located in Sundargarh district. Manganese ore bodies are confined to the gondites of Ghoriajhor Formation belonging to Gangpur Group which comprises of phyllite, mica schists, quartzite and conglomerete. The manganese ore bodies are interstratified with other sedimentaries. The principal manganese minerals present are braunite, hollandite, spessartite, rhodichrosite, pyrolusite, psilomelane and manganite. The $MnO_2$ content of the ores varies from 40 to 82% with average of 56%.

Important localities are Ghoriajhor, Baragarha, Simulgarha, Prichard hill, Shrager hill, Monmunda, Mohalgarha, Tetulgarha, Baladgarha, Kusumgarha etc.

**(c) Ore deposits associated with Eastern Ghats Supergroup:** In this belt manganese ore deposits are located discontinuously over a long linear belt of 150 km length in Koraput, Rayagada, Kalahandi and Balangir districts. Manganese ores are associated with kodurites, feldspathic quartzites, calc-silicate granulite etc. The manganese ore deposits occur as tabular bodies both as bedded and replacement deposits. The ores are localised along structurally weak planes like faults, shears, joints, foliations etc. as streaks, pockets, lenses, veins, discontinuous linear bodies and disseminations. Important manganese minerals in this belt are braunite, hausmanite, pyrolusite, psilomelane, manganite etc. Graphite is invariably present as minor flakes in the manganese ores. The $Mn_2$ content varies from 16.9 to 64.45%. Important localities are Nishikhal, Podakana, Taldhodshi, Kutinga, Devjholla, Lilliguma, Ambadola in Koraput-Rayagada district and Khagsabahal, Gadashankar, Tamiya, Biarpali, Uchhabapali, Kanaital in Balangir district.

The total Odisha resource of manganese ore is about 190 million tonnes which accounts for about 44% of the total Indian resources.

**(iii) Jharkhand:** Replacement and lateritoid type of manganese deposits ore found in the Barjamda area located in the northern side of the Jamda-Koira valley (horse-shoe shaped synclinorium) in the Singabhum district. The manganese ores occur as pockets in the manganiferous ferruginous shales stratigraphically occurring with the banded iron formation. The ore minerals are pyrolusite, psilomelane, manganite etc.

**(iv) Madhya Pradesh and Maharastra:** The manganese belt of Balaghat-Chindwara districts of M.P. and Nagpur-Bhandara districts of Maharastra is an arcuate belt with a length of about 210 km and width of about 30 km. The ore bodies are classified as primary reef or bedded type associated with metapelites, metapsammites and gondite belonging mostly to Mansar Formation and partly to Chorbaoli and Lohangi Formations of Sausar Group. The ore bodies occur as tabular bands and lenses concordant with the enclosing country rocks. Braunite, rhodocrosite, spessartite, hausmanite and rhodonite are the important primary minerals alongwith secondary minerals like pyrolusite, psilomelane, manganite etc. Ore bodies are also found as replacement and as detrital bodies. The ore bodies contain high manganese (averaging 46% Mn) and low phosphorous (varying from 0.03 to 0.1 %), iron (less than 7%) and silica (2 to 7%).

The ore bodies represent metamorphosed syngenetic manganiferous beds confined mostly to Mansar Formation of Sausar Group. The metamorphosed sediments under prolonged periods of weathering were altered to secondary oxides.

There are more than 200 deposits in this belt. Some of the important localities are given below.

Madhya Pradesh: Balaghat district - Ukwa, Laugar, Ramrama, Bharweli, N. Tirodi, S. Tirodi

Chhindwara district - Gowari Wadhan, Kachidhara

Maharastra: Nagpur district - Kandri, Mansar, Kodegaon, Gumgaon, Ramdongri

Bhandara district - Dongri Buzurg, Chikla, Sitasaongi

**(v) Karnataka:** Replacement and lateritoid type manganese deposits are mostly confined to phyllite, chlorite schist which are associated with quartzite, limestone and banded iron formation of Dharwar Group. The ore bodies occur both as concordant bands and lenses and discordant bodies in the host rocks. The manganese minerals of the deposits are usually pyrolusite, braunite, psilomelane and wad. The manganese ores contain 30-45% Mn, high Fe (10-20%) and low phosphorous (0.025%).

Manganese ore bodies are distributed in the Shimoga, Chitaldrug, Tumkur, Bellary, North Kanara and Belgaon districts. Ore of the most important deposits is located at Sandur valley in Bellary district.

**(vi) Rajasthan:** Medium grade manganese deposits are located within quartzites and phyllites of Aravalli Group. Important deposits are located at Itala, Sevania, Kalakhunta of Banswara district and also in Udaipur and Sawai-Madhopur districts. The ore bodies contain 25 to 46 % manganese. The ore minerals are pyrolusite, psilomelane, braunite and wad.

**(vii) Gujarat:** In this state manganese ores occur in association with gneisses, phyllites and quartzites of Champaner Group of Precambrian age. Manganese ore deposits occur in Panchmahal, Baroda, Sabarkanth and Banaskanth districts out of which the deposits of Panchmahal district are very important. The ore bodies are found as bedded deposits and can be classified as gonditic types. The mineralogy includes pyrolusite, psilomelane and braunite. The ore bodies contain 45-50% Mn. Important localities in Panchmahal district are Sivarajpur, Bamankura, Pani etc.

**(viii) Goa:** Large deposits of mangenese ores of lateritoid and replacement types occur in association with iron ores. Ore bodies occur as lenses, pockets and discordant bodies in shale and phryllites associated with banded iron formation. Manganese deposits occur in Sanguem and Bordez districts. The ore bodies of this state contain 41-56% manganese and utilized for metallungical and battery industries.

**(ix) West Bengal:** Manganese ore deposits are found in the western part of Medinipur district around Simulpal, Banspahari, Birmadal etc. as small pockets within Archaean schists and gneisses. The manganese content in these deposits is low which is around 30% and the deposits are small.

**4.8.7. Reserve:** Total resources so far estimated of manganese ores in India is 430 million tonnes.

## 4.9. COPPER ORES

### 4.9.1. Introduction

Copper is one of the most important non-ferrous metals having great application in the electrical industries. Earliest copper-mining dates back to 3500 B.C. in Egypt. It is the earliest known metal to the human race ever since the advent of prehistoric Chalcolithic age (Bronze Age). Its meagre production in our country, falling far short off the internal requirement, makes it a strategic metal for India. Geochemically, copper is chalcophilic having strong affinity for sulphur and as such in nature it most abundantly combines with sulphur to form sulphides of copper and iron or copper only. Copper belongs to I B of the periodic table having atomic number of 29 and atomic weight of 63 .55. It occurs in two valency states viz. $Cu^{+1}$ (Cuprous) and $Cu^{+2}$ (Cupric).

### 4.9.2 Mineralogy

About 165 Cu-bearing minerals are known to occur in the nature. Only a few of these, comprising mainly sulphides and subordinately oxides have economic viability to form ore minerals. There are also hydrated carbonates, hydrous silicates, sulpho-arsenides and sulpho-antimonides of less economic importance. The important ore minerals of copper are as follows:

(i) Chalcopyrite: Cu and Fe double sulphide ($CuFeS_2$)
(ii) Bornite: Variegated Cu-sulphide showing peacock iridescent colours ($Cu_5FeS_4$)
(iii) Covellite: Indigo blue coloured copper sulphide (CuS)
(iv) Chalcocite (Copper glance): Copper sulphide ($Cu_2S$)
(v) Cuprite (Red oxide of copper) ($Cu_2O$)
(vi) Malachite: Green coloured hydrated Cu-carbonate
(vii) Azurite: Blue coloured hydrated Cu-Carbonate
(viii) Chrysocolla: Hydrated silicate of Cu

The most important ore of copper from the commercial point of view is *chalcopyrite* which is a double sulphide of copper and iron. Its chemical formula is $CuFeS_2$ containing in its purest form 34.5% Cu as its highest theoretical tenor. Important physical properties of chalcolpyrite include its golden yellow colour, massive form, greenish black (shining) streak (most diagnostic), inferior hardness

(3.5-4) and moderately high specific gravity (G = 4.2). It responds to flame test with sky-blue coloured flame using HCl, to borax bead and microcosmic salt bead tests with blue and opaque tints in oxidizing and reducing flames respectively.

### 4.9.3 Mode of occurrence

Primary Cu-ores (chalcopyrite mostly) occur as bodies of variable forms in almost all kinds of rocks-sedimentary, igneous and metamorphic. Based on form of the ore bodies, the copper deposits may be grouped into the following general types.

(i) **Disseminated ore bodies** in which the ore minerals are more or less dispersed throughout the body of the host rocks. The ore bodies occur in form of primary sulphides unevenly distributed over the host rocks. These are large bodies of low tenor and grade, more or less conforming to porphyry type. Bingham Cu-deposit in Utah, U.S.A. is an important world example. Classic Indian example is that of Malanjkhand porphyry ore body located is Balaghat district of Madhya Pradhesh.

(ii) **Massive ore bodies:** These are ore bodies formed by more or less complete replacement of host rocks by ores of Cu precipitating from Cu-Fe-S rich hydrothermal solution. Geometrically these either form (a) irregular shaped and (b) lenticular shaped ore bodies which comprise other sulphides like Sphalerite (ZnS), Pyrrhotite ($Fe_{1-n}$ S) and Pyrite ($FeS_2$). Ore bodies constitute typical isometric form.

**World example:** Bisbee, Arizona, USA and Rio Tinto of Spain.

**Indian example:** Khetri Cu-belt, Rajasthan and Singhbhum Cu-thrust belt, Jharkhand.

**(iii) Vein / Lode ore bodies:**

(a) Fissure veins: Hydrothermal cavity filling veins in faults and joints etc.

(b) Replacement lodes of composite veins formed by metasomatic replacement along closely spaced shear zones and schistosity planes in host rocks of granites and foliatedmetamorphites. These are tabular ore bodies composed of primary sulphides of Fe, Cu and Ni ores deposited along shear planes and rock cleavages giving rise to long and flat, comparatively thin and deeply penetrative ore zones having great down dip continuity. These are formed by volume per volume replacement of country rocks by Cu-sulphide ores facilitated by inte-rconnected structural openings.

**World example:** Fissure vein type deposits of Butte, Montana, USA and replacement type deposits of Bisbee, Arizona, USA.

**Indian example:** Singhbhum Cu- Thrust belt, Jharkhand and Khetri Cu- belt, Rajasthan for replacement types.

**(iv) Stratabound ore bodies of tabular form and syn-sedimentary-remobilized nature:** These are flat bodies of tabular form present within sedimentary strata showing pronounced remobilization of primary sedimentary Cu-ores formed in an euxenic (reducing) environment. These are tabular in form showing concordant to pene-concordant attitudes being bound within definite strata and as such show extensive strike length and considerable width.

**World example:** Kupferschiefer, Mansfield, Germany.

**Indian example:** Agnigundla Cu-Pb-Zn belt, Cuddapah basin, Andhra Pradesh and Rajpura Cu-based Polymetallic belt, Rajasthan.

Besides the above, minor types of occurrences are those of pipe bodies, stockworks, stringers and pockets.

**(v)** Based on genetic-cum-form of are bodies, the deposits are classified into

(i) **Cavity filling types** in which ores occur as infillings of primary and secondary products of space amygdules of Cu-ore, ore bands along bedding planes, polymetallic base metal ores in magmatic, tectonic and collapse breccias, fissure veins along faults and joints, stockworks of interlaced veinlets.

(ii) **Replacement types** in which Cu-ores are deposited as hydrothermal products of disseminated, massive and lode (vein) deposits through replacement of country rocks.

### 4.9.4. Uses

Copper ores are the primary source of the copper metal which finds various uses in the modern industry oriented society. Being the oldest metal used by ancient mankind, today its uses proliferated manifold. High melting points, softness but at the same time extreme toughness, high electrical conductivity, high degree of ductility and malleability of copper metal and alloys make them most prized metal and alloys in particular. The uses are summarized as follows:

(i) Domestic uses as a constituent of various carats of gold in making ornaments, and house-hold vessels/containers.

(ii) Industrial uses:

(a) Extraction of Cu metal in smelters. This metal (refined) finds important uses in electrical industries as Cu-wires which make conductors, windings, high transmission wires (lines), automobiles, nonferrous castings bearing materials and heat transfer equipments. These uses constitute more than 50% of its consumption.

(b) As alloys such as gunmetal(Cu-Sn), bronze (Cu-Sn-Zn) and brass (Cu+Zn) find uses in special containers, machines, architecture, statues, special water bottles and domestic utensils.

(c) Chemical industries use subordinate amount of this metal inform of (a) blue vitrol - a Cu-sulphate employed in printing and dyeing textiles, (b) Cu-chloride as a disinfectant, (c) Cu-carbonate minerals such as green malachite and blue azurite are used as natural paints (d) $Cu_2O$(Cuprous oxide) is used as a pigment in the manufacture of anti-foul paints to be coated on steel and wood furniture, (e) CuO (Cupric oxide) finds use in tinting glass and ceramic wares.

### 4.9.5. Genesis

Based on modes of origin, the Cu-ore deposits may be classified into the following genetic classes:

(i) Magmatic (igneous) process: Some primary Cu-sulphide deposits associated with platinum group of minerals occur as product of late magmatic residual immiscible liquid segregation and injection processes.

(ii) Contact metasomatic Cu-deposit formed by pyrometasomatic process related with granitic intrusions.

(iii) Hydrothermal process: Both cavity filling and metasomatic replacement sub-processes account for the major primary Cu-deposits of the world.

(iv) Syn-sedimentary-remobilization process explains the origin of some large and extensive bodies of Cu-bearing minerals such as copper deposits of Mansfield, West Germany.

(v) Oxidation and secondary sulphide enrichment sub-processes tend to make the leaner primary Cu-ores enriched in Cu-metal.

### 4.9.6. Global Distribution

The leading countries of the world endowed with bountiful resources and production of Cu-ores are:

(i) North America comprising USA and Canada. In USA deposits are at Bingham, Utah; Bisbee, Arizona; Butte, Montana. In Canada deposits are at Ontario and Quebec states

(ii) South America: In Chuquicamata, Chile and few locations in Peru
(iii) Russia: Urals and Altai regions
(iv)Africa: Large deposits in Zambia, Zaire and Union of South Africa
(v) Australia: Broken hills area of New-south-Wales state
(vi)Phillipines
(vii)Newguihea
(viii) China
(ix)Austria

### 4.9.7. Indian Distribution

Geologically Indian deposits are mostly confined to the Precambrian (Archaeoproterozoic) rock formations located at various parts of the peninsular India. There are about 600 locales where Cu-mineralization is recorded but astonishingly, the productive and promising ones are only a few large and medium sized deposits. Despite having an estimated reserve of all grades put .around 632 million tonnes, Indian present mining potential of Cu-ores is confined within 10 deposits of mineable status. These are located in the Precambrian hard rock terrains of Jharkhand, Rajasthan, Madhya Pradesh, Karnataka, Maharashtra and Andhra Pradesh. India has at present four major and more than six medium sized Cu-belts.

**(i) Singhbhum Cu-belt, Jharkhand State:** It is a 160 km long belt which is arcuate shaped shear zone. It starts from Duarpuram in Jharkhand in the west and takes a curved pattern with a sharp bend near Tatanagar and then enters into Mayurbhanj district of Odisha through southern Singhbhum district with a NNW-SSE strike. After Tatanagar, the belt narrows down to 5-2 km in width passing through Rakha, Roam, Siddheswar, Tamapahar, Pathargora sectors and then Mosabani-Dhobani area. The Cu-sulphide ore occurs in form of two important lodes named as west lode and the main lode are mineralization is confined to Singhbhum group of rocks (soda granite and quartz-feldspar-mica-chlorite schist). Ore is predominantly chalcopyrite associated with other Cu-Fe-Ni sulphide minerals apatite-magnetite and uranium ores. The tenor of ore varies from 2.5 to 1.6% Cu. Mosabani group of mines have been almost exhausted. Presently, northern sectors of Rakha and Roam sector are being exploited.

**(ii) Khetri Cu-belt, Rajasthan:** It is the second largest Cu-belt that strikes NE-SW over a length of 80 Km between Singhana in the north and Raghunathgarh in the south. The ore mineralization occurs in the contact zone between Ajabgarh and Alwar Group of Precambrian metapelites (schists). Mineralization is confined to horse-tail shaped intersecting shear zones forming lodes and stringers in six sectors, the porthern Madan-Kundan and Kolhan sectors contain workable deposit. It is under active mining by Hindusthan Copper Ltd in four sectors.

**(iii) Malanjkhand Cu-deposit, Balaghat district, Madhya Pradesh:** Discovered in 1968, this arcuate shaped belt shows Cu-mineralization in quartz reef cutting across Bundelkhand granite. Cu-mineralization body is a steeply dipping quartz reef along shear zone. It is about 2 km long with depth continuity up to more than 200 metres and contains about 50 M.T. ore with about 1.4% Cu. It is described to be a porphyry type Cu-deposit of India and has molybdenite ($MoS_2$) ore.

**(iv) Agnigundla belt (Cu-Pb), Guntur district, Andhra Pradesh:** This belt located in the north-eastern part of Cuddapah basin being associated with dolomite and quartzite rocks of Upper Cuddapah age. Cu-mineralization associated with galena is proved in 3 blocks of Nalaconda, Dhokunda and

Bandalamottu over a strike length of about 6 km and depth of 0.5 km.

Comparatively smaller but productive deposits occur in the following areas.

**(v)** Ambamata belt, Banaskantha district, Gujurat: It is a promising deposit with a grade of 1.7% metal.

**(vi)** Kho-Dariba belt, Alwar dist, Rajasthan in Delhi Group of rocks with 2.5% Cu. It is under development by HCL.

**(vii)** Bhagoni deposit, Alwar dist, Rajasthan: 1.5 km long belt containing 1.1 % Cu.

**(viii)** Garubathan, Darjeeling district, West Bengal: A very promising one.

**(ix)** Ingladhalu deposit, Chitradurga district, Kamataka (small-scale mining): Cu-ores occur in greenstone zone of Dharwar rocks.

**(x)** Kalyadi deposit, Hassan district, Kamataka: 0.5 km long belt with low grade Cu-ore under development.

**(xi)** Dikchu and Bhutang deposits, Ranjit Vally, Sikkim: Ore is in Daling rocks of Precambrian age. The deposits contain 0.6-1.3 % Cu under working by Sikkim Mining Corporation.

**(xii)** Mamandur, South Arcot district of Tamilnadu: Ores in gneisses and charnockites of Eastern Ghats rocks, being worked on small scale by private sector.

Besides the above, smaller deposits of less potential but high promise are:

(i) Mailaram, Khamam district, Andhra Pradesh

(ii) Purbanera belt, Bhilwara district, Rajasthan.

(iii) Pular-Parsori belt, Nagpur distrtict, Maharastrta.

(iv) Pratapgarhdeposit, Alwar district, Rajasthan.

(v) Madhupura deposit, Alwar district, Rajasthan.

(vi) Baleswar deposit, Sikar district, Rajasthan.

(vii) Deri-Basantgarh deposit, Sirohi district, Rajasthan.

(viii) Thaneswar deposit, Chanda district, Madhya Pradesh.

Apart from these, seemingly uneconomic Cu-occurrences are located in Uttar Pradesh (Bageswar and Askot), Andhra Pradesh (Gani-Kalva, Chelima), Bihar (Baragonda), Madhya Pradesh (Dhandukuia) and Meghlaya (Umpyrtha). The total resources of Cu ores in India is 1558 million tones.

## 4.10. CHROMIUM ORES

### 4.10.1. Introduction

Chromium, a metal of vital industrial importance, is known for its astoundingly strong alloying property. Chromite, the ore mineral of chromium was discovered by Levites of Paris, France by the fag end of 18th Century. In chromite, the sole ore of chromium, Cr is trivalent which is non-toxic and harmless. However, it may turn awfully toxic and hazardous to health, when trivalent Cr is converted to hexavalent Cr ($Cr^{+6}$) by mine waters. $Cr^{+3}$ has atomic number of 24 and atomic weight of 52.

### 4.10.2. Mineralogy

There are a few number of naturally occurring Cr-bearing minerals inform of oxides and hydro-silicates but the only mineral commodity having economic importance is “CHROMITE” which is a Cr-rich member of the chromite-magnetite-spinel solid solution series.

Chemically pure chromite is a double oxide of Fe and Cr. The general chemical formula of chromites is $R^{+2}O.\ R^{+3}{}_2O_3$ in which $R^{+2}$ denotes bivalent Fe(ous), Mg and Mn and $R^{+3}$ stands for trivalent element of Cr, Fe(ic) and Al.

The ideal chemical formula (Theoretical chemical formula): $FeO.Cr_2O_3$ or $FeCr_2O_4$ which contains 68 % $Cr_2O_3$ and 32% FeO in its purest form.

The chief chemical impurities are MgO, $Al_2O_3$ and $MnO_2$ where as the physical impurities comprise the ultramafic and mafic host rocks and their alteration products.

The principal physical properties of normal chromite are its (i) octahedral form (ii) granular nature (iii) iron black to brownish black colours and streak (iv) H = 5.5 and G = 4.5 to 4.8. Chemically, chromites powder responds to borax and microcosmic bead tests, thereby turning green.

**4.10.3. Mode of occurrence**

Chromite is invariably confined to the ultramafic rocks such as dunite, peridolite and serpentine and less commonly associated with pyroxenitic and gabbroic rocks. Based on textural criteria, the following varieties/types of chromite bodies may be recognized.

(a) Based on grain size (granularities), chromites may be classified into (i) coarse-grained (ii) Medium-grained (iii) Fine-grained.

(b) Based on grain-shapes (fabrics), chromites could be described to be (i) Euhedral (perfect / partially modified octahedral) (ii) Subhedral (with partly developed crystal outlines) (iii) Anhedral (with almost undeveloped crystal faces), (iv) Most chromite grains show a granular mosaic fabric formed of equidimensionally equigranular chromite crystals.

(c) Based on the combination of textural, structural and physico-chemical aspects, chromites could be divisible into (i) massive type (ii) Disseminated type (iii) Banded type (iv) Friable / powdery type (v) Lateritic or Ferruginous type (vi) Conglomeratic type (vii) Siliceous type (viii) Talcose type and (ix) Placer / Float type.

(d) Based on multiple criteria, chromites may be classified into:

(i) Stratiform bodies which are large, tabular ore, bodies characterized by extensive lengths and multiplicity of bands showing typical magmato-sedimentary features, geologically older age, lower Cr:Fe ratio, lower Al:Cr ratio, more euhedralism of grains and better sorting.

(ii) Podiform bodies which are non-tabular lensoidal and pod (eye) shaped bodies characterized by smaller and least extensive ore bodies, confinement to geologically very young (Tertiary age) and tectonically very unstable terrain, ubiquitous presence of orbicular and nodular features, confinement to active subduction zone, higher aluminosity ($Al_2O$%), comparatively higher Cr:Fe ratio, higher MgO:FeO ratio, more commonly anhedral grains and poor sorting of grains.

Examples: (STRATIFORM):

World: (i) Bushveld Igneous complex, South Africa (Transvaal)

(ii) Great dykes of Rhodesia, Africa,

(iii) Stillwater complex of Montana, U.S.A.

India: (i) Sitampundi chromite belt, Salem dist, Tamilnadu.

(ii) Sukinda chromite belt, Jajpur dist, Odisha.

(iii) Boula-Nausahi belt, Keonjhar dist, Odisha

Examples (PODIFORM):

World: (i) Sialkot Ophiolite complex, Baluchistan, Pakistan.

(ii) Troodos Ophiolite complex of Cyprus.

India: (i) Ophiolite belt ofUkhrul, of Moreah district, Manipur, NE Himalayas.

(ii) Ophiolite belt of Ladakh, Himalayas (Jammu and Kashmir State).

### 4.10.4 Uses

**(i)** Chromite of various grades is used in (i) extraction of Cr-metal from high grade chromites (ii) in the metallurgical field chromium is used as an indispensable alloying metal for the manufacture of (a) high carbon ferrochrome, (b) medium carbon ferrochrome and (c) low carbon ferrochrome (d) charge chrome (partially reduced chromite) and (e) silico-chrome.

**(ii)** From these alloys, varieties of stainless steel and special alloy steel with Ni, Mo and Co metals are produced. Chrome steel types make the products hard, tough and anti corrosive. The special chrome-steel is rustless and durable. These are used in (i) manufacture of household utensils, (ii) automobile parts, (iii) aeroplanes and (iv) trains.

**(iii)** Refractory industries: Chromite is the basic raw materials for the manufacture of neutral refractory bricks used as linings in open hearth furnaces in iron and steel industries. As refractory, chromite has high temperature of melting and hence can withstand very high temperature operations without spalling, shrinkage, fusion and che.mical action.

**(iv)** Chemical industries: High grade chromite is used in the manufacture of chemicals like Na-chromate, Na-dichromate, K-dichromate, Al-dichromate, Ammonium dichromate, chromic sulphate, chromic chlorate and nitrate etc. which find uses in textile, chemical, paint and pigment industries.

**(v)** Other industries: Cr-salts are also used in photography, painting and lithography. Chromic oxide (chrome green) powder is used for polishing ore/metal optical glass specimens.

**4.10.5. Grades:** These are:

(i) Metallurgical grade with high Cr-Fe ratio and crystalline lumpy nature of ore.

(ii) Refractory grade with >40% $Cr_2O_3$ less $SiO_2$ least CaO and $Cr_2O_3$ + $Al_2O_3$ =60%

(iii) Chemical grade: $Cr_2O_3$>44%; Cr:Fe=1.6:1; should be fine grained; very low in $SiO_2$ and CaO contents.

### 4.10.6. Genesis

Based on mode of origin the chromite deposits of the world could be products of (i) Early magmatic dissemination (ii) Early magmatic segregation (iii) Early magmatic injection (iv) Late magmatic residual segregation (v) Late magmatic residual injection (vi) Hydrothermal processes / sub processes.

Larger bulk of the global deposits is of early/late magmatic segregation origin.

### 4.10.7. Indian Distribution

In India, most of the deposits belong to Precambrian rocks (Archaeo-Proterozoic) while a few are of Teritiary age. In the former, these are confined to the Iron Ore, Dharwar and Eastern Ghats Supergroup of rocks. Geographically, chromite deposits of different grades and quantities are confined to the states of Odisha, Andhra Pradesh, Tamilnadu, Jharkhand, Karnataka, Maharashtra, Jammu and Kashmir, Nagaland and Manipur. Chromite mining in India dates back to 1907 in Karnataka (Mysore).

**(i) ODISHA:** Odisha contains more than 93% of the Indian resources amounting to about 190.02 million tonnes. This state is also the most leading producer of chromite in India. The chromite deposits are exclusively confined to the vast area forming the junction among three districts of Jajpur, Keonjhar and Dhenkanal where these occur as more or less stratiform bodies hosted by altered ultrabasic-basic rocks. The active mining centres are located in the (i) Sukinda chromite belt (ii) Boula-Nausahi belt and (iii) Detached bodies in Dhenkanal district (western extension of the Sukinda belt).

**(a) Sukinda chromite belt:** This deposit located in the Jajpur district of Odisha, is the largest chromite belt in India. The Cr-ore occurs as bands/seams in the altered dunite-peridotite in the Sukinda valley which is bordered in the north and south by Daitari and Mahagiri ranges respectively. It is the largest Cr-belt of its kind not only in India but also in Asia. The chromite bodies belong to stratiform type in which the ore bodies occur as concordant bands of great lengths and considerable widths having very good down dip extension. There occur six chromite lodes / seams which are folded into a broadly westerly plunging synformal fold. The belt starts near Kansa in the east and then fans out westerly up to Maruabil over a length of about 20 km and maximum width up to 5 km. There are six chromite bands of which five bands in the north are composed of soft-friable and brown ore. Only the $6^{th}$ band exposed in the southernmost limit is composed of hard and lumpy (grey) ore. Ores (both brown and grey) are of high grade nature with higher $Cr_2O_3$ (50% and above), Cr: Fe ratio = 3 to 4, lower total FeO and higher MgO.

Important and commercially viable chromite deposits are being exploited here since 1951, consequent upon its discovery by one free-lance prospector Mr. Aikath.

The active mining activities are being undertaken here by Odisha Mining Corporation (OMC), Tata Iron and Steel Co. (TISCO), Ferro-alloys Corporation (FACOR), Jindal Ltd. IMFA Ltd.  and a couple of other mining enterpreuners. There is an underground mine at Kathpal worked by FACOR

Total reserve of Sukinda belt is 170 million tonnes of all grades in the entire belt including Kathpal and Moulabhanj in the west.

**(b) Boula-Nausahi chromite belt:** Located in the Anandapur subdivision of Keonjhar district, Odisha, this is the second largest chromite field in India. This belt has a strike length of about 3 km along NNW-SSE trend with widths variable between 15 to 20 m and large easterly down-dip extension of chromite lodes. The belt is thick in the middle with gradual tapering to the north and south. The geological environment is almost akin to that of Sukinda. While more than 70% of Sukinda is soft and friable ore, Nausahi belt contains only hard and lumpy ores conforming to the characteristics of stratiform type. It has four lodes of chromite striking NNW-SSE (average) which are designated as Durga lode and Laxmi lode, containing normal chromite of high grade and medium grade nature in the west and the Shankar-Ganga composite lode in the east containing medium to low grade magnetic ores intimately associated with base metal sulphides and platinum-bearing minerals. The chromite mining history of this smaller belt dates back to 1944. At present active mining for chromite is being intensified in the three lease holds of FACOR, IMFA and OMC Ltds in the northern, middle and southern sectors respectively. The estimated reserve of all grades of Cr-Ore in, this complex is of the order of 10.7 million tonnes. At present active underground mining is going on in both IMFA and OMC lease holds in full swing.

**(c) Deposits located in Dhenkanal district:** These are smaller and isolated ore bodies found in ultramafics further to the west of main Sukinda belt. Smaller deposits occur in Kathpal, Moulabhanj, Bhuasuni, Asurbandh, Ghotringa and Kantol etc. These deposits form isolated bodies intruded into granitic rocks.

**(d) Other Cr-deposits in India:** Jajpur- Keonjhar-Dhenkanal triple junction area of Odisha contains almost the entire workable reserves of India thereby occupying an enviable position in the country's chromite map. Other Indian deposits are given in Table 4.4. The total chromite resource of India is 203 million tonnes.

## 4.11. ALUMINIUM ORE

### 4.11.1. Introduction

Aluminum is the second abundant metallic element next to silicon present in the earth‟s upper crust constituting thereby about 8.07% of the crust.

**Table 4.4. Indian deposits of chromite**

| State | District | Locality | Type / characteristics |
|---|---|---|---|
| Andhra Pradesh | Krishna | Kondapalli | Tabular lenses associated with anorthosite |
| Jharkhand | Singhbhum | Jojohatu, Roroburu | As lenses and bands |
| Jammu and Kashmir | Kargil | Ladakh | Podiform bodies of Cretaceous Tertiary age |
| Karnataka | Mysore<br>Hassan | Sindhuvalli<br>Byrapur | As bands and tabular lenses in ultramafics of Dharwar age |
| Maharashtra | Bhandara<br>Ratnagiri | Pauni,vagda<br>Kankauli | As stratiform bodies in ultramafics of Sakoli age |
| Manipur | Ukhrul | Moreha, Nepali, Basti and Tengapal | Sporadic occurrences of podiform chromite |
| Tamilnadu | Salem | Sittampundi | Stratiform layered body interbanded with anorthosite over a length of about 19 Km. The grade of ore is low. |

Aluminium is a silverwhite coloured durable and light metal belonging to Group III(A) of the periodic table. Aluminium (Al) has atomic number of 13, atomic weight of 27, ionic charge(valency) of 3+, co-ordination numbers of 4 and 6 and ionic radius of 0.53Å. Aluminum is the miracle metal of 20$^{th}$ century, having emerged as one of the very important non-ferrous metals. Its" commercial extraction from bauxite was patented by Hall in 1886. Despite its late entry into the industrial arena, aluminum has assumed enviably paramount position among the nonferrous metals in the world and shall continue as such for the 21st century. In India, its" advent was made in 1943 as the year of a new era of emergence of this light metal.

### 4.11.2. Mineralogy

There are many aluminium bearing minerals (feldspars, feldspathoids and alumino-silicate minerals) but their low contents of aluminium and compositional nature do not permit economic extraction of aluminium metal. Thus, there are three possibilities of getting this metal from the minerals. These are:

(i) Corundum ($Al_2O_3$) - Hardly used for extraction because of its very low reserve.

(ii) Cryolite ($Na_3AlF_6$) - Previously used as source of Al metal but not at present due to its paucity of reserve consequent upon the almost exhaustion of the then workable West Greenland deposits. Presently it is replaced by synthetic cryolite.

(iii)Bauxite - It is the principal and the only commercial source of aluminium the world over today. It is named after Le Baux of France where it was discovered by Berthier in 1821.

### Chemical Composition

Bauxite, in the strict sense, is a rock as it comprises more than one hydrous aluminous minerals. Mineralogically, it may be described as a hardened and partially crystallized hydrogel comprising principally three hydroxide minerals of aluminium such as (i) Gibbsite - $Al_2O_3.3H_2O$ a trihydrate aluminium oxide with 34.6% Al in its purest form. It is also named as hydrargillite. (ii) Diaspore - $HAlO_2$ a monohydrate oxide of Al (45% Al) in purest form. (iii)Boehmite - AlO (OH) a monohydrate oxide of Al (45% Al) in purest form. Of these three only gibbsite of crystalline form is identifiable under normal petrological microscope.

Other minerals subordinately present in bauxite are iron oxide and hydroxide minerals (hematite and goethite), kaolin and lithomargic clays as physical impurities. The chemical impurities include iron oxides, silica ($SiO_2$), titania ($TiO_2$), lime (CaO) and magnesia (MgO).

**(i) Physicai properties**

Bauxite is greyish white to brownish white coloured with, commonly earthy to granular masses, inferior hardness, mostly light specific gravity (G = 3-3.5)

**(ii) Chemical character**

On reaction with heated cobalt nitrate mixed charcoal cavity test, it gives blue and unfused residue indicative of aluminium. As bauxite invariably contains Fe-oxide, it also responds to various bead tests for Fe.

### 4.11.3. Mode of ocurrence

Based on form, geometry and technical attributes, bauxite may be classified into the following textural varieties and structural types.

**(i) Textural varieties:** Based on textural characters, bauxites are classified into

**(a)** Massive variety showing compact and homogenous texture, devoid of layering / banding.

**(b)** Pisolitic variety showing pea shaped rounded and elongated units having concentric rings.

**(c)** Oolitic variety which differs from pisolite in being smaller in size and more regularly shaped.

**(d)** Spongy variety showing cavernous nature having more porosity.

**(e)** Amorphous variety showing very fined grained bauxite with earthy look and feel.

**(ii) Types based on mode of occurrence in particular:** Mode of occurrence includes form (shape), spatial geometry and structural characters of ore bodies. The various types are:

**(a) Blanket type:** It occurs as tabular apron-shaped bodies at or near the flat topped plateaus. There are of two subtypes such as high level occurrences capping peneplains at higher altitudes and low level flat bodies occurring at lower altitudes with reference to mean sea level. Blankets are flat (horizontal) to little slanting (undulating) sheets or tabular lenses under thin cover. On differential denudation, the dissected plateaus form mesas and buttes. The extensive insitu bodies vary in thickness from a few metres to more than 20 metres. A typical laterite-bauxite profile in blanket type occurrence as observed in Amarkantak plateau of Deccan trap basaltic province, Central India is given in (Fig. 4.2). The parent rocks from which bauxite is derived comprise

(a) Quartz free nepheline syenite which is the ideal source rock for high grade bauxite. It is lacking in India.

(b) Quartz free basaltic, gabbroic and ultramafic rocks.

(c) Quartz bearing metasediments i.e. khondalites under special weathering conditions can undergo bauxitisation admixed with lateritisation.

World example of blanket type is that of Arkansas, U.S.A.

**(b) Interstratified bedded type:** These are of sedimentary nature occurring as extensive beds and flat lenses which lie on the surfaces gf unconformities (Fig.4.3). In India, these form horizontal to slowly inclined flat bands or lenses within sedimentaty formations. Bauxitic beds are of fairly large areal coverage of several $km^2$ and of fairly good thickness of the order of several tens of metres.

**World example:** Gold coast and British Guinea bedded bauxite deposits

**Indian example:** Interstratified bedded deposits in Saurastra and Kutch areas of Gujurat.

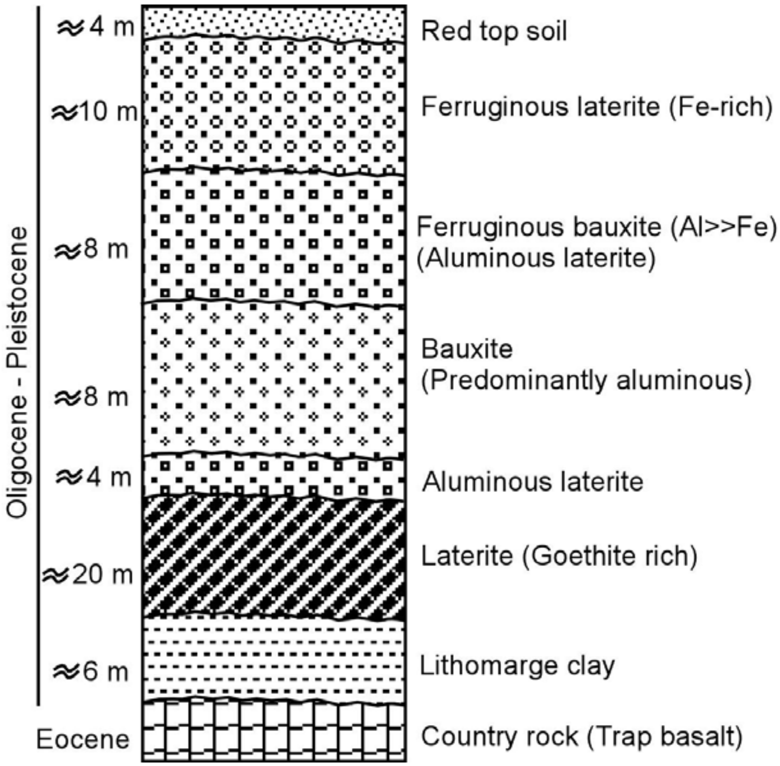


**Fig. 4.2: A typical blanket type bauxite profile**

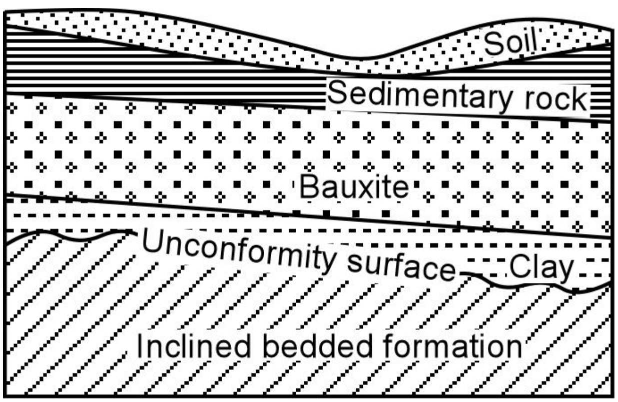


**Fig. 4.3: Interstratified bauxite associated with unconformity**

**(c) Pockety or Terrarosa type:** These occur as partial infillings of funnel shaped sink holes and depressions in impure aluminous limestones (Fig. 4.4). Bauxite bodies are isolated pockety type occurrences sheathed (toothed) within impure limestone or dolomite

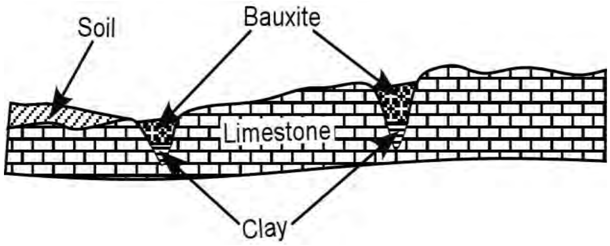


**Fig. 4.4: Pockety (terrarosa) type bauxite associated with limestone**

bands. These are smaller and discrete bodies occupying the funnel shaped solution cavities. Mineralogicaly, this type is predominantly composed of diaspore ($HAlO_2$).

**World example:** In France, Italy and Hungary of Southern Europe as pockets in limestone / dolomite.

**Indian example:** Riasi and Poonch in Udhampur district, Jammu.

**(d) Detrital type:** These of reworked, breciated and transported (drifted) type, redeposited in depressions / valleys. It forms conglomerates and breccias of bauxite of commonly low level occurrences as valley-fills. It is heterogeneous in character, and very ill assorted.

**Indian example:** (i) Low level occurrence at Katni, Madhya Pradesh. (ii) Rataria, Cutch district, Gujurat.

### 4.11.4. Tenor and grade

The alumina content in terms of $Al_2O_3$ of bauxites used in metallurgical industry varies from >50% down to 44%. This lower value of tenor is acceptable for bauxite in view of the availability of the modem technological progess. The bauxite-laterite ore of the East Coast bauxite deposits belongs to the later type of tenor. Bauxites are divisible into the following grades with their contents of various elemental oxides.

| Grades | $Al_2O_3$% | $Fe_2O_3$% | $SiO_2$% | $TiO_2$% | Form / state |
|---|---|---|---|---|---|
| Metallurgical grade | >50-44% | 7-18% | <5% | <4% | Pulverised |
| Refractory grade | >55% | <3% | 2%-5% | <2.6% | Calcined |
| Chemical grade | >58% | <3.0% | 2%-10% | <3% | Dehydrated (dried) |

### 4.11.5. Uses

Bauxite is the only commercial source of aluminium that forms the backbone of present day electrical industry. It is one of the most useful non-ferrous metals, next to copper. The metals and alloys, find extensive industrial uses. In its calcined brick forms, bauxite is an important refractory material. The various chemical compounds obtained from bauxite are used in chemical and allied industries.

**(i) Metallurgical uses:** Prized properties of aluminium are its (a) high electrical and thermal conductivities, (b) lightness (c) high light and heat reflecting power (d) resistance to corrosion (e)alloying property (f) high ductility and malleability which permit the metal/its alloys to be rolled and drawn into sheets of required shape and thickness.

Aluminum metal is used in the production of

(a) Electric high transmission wires and cables, thereby considerably replacing costly copper metal.

(b) Structural materials used in trains, vehicles, machineries.

(c) Package and storage materials as thin sheets/foils for food and beverage materials.

(d) House-hold materials including utensils.

(e) Various alloys with Cu, Mg, W, Ni and Zn which have wide range of household/industrial utilities. These alloys are Duralumin (Al-Cu-Mg alloy), Magnalium (Al-Mg alloy), Wolframinium (Al-Cu-W alloy) and aluminium silver (Al-Cu-Ni-Zn alloy).

(f) Al metal sheets / foils are used as light and heat reflectors. The light alloys mentioned above are variously used in manufacture of aeroplanes, train compartments, motor vehicles and varieties of machineries.

**(ii) Refractory uses:** Calcined bauxite is used in different shapes and sizes as refractory bricks as internal linings of kilns and furnaces in cement production and metallurgical smelters.

**(iii) Chemical uses:** A variety of chemicals are obtained from calcined bauxite (heated out of air contact). These are (i) alumina (dry) (ii) alum (hydrated aluminium-potassium sulphate) (iii) Al-sulphate and Al-chloride. These chemicals find extensive uses in the fields of tannery, dyeing and sugar decolourisation (iv) calcined bauxite for purification of kerosene (v) alumina cement.

Besides, calcined bauxite is also used to manufacture alumina cement and alumina powder.

### 4.11.6. Origin

Genetically bauxites are formed by the following processes:

(i) Process of residual chemical concentration in which bauxite is formed by the secondary process effecting concentration of insoluble chemical constituents of $A1_2O_3$, $Fe_2O_3$ and $TiO_2$ left out in the source rocks comprising aluminosilicate minerals of feldspars and feldspathoids. These suitable rocks of aluminosilicates get, subjected to differential weathering in presence of

(a) Special climatic conditions (warm, humid tropical to subtropical witnessed by alternate wet and dry seasons) at and above 20°C.

(b) Good underground drainage condition to effect removal of leached out silica and soluble alkali constituents. This results in increase of insoluble constituents of aluminium and iron hydroxides which form the bulk of resultant insoluble residue.

(c) Availability of chemical reagents to accelerate intense chemical weathering.

(d) Presence of suitable geomorphic conditions in form of erosional peneplain surface to effect long continued chemical reaction.

(e) Time: The process needs to be operative over long time period.

(f) Long continued crustal stability is needed to prevent removal of residual products by erosion. .

(g) Presence of other favourable preservative condition to minimize the removal of residual products.

**4.11.7. World distribution**

The leading countries of the world having sizeable reserves of bauxite-laterite deposits are U.S.A., Russia, Canada, Australia, Brazil, China, British Guayana, France, Surinam, Hungary, Ghana, Rumania, and Jamaica.

**4.11.8. Indian distribution**

Geologically, Indian bauxites associated with laterites are said to have been formed during Pleistocene period. The sedimentary (bedded) type belongs to Gaj Series of Lower Miocene age and hence older than lateritic type. Terrarosa type bauxite in limestone is of Eocene (Lower Tertiary) age. Geographically Indian bauxites are confined to about 12 states including Odisha as the most leading one endowed with about 72% of Indian reserves. The state wise geographical distribution is as follows:

**(i) Andhra Pradesh:** East Godavari and Vishakhapatnam districts (later forming the southern part of the East Coast bauxite deposits located in the

Vishakhapatnam district, where this belt was discovered in 1970. It is a 400 km long and 30 km (maximum) wide belt distributed in parts of Andhra Pradesh (Vishakhapatnam dist.) and Odisha. In Andhra Pradesh, the important deposits are those of Galikonda, Jerrela, Gudem, Sapparla and Anantagiri.

**(ii) Gujurat:** Low level Bauxites occur in Kutch, Saurastra, Jamnagar, Bhavnagar Junagarh, Kheda and Amreli districts.

**(iii) Goa:** In Peruem and Malpem localities.

**(iv) Jharkhand:** Ranchi, (Lohardaga, Bagru hill) and Gumla districts.

**(v) Bihar:** Rajmahal, Monghyr and Palamau districts.

**(vi) Kamataka:** Belgaon, North and South Kannad, Chikmangalur districts.

**(vii) Kerala:** Quilon and Trivandrum districts.

**(viii) Madhya Pradesh:** Bastar, Balaghat, Sarguja, Mandala, Rewa, Satna, Durg and Raigarh districts. Important economic occurrences of great quantum and quality are Amarkantak plateau and Maikala range. At Katni in Jabalpur district, there is low level detrital (transported) occurrence. .

**(ix) Rajsthan:** Dungarpur district.

**(x) Jammu and Kashmir:** Mainly diasporic variety in karstic pocket form in limestone near Riasi and Poonch localities ofUdhampur district.

**(xi) Tamilnadu:** Salem, Nilgiri of Madurai districts.

**(xii) Odisha:** Odisha has the largest reserve of bauxite-laterite with 44% $Al_2O_3$ as the cut-off grade in India. The high level blanket type of deposits occur in great abundance where bauxite forms flat cappings in the peneplained hill ranges of the Precambrian Eastern Ghats range over altered khondalites mostly and the charnockites subordinately. It forms the north eastern extension of the celebrated East Coast bauxite deposits. Bauxitic blankets are prevalent on the denuded flat tops of the hill ranges in Koraput, Kalahandi, Phulbani, Balangir and Sambalpur districts. The thickness of lateritic bauxite aprons varies from 10-30 mover large areal extension. Economically important plateau deposits are:

(1) Koraput district at Panchpatmali, Pottangi, Kodingamali and Balada.

(2) Raygada district at Baphalimali, Pasangmali, Sijimali and Chandgiri

(3) Kalahandi district at Karlapat, Kutrumali and Lanjigarh.

(4) Bolangir-Bargarh districts at Gandhamardhan.

Besides there are smaller but good grade bauxite associated with Iron Ore Group shales in Sundergarh district at Tantra, Kusumdihi and Jaldihi. Bauxite is also associated with weathered profile of basic rocks at Dolkata-Kuanr in Keonjhar district. Of these, the Panchpatmali (21 km long plateau) is the most important deposit being exploited by NALCO since 1984. This has an alumina plant at Damanjodi and Al-smelter near Angul.

The total bauxite resources in India is about 3480 million tonnes out of which the resources in Odisha is about 1810 million tonnes.

## 4.12. COAL

### 4.12.1. Introduction

The term "Coal" is originated from the Sanskrit term "Kala" and Anglo-Saxon on term "cole" which means black. It is one of the "fossil fuels" or "mineral fuels" and is the principal source of heat and energy. Coal is rightly called "Black Diamond" since it is more valuable than diamond in terms of monetary value and its usefulness.

The existence of coal was known since earliest times even in the Bronze Age (3000 BC) but the first reference to coal in the literature is found in 4$^{th}$ century B.C. by Aristotle. In ancient India, during the Indus valley civilization (3000-1500 BC), coal was used for extraction of metal. In India, the first coal mine started working in Raniganj coal field near Sitarampur in the year 1774. The demand for coal was increased in India in 1853 after it was used in railway steam engines.

Coal may be defined as vegetal matter that has been subjected to a variety of geological and chemical processes with remarkable changes in physical property and chemical composition. The changes mainly involve the darkening of colour, an increase in hardness and compactness, loss of moisture and volatiles and an increase in carbon content.

Coal is often loosely referred as mineral because of its valuable nature like that of the mineral wealth and in this case the term mineral is used from the economic view point. But in the strict sense of the term, coal can never be called a mineral since it does not have fixed chemical composition and atomic structure. However coal can be called a rock as it satisfies the definition of a rock containing macerals and minerals and it occupies considerable portion of the earth‟s crust with persistent geological properties.

### 4.12.2. Uses of coal

(i) The main use of coal is in the generation of electricity in thermal power plants.

(ii) Coal is used as domestic fuel in many households.

(iii) It is also used as a fuel for the production of iron and steel, cement, fertilizer, chemicals, paper, glass, textile, rubber, sugar, abrasive, ceramic, refractory, asbestos products etc.

(iv) Coal is converted to hard coke and used for metallurgical purposes.

(v) During the manufacture of hard coke, several byproducts are formed such as volatile oil, tar, coal gas etc. The coal gas contains water vapour, ammonia and various hydrocarbons (benzene, toluene, napthas, phenol, cresol, xylenol, napthalene anthracene etc.)

(vi) Various chemicals are prepared from coal tar by distillation such as light liquid oil, napthalene, phenol, carbolic acid, heavy creosote-anthracene oil etc.

(vii) In high temperature carbonization, coal produces tar and light oil which are used as raw materials for many important products such as synthetic rubber, plastics, deodorants, photographic materials, various chemicals and medicines.

(viii) Tar is used for construction of roads.

(ix) The residual products from the combustion of coal i.e. fly ash, flue dust, coal ash and cinders are used in the manufacture of cement and concrete products in the construction of roads.

(x) The coal ash sometimes contains rare elements like germanium, vanadium etc.

(xi) Peat is mostly used as a fertilizer because of its rich nitrogen content (~2%).

In India thermal power stations consume 35% of the coal followed by iron and steel industries (15%), coal gasification (15%), domestic use (5%) and others.

### 4.12.3. Physico-chemical characteristics of coal

Lignite is light brown to dark brown in colour whereas others are greyish black to pitch black. Lustre varies from metallic, vitreous, pitch like, resinous to dull. Specific gravity varies from 1.2 in lignite to 1.5 in anthracite. Hardness varies from 2.5 to 3.0.

The principal chemical constituents of coal are carbon, hydrogen and oxygen with small amounts of nitrogen, sulphur, phosphorous, arsenic and other elements. There is a gradual increase of carbon and decrease of oxygen and hydrogen from wood to anthracite. Carbon content in soal varies from 50.0 % in peat to 94% in anthracite.

There are two methods of analysis to express composition and quality of coal. These are proximate analysis and ultimate analysis.

**4.12.3.1. Proximate analysis:** This analysis is done for general purpose. It includes moisture, volatile matter, fixed carbon and ash content.

Moisture is present in coal due to the absorption of water through the surface in the pores of the coal. The loss in weight after the dry coal sample heated at a temperature of 108° ± 2°C in an oven to the total weight is the moisture content which is expressed in percentage.

The volatile matter of a coal is the substance which escapes when coal is heated at temperatures of 900° ± 10° C for a period of seven minutes. Ash is obtained by the complete combustion of the inorganic mineral matter of coal. The mineral matter in coal is of two types; one is inherent or original mineral matter derived from the plants and the other is extraneous mineral matter added during the formation of coal. The amount of ash varies from 2 to 25% in different ranks of coal and also in the coals of the same rank. Fixed carbon is the weight loss upon combustion of a devolatised coal sample. It is estimated by deducting the sum total of moisture %, volatile matter % and ash % from 100.

Calorific value is the most important parameter for the assessment of the quality of coal since it is a measure of the available heat produced from it. It is determined in the laboratory with a bomb calorimeter.

**4.12.3.2. Ultimate analysis:** It is the elemental analysis of coal which contains carbon, hydrogen, nitrogen, sulphur, phosphorous, chlorine etc. in varying amounts. For the evaluation of coal properties, ultimate analysis of coal is more important. The carbon content increases progressively from 65% in lignite to 94% in anthracite.The oxygen content decreases progressively from 30 to 40% in lignite to 1-2 % in anthracite.

### 4.12.4. Types of coal

Coal is formed by transformation of the plant materials. The transformation may be complete or may be arrested at anyone stage giving rise to coals of varying maturity which is denoted by the term "Ranks of coal". The percentage of carbon, volatile and moisture content determine the ranks of coal. Different ranks of coal are Peat, Lignite, Sub-bituminous, Bituminous, Semi-anthracite and Anthracite showing gradual increase of carbon content and decrease in volatiles, moisture content, hydrogen, oxygen etc. A brief description of each type is given below.

**(i) Peat:** It is not regarded as coal though it is the first stage in formation of coal. It is formed by the accumulation of decayed vegetal matter in moist places. Its colour varies from light brown to dark brown. It is light, porous and fibrous matter containing recognisable plant remains. It is not an economic fuel. Since its nitrogen content is high (around 2%), it is used for making fertilizer. It contains about 85% moisture, 10% volatile matter and 5% carbon.

**(ii) Lignite:** It is the second stage of coal formation. It is brown to black in colour where original plant components are recognisable in consolidated form. It possesses woody texture or is composed of finely divided plant tissues. It gives a brown streak and burns with little or no smoke. Lignite contains about 20-60% moisture, 40-80% combustible matter, 40% volatile matter and 20% oxygen. It is used for distillation, combustion, gasification, organic fertilizer and in the thermal power stations.

**(iii) Sub-bituminous coal:** It is black in colour, waxy and banded. It is denser and harder than lignite and has lower moisture content (12-25%) but 80 to 90% combustible matter. It has a brown streak and gives off smoke when it bums. Some varieties disintegrate on exposure to air. It is a good fuel.

**(iv) Bituminous coal:** This coal burns like bitumen with a yellow smoky flame and hence the name. It is jet black in colour and darker than subbituminous coal. It is brittle, dense, banded and well jointed coal which usually breaks into prismatic and cubical blocks. It has less than 10% moisture and more than 90% of combustible matter. It also contains 15 to 45% volatile matter and 4 to 5% of hydrogen. This type of coal may be coking or noncoking. Usually this is used for manufacture of metallurgical coke.

**(v) Semi-anthracite:** It is harder than bituminous coal but not as hard as anthracite. It burns first with a short yellow flame and then with a blue flame. It mainly contains combustible matter.

**(vi) Anthracite:** It is characterised by faintly visible banding which may not be seen at times. It is black, hard, dense coal with black streak and glossy lustre. It does not soil finger and breaks with conchoidal fracture. It is difficult to ignite readily and burns with a short, faint, blue non-luminous flame without smoke. It has the highest content of combustible matter. Its volatile matter varies from 5-10%. Because of its heating power and smokelesssness, this coal is in great demand for metallurgical purposes.

A commercial classification of coal has been made on the basis of ash content in coal. Noncoking coals have been classified into different grades such as A, B, I , II, III(A), III(B) with ash content less than 15% , 15-17%, 17-20%, 20-24%, 24-28% and 28-35% respectively. Similarly coking coals are classified into 11 grades.

Department of coal, ministry of Energy, Government of India classified Indian noncoking coals into seven grades (A, B, C, D, E, F, G) on the basis of amount of energy generated by burning the coal out of which „A" is the highest grade and „G" is the lowest grade. The coking coals are classified on the basis of ash content into six grades such as steel grade I, II, washery grade I, II, III and IV.

### 4.12.5. Macroscopic and microscopic constituents of coal

Hard coals are classified into two types at macroscopic scale such as humic or banded coal and sapropelic or non-banded coals. The macroscopic constituents in each type are given below.

**(i) Humic (banded) coal:** It contains four major constituents. These are

(a) Vitrain - Black colour, bright, brittle, fissures are present

(b) Clarain - Black colour, semi-bright, finely stratified

(c) Durain - Black or greyish black colour, hard

(d) Fusain - Black colour, fibrous, silky lustre, soft, friable

**(ii) Sapropelic (Non-banded) coal:** These are of two types as given below.

**(a) Cannel coal:** Black colour, dull or greasy luster, homogenous, hard, conchoidal fracture and black streak

**(b) Bug head coal:** Brownish black colour, brown streak, dull lustre, homogenous hard and conchoidal fracture

There are very small micropetrographic constituents in coal which are known as macerals like vitrinite, exinite, inertinite etc. which can be identified with the help of petrological microscopes (reflected type) with oil immersion objectives.

### 4.12.6. Mode of occurrence

Coal is found in sedimentary rocks as layers and beds. The dominant sedimentary rocks with which coal is associated are sandstone and shale. In some cases coal seams are associated with fireclay and limestone. The sediments in between coal seams are usually laminated and are laterally impersistent. The sediments in between coal seams may be composed of sand, silt, clay, etc.

In most of the Gondwana coal fields of India, sediments occur usually in cyclic order starting from sandstone successively overlain by shaly sandstone, shale, sandy shale, carbonaceous shale and coal. In the Tertiary coal fields of Meghalaya, carbonaceous shales or shales lie at the base with sandstone or carbonaceous shale at the top.

The thickness of coal seams varies from less than a metre to hundreds of metres. Laterally a seam may extend from a few metres to hundreds of kilometres.

The coal seams exhibit various structures such as banding, cleats, ball structures etc. The banding is composed of layers of variable physical properties differing in texture and lustre. Coal seams are affected by three sets of joints known as cleats out of which one is almost horizontal and the other two are vertical. The "Ball Coals" are spheroidal or oval shaped bodies of coal embedded within coal seams.

### 4.12.7. Origin of coal seams

The coal seams have originated either in swamps or in brackish or fresh water basins.

Vegetal or plant debris are the source material for coal formation, although the class of vegetation has varied considerably during successive ages. However, there are no marked changes in the chemical composition of coal. It is found that coal is composed of cellulose, lignin and protein with varying amounts of resins, waxes, fats, gums etc. The properties of the above substances vary greatly in different plants and hence they influence composition of coal. To account for considerable thickness of coal, there must have been luxuriant growth of vegetation. The swampy regions are suggested to be the ideal sites of growth of the plants followed by bacterial decay and decompositicm of plant material. Subsidence of depositional site after deposition of sediments and coal can account for the cyclic pattern of sedimentation.

There are two theories to explain the origin of coal seams and for the accumulation of the vegetal matter. These theories are (1) Insitu theory and (2) Drift theory.

**(i) Insitu theory:** The dense forests covered the earth millions of year ago which were buried at the place of their growth under a cover of sediments due to disturbances on the surface of the earth. In course of time, due to pressure of the overlying sediments and temperature, the vegetal matter was transformed into coal. Due to overlying load and other structural disturbances, the basin of deposition was subjected to subsidence with new cycle of plant growth and sedimentation. This process continued successively for quite long period of time as a result of which coal seams were repeated along with inter-seam sedimentation. The evidences in favour of such a theory are:

(a) A vast amount of plant material is being accumulated in the swamps of the present day.
(b) Numerous fossilised tree trunks are found standing erect with their roots firmly fixed in the under clays of the soil on which vegetation grew.
(c) The constancy of composition and quality of coal seams over wide regions suggest deposition of vegetal matter in still water without undergoing much transportation.
(d) There is general absence of detrital materials like sand and clay in coal.
(e) Aquatic fossils are usually absent in coal.

**(ii) Drift Theory:** According to this theory, the constituent vegetal matters of coal are transported from the place of their origin to their place of accumulation by agents like running water, glacier etc. The place of accumulation may be deep lakes, river valleys, estuaries etc. which are covered by sediments like sand and clay after accumulation of the plant materials. The place of accumulation sank simultaneously with deposition as a result of which the sedimentary sequences were repeated and the thickness of the sediments was increased.

The evidences in favour of drift theory are:

(a) Upright tree trunks are usually absent in coal seams formed by this process.

(b) The coal seams show wider variation in composition.

(c) Large amounts of detritital materials like sand and clay are found in the coal seams.

(d) In the region of virgin forests, large quantity of timber and other vegetal materials are being transported by present-day rivers.

### 4.12.8. Origin of Coal

Transformation of vegetal matter into coal involves two processes i.e. biochemical processes and geochemical process.

**(i) Biochemical Process:** This is also called humification. In the initial stage, the plant materials are decomposed due to process of oxidation aided by fungi and aerobic bacteria. The hydrogen ion concentration (pH) and redox potential (Eh) controlled the changes. The decay by fungi and bacteria was arrested after a certain limit when the plant debris were covered by sediments. At this stage, anaerobic bacteria acted upon the plant debris but the rate of decomposition was relatively slow. In anaerobic condition, the protoplasm, proteins, starches and cellulose were decomposed rapidly. The waxy layers of plants such as cuticles, spores, pollens and resins were not affected much by bacteria. The accumulated vegetal matter was subjected to pressure of the overlying load and temperature and depending on the pressure and temperature, wood is transformed into coal. In addition to the overlying load, pressure and temperature is being supplied by tectonic events or disturbances. The process from accumulation of plant debris to formation of coal takes at least one million year and hence time is an important factor in coal formation.

**(ii) Geochemical Process:** This is also called coalification that involves progressive change in composition of organic material in series from wood-peat-lignite-bituminous- anthracite. When peat is buried and compacted, the percentage of oxygen is reduced due to loss of water and carbon dioxide with resultant increase in carbon content. The cellulose and lignin of the plant materials which are complex substances composed of carbon, hydrogen and oxygen are subjected to various complex processes giving rise to coal of different ranks.

### 4.12.9. Indian distribution of coal

Nearly 80% of coal reserves of the world are distributed in formerly USSR, USA, China, Australia, India, Germany and South Africa.

Coal occurs in geological periods from Carboniferous to Miocene. The Carboniferous coals are found in many countries of the world. Although Permian coals are less widespread, these are abundantly found in countries like India, Alaska, China, Russia, South Africa and Australia. The Triassic coals are found in Australia, Central Europe and eastern Asia. Jurassic coals are found in India, Alaska, China and Austria. Cretaceous coals are found in North America (western) and central Europe and high rank Tertiary coals are located in Alaska. Coal deposits of Miocene age are found in Antarctica.

In India, workable coal occurs in only two geological horizons namely Lower Gondwana period (mostly Permian) and Tertiary (mostly Cainozoic) period. Small quantities of inferior grade coal are found in the Upper Gondwana period of Jurassic age and in other periods.

#### (i) Gondwana coal fields of India

Gondwana coals occur in two time slots namely Permian age of Lower Gondwana and Jurassic age of Upper Gondwana. Nearly 90% of India‟s coal production comes from the Lower Gondwana coal fields. Coal fields of Lower Gondwana age occur mostly in the states of West Bengal, Bihar, Madhya Pradesh, Odisha, Andhra Pradesh, Maharastra and Uttar Pradesh.

**(a) West Bengal**

The most important coal fields are known as Damodar valley coal field which includes Raniganj coal field. Raniganj coal field has an area of about 1500 sq km with Asansol in the centre. Coal seams occur both in the Barakar and Raniganj formations. Other coal fields in the Damodar valley area are Barjora, Birbhum, Darjeeling and coal fields of Domra-Panagarh, Deocha etc.

**(b) Bihar and Jharkhand**

Jharia coal field is situated at a distance of 260 km northwest of Kolkata in the heart of Damodar valley. It is one of the most important coal fields which contains prime coking coals and is situated in Dhanbad district with an area of about 456 sq km. The coal bearing horizons belong to Barakar and Raniganj formations. This coal field contains 49 seams in the Barakar formation out of which 23 seams are persistent as well as regional in distribution and are mined. In the Raniganj formation of Jharia coal field area 3 regional seams and 13 local seams are present. In this coal field, the coals of the upper seam of the Barakar formation are of coking variety.

Other coal fields in Damodar valley area are at Chandrapura, Bokaro, Ramgarh, Karanpura, etc.

In addition to the Damodar valley area, other coal fields are at Rajmahal, Deogarh, Hazaribag (Giridih, Chope, Itkhori), North Koel valley (Auranga, Hutar, Daltonganj).

**(c) Madhya Pradesh South Rewa region**

In south Rewa region one of the important coal field is at Singrauli where coal seams are located in Barakar and Raniganj formations. Other coal fields are at Sohagpur, Umaria, Korar, Johilla, etc.

Important Satpura coal fields are located at Mohpani, Sonada, Shahpur, Dulhara, Pathakhera, Bamhanwara, Kanham valley, Pench valley etc.

**(d) Chhatishgarh**

Important coal field in North Chhatisgarh area include Tatapani, Jhilimili, Sonhat, Chirimiri, Kurasia, Koreagarh, Bisrampur, Bansar, Lakhanpur, Panchbhaini, Sendurgarh etc.

In the South Chhatisgarh coal field area, important ones are at Hasdo-Rampur, Korba, Mand river, Raigarh etc.

**(e) Maharastra**

Coal fields of Maharastra can be divided into 2 broad categories i. e. coal fields of Nagpur region and those of Wardha valley.

Coal fields of Nagpur region: It includes coal fields located at Kamptee, Bokhara and Umrer. Coal seams are restricted mostly to Barakar F.ormation.

Wardha valley: In this region coal fields are located mainly at Bandar, Warora, Rajur, Ghugus, Ballarpur etc. in Chandrapur district.

**(f) Andhra Pradesh**

Different coal fields include those located in Pranhita-Godavari valley, in an area of 500 sq km. Different coal fields are located at Tandur, Jangaon, Chinnur, Karlapalli, Alapalli, Lingala, Singareni etc.

**(g) Odisha**

In Odisha, two main coal fields are located i.e. Ib-river coal field and Talcher coal field. The Ib river coal field covering an area of 520 sq km is situated in Sambalpur, Jharsuguda and Sundargarh districts of Odisha. The coal seams are found mainly in Karharbari and Barakar formations and sometimes in Middle Kamthi (Middle Raniganj) formation in Lower Gondwana Group. Three main coal horizons are there in this field such as Ib-seam, Rampur seam and Lajkura seam. Besides these three seams, there are many local seams such as Parkhani seam, Belpahar seam etc. In the Ib-valley coal field area, coal mining is being undertaken at Belpahar, Lakhanpur, Talabira, Gopalpur (Basundhara), Khinda etc.

Talcher coal field area lies at a distance of 130 km north-west of Bhubaneswar in Angul and Dhenkanal districts of Odisha. The coal seams in these areas are found mainly in Barakar formation (12 seams) and Karharbari formation (one seam). Important coal mines are Ananta, Lingaraj, Jagannath, Bharatpur, Kalinga, Balanda, Nandira, Deulbera, Talcher etc.

Total coal resources of Odisha is about 75073 million tonnes out of which Ib-valley coalfield has a resource of 24198 million tonnes and Talcher coalfield has a resource of 50875 million tonnes.

**(h) Uttar Pradesh:** The eastern part of Singrauli coal field extends into the Mirzapur district where the coal field is located at Kota.

**(i) Assam:** Coal seams belonging to Barakar Formation are found in the Abor, Aka and Daphla hills in the Himalayan region and also in the Garo hills area.

**(j) Sikkim:** Coal seams are found in the Ranjit valley.

**(k) Gujarat:** Subbituminous type of coal is found in the Upper Gondwana (Cretaceous) sediments in Kutch, Surendranagar and Mehsana districts. Important localities are Ghuneri, Thangadh etc.

**(ii) Tertiary coal fields of India**

**(a) Meghalaya:** Coal deposits are located within a narrow belt extending from Garo hills through Khasi hills upto Jaintia hills in the Palaeocene and Eocene rocks. These coals are of bituminous type.

**(b) Assam and Arunachal Pradesh:** Coal deposits occur within a long narrow belt trending NE-SW ranging in age from Upper Eocene to Oligocene. Coal deposits in these states are found in the Barail Group. Important coal fields are Makum, Namchik, Namphuk etc.

**(c) Nagaland:** Coal seams occur in the Barail Group of Oligocene age in the Borjan coal field. Other coal fields in this state are at Safrai, Jhanzi, Disai etc.

**(d) Jammu:** The coal bearing horizons are confined to the basal part of the Eocene bed belonging to Subathu Group. Coal fields of economic importance are located at Kura, Kalakat, Metka, Mahogala etc.

**(iii) Lignite deposits of India**

Lignite contributes about 4% of the total energy needs of the country. Since in comparison to coal, it is low in ash and sulphur content, it creates less environmental hazards. Lignite is distributed in Tamil Nadu, Pondicherry, Kerala, Karnataka, Andhra Pradesh, Maharashtra, Gujurat, Rajasthan, Jammu and Kashmir etc.

**(a) Tamilnadu:** One of the most important lignite fields of the country is situated at Neyveli in South Arcot district. The lignite deposit belongs to Cuddalore Formation of Upper Miocene age. Important localities are Neyveli, Veeranam, Kudikadu etc. Lignite occurrences are also located in Trichinapoly, Tanjavur and Ramanathapuram districts.

**(b) Pondicherry:** In the continuation of Tamilnadu, one of the most important deposits is located at Bahur where lignite deposits are also associated with Cuddalore Formation.

**(c) Gujarat:** Lignite deposits are associated with middle Eocene rocks in Kutch, Bhavnagar, Surat and Bharuch districts. These lignites are associated with grey and gypseous clays.

**(d) Rajasthan:** Carbonaceous horizons and lignite occur in the Tertiary basin of western Ragasthan and are scattered in the districts of Bikaner, Barmer, Nagaur etc. in the Eocene rocks.

**(e) Jammu and Kashmir:** Lignite is located in patches belonging to Karewa Formation of Pleistocene age at Nichahom, Tangmarg, Nagbal, Chowkibal etc.

**(f) Kerala:** Lignite along with peaty lignite and woody lignite occur in association with clay beds in Alleppey, Kannannore,Ernakulum, Quilon and Trivandrum districts.

### 4.12.10. Resource potential of coal and lignite

Total coal resource of India is about 3,01,564 million tonnes out of which about 90% occurs within a depth range of 0-600 metres. More than 95% of our coal resources occur in seven states like Bihar, Jharkhand, Madhya Pradesh, Chhatisgarh, West Bengal, Odisha and Andhra Pradesh. There are many areas which are yet to be explored in detail and hence the coal reserve is likely to be increased in future.

The total lignite resource of India is about 43,247 million tonnes out of which about 90% of the reserve is located only in the state of Tamil Nadu.

## 4.13. PETROLEUM

### 4.13.1. Introduction

Petroleum is a fossil fuel like coal. While coal is solid non-crystalline carbon, petroleum is essentially a viscous liquid composed of hydrocarbons. The word „petroleum‟ is derived fromthe combination of two Latin words i.e. „petra‟ meaning rock and „oleum‟ meaning oil. This commodity is variously termed as mineral hydrocarbon or mineral oil or crude oil or black / liquid gold. Man knew the use of petroleum substance in form of solid bitumen (asphalt) to construct the houses during Neolithic age. Historically its use could be traced back to 3000 B.C. when Egyptian, Sumerian and Babylonian civilizations prevailed. The Chinese and Japanese were aware of its use as far back as 3$^{rd}$ century A.D. As revealed by Marcopolo‟s book of travels, Oil trade in European Soviet Union dates back to 13$^{th}$ century A. D.

In the modern world the first ever oil well was that of Titusville in U.S.A. drilled by Erwin Drake in 1859. Oil strike in India dates back to 1867 when the first ever oil spudded on Indian territory from a well (second oldest in the world) located at Margherita in Assam. It was productive only for a few years. However, the golden era of Indian oil production heralded with discovery of the spectacular Digboi oil field located in Assam in the year 1889. It is one of the oldest oil fields in the world having been relentlessly productive for the last about 120 years spanning over three centuries that is the fag end of 19$^{th}$ century, full 20$^{th}$ century and first decade of 21$^{st}$ century.

### 4.13.2. Constitution

Petroleum (crude oil) is composed of a variety of hydrocarbons which belong to a number of homologous saturated to unsaturated and close to open structured natural C-H compounds. These are divisible into the groups/serieses which include

(a) alephatic or alkane group of hydrocarbons of (i) Paraffin series (ii) Ethylene series (iii) Acetylene series and (b) Aromatic group hydrocarbons of (iv) Naphthene series (v) Benzene series (vi) Napthalene series. Of the above, the main bulk of viscous liquid petroleum belongs to paraffin, ethylene and napthene series comprising hydrocarbons of intermediate carbon numbers ($C_{10}$ to $C_{16}$). Natural gas comprises fluid to gaseous hydrocarbon of lower carbon members ($C_1$ to $C_9$) such as methane, ethane, propane etc. The solid to semi-solid hydrocarbons ($C_{17}$ to $C_{30}$) include asphalt ozokerite, elaterite, albertite, gilsonite and mineral pitch or tar.

### 4.13.3. Elemental composition

Major elements present in petroleum are carbon (C) and hydrogen (H). Elements present in subordinate proportion are nitrogen (N), Oxygen (O) and Sulphur (S). The following is the percent range of elements present in petroleum:

| | | |
|---|---|---|
| C = 82 - 87 % | N = 0.01-2.4 % | S = 0.1-5.5% |
| H = 11.5 - 14.5 % | O = 0.1-7.4% | Rest = Traces of inorganic elements including vanadium and nickel metals |

### 4.13.4. Physical properties

Petroleum shows somewhat wide variations depending upon source organic material and geological processes involved in its formation. However, the generalized physical properties are:

- **(i) Colour:** Crude oil is variously coloured being pale yellow, brown, red, green and black. In thick layers it is opaque to transmitted light. Heavy oils are usually light coloured (yellow to green) where as light oils are dark coloured (deep brown to black).
- **(ii) Odour (smell):** Varies with hydrocarbon composition. Paraffin and napthene rich oils emit agreeable and pleasant odours whereas nitrogen and sulphur rich oils emit bad / nonpleasant smell.

**(iii) Viscosity:** Heavy oils are more viscous (less flowable) than light oils. This property is directly proportional to specific gravity and temperature.

**(iv) Specific gravity:** In general, it is less than 1.0 which is the value of pure water. In API (American Petroleum Institute) scale it is expressed in terms of 0°-100° where in 0° = 1.076 (heavy), 50° = 0.779 and 100° = 0.611 (light).

**(v) Heating value:** It is more than that of coal. Its value in oil ranges from 18,500 to 19,900 BTU per pound of oil (British Thermal Units) or 10,000 to 11,000 calories per gram in CGS (metric units). Light oils have higher heating value thah heavy oils.

**(vi) Optical property**: Oils have the property to rotate the plane of polarization of transmitted light. This rotational property is exhibited more prolifically in oil fractions showing intermediate values of boiling points i.e. 250-300°C.

### 4.13.5. Uses

Petroleum enters into our daily lives in a thousand and one ways ranging from a pin to elephant. It is the key fossil fuel of modem times in the world having indispensable uses in the industrial, transportational, communication and agricultural fields. The uses are briefly summarized as follows:

It is one of the chief conventional energy sources used for easy and quick transport-conveyance and for production of thermo-electricity. The different distillates from crude oil yield are:

(i) Diesel and petrol are used as chief fuels for vehicle (scooters, motorbikes and cars) and ships.

(ii) Aviational fuel i.e. gasoline used in aeroplanes as turbine fuels.

(iii) Diesel specifically used to drive vehicles and locomotives (rail engines). There are two types of diesel viz. light and high speed.

(iv) Kerosene to light lanterns, lamps and to run stoves etc.

(v) Produces thermo-electricity (oil based electric power generations). Gas is also used for this purpose.

(vi) Natural gas marketed as Indane and Cal gas used for domestic and hotel cooking (LPG).

(vii) Petrol and diesel are used as fuels to run the heavy machineries like war and other tankers (mining and drilling machines and giant rollers).

(viii) Lubricating oil (Mobil) to keep the componental parts of the machines in good working condition in automobiles.

(ix) White oils (colourless and odourless) as base for preparing cosmetics e.g. hair oil, snow etc.

(x) Naptha and natural gas are used to manufacture fertilizers.

(xi) Different kinds of petrochemicals produced as by products of oil refineries have lot of utilities as summarized below:

(xii) Various organic compounds yield chemicals and solids which comprise (a) plastics (b) cosmetics (c) synthetic fibres and fabrics such as polyethylene, polypropylene, polybutylene which are used as bags for packaging of materials as insulators, pipes, canes and automobile parts. (d) Different kinds of oils such as turpentine oil (for wood preservation), jute oil (for jute processing), melorial oil (as mosquito and fly repellant) and furnace oil (for boilers) obtained as byproducts. (e) Paraffin wax for making candles, match stics, vaseline, grease and lipsticks, (f) Alcohols, (g) Synthetic rubber, (h) Explosives (gelatins), (i) Varnish paints, (j) Petrol washing of synthetic cloths, wood and warm cloths (suits, sweaters, blankets etc.), (k) B.O.C. carbon blocks and paints, (l) Petroleum coke as electrodes, (m) Perfumes, (n) Dyes, (xv) Medicines, (o) Synthetic resins, (p) Asphalts, bitumens, oil-tars for making dust-proof roads.

### 4.13.6. Mode of occurrence

Petroleum is associated invariably with sedimentary rocks varying in age from Upper Palaeozoic to Late Tertiary. In India oil and natural gas are exclusively confined to the sedimentary rocks of marine to estuarine facies which vary in geological age from Eocene to Pliocene periods.

In source rocks (shale, clays and siltstones) oil occurs as discrete and dispersed droplets which do not make commercial deposit. From source rocks, oil migrates to reservoir (carrier) beds / rocks to make accumulations. This migration of oil is effected by either transverse (or vertical) or longitudinal (lateral) movements under the influence of compaction, capillary force and buoyancy effects. Greater the porosity more will be the amount of oil in a reservoir rock which can transmit and yield greater quantum of oil through permeable sandstones and limestones. This situation alone can hardly contribute to the accumulation unless the geo-structural configurations (attitude) of the reservoir rocks (sandstones, conglomerates and limestones) are favourable to form payable oil areas termed as oil pools, which are rocks with their permeable domains saturated with oil-gas-water layers. Such conditions or configurations which conduct the flow of oil and gas and store them in subterranean hydrocarbon reservoirs, under favourable geo-structural framework overlain by impervious strata (rocks) comprising inclined / folded / faulted reservoir strata, are termed as traps. The traps are divisible into:

(i) Structural traps such as plunging folds (Fig. 4.5), monoclines, faults / thrusts (Fig. 4.6), faulted anticlines, domes (anticlinal folds with quaquaversal dips) and salt domes (Fig. 4.7).

(ii) Stratigraphic traps such as unconformities, sandstone lenses, shoe-string sand bodies and

(iii) Combination traps such as overlaps, synclinal folds and truncated uparched structures etc.

### 4.13.7. Origin

The oil genesis is not free of controversy. The aspect of origin is shared by two schools of thought i.e. inorganic and organic. While the inorganic concept of oil genesis is held by chemists and geochemists, the organic concept is justifiably advocated by geologists and geophysicists, with more confidence.

**(i) Inorganic origin of petroleum:** The inorganic views are based on less convincing and more theoretical surmises (scientific guesses). The evidences put forth by inorganic proponents such as Humboldt, Berthelot, Moissan, Silvesti, Mandeleef and Sokolov in 19$^{th}$ century are mostly of more hypothetical nature which fail to account for oil formation in profusion in the sedimentary rocks. These ideas were grossly insufficient to explain the gross physical, chemical and compositional (large number and varieties of hydrocarbons) properties. Few hypotheses concerning inorganic origin are those of (i) carbide (alkali) hypotheses, (ii) volcanic hypotheses, (iii) cosmic hypotheses and (iv) limestone-gypsum-hot water hypothesis.

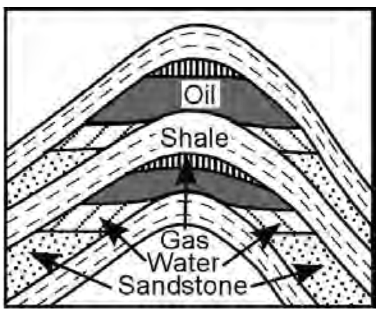


**Fig. 4.5: Anticlinal trap**

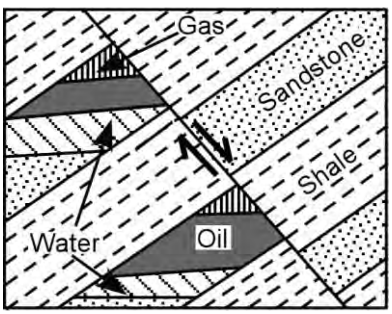


**Fig. 4.6: Fault trap**

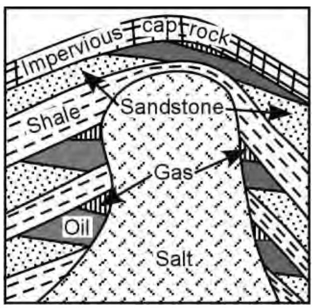


**Fig. 4.7: Salt dome trap**

**(ii) Organic origin of petroleum:** Organic origin of oil is strongly attested by the following aspects:

(a) The nature and range of great number of hydrocarbon series present in natural oil.

(b) Intimate association of oil with plant and animal microfossils.

(c) Confinement of oil to porous and permeable sedimentary rocks (sandstones and limestones).

(d) Composition and homologous nature of organic matter contained in carrier sedimentary rocks.

(e) Presence of hemin and chlorophyll which are found in animals and plants respectively.

(f) Optically positive nature of liquid hydrocarbons.

(g) Experimental proofs of producing liquid hydrocarbons from low order plants and animals sources such as phyto-planktons and zoo-planktons.

**(iii) Transformation of organic matter to liquid hydrocarbons**

The source materials of petroleum comprise organic materials of mostly low order plants and animals which consist of a complex mixture of resistant, solid to semi-solid carbon compounds, which under the influence of wide range of physical, chemical and geological parameters invoke the actions of energy in form of certain agents. These agents, effecting conversion of semisolid organic debris to liquid ± gaseous hydrocarbons, are (i) thermal energy (temperature alongwith pressure), (ii) bacterial activity, (iii) radioactive energy and (iv) catalytic agent (vanadium and nickel traces) which lower the critical temperature for conversion. Of the above, roles of anaerobic bacterial agents, catalytic agent and radioactive ($\alpha$, $\beta$, $\gamma$) rays are thought to be more prevalent and effective in final oil generation. At present, biogenic origin of oil and gas is credentially accepted.

### 4.13.8. Geographic distribution

Geologically, oil and gas are prevalent in suitable reservoir rocks of wide geological range from Cambrian to Pliocene ages, in the world, where as in India, oil is exclusively confined to the marine - estuarine sedimentary rocks of Tertiary (Eocene-Miocene) age. It is also abundantly found in marine shelf sediments in the offshore of many global maritime countries including east and west coasts of India.

**(i) Global distribution:** The prime oil reserves are located in

(a) USA-Gulf coast of Texas, Rocky mountain belt (California state) and Appalachians (New York).

(b) Canada-Extension of Rocky mountain foothills.

(c) Middle East countries of Iran, Iraq, Saudi Arabia, Baharein, Kuwait (persian Gulf area)

(d) West coastal tract of South America along the Andes mountain belt (Colombia, Venezuela etc.)

(e) Mexico oil region (Mid-America) offshore oil.

(f) West Indian islands (Caribbeans)

(g) Russia - Northern Caucasus mountains (Baku and Bronzy fields) and Volga region of Urals.

(h) Germany - Rumania: oil with salt domes.

(i) United Kingdom and France - North Sea offshore fields.

(j) Myanmar- Arkan coastal belt.

(k) China, Indonesia, Australia and South Africa.

**(ii) Indian distribution:** Indian petroleum and gas fields are exclusively confined to the Tertiary (Eocene-Oligocene-Miocene) marine geosynclinal shelf sediments confined to a few number of productive basins. Majority comprise of gas mixed oil fields, while very few are preponderantly gas fields. The reservoir rocks are more commonly sandstones and less commonly limestones (as in case of some offshore fields). The reservoir rocks under suitable trap conditions have afforded congenial geo-structural situations to form productive oil fields.

Before independence, the only productive oil field was Digboi (Assam) which is still productive. After independence, Oil and Natural Gas Commission (ONGC) formed in 1956, Indian Oil Corporation formed subsequently on liquidation of erstwhile Burma Shell Company, some foreign companies consequent upon the advent of globalization and liberalization policies and Reliance Oil (Indian private sector) company have discovered new emerging fields in both Indian on-shore and off-shore zones. These oil and gas fields are as follows:

**(a) Assam - Arkan basin:** (Oil in Tipam and Barail Formations in Upper and Lower Assam-Tripura region including NE states): The productive oil fields are (a) Digboi, (b) Moran, (c) Rudrasagar, (d) Lakwa, (e) Sonari, (f) Amguri, (g) Tripura (big gas field).

**(b) Cambay basin:** About 56,000 $km^2$ area of Tertiary marine sediments composed of sandstones contain huge reserves of oil and gas in mostly structural traps. This basin is mostly within Gujrat between Surat in the south and Tharad in the north. The southern part is partially in the gulf of Cambay. It is a north - south elongated and comparatively narrow marine basin with faulted base. Most of the oil traps are of structural type comprising faulted anticlines. Of the 51 oil and gas fields, the most productive are (a) Ankleswar, (b) Kalol, (c) Lunej, (d) Cambay, (e) Mehsana, (f) Nowgaon, (g) Balah, (h) Dahej.

**(c) Bombay high off-shore fields:** Discovered in 1974, this oil and gas field is located about 160 km north-west of Mumbai city. It is the southern extension of the Cambay basin and forms a part of the Arabian continental shelf. As it shows a geophysical high, it is called Bombay high. The shelf bottom has a faulted basement. Oil and gas occurs in porous and permeable carbonate (limestone) rocks of Middle Miocene age. Oil occurs in several anticlinal structures. Light oil occurs in three horizons mostly in foraminiferal limestone. The oil fields are (a) Giant Bombay High proper and (b) Fourteen comparatively smaller fields of Bassein, Heera, Panna, Ratna, Tapti, Neelam and Mukta etc. This is the largest composite field that provides about 60% of entire Indian output which is more than 20 million tonnes of oil per year.

**(d) Krishna-Godavari (K.G.) basin ofAndhra Pradesh:** Oil and gas were discovered since 1981 in the coasta1on-shore and off-shore regions of (a) Narsapur, (b) Razde, (c) Machilipatnam and (d) Bhimapalli locations. Off late, KG basin oil and gas have been rediscovered and reassessed by the Reliance (Energy) Company.

**(e) Kaveri off-shore fields in Tamilnadu:** Oil and gas have been productive on smaller scales at Nariman, Porto-Novo, Palk Bay and Kovil.

**(f) Rajsthan (Jaisalmer basin):** At Dandewada, Tanot and Ramgarh, large gas deposits have been proved.

Besides the above, there are good prospects of oil and gas fields in Bengal basin, Mahanadi off-shore, Punjab, Andaman, Palar and Kutch basins as well as a few more which need intensified exploration.

The total resources of crude petroleum in India is 762.74 million tonnes and that of natural gas is 1427.15 billion cubic metres.

## 4.14. MINERAL DEPOSITS OF ODISHA – AN OVERVIEW

Odisha is very rich in mineral resources. Its resource position with respect to India is very good. With respect to Indian resource position, Odisha possesses

93% chromite, 92% nickel ore, 69% cobalt ore, 55% bauxite, 51% titaniferous magnetite, 40% limestone, 36% pyrophyllite, 33% iron ore (hematite), 26% sillimanite, 25% each fireclay and garnet, 24% each coal & zircon and 20% vanadium ore resources. The state has almost all the resources of ruby and platinum ore. With respect to utilization, Odisha is the leading producer with respect to chromite, graphite, bauxite, manganese ore, iron ore, sillimanite, quartzite, pyroxenite and dolomite.

The mineral deposits of Odisha can be classified into three broad types as given below.

(i) **Ore mineral deposits** – This includes iron ores, manganese ores, base metal deposits, bauxite, chromite, nickel ores, tin ores, PGE and gold occurrences.

(ii) **Industrial mineral deposits** – This include asbestos, beach placers, china clay, fire clay, graphite, limestone and dolomite, gem stones, pyrophyllite, quartz and quartzite, high magnesia rocks, talc-soapstone-steatite, kyanite and sillimanite, mica etc.

(iii) **Fuel deposits** – This includes coal

A detailed description of all the mineral deposits of Odisha is given in the following pages.

**4.14.1. Ore mineral deposits**

**(i) Iron Ores:** Iron ores of Odisha are found in two different geological set ups, one associated with the basic intrusive as magmatic deposits, the other associated with the protores like banded hematite jasper/chert/quartzite. Important deposits occur in the districts of Mayurbhanj, Keonjhar, Sundargarh, and Jajpur districts. Minor occurrences occur in the districts of Nawarangpur and Deogarh.

**(a) Mayurbhanj district:** In this district, iron ore deposits of magnetite type are found in association with basic intrusives like gabbro in Kumardhubi, Betajharan areas. These magnetites are titaniferous and vanadiferous containing 10 to 25%

$TiO_2$ and 2 to 7% $V_2O_5$. Iron ores associated with highly metamorphosed rocks like banded hematite/magnetite quartzite of Iron Ore Supergroup which is assigned as an older age are located in Badampahar, Sulaipat and Gorumahisani areas over a stretch of 40km. Mining which was closed for some time due to lowering of the grade has again started in ihis belt due to demand for iron ores in local and international market.

**(b) Keonjhar and Sundargarh district:** The iron ores in these districts are associated with less metamorphosed banded hematite jasper/chert (BHJ/C) of the relatively younger Iron Ore Group. They form a synclinorium running in NNE – SSW dirction with closure towards south. The iron ores occur either as synsedimentary deposits or as epigenetic deposits being derived from the protores like BHJ/C due to the processes of leaching and /or enrichment. The different varieties include (i) hard ores (steel grey to brownish, massive and laminated), (ii) moderately hard ore(laminated), (iii) soft ores (flaky, friable and powdery), (iv) lateritic ores. (v) biscuity ore (vi) canga ore. The ore minerals include hematite with subordinate amounts of goethite, magnetite, specularite etc. The chemical composition of hard ore shows variation of Fe from 59.60 to 69.50%. In Keonjhar district, important iron ore deposits are Thakurani Pahar, Sidhamat Parbat, Durga Parbat, Joda east and west, Banspani Pahar, Dal Pahar, north and west of Kurband, Jhiling Pahar, Longlota Pahar, Guali, Kiriburu, Kalta and Gandhamardan.. In Sundargarh district, the important iron ore deposits are Khandadhar, Malangtoli, Dandrahar Pahar, Taldih, Kalta, Basada, Baliapahar, Badamgarh Pahar, Hitikuda, Rakmo, Daringburu and Barsuan.

**(c) Jajpur district:** Important high grade deposits of iron ores of massive, laminated and powdery ore types occur in Daitari hills of Jajpur district which are associated with banded hematite quartzites of Iron Ore Group which are moderately metamorphosed. Important deposits are in Tomka, Daitari etc.

A small deposit of iron ore of associated with banded hematite quartzite is located in Hirapur area of Nawarangapur district. Besides, smaller occurrences of iron ores also occur in Deogarh area of Deogarh district and Pallahara area of Angul district.

The total resources of iron ores(hematite) in the state is 5930.2 million tonnes and that of magnetite is 0.199 million tonnes.

**(ii) Manganese ores**

The manganese deposits of Odisha are located in 4 distinct geographical belts having separate geological set ups. These four belts are: (i)Bonai – Keonjhar Belt in Sundargarh and Keonjhar districts, associated with rocks of Iron Ore Group such as chert-shale sequence and laterites, (ii) Kuttinga – Nishikal – Ambadola – Patna belt in Koraput, Kalahandi and Balangir districts, associated with Khondalite suite of rocks of the Eastern Ghats Supergroup, (iii) Ghoriajhor belt in Sundargarh district associated with Gonditic rocks of Gangpur Group and (iv) Bamra subdivision of Sambalpur district associated with laterite in the metasediments.

**(a) Bonai - Keonjhar belt** (Jamda - Koira Valley) associated with Iron Ore Supergroup (Keonjhar and Sundargarh districts). The horse-shoe shaped belt of Keonjhar-Sundargarh district houses both iron ore and manganese ore deposits. The manganese ore bodies are confined to the shale – chert sequence of Upper Shale Formation in the valley region of the NNE plunging synclinorium. The manganese ore deposits occur scattered over an area of 500 $km^2$ bounded by Barbil in the north; Dubna in the south and Bhutura in the southwest. There are about 200 (large and small) deposits most of which are under active exploitation. The manganese ore bodies occur as pockets and lenses, and veins within lateritoid rocks and lower lithomerge horizons in the core region of the Horse Shoe synclinorium. Most parts of the manganese deposit are of epigenetic nature but there is also some manganese mineralization in the lower shale below the BIF which is of syngenetic origin. Manganese deposits of this belt have very low phosphorous content. Important localities are Joda, Roida, Kusumdih, Orahari, Kalimati, Mahulsuka, Dubna, Bhutara etc.

**(b) Kuttinga – Nishikal – Ambadola – Patna** belt associated with Eastern Ghats Supergroup (Balangir, Rayagada, Koraput and Kalahandi districts): The manganese ore deposits are confined to the Khondalite Group of rocks belonging to Eastern Ghats Supergroup. The deposits are scattered over a 32 km long north – south belt having a width varying from 5 to 10 km. The different rock types of the area include khondalite, quartzite, charnockite, calc-silicate, granite gneisses, migmatite, leptynite etc. The manganese ore bodies occur as (a) massive tabular bodies, alternate bands and lenses in manganiferous khondalite; (b) reticulate veins and small pockets of disseminations in brecciated quartzite and (c) small lenses and pockets within laterite. The ore bodies are hard, lumpy, streaky, cavity filled, brecciated, friable and botryoidal types. Manganese deposits of Balangir district are confined to a 25 km long belt consisting of lateritised schists of Khondalitic suite. The ore bodies occur as bands and pockets. Important deposits are Dunguripali, Bhaludungri, Godasankar, Birpali in Balangir district and Kutinga, Nishikal, Podakona, Taldoshi, Liliguma, Devjolia, Taldoshi, Ranga, Karajolia etc. in Rayagada, Koraput and Kalahandi districts.

**(c) Ghoriajhor belt** associated with Gonditic rocks of Gangpur Group (Sundargarh district): The manganese ores are associated with the gonditic rocks, mica schists and phyllites of Gangpur Group occur as impersistent bodies Gangpur Group.The deposits are structurally conformable with the associated rocks and extend in length upto 300 m with thickness of over 6 m. Important deposits are located in Manomunda, Ghoriajhor, Kharkamunda etc.

**(d) Bamra deposit (Sambalpur district):** In this district, manganese ores occur in a 25 km long lateritized zone in the Bamra sub-division. The ore is sporadically distributed in the laterite.

The total resources of manganese ores in the state is 190.047 million tonnes.

**(iii) Base metals:** Lead-zinc and copper ore deposits are included under this category. The resource position of these deposits in Odisha is very less.

**(a) Lead – Zinc Ore deposits:** These deposits are located in Sundargarh, Mayurbhanj, Balangir, Kalahandi and Deogarh districts.

In **Sundargarh district**, an important deposit occurs in Sargipalli between Lokdega and Bharatpur covering a stretch of 1600 m in garnetiferous mica schist belonging to Gangpur Group of rocks. The southern limb of a major synclinal fold is found to be mineralized. There are four major lodes with pinch and swell structure. The major ore mineral is galena with subordinate sphalerite and chalcopyrite occurring as disseminations, bands, veins, stringers and fine laminae. The other minerals in minor amounts are pyrite, pyrrhotite, arsenopyrite, cubanite, bornite and tetrahedrite. The ore body contains an average 6.73% Pb, 0.33% Cu and 0.4% Zn. A total reserve of 6.54 million tonnes is found with grade of 5.75% Pb. Minor occurrences of Pb, Zn and Cu are found in Siphripara, Giringkela – Surgura, Kiringera, Beligocha and Kanchera.

In **Mayurbhanj district** minor occurrences of galena are found at Pithabata, Beradiha, Patingia, Champagarh, Shanjabani and Nandabani. In **Bolangir district**, lead and copper mineralisation is observed in quartz veins and quartz breccia reefs to the east of Saintala intermittently for a length of 29 km. Lead and copper mineralizations are found from Jalerpodar, Bodipara, Ampali, Limpara, Norabahal, Badmal and Papsi. In Kalahandi district, minor occurrences of galena occur in brecciated quartz vein at Baminipada, Toresinga, Khairamal, Sishakhal and Pipalpadar. In addition to the above galena mineralisation is found at Gangajal of **Deogarh district**, Junai in **Sambalpur district**, Padampur in **Jharsuguda district** and Kermali in **Baragarh district**.

In Odisha a total resources of 1.75 million tonnes of lead ore is found.

**(b) Copper:** Copper ore occurrences of minor nature are found in Mayurbhanj and Sambalpur districts. In **Mayurbhanj district** promising copper mineralization has been located in three sectors such as Kesarpur, Madansahi and Dudhiasol out of which, Kesarpur sector is most promising where the mineralization is for more than 3 km with nearly 1km width. The copper mineralisation occurs in sheared metabasics belonging to the Iron Ore Supergroup. Copper ore is found as stringers, veins, disseminations and lenticular bodies. The chief copper mineralization is chalcopyrite with pyrite and pyrrhotite associated with minor amounts of nickel and cobalt. Traces of zinc in the form of sphalerite are also found.

In **Sambalpur district c**opper mineralization has been located near Adash over a strike length of about 300 m in rocks of Eastern Ghats Supergroup. Copper mineralization found in form of disseminations, stringers and veinlets in silicified metabasic rocks having contact with granite gneiss. Chalcopyrite is the chief ore mineral associated with pyrite and pyrrhotite.

In Odisha a total resource of 6.05 million tonnes of copper ore is found.

**(iv) Bauxite:** Odisha is very rich in bauxite resources. On the nature of the source rocks, the bauxite deposits of Odisha can be broadly classified into five categories

- **(a)** Large cappings over khondalite/khondalitic rocks of Eastern Ghats Supergroup in Koraput, Kalahandi, Phulbani, Bolangir and Sambalpur districts.
- **(b)** Cappings developed over charnockite, diorite /dioritic gneisses of Eastern Ghats Supergroup in Koraput and Kalahandi districts.
- **(c)** Minor cappings over shales of Chhatisgarh Group in Nuapada District.

**(d)** Minor cappings over mafic volcanics and shale of Koira Group in Keonjhar and Sundargarh districts

**(e)** Capping over Simlipal volcanic rocks of Simlipal in Mayurbhanj district.

The first two categories are of very large areal extension with greater thickness. With the bauxite occurrences of the neighbouring state Andhra Pradesh with same geological set up and continuity they form the famous East Coast Bauxite deposits. These are high level bauxite deposits at an altitude varying from 900 to 1400 m. The principal mineral is gibbsite with $Al_2O_3$ content varying from 40 to 56%. These bauxites are generally low in silica (1-3%) and titanium (<2.5%) and high in iron (8 -28%). Different localities of bauxite are given in Table 4.4.

The total resources of the state are 1810 million tones with a proved reserve of 132.3 million tones.

**Table 4.4: Bauxite deposits of Odisha**

| District | Locality of deposit |
|---|---|
| Koraput | Panchpatmali,Pottangi,Maliparbat,Ballada,Kodingamali,Hatimali, Gurji, Kakrimali,Chintamgundi Kornapadikonda, Medamgundi |
| Rayagada | Baphilimali, Sasubohumali, Pasangmali, Majhigaonmali, Sijimali, Tikrimali, Budharajamali, Taljhir, Dabuguda, Nunapaimali, Nangalghatmali. Kashipur, Kashinguda, Manjimali |
| Kalahandi | Karlapat-Pollingpadar, Kutrumali-Tangridongar, Lanjigarh, Niyamgiri, Keluamali, Krishanmali. |
| Phulbani | Anamini Parbat, Rukunicuttack, Deomal, Ushabali, Mandura, Kotgod, Belagad, Guruli |
| Keonjhar | Dholkata pahar, Kuanr |

| | |
|---|---|
| Sundargarh | Tantra, Kodalia , Jaldihi, Kusumdihi, San Indupur |
| Malkangiri | Korkanda |
| Mayurbhanj | West of Nawana and east of Simlipalgarh and Bakua |
| Nuapada | Khariar Highlands at Lohdungri |
| Balangir-Bargarh | Gandhamardan |

**(v) Chromite:** Odisha has the highest reserve of chromite in the country. The chromiferous ultramafic complexes are intrusive into the rocks of Precamrian age. The chromite deposits in the state are distributed in the districts of Jajpur, Keonjhar, Dhenkanal and Balasore. Two distinct and large belts of chromite are located in the state such as (a) Sukinda belt and (b) Boula- Nuasahi belt

**(a) Sukinda belt:** In **Jajpur and Dhenkanal districts**, chromite ultramafic belt trends in east-west trending valley bounded by the Daitary hill ranges to the north and Mahagiri hill ranges towards the south. The belt extends over a length of 20 km from Kansa in the east upto Maruabil in the west covering an area of approximately 40 sq km. The valley is narrow at the eastern end and gradually widens towards west.

The ultramafic rocks like peridotite and dunite are intrusive into the Precambrian metamorphites namely quartzite and quartz-muscovite-sericite schists. The dunite and peridotite rocks are almost wholly serpentinised and are intruded by pyroxenite. The chromite bodies of Sukinda area are thick in the southern side but gradually become thinner towards the northern part. The lengths of the ore bodies vary from 200 m to as much as 7 km in length, and have variable thickness from 0.3 to 50 m. The ore bodies occur as lumpy ores, friable ores, ferruginous ore, banded ore, disseminated ore etc with $Cr_2O_3$ varying from 30 to

50%. Important localities are Bhimtangar, Kaliapani, Sukerangi, Saruabil, Kalrangi, Talangi, Ostapal, Gurjang.The western part of Sukinda ultramafic complex extends into Dhekanal district. Chromite ore bodies are also found south of Mahagiri range in Bhuban area. Other occurrences in Dhenkanal district are Katpal, Maulabhanj, Asurbandh, Birasal, Ghotringia, Kandragadia etc.

**(b) Boula-Nuasahi chromite belt:** This belt is located in Anandpur subdivision of **Keonjhar district** with a strike length of 3 km along NNW-SSE dirction with width varying from 15 to 20 m. The belt is thick in the middle which tapers to the north and south. Two phases of ultramafic intrusives have been identified in the area with the older phase represented by dunite-chromitite and the younger phase representing peridotite – pyroxenite. The chromite ore bodies occur as tabular bodies and interlayered with thick zones of dunite and chromitite. In this belt the $Cr_2O_3$ varies between 40 and 50% and are of metallurgical grade. Ore bodies occur as disjointed bands with pronounced lateral and vertical displacements. The ore bodies spread over a strike length of 3 km in N-S direction and often show branching with pinch and swell structures. Chromite bodies occur as thin seams and also as lenses, sack form bodies, pockets, thin stringers and disseminations.Important localities are Gobardhanpur, Boula, Nuasahi, Bangur, Phulijhar etc.

Besides these two belts in three districts, smaller deposits are also found in Bhalukasoni area of Nilgiri subdivision of Balasore district, Ramagiri area of Koraput district and Bhaludungri area of Sundargarh district.

The total resource of chromite in the state is 190.02 million tonnes.

**(vi) Nickel:** Nickel ore occurs associated with limonitised and silicified ultrabasic rocks in Jajpur, Keojhar and Mayurbhanj districts.

**(a) Jajpur district:** In the Sukinda area irregular nickel enrichment is found in the limonitic cappings over the ultramafic complex. The nickel ore is of lateritic type and the mineralisation is related to intense weathering and limonitisation of the silicified ultramafic rocks. At some places they occur in association with chromite bodies. Important occurrences are Kansa sector, Kamardah–Saruabil–Sukerangi sector, Kaliapani sector and TISCO mining area sector.

**(b) Keonjhar district:** The ultrabasic rocks such as dunite, peridotite and harzburgite in the N-S trending Nuasahi Ultramafic Belt and their altered product contain nickel concentrations varying from less than 50 to 400 ppm.

**(c) Mayurbhanj district**: In Simlipal area, Nickel is concentrated within chemically weathered ultramafic rocks of the Amjori sill and also in the laterite and soil cover. Ni occurs in Gurguria and Nawana with average grade of 0.9% Ni.

The total resources of nickel ore in Odisha is 174 million tonnes.

**(vii) Tin ore:** Malkangiri has the most important deposit of tin ore cassiterite ($SnO_2$). In this district the deposits are located in pegmatites intrusive into Tulosidongar Formation of the Precambrian Bengpal Group of rocks. Important locations are at Mundaguda, Mohapadar, Vedurpalle, Dumguda and Bajirpador. Cassiterite also occurs as colluvial, eluvial and alluvial placer deposits surrounding the mineralized pegmatites around Mundaguda. Other associated minerals are ilmenite, rutite, zircon, magnetite, tourmaline, monazite and quartz.

Besides pegmatites in Sonepur district at the confluence of Tel and Mahanadi and in Boudh district at Ambuda, Manmunda, Bamunda and Karunapalli contain cassiterite.

The total resource of tin ores in the state is 15494 tonnes.

**(viii) Platinum Group of elements (PGE):** PGE includes platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), osmium (Os) and iridium (Ir) are the rarest of precious metals and so very few occurrences are known in the world. In Odisha PGE are found in the following areas of Singhbhum - Odisha craton.

(a) Sukinda, Jajpur district: In the ultrmafics Pt ranges from 2 to 400 parts per billion (ppb), Pd ranges from 1 to 500 ppb

(b) Boula-Nuasahi, Keonjhar district: This is an important occurrence in ultramafic rocks containing PGE mineralization in strike length of 2.2 km with width varying from 1 to 24 m and has a reserve of 10 million tones with 1.0 gm/tone of Pt + Pd.

(c) Amjori Sill, Mayurbhanj district: This layered intrusion contains Pt upto 200 ppb and Pd upto 60 ppb

Total resources of platinum in the state is 14.2 tonnes

**(ix) Gold:** Most of the gold occurrences of Odisha are reported as stream placer deposits but in the northern Odisha there are some evidences of in situ gold deposits. Placer gold occurrences are found in the places given in Table 4.5.

### 4.14.2. Industrial mineral deposits

**(i) Asbestos:** In Odisha smaller occurrences of asbestos are located in the districts of Kalahandi, Sundargarh, Mayurbhanj and Keonjhar. In Kalahandi distrct, minor occurrences of asbestos are found from talc-tremolite- actiolite – chlorite schists of Bengpal Group at Sanibahal. Other occurrences are located in Rangra in Sundargarh district, Balidih and jashipur in Mayurbhanj district and Ranki and Gopalpur in Keonjhar district.

Odisha has a total resource of 56700 tonnes of asbestos.

**(ii) Beach sand:** The southern part of the coastal parts of Odisha in Puri and Ganjam districts is rich in heavy minerals such as ilmenite, zircon, rutile, monazite, garnet, sillimanite etc. in addition to minor constituents like staurolite, spinel, magnetite, etc. These minerals which are found as accessory minerals in

Eastern Ghats Supergroup of rocks are released on weathering. They undergo transportation by various agents and are effectively concentrated at beaches as placer deposits. Although concentrations are spread throughout the coastal tracts of Odisha, rich concentrations are located in Ganjam district of Odisha near Chhatrapur - Gopalpur. It extends for a length of 22 km with an average width of 1.54 km. Other areas of beach placer deposit occurrences are Ramayapatna, Markandi, Mayurpada, Niladripur, Kantiagarh, Jatiapahar, Arunpur, Paluru, Prayagi, Ramchandi etc. The average grade of the heavy mineral is about 20% with ilmenite (8.80%), rutile (0.38%), monazite (0.27%), garnet (6.70%), zircon (0.31%) and sillimanite (3.40%).

**Table 4.5: Gold occurrences in Odisha**

| District | Locality |
|---|---|
| Angul | Tikiria and Ouli river bed, Katni, Dolia and Gundichanali, Ramiala, Betali river gravels |
| Keonjhar | Kanjipani and Salaikana near Telkoi indicated gold content varying from 0.1 to 0.6 gm/tonne but in a few samples 1.2 g/t |
| | Gopur and adjoining areas indicated gold value of 1.0 g/tonne but sometimes even 10g/tonne. |
| | The gravel bed near Hanumanthia nala is reported to contain approximately 0.2gm of Au per cu.m. |
| | Other areas are Sunajhar and Rangadhi, Bangir nala areas, Sonapenth, Gopinathpur, Bamnipal, Bangir nala |
| Koraput | Dasamantapur, Gobindapalle,Kollaru, Kurlu nala bed, Bhattigunda, Dadigunda and Malayguda in Kolab River catchment area |

| | |
|---|---|
| Mayurbhanj | Jashipur, Suriagora, Gohaldongri, Ruansi, Munisahi, Bijatola and Kalimati areas adjacent to Kunderkucha belt of Jharkhand, Sulaipet area, Suriagera, Kudersai and Sigora along Borai river, Ruansi and Gohaldungri along the Godia stream . |
| Sundargarh | Minor occurrences of alluvial gold have been reported from the areas near Giringkela and Suriagera of Himgiri taluk. The gravels of rivers Ib, Koel and Brahmani at Jareikela, Raghunathpalli, Sargipalli,, Kusumura, and Sarbahal, Bonai, Kuljhar |
| Sambalpur | Tahud, Soramohan, Dantamure and Hiraaaakud |

Odisha has a total resources of 38.58 million tonnes of ilmenite, 25.39 million tonnes of garnet, 16.15 million tonnes of sillimanite, 1.62 million tonnes of rutile, 1.21 million tonnes of zircon and 0.87 million tonnes of monazite.

**(iii) China clay:** China clay is a grayish white to white coloured clay with approximate composition of kaolinite. China clay deposits in Odisha are located in Mayubhanj, Keonjhar, Koraput, Cuttack, Ganjam, Phulbani and Balangir districts associated with rocks as given in Table 4.6.

The total resource of china clay in Odisha is 280.9 million tonnes.

**(iv) Fireclay:** The clay mineral present in fireclays is basically kaolinite. Fire clays are almost exclusively used for manufacture of refractory bricks since they can withstand temperatures of more tha $1500^0$ C. They occur as bedded depoits of considerable dimensions. The fire clay doposits are usually associated with coal measures of Gondwana Supergroup.

In Odisha fire clay deposits are confined to three geographic belts viz. (i) Fireclay deposits of Talcher coal field areas in Dhenkanal and Angul districts, (ii) Fireclay deposits in Ib river coal field areas in Jharsuguda and Sundargarh districts and (iii) Fireclay deposits of Upper Gondwana Athgarh Formation in Cuttack and Khurda districts

In Talcher coal field areas fireclay has been located in collieries like Jagannath, South Balanda and near villages like Kaniha and Ghantikhal. In Ib river coal field area, fireclay occurrences are located in Jurabaga, Darilpalli, Rampur, Kuropali, Baripahar, Lukopali and Khindia of Jhrsuguda district and Kiripsora, Gopapali, Kathpali, Khutijharia, Kurutoi, Juraboga, Girsuan, Jamakani etc. of Sundargarh district.Large fireclay deposits are found in Talabasta, Ghantikhal and Brahmanibasta of Cuttack district and Jagannath Prasad, Andharua and Bantala in Khurda district where they are associated with Upper Gondwana Athagarh Formation.

The total resorces of fire clay in the state is of the order of 170.07 million tonnes. There are around 20 mines in the state accounting for 16% of the total production of fire clay in India.

**Table 4.6: China clay occurrences in Odisha**

| District | Associated rock | Locations |
|---|---|---|
| Mayurbhanj | Weathered granite | Badampahar, Karanjia, Jashipur, Ramchandrapur, Chanchbani, Dumuria, Jamda, Kadodiha, Thakurmunda |
| Keonjhar | Weathered granite | West of Keonjhar,Taranipukuri–Amvapara, Sandi Murra |
| Koraput | Weathered shale | Baipariguda, Kallaru and Ramagiri |
| | Kaolinised gneisses | Obuguda, Misoriguda, Pukkili, Jodiguda, Madhupur |
| Cuttack | Feldspathised gneisses | Banrapal, Foot of the Baideswar Hill |
| Dhenkanal | Feldspathised gneisses | Sibalopose |

| | | |
|---|---|---|
| Sundargarh | Gondwana sandstone and shale | Amatpani, Laidega, Baraibera, Kardega, Baraibera and Bangura |
| Ganjam | Weathered gneisses, Weathered granite | Satarpally,Jillinda, Sarangoda, Siringi, SE of Barahmpur |
| Phulbani | Weathered gneisses | Karanda, Bahanda |
| Balasore | Highly decomposed gneisses | Arubandha, North of Gardihi |
| Balangir | Weathered gneisses, pegmatites and schists | Sargod, Baludongri, Khola, Ghichampra, Sagupali, Ghuhukilikra, Barasinghari, Dangchancha |

**(v) Graphite:** Odisha is the leading producer of graphite which occurs associated with rocks of Eastern Ghats Supergroup. Graphite occurs in the districts of Bolangir, Sambalpur, Kalahandi, Phulbani, Nayagarh, Puri, Rayagada and Dhenkanal. The graphite occurrences in state are geographically distributed in six belts, viz, Sargipalli, Titlagarh, Tumudibandh, Nishikal, Muniguda and Dhandatapa belts covering an area of about 15,500 sq km.

**(a) Sargipali belt:** Graphite deposits occur in association with quartz-feldspar-garnet-sillimanite schist/gneiss particularly at the contact zones of migmatite, granite gneisses and pegmatites in Balangir and Bargarh district. Important localities are Danga Chancha, Temrimal, Baudan, Gangadar, Banjipali, Turekela, Nagphena, Bendar, Bonaimal, Ganjapadar, Bangipal and Dudukamal.

**(b) Titlagarh belt:** It contains three mineralized areas at Malisira, Sialgolingi and Pampur-Madanpur.Graphite occurs as bands,lenses and pockets in garnetiferous quartzites and granite gneiss.

**(c) Tumudibandh belt:** This belt runs in the districts of Phulbani, Rayagada, Kalahandi and Gajapati districts. Important areas are Tumudibandh, Muniguda, Belghar, Jagdalpur, Laxmipur etc.

**(d) Nishikal – Kinchikhal Belt:** This belt spreads over an area of 190 sq km where graphite is associated with koduritic manganese ore bodies. The graphite occurs as cryptocrystalline and phenocrystalline grains as dissemination, pockets, clots, veins, lenses and bands.

**(e) Muniguda belt:** This belt runs in a NE – SW direction for about 38 km in Rayagada and Phulbani districts. Graphite occurs as flaky and amorphous types as disseminations and pocket deposits within migmatised khondalite and along the contacts of khondalite with granite and/or leptynite. Important localities are Berhsagaon, Durhugi, Karlagi, Katikhole etc

**(f) Dhandatapa Belt:** This belt is located in Athmallk subdivision of Angul district which is 40km long and 10km wide. Important locations are in Akharkata, Adeswar, Girida and Kamalpur.

In addition to the above, smaller occurrences of graphite are located in Adash area of Deogarh district and Daspalla area of Nayagarh district in association with khondalites.

The total resource of graphite in the state is 8.67 million tonnes.

**(vi) Limestone and Dolomite:** Vast resources of limestone occur in Odisha in three geological settings viz; Gangpur Group, Chattishgarh Group and Eastern Ghats Supergroup of rocks in addition to minor occurrences associated with Iron ore Supergroup in Keonjhar district.

**Sundargarh district:** In this district, the limestone and dolomite deposits are associated with Birmitrapur Formation of Gangpur Group. The general structure of the Gangpur rocks is a synclinorium. The major deposits are located at Biramitrapur, Hatibari, Purnapani in the northern limbs; Lanjiberna, Gomardiha, Khatkurbahal, Kutra in the southern limb and Dubkbera in the core of the synclinorium. The average width varies between 609 and 761 m out of which dolomite forms 364m to 457m and limestone 245m to 300m. The limestone is fine to medium grained and grey in colour. The CaO content in the rock varies from 30 to 52%.

**Koraput district:** Crystalline limestones are associated with calc-granulites of Eastern Ghats Supergroup and are found as discontinuous lensoidal patches. Important localities are Ampavalli, Gondivalasa containing 41 to 50% CaO.

**Malkangiri district:** The limestones of good quality are found interbanded with purple shales, slates and quartzite belonging to Indravati Group. Good quality limestone occurs at places like Kattameta, Nandiveda.

**Nawarangpur district:** Limestone and dolomite occur as linear discontinuous bands in association with shale and quartzite of Indravati Group at Gupteswar-Binsuli.

**Baragarh district:** Limestone associated with shale, sandstone are found in form of an asymmetrical anticline plunging north-west between Dungri and Banjipali.The thickness of limestone band varies from 1.2m to 7.9m, but at south of Badmal the band attains a maximum thickness of 30m.

**Keonjhar district:** Dolomite and dolomitic limestone occur associated with manganiferous formations of Iron Ore Group near Bhadrasahi and Kasia. These limestones are stromatolytic at places.

**Nuapada district:** Crystalline limestone occurs associated with Khondalite and quartzite of Eastern Ghats Supergroup of rocks near hariar.

The total resource of limestone in the state is 1782.987 million tonnes and that of dolomite is 673.04 million tonnes.

**(vii) Gemstones:** Odisha is very rich in gemstones of various types. The gemstone occurrences in different districts of Odisha are given in Table 4.7.

**Table 4.7: Gemstone occurrences of Odisha**

| District | Places with type of gemstones |
|---|---|
| Kalahandi | Ruby - Jilingdhar- Hinjilibahal belt;<br>Blue iolite - Orhabahal-Urharanga area<br>Hessonite garnet and zircon - Ghatspara-Singjharan areas<br>Chrysoberyl and cat‟s eye - Sirjapali-Tundla areas<br>Rhodolite and almandine garnet - Banjipadar-Sargiguda sector |
| Balangir | Emerald, topaz, heliodor and aquamarine - Ghuchepara-Antarla sector<br>Chrysoberyl and Cat‟s eye - Ghumsar-Dehli belt<br>Chrysoberyl and orange, brownand yellow zircons - Muribahal – Tentelkhunita Sector<br>Aquamarine,topaz and amethyst - Sanaibahal- Suklimuri sector |
| Sonepur | Greenish blue to sea blue aquamarine - Badmal-Mursundi and Binika-Sonepur.<br>Garnet, cat‟s eye, topaz, smoky quartz and diamond - Gravel beds of Mahanadi River<br>Rhodonite garnets - Naktamunda-Siali areas |
| Sambalpur | Aquamarine, Heliodor at Charbati - Beldihi near Rairakhol.<br>Aquamarine, gem quality garnets,(rhodolite and almandine), iolite and amethyst occur at Bagdhapa-Tablai.<br>Red opaque corundum,pyrope garnet, iolite, green tourmaline, alexandrite and aquamarine occur associated with pegmatites at Meghpal-Ranchipada areas |

| | |
|---|---|
| Nuapada | Transparent to light blue sapphire - Katamal –Babebir-Amera sector. Sapphire, Iolite and almandine garnets - Damjhar-Burhpara-Mantritarai<br>Pink and red garnet, Blue iolite and fibrolite – Sardhapur - Patialpada.<br>Diamond – Kalamidadar and Amlidadar areas. |
| Rayagada | chrysoberyl and cat"s eye - Paikdakulguda-Hatamuniguda areas,Karla – Ghatsi -Karanjgurha areas<br>Sillimanite, cat"s eye -Irukubadi-Tarhama. |
| Boudh | Garnets, chrysoberyl, cat"s eye, topaz,zircon, moonstone, agate and diamond - gravel beds of Mahanadi River, Tel river<br>garnets, topaz,Cat"s eye, iolite, tourmaline and diamond - Kantamal and Manundo<br>Gem quality tourmaline - Bargocha area. |
| Angul | Garnet (rhodolite) and corundum - Magarmuhan-Jhilli- Nuagan belt. |
| Deogarh | Hessonite and rhodolite - Budido - Palsma –Jharpost |
| Jharsuguda | Green tourmaline – Bagdihi |
| Phulbani | Chrysoberyl and cat"s eye – Belghar<br>Diamonr – Gravel beds of Mahanadi basin |

**(viii) Pyrophyllite**

In Odisha pyrophyllite deposits are found in Keonjhar, Mayurbhanj, Sambalpur and Sundargarh districts. In Keonjhar district, a 90 km long belt extending from Rebna-Palaspal in the south to Remuli – Joda road in the north has been delineated and found to be pyrophyllite bearing. In this district, the main deposits occur at Dhobakuchuda, Balabhadrapur, Amjor, Baliadihi, Salrapent, Madrangajodi, Dalimpur, Nitigotha, Buriadihi, Sidhamath, Sarasposi, Ukuchabeda, Raduan, Bolaniposi, Rampakot, Rebna, Palaspal but their grade is highly inconsistent.

Smaller occurrences are also located near Manada, Jashipur, Kankarani, Gorumahisani, Bangiriposi and foot hills of Simlipal in Mayurbhanj district; Jamardungi near Hirakud in Sambalpur district and by the side of Barkot-Lahunipada road (within 5 km from Lahunipada) in Sundargarh district.

The total resource of pyrophyllite in Odisha is 12.29 million tonnes.

**(ix) Quartz and quartzite**

In Odisha, quartz and silica sand deposits are located in the districts like Sundargarh, Balangir, Jharsuguda, Sonepur, Kalahandi, Nuapada, Boudh, Bargarh, Mayurbhanj and Keonjhar. In Sundargarh district, important quartz deposits are located near Biramitrapur, Damadapara, Gobira, Charabera, Talsara, Pansuan, Bhalulate, Bijadihi, Soidihi, Atha Ghat, Sampapaibat, Ramhri, Nevotoli, Bhadapur, Manjmunda, Lohadar, Danakudar and Koilijhar. In Balangir district, a major quartz reef occurs at the road-side between Saintala and Belgaon. Another deposit of good grade and reserve occurs at Ghagabahl near Tureikela. The total resource of Odisha is 73.94 million tonnes.

Quartzite deposits in Odisha are located in Jharsuguda, Balangir, Kalahandi, Koraput, Mayurbhanj, Keonjhar, Sambalpur, Sundargarh, Phulbani, Angul and Bargarh districts. The total resource of quartzite in Odisha is 60.4 million tonnes.

**(x) High magnesia rocks**

Odisha is very rich in high magnesia rocks which are associated with rocks of Iron Ore Group. Dunite, peridotite, serpentinite, saxonite and pyroxenite associated with chromite deposits of Sukinda area of Jajpur district and Boula-

Nuasahi area of Keonjhar district are high magnesia rocks having requisite chemical specifications to be used as flux in steel making process. Other areas of occurrence of high magnesia rocks in the Singhbhum craton are (a) Managovindapur of Jajpur district (b) Bhuban-Asurbandha-Maulabhanja of Dhenkanal district (c) Bhalukasoni near Nilgiri of Balasore district (d) Notopahar, Thakurmunda, Amjori, Badampahar of Mayurbhanja district (e) Rajabasa, Jharabeda, Bonai and Darjing of Sundargarh district (g) Kaliahata of Keonjhar district and (h) Thelkobadi of Kuchinda subdivision of Sambalpur district. However, these bodies are of smaller dimensions.

In the Bastar craton of western Odisha, smaller occurences of high magnesia ultramafic rocks occur at Ramgiri of Koraput district and Pagarpani of Bargarh district. In the Eastern Ghats granulite terrain, high magnesia ultramafic bodies of smaller dimensions are reported near Kiakata of Boudh district, Ghusramal near Rairakhol in Sambalpur district and Mukundpur (on Berhampur-Rayagada Highway) in Rayagada district (Mukherjee and Patra, 1996).

**(xi) Talc-steatite-soapstone**

In Odisha talc, steatite and soapstone deposits are located in Mayurbhanj, Sambalpur, Sundargarh, Ganjam, Dhenkanal and Koraput districts. Important localities in Mayurbhanj district are Dindarani parbat, Dublabera, Myrisahi, Kendumunda, Diring, Similipahar, Nulungi, Jharbera and Bhaludungri. In Keonjhar district, smaller occurrences are located around Keonjhargarh. Other smaller occurrences are located in Katpada, Kendupati and Jeypore in Koraput district and Ballgol, Ambasar, Champajhar and Garhpur in Cuttack district.

The total resources of these minerals in Odisha is 0.820 million tonnes.

**(xii) Kyanite and sillimanite**

In Odisha refractory grade kyanite deposit is located in Panijia area of Mayurbhanj district where it is associated with dumortierite bearing rocks. Other two occurrences in this district are Purnapani and Similipal. Other occurences of kyanite are reported at and near Magarmuhan, Toradanali, Jhilli, Golagadia, Sikheswar and Kodabasanta in Pallahara and Kamakhyanagar subdivisions of Angul and Dhenkanal districts. At present the kyanite production in Odisha is confined to the Panijia area of Mayurbhanj district.

In Odisha, sillimanite alongwith other heavy minerals are being released from rocks of Easternghats Supergroup such as khondalite, leptynite, charnockite etc by weathering. These heavy minerals are transported into the sea and later concentrated as beach placer deposits along the coastal areas of Odisha. The beach sands of Ganjam and Puri coasts contain sillimanite upto the extent of 3%. In the Odisha sands complex of Indian Rare Earths Limited, siliimanite is produced along with ilmenite, rutile, zircon, monazite and garnet. In Kahatua of Sundargarh district, sillimanite forms about 3 to 5 % of the quartzites and quartz schists. It is also located from Tilsora and Phatsinagar. In Sambalpur district fibrous sillimanite is located near Golabandh. Utunia, Palsoma, Mumorphol and Lugupoda.

The total resource of sillimanite in Odisha is 13.102 million tonnes.

**(xiii) Mica:** In Odisha, mica occurrences are mostly localized in the pegmatitic bodies in Balangir, Kalahandi, Koraput, Phulbani and Sundargarh districts. In Balangir district both muscovite and biotite occurrences are located in small pegmatite veins of Beramal, Bhurpara, Sikkar, Palrapalle, Banjab, Godageda, garimal etc. In Kalahandi district the occurrences are Komorjhori, Thalkodebse and Godal. Muscovite occurrences in association with pegmatites are located in Anartopalla, Gamisapalle, Polleru, Dupinikuda, Eranguta, Tentolkhunti and Pilibasini in Koraput district; Gopalpur, Dharnakud, Banlsing, Chichanga, darikupa and Chopura in Phulbani district; Ghoriajor, Tungaumunda, Diamunda, KadlimundaSalijarria, Bindujharia and Phatatangar in Sundargarh district.

### 4.14.3. Fuel deposits

**(i) Coal:** Odisha has almost 24% of the total coal resources of the country. There are two major coal bearing areas in the state belonging to Lower Gondwana such as (a) Talcher coal field and (b) Ib valley coal field. The major coal bearing formations in both the coal fields of Odisha are found in Karharbari and Barakar Formations.

**(a) Talcher coalfield:** This field is distributed in the districts of Dhenkanal, Angul and Sambalpur with a basinal area of about 1813 sq. km. This field is characterized by east-west trending strike faults resulting repetition of coal seams. Eleven coal seams (I to XI) are found in this field with only one seam (Seam I) associated with Karharbari and the rest (Seam-II to Seam-XI) are associated with the Barakar rocks. Seam I is developed in Deolbera, Talcher, Balanda and Nandira collieries. The thickness of seam II (Jagannath seam) varies from 35 to 50 m and is exploited in the Handidhua (now Talcher), Jagannath, Bharatpur and Nandira collieries. The thickness of Seam III varies from1.4-10 m and is highly interbanded with inferior quality coal. The thickness of Seam-IV is about 10m and the coal bands are interbanded with dirt bands. The Seam-V has a thickness varying from 8 to 33m. The Coal seams VI (2-24.5 m), VII (21-43.5m),VII (25-37m) and IX (12-15m) have been encountered only in boreholes. The VIII and IX coal seams coalesce in the west of Gopalprasad - Utkal blocks to give favourable condition of exploitatation in spite of having interbanded nature with other sedimentaries. The last two seams Seam Nos. X & XI are highly impersistent and interbanded in nature. The coal is of inferior quality and contains high moisture and ash.

**(b) Ib-valley coalfield:** This coalfield describes westerly plunging synclinal fold and is like a half elliptical basin closed towards southeast. Structurally this coal field is much less disturbed. Only one seam named as Ib seam with thickness varying from 2.29 to 10.3 m occurs in the Karharbari Formation whereas four coal horizons,namely Rampur, Lajkura, Parkhani and Belpahar seams from bottom to top occur in the Barakars.The Ib seam is being mined in Orient and Rampur collieries at Belpahar by both underground and open cast mining. The Rampur coal seam which attains a thickness of 27 to 80m in the area comprises of alternations of shale and coal.This is exploited in Orient, Rampur and Belpahar area. The overlying Lajkura horizon is highly interbanded with shale. This band has a thicknss varying from 50 to 88 m and has high ash content (29 to 45%). The Parkhani seam has a thickness varying from 0.5-10.45m and is also highly interbanded with shale.The topmost coal seam i.e., the Belpahar seam is 24 to 30m thick and displays coal-shale laminations.The Parkhani and Belpahar seams are not encountered in the Hemagiri (Hingir) sub-basin, locatedin the northern part of the Ib river coalfield.

Though Odisha is endowed with large reserves of coal, the coals are of inferior quality except that of the Ib seam of Ib valley coal field. They are highly interbanded with shale and have high moisture content (5.2% to 8.4%) and high ash content. All the coals are noncoking.

The total coal resources of Odisha is 75073 million tones with Talcher coal field area having a reserve of 50875 million tones and Ib valley coal field area having a reserve of 24198 million tonnes.

## 4.15. SAMPLE QUESTIONS

### 4.15. 1. Long questions

(i) What are magmatic mineral deposits? Describe the features of magmatic process with special reference to its subdivisions giving examples.

(ii) Define “hydrothermal solution”. Give an account of hydrothermal process with special reference to its prerequisites, classification and salient aspects related to resultant geometric types of deposits. Cite important global and Indian examples.

(iii) What should be the bare embodiments of an ideal classification scheme? Give the outline of Bateman‟s classification of mineral deposits in vogue. Briefly discuss the merits and demerits of this classification.

(iv) Give the outline of Lindgren‟s classification of mineral deposits. Discuss their merits and demerits.

(v) Describe iron ore deposits with special reference to their mineralogy, use, mode of occurrence and Indian distribution

(vi) Name the chief ore mineral of cupper giving its chemical composition. Enlist other Cu-bearing minerals used as ores. Give the important physical properties of the chief ore. Briefly describe the uses, mode of occurrence and Indian geographic distribution of Cu-ores.

(vii) Briefly describe the mineralogy, mode of occurrence, uses and Indian distribution of bauxites.

(viii) Briefly describe chromite with reference to its mineralogy, mode of occurrence, chief uses and Indian (geographic) distribution.

(ix) Describe manganese ore deposits with special reference to their mineralogy, use, mode of occurrence and Indian distribution.

(x) Describe coal deposits with special reference to their origin and Indian distribution.

(xi) Give the composition, mode of occurrence, uses and geographic distribution of petroleum in India.

(xii) What is an oil pool and how it is formed?

(xiii) Briefly describe the important oil and gas traps. Shortly describe the salient aspects of petroleum genesis.

### 4.15.2. Write short notes on

(i) Iron ore deposits of Odisha
(ii) Manganese ore deposits of Odisha
(iii) Coal deposits of Odisha
(iv) Origin of coal seams
(v) Origin of coal
(vi) Mode of occurrence of iron ores
(vii) Uses of manganese ores
(viii) Origin of petroleum

### 4.15.3. Short type questions (3 to 5 sentences)

(i) Scope of economic geology
(ii) Sublimation process
(iii) Contact metasomatism
(iv) Ore minerals of manganese
(v) Placer deposits
(vi) Drift theory
(vii) Magmatic dissemination
(viii) Talcher coal field
(ix) Liquid immiscibility
(x) Cavity filling process
(xi) Singhbhum Cu-thrust
(xii) Early magmatic seggregation
(xiii) Uses of Cu-ores
(xiv) Khetri Cu-belt
(xv) Stratiform chromite deposit
(xvi) Malanjkhand Cu-belt
(xvii) Podiform chromite deposit
(xviii) Sukinda chromite belt
(xix) Uses of chromite
(xx) Chromite resources of Odisha
(xxi) Refractory uses of bauxite
(xxii) Magmatic chromite deposits
(xxiii) Blanket type baxites
(xiv) Metallurgical uses of bauxite
(xv) Detrital type bauxites
(xvi) Panchpatmali bauxite deposit
(xvii) Texural varieties of bauxite
(xviii) Cambay basin oil fields
(xix) East coast bauxite region
(xx) Assam-Arkan oil fields
(xxi) Chief uses of petroleum
(xxii) Name ore minerals of iron

(xxiii) Solid hydrocarbons

(xxiv) What is BHC ?

(xxv) Natural gases

(xxvi) What is Peat ?

(xxvii) Offshore oil fields of India

(xxviii) Abiogenic origin of petroleum

(xxix) Classification of natural economic materials

(xxx) Basic differences between metallic and non-metallic minerals

(xxxi) Concept/definition of ore and gangue with narration

(xxxii) Tenor and grade: definitions, narration and comparison

(xxxiii) Nature and source of hydrothermal solution

(xxxiv) Phyco-chemical factors involved in the formation of mineral deposits

(xxxv) Manganese ore deposits of Keonjhar and Sundergarh district

(xxxvi) Principal and productive copper belts/deposits in India

(xxxvii) Principal type of chromite occurrences

(xxxviii) Chemical composition of chromite

(xxxix) Trivalent and hexavalent chromiums

(xxxx) Odisha‟s position in chromite map of India

(xxxxi) „Bauxite is both a rock and a mineral‟ – explain

(xxxxii) Favourable palaeo-climatic and physiographic conditions for bauxitisation

(xxxxiii) Generalised profile of blanket type of bauxite deposit

(xxxxiv) Elemental composition of petroleum

(xxxxv) Differentiate between source rocks and reservoir rocks

(xxxxvi) Geological distribution of oil and gas in India

(xxxxvii) Mode of occurrence of oil and gas

(xxxxviii) Iron ore deposits of Keonjhar district

(xxxxix) Mode of occurrence of Cu-ores

(xxxxx) Origin of bauxite

### 4.15.4. Distinguish between the following pairs

(i) Early magmatic and late magmatic deposits

(ii) Hypogene processes and supergene processes

(iii) Syngenetic and epigenetic ores

(iv) Cavity filling process and metasomatic replacement process

(v) Metamorphic minerals and metamorphosed minerals

(vi) Plutonistic and neptunistic thoughts on oregenesis

(vii) Hypothermal and epithermal deposits

(viii) Breccia fillings and vesicular fillings

(ix) Fissure veins and replacement lodes

(x) Sedimentary deposits and meta-sedimentary deposits

(xi) Oxidized ores and supergene sulphide ores

(xii) Paragenesis and zoning

(xiii) Distinction between aliphatic hydrocarbons and aromatic hydrocarbons

(xiv) Distinction between liquid hydrocarbons and solid hydrocarbons

(xv) Coal and mineral oil

### 4.15.5. Multiple choice types

(i) Pure (100%) hematite is a

(a) a metal (b) an ore

(c) a metallic gangue (d) an ore mineral

(ii) An ore mineral is

(a) a naturally formed product (b) an artificially formed product

(c) a naturally formed metallic product (d) a nonmetallic product

(iii) Gangue comprises

(a) rock forming minerals (b) non-industrial minerals

(c) non-metallic wasteful minerals (d) all of the above

(iv) The term „tenor" refers to percentage of

(a) an element
(b) a metallic compound
(c) a metal
(d) a non-metal

(v) By evaporation $CaSO_4$ is precipitated as

(a) anhydrite
(b) anhydrite
(c) both gypsum and anhydrite
(d) gypsum, anhydrite and plaster of paris

(vi) Temperature range of hydrothermal solutions is

(a) 100° – 500° C
(b) 50° – 500° C
(c) 100° – 700° C
(d) 50° – 700° C

(vii) The galaxy of economic geologists comprising Werner, Sandburger, Brauer and Schneiderhohn belong to

(a) USA
(b) France
(c) Germany
(d) England

(viii) Hydrothermal class of deposits characterized by the lowest temperature range is termed as

(a) epithermal
(b) telethermal
(c) xenothermal
(d) leptothermal

(ix) Crustal average of Cu in gms per tonne is

(a) 13
(b) 55
(c) 70
(d) 75

(x) Principal ore of Cu in world is

(a) Malachite
(b) Chalcopyrite
(c) Covellite
(d) Chalcocite

(xi) Peacock iridescent colour is exhibited by

(a) Covellite
(b) Tenorite
(c) Bornite
(d) Malachite

(xii) Typical bright green colour is exhibited by

(a) Bornite (b) Azurite

(c) Malachite (d) Chrysocolla

(xiii) Earliest metal used by mankind is

(a) Fe (b) Cu

(c) Mn (d) Pb

(xiv) The heaviest Cu-ore is

(a) Chalcocite (b) Cuprite

(c) Tenorite (d) Native copper

(xv) The richest Cu-ore bearing country in the world is

(a) USA (b) Russia

(c) Zambia (d) Chile

(xvi) Cu-ore that crystallizes in cubic system is

(a) Tetrahedrite (b) Chalcopyrite

(c) Chalcocite (d) Covellite

(xvii) The highest electrical and thermal conductivity is shown by

(a) Al (b) Cu

(c) Mn (d) Fe

(xviii) Thick tabular bands of chromite characterized by large strike extension belong to

(a) podiform type (b) alpine type

(c) lentiform type (d) stratiform type

(xix) Type of chromium hazardous to human health is

(a) trivalent (b) hexavalent

(c) octavalent (d) pentavalent

(xx) Layered chromite deposits belong to

(a) fissure form type (b) stratiform type

(c) sack form type (d) podiform type

(xxi) The longest occurrence of chromite deposit in the world is that of

(a) South Africa (b) Zimbawe

(c) Russia (d) USA

(xxii) The site of earliest chromite mining in India belongs to the state of

(a) Odisha (b) Andhra Pradesh

(c) Karnataka (d) Tamilnadu

(xxiii) Podiform chromites in India are located in the

(a) Himalayan region (b) Indogangetic region

(c) Peninsular region (d) coastal region

(xxiv) Normal stainless steel contains

(a) Fe and Ni (b) Fe and Cr

(c) Fe and Co (d) Fe and Mg

(xxv) Theoritically pure chromite contains

(a) 38 % $Cr_2O_3$ (b) 48 % $Cr_2O_3$

(c) 58 % $Cr_2O_3$ (d) 68 % $Cr_2O_3$

(xxvi) Which of the following state does not have a chromite deposit

(a) Kerala (b) Jharkhand

(c) Manipur (d) Tamilnadu

(xxvii) Bauxite is invariably associated with

(a) iron stones (b) shales

(c) laterites (d) clays

(xxviii) The largest individual reserve of Indian bauxite occurs in

(a) Bagru hill in Jharkhand (b) Amarakantaka plateau in M. P.

(c) Panchpatmali plateau in Odisha (d) Belgaon in Karnataka

(xxix) Bauxite is not used in

(a) refractory industry (b) chemical industry

(c) abrasive industry (d) paint industry

(xxx) Bauxite is a product of

(a) mechanical weathering (b) physical weathering

(c) chemical weathering (d) biochemical weathering

(xxxi) Aluminium is the best substitute for

(a) Magnesium (b) Nickel

(c) Copper (d) Zinc

(xxxii) Bauxite with high porosity is termed as

(a) massive variety (b) pisolitic variety

(c) clayey variety (d) Spongy variety

(xxxiii) The largest singular oil field in India is

(a) Digboi (b) Ankaleswar

(c) Bombay high (d) Naharkatiya

(xxxiv) Mineral oil is lighter than

(a) gas (b) water

(c) both gas and water (d) bitumens

(xxxv) The abandoned Indian oil field is

(a) Galeki (b) Rudrasagar

(c) Badarpur (d) Digboi

(xxxvi) Which of the following states does not have an oil field

(a) Maharastra (b) Andhra Pradesh

(c) Arunachal Pradesh (d) Kerala

(xxxvii) Elementally, oil has the highest percentage of

(a) N (b) O

(c) H (d) C

(xxxviii) The term „Petroleum" is derived from the combination of two

(a) Greek words (b) Latin words

(c) English words (d) German words

(xxxix) In Bombay High, commercial petroleum is mostly associated with

(a) sandstones (b) conglomerates

(c) siltstone (d) limestone

(xl) In natural state petroleum is a

(a) gas (b) pure liquid

(c) viscous liquid (d) viscous semisolid

(xli) Butane is a member of

(a) liquid hydrocarbon (b) solid hydrocarbon

(c) gaseous hydrocarbon (d) none of the above

(xlii) The chemical composition $FeS_2$ corresponds to that of

(a) Pyrite (b) Pyrrhotite

(c) Goethite (d) Limonite

(xliii) The Stratigraphic unit with which Gonditic type manganese deposits in Odisha are associated with is

(a) Iron Ore Group (b) Gangpur Group

(c) Eastern Ghats Group (d) Gondwana Supergroup

(xliv) In Odisha, coal deposits are associated with rocks of

(a) Lower Gondwana (b) Upper Gondwana

(c) Tertiary (d) Quaternary

(xlv) The transformation of woody matter to peat is known as

(a) Humification (b) Coalification

(c) Hydrogenation (d) Carbonization

(xlvi) Out of the following, which one is the highest ranked coal?

(a) Lignite (b) Anthracite

(c) Bituminous (d) Peat

(xlvii) Which one of the following minerals is used in dry cell battery?

(a) Psilomelane (b) Magnetite

(c) Pyrolusite (d) Pyrite

**Answers:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (i) | d | (ii) | c | (iii) | d | (iv) | c |
| (v) | c | (vi) | b | (vii) | c | (viii) | b |
| (ix) | b | (x) | b | (xi) | c | (xii) | c |
| (xiii) | b | (xiv) | d | (xv) | d | (xvi) | a |
| (xvii) | b | (xviii) | d | (xix) | b | (xx) | b |
| (xxi) | a | (xxii) | c | (xxiii) | c | (xxiv) | b |
| (xxv) | d | (xxvi) | a | (xxvii) | c | (xxviii) | c |
| (xxix) | d | (xxx) | c | (xxxi) | c | (xxxii) | d |
| (xxxiii) | c | (xxxiv) | b | (xxxv) | c | (xxxvi) | d |
| (xxxvii) | d | (xxxviii) | b | (xxxix) | d | (xl) | c |
| (xli) | c | (xlii) | a | (xliii) | b | (xliv) | a |
| (xlv) | a | (xlvi) | b | (xlvii) | c | | |

**4.15. 6. Fill in the blanks**

(i) Ore is __________________.

(a) a pure metal
(b) a metallic compound
(c) an ore mineral only
(d) an ore mineral + gangue

(ii) __________________ is devoid of anionic counterpart.

(a) oxide
(b) sulphide
(c) native
(d) sulphosalt

(iii) Wall rock alteration is characteristic of _________________ effect.

(a) magmatic
(b) contact metasomatic
(c) hydrothermal
(d) metamorphic

(iv) ___________________ is reckoned as the father of economic geology.

(a) Bateman
(b) Lindgren
(c) Beaumont
(d) Agricola

(v) Halite is ______________.

(a) KCl (b) $CaCl_2$

(c) NaCl (d) $MgCl_2$

(vi) The earliest systematic classification of mineral deposits proposed in the early 20th century belongs to

(a) Bateman (b) Spurr

(c) Graton (d) Lindgren

(vii) Concentrated furnace product composed of iron and copper sulphides is called ___.

(a) ingot (b) matte

(c) slag (d) melt

(viii) Cu + Ni alloy is termed as _______________ metal.

(a) bell (b) gun

(c) monel (d) bronze

(ix) The streak of chalcopyrite is ______________.

(a) green (b) greenish grey

(c) greenish black (d) grey

(x) ____________ is the principal ore mineral of copper, the world over.

(a) cuprite (b) copper pyrites

(c) bornite (d) covellite

(xi) Green coloured Cu-mineral is ________________ .

(a) azurite (b) malachite

(c) bornite (d) cuprite

(xii) Pure chalcopyrite contains ____________ % of Cu.

(a) 34.5 (b) 36.6

(c) 56.5 (d) 65.5

(xiii) Use of Cu was known ever since the __________________ .

(a) copper age (b) brass age
(c) bronze age (d) stone age

(xiv) Most of the Cu-ores in the world are ____________________ .

(a) oxides (b) sulphides
(c) carbonates (d) sulpho-salts

(xv) Cu is a __________________ metal.

(a) ferrous (b) base
(c) light (d) precious

(xvi) Number of Cu-mines in Odisha is ________.

(a) two (b) one
(c) zero (d) three

(xvii) ___________ Indian Cu-deposit is appreciably molybdenite bearing.

(a) Khetri (b) Rajpura
(c) Malanjkhand (d) Ambamata

(xviii) In ___ Cu-belt of India, Cu minerals are associated with Uranium ore.

(a) Khetri (b) Ambamata
(c) Singhbhum (d) Mailaram

(xix) The cupriferous metallic belt occurring in Cuddapah basin in India is ______.

(a) Mailaram (b) Ganikalva
(c) Zangamarajpalle (d) Agnigundala

(xx) Odisha contains about _______ % of Indian chromite.

(a) 68 (b) 78
(c) 88 (d) 98

(xxi) Modern mining of Odisha chromite started at _____________.

(a) Sukinda (b) Katpal
(c) Nausahi (d) Maruabil

(xxii) Sukinda chromite belt, the largest in Asia, is ___________ km long.

(a) 10 (b) 20

(c) 30 (d) 40

(xxiii) Most of the economically viable chromite deposit of the world are formed by ____________ process.

(a) magmatic (b) contact metasomatic

(c) hydrothermal (d) sedimentary

(xxiv) Trihydrate $Al_2O_3$ is ________________ .

(a) bohemite (b) gibbsite

(c) diaspore (d) cliachite

(xxv) Alumina is _______________.

(a) hydrated $Al_2O_3$ (b) $Al_2O_3$

(c) Al metal (d) $Al(OH)_3$

(xxvi) Geological age of bauxite formation is mainly_____________.

(a) Jurassic (b) Cretaceous

(c) Tertiary (d) Pleistocene

(xxvii) The source rock of the best grade of bauxite in the world is _________ .

(a) khondalite (b) basalt

(c) aluminous limestone (d) nepheline syenite

(xxviii) The pockety type bauxite associated with limestone is __________ shaped.

(a)lens (b) tabular

(c) funnel (d) irregular

(xxix) Lohardaga bauxite at Bagru hill is located in the ____________ state of India.

(a) Bihar (b) Jharkhand

(c) Chhatisgarh (d) West Bengal

(xxx) Magnalium is an alloy of Al and ______________.

(a) Zn (b) Pb

(c) W (d) Mg

(xxxi) The residual bauxite formation is best facilitated by ____________ climate.

(a) arid (b) temperate

(c) tropical (d) cold

(xxxii) Panchpatmali bauxite deposit is located in _________ district of Odisha.

(a) Raygada (b) Kalahandi

(c) Bolangir (d) Koraput

(xxxiii) Bauxite blankets of Madhya Pradesh and Maharastra are principally derived from ________ rocks.

(a) basaltic (b) gabbroic

(c) noritic (d) ultramafic

(xxxiv) Odisha is endowed with about ___________ million tones of bauxites.

(a) 2600 (b) 2400

(c) 1800 (d) 1000

(xxxv) Odishan bauxite deposit at __________ plateau is shared by Bolangir and Bargarh districts.

(a) Pareshnath (b) Gandamardan

(c) Karlapat (d) Lanjigarh

(xxxvi) The largest public sector company involved in exploitation of Odishan bauxites is ____________ .

(a) BALCO (b) UTKAL ALUMINA

(c) NALCO (d) VEDANTA

(xxxvii) NALCO"s alumina plant is located at __________________.

(a) Panchpatmali (b) Kakirgumma

(c) Damanjodi (d) Angul

(xxxviii) Richest oil containing country in the world is_______________.

(a) USA (b) Russia

(c) Mexico (d) South Arabia

(xxxix) In Indian subcontinent, most productive oil horizons are confined to _________ strata.

(a) Ordovician (b) Cretaceous

(c) Tertiary (d) Quaternary

(xl) The source rocks for petroleum are _________ shales.

(a) marine (b) lacustrine

(c) riverine (d) glacial

(xli) ______________ is the best structural trap for petroleum accumulation.

(a) syncline (b) anticline

(c) fault (d) joint

(xlii) The source material for oil is _____________.

(a) phytoplankton (b) zooplankton

(c) both of them (d) none of them

(xliii) Black gold refers to _____________.

(a) black diamond (b) graphite

(c) coal (d) crude oil

(xliv) Iron ores in Bonai - Keonjhar belt are associated with ____________.

(a) Sandstone (b) Shale

(c) BHJ (d) Granite

(xlv) Manganese ore deposits in M.P.and Maharastra belong to are associated with ____________ Group of rocks.

(a) Sausar (b) Aravalli

(c) Iron Ore (d) Delhi

(xlvi) The most important ore minerals of manganese in Jamda – Koira valley are ___________ and ______________.

(a) pyrolusite and braunite (b) pyrolusite and pslomelane

(c) pyrolusite and rhodonite (d) pslomelane and rhodonite

(xlvii) The coals of Odisha are mostly of _______________ type.

(a) peat (b) lignite

(c) bituminous (d)

(xlviii) In addition to the Talcher coalfield, the other coalfield in Odisha is ___________.

(a) Ib-river valley (b) Baitarani river valley

(c) Jharia (d) Raniganj

(xlix) In Jajpur district of Odisha, iron ores occur at _______________.

(a) Sukinda (b) Daitari

(c) Kalinga Nagar (d) Joda

(l) The most important lignite deposit of India is located in the state of _____ .

(a) Tamilnadu (b) Andhra Pradesh

(c) Assam (d) Jharkhand

**Answers:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (i) | d | (ii) | c | (iii) | c | (iv) | d |
| (v) | c | (vi) | d | (vii) | b | (viii) | c |
| (ix) | c | (x) | b | (xi) | b | (xii) | a |
| (xiii) | c | (xiv) | b | (xv) | b | (xvi) | c |
| (xvii) | c | (xviii) | c | (xix) | d | (xx) | d |
| (xxi) | c | (xxii) | b | (xxiii) | a | (xxiv) | b |
| (xxv) | b | (xxvi) | d | (xxvii) | d | (xxviii) | c |
| (xxix) | b | (xxx) | d | (xxxi) | c | (xxxii) | d |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (xxxiii) | a | (xxxiv) | c | (xxxv) | b | (xxxvi) | c |
| (xxxvii) | c | (xxxviii) | d | (xxxix) | c | (xl) | a |
| (xli) | b | (xlii) | c | (xliii) | d | (xliv) | c |
| (xlv) | a | (xlvi) | b | (xlvii) | c | (xlviii) | a |
| (xlix) | b | (l) | a | | | | |

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# CHAPTER – 5

# GROUND WATER GEOLOGY

## 5.1. INTRODUCTION

Water, in form of surface and subsurface water, occurs almost everywhere, although its amount may vary from place to place. Water may occur in liquid, solid or gaseous form. It is indispensable for all animals and plants and there can be no life without water. Huge quantity of water amounting to 97.2% occurs in sea and nearly 2.0% occurs as ice sheets. Thus about 99.2% of available water of the earth is unsuitable for direct use. Out of the remaining 0.8%, almost one third is in form of surface water and two third is in form of ground water. Next to water in the ice caps and glaciers, groundwater reserves form the largest fresh water resources. Out of the total ground water resources, only about 0.25% amounting to $34\times 10^4$ Mham (Million hectare-metres) can be economically exploited. According to one estimate, the total available ground water on the earth is 25% of all fresh water and out of this water, which is easily exploitable up to 700m depth is 11% and the balance lies between a depth of 700 to 3000 m. At present, nearly one-fifth ground water needs of the world is met from ground water resources and so a vast base needs to be utilized by human beings for various uses. Groundwater is a replenishable source which gets recharged mainly from precipitation i.e. rainfall and snow fall. Besides, very small quantity of water may get replenished partly from "connate water" i.e. water entrapped within the sediments at the time of sedimentation or from "juvenile water" i.e. the water associated with magmatic or related processes.

## 5.2. DEFINITION OF GROUNDWATER

To a lay person, the water occurring below the surface of the earth is ground water but it is never the case. Without any specification ground water can be said to be the water occupying all the voids or interstices within a geologic stratum. Hence the voids should be completely saturated with water in a zone lying below the surface called the "zone of saturation". This zone is different from the zone, which lies above it immediately below the surface where voids or interstices are filled up partly with water and partly with air called "zone of aeration".

Ground water in the strict sense of the term can be defined as the water which occurs in the geologic materials in the zone of saturation where the pore spaces, voids, interstices etc. are completely saturated with water.

At the time of rainfall or melting of the snow, a significant portion of water is carried by streams and rivers as run off' into the larger water bodies like oceans, seas and sometimes to lakes. Part of the rainfall or snow fall is recharged into the ground and move by gravity through interconnected voids underground until they reach the zone of saturation.

Ground water occurs within the pore spaces of the geologic materials which may be of primary origin or secondary origin. The primary pore spaces are developed at the time of the formation of the rocks e.g. vesicles in volcanic rocks, pores within sediments etc. The secondary porosity is formed due to deformations and weathering, e.g. joints, fractures, cracks, weathered zones etc. Fig. 5.1 explains the occurrence of groundwater below the surface of the earth. From the figure it can be seen that at a particular depth the geologic materials lack voids and water if present, is chemically bound in rocks and minerals. This zone is called the zone of internal water. Above this zone lies the zone of interstitial water that is the zone where the materials are characterised by voids, interstices or pores and the water is in free motion. This zone can be subdivided into two i.e. the zone of aeration and the zone of saturation.

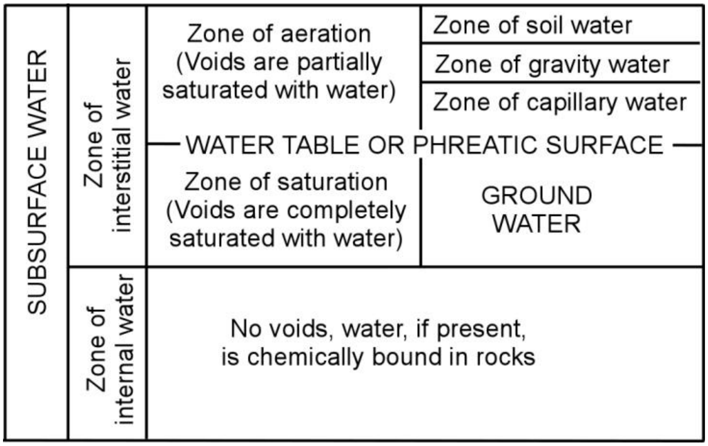


**Fig. 5.1: Vertical distribution of subsurface water**

## 5.3. ZONE OF AERATION

The zone of aeration is the zone which lies close to the surface and the pore spaces in this zone are partially filled up with air and the rest with water. The water present in this zone is known as "vadose water". Its thickness varies to a considerable extent depending on the climatic factors. In the swamps and marshy regions, it may have zero thickness i.e. the zone of aeration may not exist since the zone of saturation lies just at the ground surface. In the arid zones, it is very thick and can have three subzones i.e. zone of soil water, zone of gravity water and zone of capillary water. The zone of soil water lies immediately below the ground surface form where water losses take place by processes of evaporation and transpiration into the atmosphere. The water in this zone is held as thin films around the soil grains. The zone of gravity water lies below the zone of soil water. Force of gravity is responsible for the movement of water from the zone of soil water into the zone of gravity water. The moisture content in this zone varies from nearly saturation to very low saturation. The next zone i.e. the zone of capillary water lies just above the zone of saturation and in this zone water moves up against the force of gravity by capillary force. The capillary rise is maximum in fine grained materials. This zone extends from the water table i.e. the upper limit of the zone of saturation up to the limit of capillary rise of water.

## 5.4. ZONE OF SATURATION

This zone lies below the zone of aeration, where pore spaces are completely filled up with water and hence the voids can be said to be saturated with water. The water which is present in this zone is known as “Ground water”. Since this zone is interconnected with the atmosphere through the zone of aeration, the pressure on the water in this zone is atmospheric and so the ground water called “phreatic water”. The zone of saturation extends to a few hundred meters depth and in this zone water freely enters into the well.

## 5.5. HYDROLOGIC CYCLE

Hydrologic cycle (Fig. 5.2) is the movement of water in a constant and endless, cyclic manner in different parts of the earth i.e. between hydrosphere (oceans and other water bodies), atmosphere and lithosphere (rocks and sediments). Water evaporates from the surface of the water bodies such as ponds, lakes, reservoirs, ocean surfaces etc. and land by the action of sun rays or wind and is transported by moving air masses. Under proper conditions, the vapour is condensed to form clouds which in turn may result in precipitation i.e. rain, hail, snow, sheet, mist, dew, frost etc. A portion of water is lost into the atmosphere by transpiration which is the process of extraction of water by plants from the soil through their roots and discharge of water into the atmosphere.

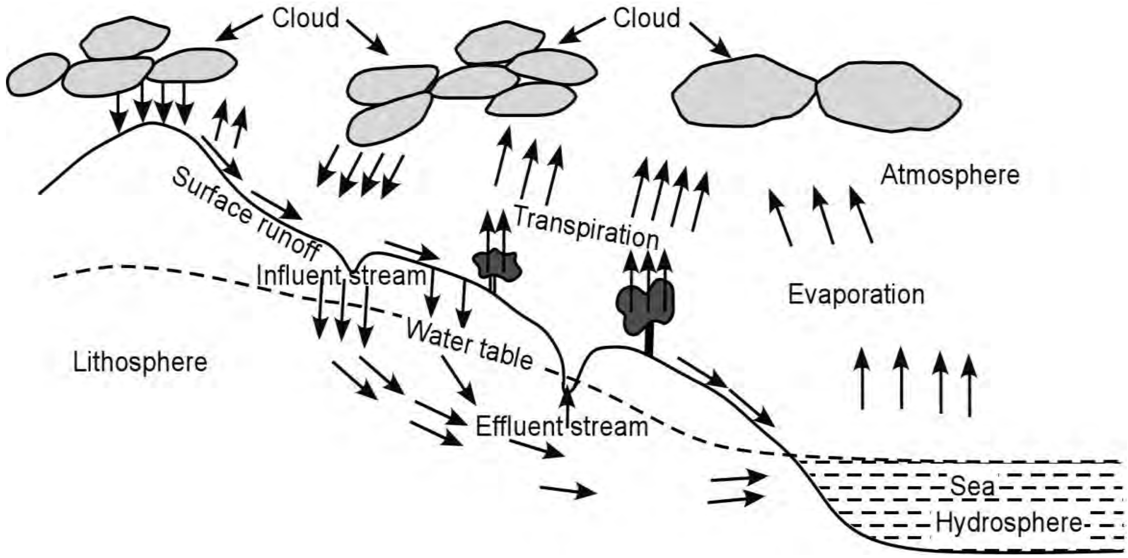


**Fig. 5.2: Hydrologic cycle**

The precipitation which falls on the land surface is distributed in several ways:

(a) A portion is retained in soil near the ground surface and is returned to the atmosphere again by evaporation and transpiration by plants.

(b) A portion is percolated into the ground through the zone of aeration into the zone of saturation and forms ground water.

(c) A very large portion moves as streams and rivers as surface run off and ultimately move into the larger water bodies under the influence of gravity. During its movement, part of the Water undergoes evaporation and a part percolates into the ground water zone.

(d) A portion of water from the streams or rivers may directly discharge into the groundwater and conversely groundwater sometimes may contribute to the stream flow.

In this way the hydrologic cycle (Fig. 5.2) is repeated again and again in a cyclic manner. There are four phases in the cycle i.e. (a) Precipitation (b) Evaporation and transpiration (c) Surface run off and (d) Ground water. The motive force for the circulation of water is either gravity or thermal energy.

However, the processes operating in the hydrologic cycle may not be steady since there are irregularities in the processes both in time and space. In some cases, the cycle may be short - circuited and in some cases one of the processes may not be operative. For example torrential rain may lead to high surface run off without much ground water component. During periods of drought, the precipitation and run off may be nil.

The amount of water involved in a particular process can be numerically calculated and the quantity of water percolating as ground water in a particular year can be found out. If

G = Amount of ground water　　E = Evapo-transpiration

P = Precipitation　　S = Surface run off

then $G = P - (E + S)$

## 5.6. ADVANTAGES OF USING GROUND WATER

As mentioned earlier, a large part of our planet is covered with water. Ground water forms about 25% of all fresh water and a large part of it occurs at a shallow depth making it more amenable for exploitation. It has many advantages over surface water which are given below.

(i) It is present almost everywhere starting from arid and drought - prone areas to areas of very high rainfall. In the areas where surface water is not adequate and dependable, ground water is the only alternative and dependable source of water.

(ii) Ground water is free from pathogenic organisms like bacteria and other pollutants causing health problems but surface water is easily affected by these.

(iii) Chemical composition is fairly constant. The chemical constituents get into the water because of its capacity to dissolve chemical constituents of the rocks in which it is stored.

(iv) Ground water is at a constant temperature and is not affected much by climatic and diurnal factors for which it can be used for heat exchange processes such as air-conditioning, refrigeration etc. In contrast to this, surface water is usually affected by temperature of the atmosphere.

(v) Turbidity and suspended solids are generally absent in the ground water because of natural filtering capacity of the soil which is not the case for surface water.

(vi) Unless there is recharge of polluted water into the ground water zone, their biological and radiogenic contamination is difficult.

(vii) No man-made reservoirs are necessary for the storage of ground water and no canal systems are required for their distribution. The pore spaces of the rocks serve as its reservoir and the interconnections of the pores serve as the conduits for its distribution.

(viii) To store ground water no space on the surface is required whereas to store surface water, space on the land is required. Similarly for the distribution of surface water, elaborate leak-proof arrangement is required.

(ix) No enemy can destroy the ground water reservoir of a country but it is not so with surface water. Now-a-days large reservoirs and the dams are the targets of enemy attack.

(x) Waste water such as industrial effluents and sewage water after treatment can be artificially recharged into the groundwater zone for further use.

(xi) Large capital investments are not required for the exploitation of ground water. It can easily cater to the need of a cluster of people and for irrigation with less cost.

(xii) The volume of groundwater storage is much larger than the surface water storage and so it cannot be easily affected by drought. However, serious drought conditions over a couple of years can bring the ground water-level down which can again be revitalized after a year of normal rainfall. It can be taken as a reliable and immediate source of water supply at times of need.

(xiii) Problem of silting and reservoir maintenance is a must for surface water reservoirs requiring large expenditure. On the other hand, no such maintenance cost is required for ground water exploitation structures.

## 5.7. PROPERTIES OF GROUND WATER-BEARING MATERIALS

### 5.7.1. Porosity

It is a storage property of the rocks or sediments which form the host for ground water. It refers to the voids, interstices or open spaces in the solid materials.

The porosity is expressed as the percentage of void space to the total volume of the mass. Thus, porosity (P) is given by the formula.

$$P = \frac{V_v}{V} \times 100$$

where $V_v$ = volume of voids

V = Total volume of rock or sediment

Depending on the origin, porosity is of two types.

**(i) Primary porosity:** The voids created during the formation of the rock e.g. voids in sediments and sedimentary rock, vescic1es in volcanic rocks etc. and

**(ii) Secondary porosity:** The voids created subsequent to the formation of the rocks e.g. features due to deformation such as joints, fractures, cleavage, schistosity, shear zones and due to weathering.

The value of porosity is independent of grain size but dependent on shape, orientation and packing and sorting as described below.

**(a) Shape:** The shape of the grains change the porosity values; for example the angularity tends to increase the porosity i.e. more the angularity of the grain, more is the porosity value and vice versa.

**(b) Orientation and packing:** In case of square packing of the grains, the porosity is relatively higher but in case of rhombic packing, the porosity is relatively less.

**(c) Manner of sorting:** If the sediments are poorly sorted i.e. constituted of particles of wider size range, porosity becomes less whereas in case o~ well sorted sediments with limited size range, the porosity tends to be more.

The porosity values of some important rocks and sediments are given below.

| Rock / Sediment | | Porosity value (in %) |
|---|---|---|
| Clay | : | 45 - 55 |
| Sand | : | 35 – 40 |
| Gravel | : | 30 - 40 |
| Shale | : | 01 - 10 |
| Limestone | : | 01 - 10 |
| Sandstone | : | 10 - 20 |
| Completely weathered rock | : | 30 - 40 |
| Slightly weathered rock | : | 1.5 – 03 |
| Fresh rocks | : | 0.05 - 0.3 |

Rocks which have very less porosity values or do not have porosity cannot yield ground water if a well is dug through them. Hence porosity is responsible for storage of water and provides scope for their movement if these are interconnected.

### 5.7.2. Specific yield

Porosity indicates the amount of water stored in the water-bearing formation but it does not indicate the yield of water from the aquifer. It is seen that due to drainage or even due to pumping, all the water stored in the formation is not removed and part of water is retained in the voids due to forces of molecular attraction, cohesion and surface tension. This water yielding capacity of the material is known as „specific yield‟.

It is expressed as the volume of water in the voids which is easily drained out to the total volume of the rock expressed in percentage.

If $W_y$ = the volume of water easily drained out from the voids; V =Volume of the rock or sediment

Then specific yield $(S_y) = \frac{W_y}{V} \times 100$

Geometry of the pores such as size, shape, distribution of pores, compaction and composition of the formations and interconnections of the pores control the specific yield.

Specific yield of some rocks and sediments is given below.

| Rock / Sediment | | Specific yield (in %) | Rock / Sediment | | Specific yield (in %) |
|---|---|---|---|---|---|
| Clay | : | 01 - 10 | Sandstone | : | 05 - 15 |
| Sand | : | 10 - 30 | Shale | : | 0.5 - 05 |
| Gravel | : | 15 - 30 | Limestone | : | 0.5 - 05 |

### 5.7.3. Specific retention

It indicates the amount of water which is retained within the pores against the force of gravity. It is expressed as the percentage of the total volume of water retained in the pores to the total volume of the rock/ sediment.

Thus, porosity is the sum of specific yield and specific retention of a rock/ sediment.

Porosity = Specific yield + specific retention

The porosity of a solid rock can be determined by heating the sample for 24 hours at a temperature of 110°C and then dipping in water for 48 hours. The total volume of water absorbed is the volume of voids. For an unconsolidated material, the sample is to be completely saturated to get the volume of the water in the voids.

**5.7.4. Permeability**

It is the property of movement of water in water bearing materials and reflects the capacity of the porous materials to transmit liquid within the pore spaces through the interconnections. Unless there are interconnections among the pore spaces, no movement of water is possible and hence the material can be regarded as „impermeable‟.

Permeability of a porous media is defined as the ability of a rock or sediment to allow passage of water through the open spaces without destroying the structure. It can be said that only porous rocks are permeable. Hence, permeability refers to the capacity of the porous media to transmit water through their pore spaces or it is the ease of movement of fluid through it. Permeability can also be defined as the flow per unit cross sectional area of the formation when subjected to a unit hydraulic head per unit length of flow i.e. per unit hydraulic gradient. The movement of water depends on the characters of the openings rather than their volume. Permeability is independent on the nature of the porous media and the nature of the fluid like its viscosity and specific weight. Low viscous fluids are also more permeable.

Permeability can be expressed by “coefficient of permeability” and coefficient of permeability can be calculated by applying Darcy's law as given below.

### 5.7.5 Darcy's Law

In the water bearing formations, the ground water flow is dependent on effects of gravity, velocity and pressure of water.

A French hydraulic engineer Darcy proposed the law known as Darcy‟s law which is valid for the laminar flows having a straight path where the flow velocity is very small. This law enables to evaluate ground water flow rates and directions. The law is as follows:

"The flow rate through media is proportional to the head loss and inversely proportional to the length of the flow path".

As per the law, if V is rate of flow, H is head loss and L is length of flow path

$$V \propto H \text{ and } V \propto \frac{1}{L} \Rightarrow V \propto \frac{H}{L} \Rightarrow V = K \times \frac{H}{L} = K \cdot I$$

Where K = Constant of the medium with respect to the liquid or coefficient of Permeability

$$\frac{H}{L} = I \text{ (Hydraulic gradient)}; \qquad K = \frac{V}{I} \text{ (m / day)}$$

The coefficient of permeability can also be expressed in terms of quantity of flow (Q).

Since Q = V × A (Q = Quantity of flow, A = Cross sectional area)

The expression can be written as K = Q / I.A (litres per day / $m^2$)

The permeability values of some common materials is given below

| Material | | Permeability (lpd /$m^2$) | Material | | Permeability (lpd /$m^2$) |
|---|---|---|---|---|---|
| Clay / silt | : | 0.05 - 100 | Sand and gravel | : | $10^3$ - 2.5× $10^5$ |
| Sand | : | 5 × $10^3$ - 15× $10^4$ | Sandstone | : | 5 - 2.5× $10^3$ |
| Gravel | : | 5 × $10^4$ - 7.5× $10^5$ | Shale | : | $10^{-5}$ - 0.1 |

### 5.7.6. Factors influencing permeability

The permeability of a water bearing formation is dependent on the following factors.

**(i) Size and sorting of the constituent grains:** If the grain size is large and the rock is composed of uniformly sized particles (well sorted) the permeability value becomes more. On the other hand, if the rock is composed of larger and smaller grains mixed together (poorly sorted) the smaller grains will occupy the voids between larger grains as a result of which the porosity and permeability become less.

**(ii) Shape of the grains:** Rounded grains in a sediment will have more intergranular spaces causing increased storage of ground water and hence more permeability values. On the other hand, in case of angular grains of the same size range there is relatively less storage of water and less permeability.

**(iii) Interconnections of the pore spaces:** Presence of large pore spaces without any continuity does not make a rock permeable where as if the pore spaces are interconnected, the rock becomes permeable. Clay which has more porosity value (45-55%) is less permeable than a sand because of lack of interconnections of the pore spaces.

### 5.7.7. Hydraulic conductivity

It is the transmission of unit volume of ground water in unit time through a cross section of unit area. The hydraulic conductivity has units of velocity i.e. m/day.

Coefficient of permeability can be determined either in the laboratory or in the field by the following methods.

**(i)** Laboratory determination by permeameters of constant head type and falling head type.

**(ii)** Field determination by (i) velocity method by applying tracers and finding out their arrivals in the observation well and by (ii) Aquifer test or well pumping test.

## 5.8. WATER BEARING FORMATIONS

Although the pore spaces in the zone of saturation are completely filled up with water, their hydrologic properties vary depending on porosity, permeability and water yielding capacity of wells. The water bearing formations are classified on the basis of these properties into four types (a) Aquifer (b) Aquifuse (c) Aquiclude (d) Aquitard.

### 5.8.1. Aquifers

These are geologic formations in the zone of saturation which store large quantity of water within their pore spaces and have the capacity of transmitting water through the interconnections of the pores freely from one part to the other. Thus, these are highly porous and permeable. e.g. sand, gravel, conglomerate, cavernous limestone etc.

Clay is fine grained, highly porous but because of its impervious nature, it cannot be called as an aquifer. Coarser materials like sand, gravel etc. are porous as well as permeable for which these can be classified as aquifers. Almost 90% of all developed aquifers consist of unconsolidated materials like sand and gravel. The aquifer can also be defined with an economic consideration as follows:

"An aquifer is a geologic formation which contains water and transmits it from one point to another in quantities sufficient to permit economic development."

### 5.8.2. Aquifuses

These are rock materials in the zone of saturation which are nonporous and hence cannot store water. The absence of voids also makes them impermeable. e.g. massive basalt, granite, well cemented sandstone etc.

### 5.8.3. Aquicludes

These are geological materials in the zone of saturation which are porous to highly porous but due to lack of inter connections of the pores, these are not capable to transmit water through them. Thus, these are porous but impermeable. e.g. clay, silt, shale etc.

### 5.8.4. Aquitards

These rock materials are capable of storing significant amount of water but their rate of water transmission is too low and they do not yield water freely to the wells. These are highly porous but semipermeable. These are sufficiently permeable to transmit water vertically but not sufficiently permeable to laterally transport water. e.g. sandy clay.

### 5.8.5. Types of Aquifers

Aquifers are usually of large areal extensions and serve as large underground reservoirs. The rocks / sediments that can hold, transmit and yield water can be called aquifers. Most common aquifer materials are constituted of

(a) unconsolidated sands and gravels occurring as alluvial deposits in the valleys, stream beds, buried valleys, coastal plains, dunes, intermontane valleys and glacier deposits.

(b) sandstones with argillaceous matrix.

(c) cavernous limestones with large solution channels, caves, underground streams etc.

(d) weathered granites, basalts, schists, gneisses etc.

(e) fractured and jointed massive rocks.

(f) volcanic rocks like basalts containing vesicular cavities, lava tunnels, columnar joints etc.

Based on the pressure of the groundwater i.e. confined or atmospheric and nature of water transmitting capacity, aquifers can be classified into 4 categories, viz.(i) Unconfined Aquifer, (ii) Confined Aquifer, (iii) Leaky Aquifer and (iv) Perched Aquifer. A brief description of each types is given below.

**(i) Unconfined Aquifer:** This is otherwise known as free, phreatic or non artesian aquifer. The level of water is the same as the upper surface of the zone of saturation and the aquifer. The water is freely in communication with the atmosphere through the zone of aeration as a result of which, the pressure on the water is atmospheric. Since it is directly connected with the atmosphere, precipitation during rainy season affects its level. The water here is said to be in water table condition or unconfined condition i.e. no confining layer is found above this aquifer. In this aquifer, the upper surface is denoted by "water table". The rise and fall of the water table is due to increase or decrease of volume of water in this aquifer. The unconfined aquifers are commonly seen in alluvial plains, coastal plains, dunes, glacial deposits and highly weathered and jointed / fractured rocks. The thickness of the aquifers varies from less than a few meters to several hundred metres. Precipitation is the chief source of groundwater in this aquifer, which percolates through the zone of aeration above the aquifers. Fig. 5.3 depicts the unconfined aquifer.

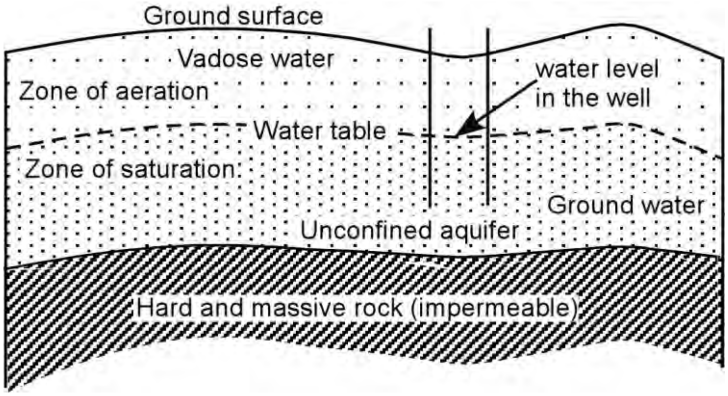


**Fig. 5.3: Unconfined aquifer**

**(ii) Confined Aquifer:** This is otherwise known as artesian aquifer or pressure aquifer. It is named as confined aquifer because of a confining layer of impervious nature lying above it. Because of the presence of a confining layer the pressure on the water (hydrostatic pressure) of the aquifer is exerted upwards which is more than the atmospheric pressure. The confined aquifers do not have a free water table. If a tight cased well is dug penetrating a confined aquifer, the water surface reaches above the top of the aquifer to a certain level which is controlled by the pressure of the water in the aquifer. The maximum level up to which water in the confined aquifer can rise up in the well is called the „piezometric‟ or „potentiometric surface‟. The piezometric surface can be defined as an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer. When the piezometric surface lies above the ground surface, a flowing well or artesian well is developed. A subartesian well condition is developed when the piezometric surface comes up but lies below the ground surface. If the piezometric surface lies below the bottom of the confining bed, the aquifer behaves like an unconfined aquifer. The rise or fall of water levels (piezometric surface) penetrating confined aquifers is due to change in the pressure rather than changes in storage volume.

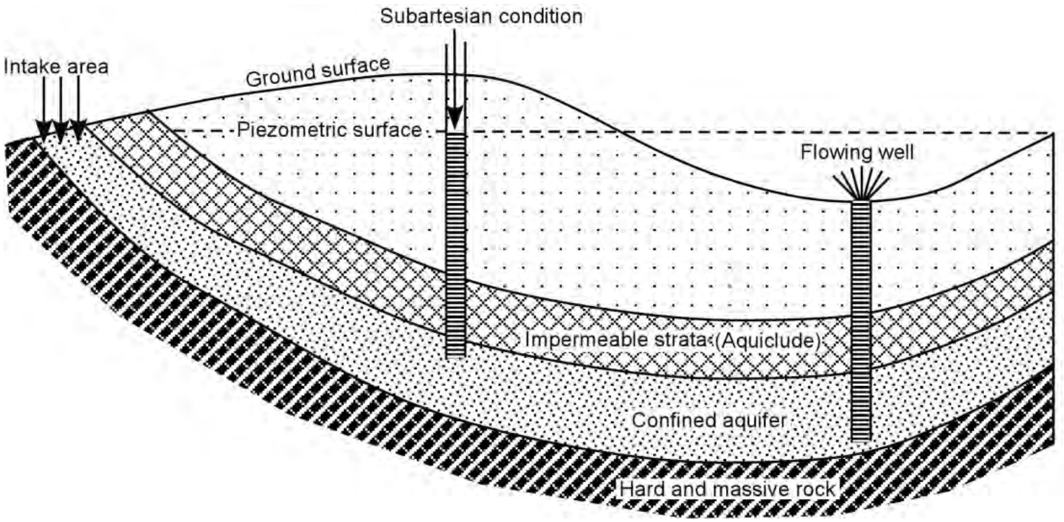


**Fig. 5.4: Confined aquifer**

In the confined aquifer water enters into it in an area where the aquifer as well as the confining layer are exposed to the surface (Fig 5.4). This area is known as recharge area and nearer to this area lies an unconfined condition. The conditions necessary for artesian or flowing well are:

(i) An inclined or synclinal water bearing formation enclosed at both its upper and lower sides by confining layers.

(ii) Exposure of the aquifer to the surface (recharge area).

(iii) Sufficient rainfall over the. recharge area to supply large amount of water.

(iv) Sufficient porosity and permeability of the formation to distribute water through out.

(v) No escape route for the water except through the wells.

(vi) Huge amount of overburden away frpm the recharge area to extend huge pressure on the water in the aquifer.

Confined aquifers either occur as a single layer or as succession of layers, the second one being more common.

**Confined aquifers of India:** Confined aquifers, with artesian to subartesian onditions, occur in the following areas.

(i) Gentle dipping beds, monoclines and synclinal strata with high pressure conditions occur in Cuddalore sandstone of Tamilnadu, Upper Cretaceous sandstone of Kutch, Rajahmundry sandstone of Andhra Pradesh.

(ii) Vescicular Deccan trap flows alternating with massive flow form ideal confined aquifer conditions in western India.

(iii) Fractured granites and metamorphic rocks lying at depth form confined aquifers in various parts of India.

(iv) Solution cavities in Vindhyan limestones in central India and Rajasthan lying in between massive limestone beds create confined aquifer condition.

(v) Alluvial terraces of river Yamuna with alternating sand and clay, gravel, sand and clay form confined aquifer conditions.

(vi) Terai belt at the foot hills of the Himalayas which form a part of the Indo-Gangetic alluvial region in Gurdaspur and Patiala districts of Punjab, Nainital district of Uttarakhand has typical artesian flowing well conditions.

**(c) Leaky aquifer:** In natural conditions getting a perfect confined or unconfmed aquifer is rather rare and many of them are partly confined i.e. semiconfined. This condition is resulted due to semi-pervious nature of the confining layer allowing measurable permeability. Due to lowering of the piezometric surface by pumping, water moves vertically from the semiconfined layer into the aquifer lying below. Due to low hydraulic conductivity of the confining layer, the horizontal flow is very less and is almost negligible.

**(d) Perched Aquifer:** An impermeable strata i.e. a clay / silt horizon or massive intrusive body in form of a dyke or sill may be present in the zone of aeration. This impermeable formation can prevent movement of water into the zone of saturation and form local zone of saturation with voids completely saturated with water in the zone of aeration. The water within this local zone of saturation is called perched water and the water bearing formation is known as „Perched aquifer‟ (Fig. 5.5). The upper surface of this perched aquifer is known as "Perched water table" which lies above the water table.

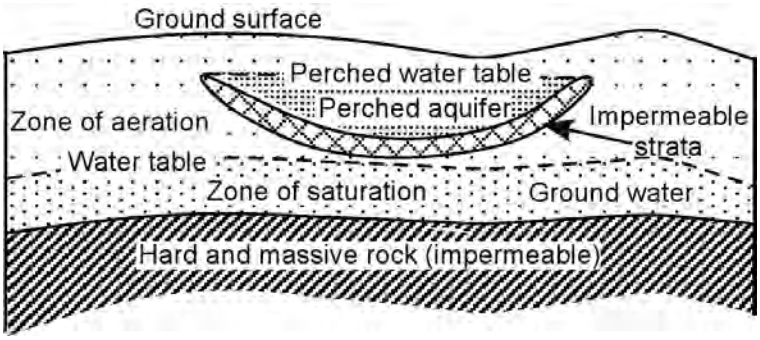


**Fig. 5.5: Perched Aquifer**

## 5.9. WATER TABLE

Under influence of gravity, subsurface water percolates downwards along the interconnections of the pore spaces up to a certain depth beyond which the rocks are devoid of voids. The percolating water saturates the water bearing formation forming the zone of saturation. The zone lying above the zone of saturation has the pore spaces partially filled up with water and partially with air and is called zone of aeration. The surface separating the zone of saturation from the zone aeration is called the "water table" (Fig. 5.6). Water table can also be defined as the water surface in a well which penetrates through the unconfined aquifer. However, this is also known as "Static water level" coinciding with the water table of surrounding aquifer. By plotting the water levels of the area on a map and / or profile; the water table map of an area can be prepared.

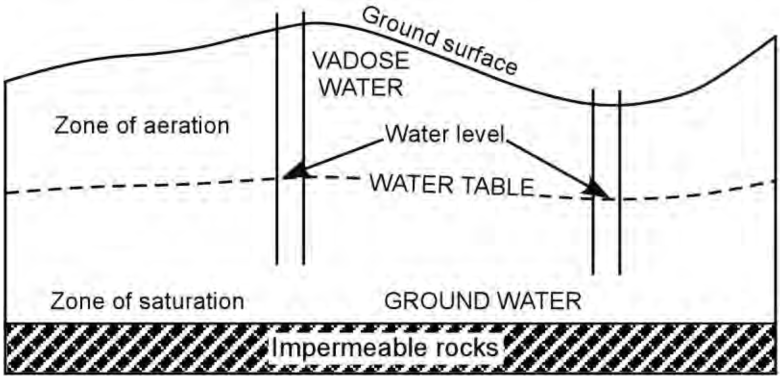


**Fig. 5.6: Water table**

Since the zone of aeration and saturation are not uniform throughout and there may be zone of impervious formation at the surface, the water table may be discontinuous. The characteristics of the water table are given below.

(a) It can be visualised and is an existent surface underground in contrast to the piezometric surface which is an imaginary surface.

(b) It is never a level surface and is not uniformly present throughout the subsurface.

(c) In many cases it duplicates the topography i.e. a subdued replica of the land surface.

(d) It fluctuates annually and seasonally due to differences in the volume of recharge from atmospheric precipitation.

(e) The water table is more uniform in flat terrain and rocks of high permeability. In the rocks of high permeability, the water table becomes flat even if there are differences in topography.

(f) The water table is usually deeper in mountainous regions and uplands and shallower in low lying and valley areas.

(g) The water table goes down when there is more withdrawal of ground water from an area.

(h) The position of the water table is influenced by geologic factors like presence of dykes, structures and permeability of the water bearing formations.

(i) Sometimes due to heavy rainfall and in humid regions, all the pore spaces in the zone of aeration are filled up with water only and hence the water table lies at the ground surface.

The depth of water table with respect to the ground surface helps in finding out the following:

(a) Delineation of recharge and discharge areas.

(b) Locating site for construction wells.

(c) Disposal of drainage.

(d) Artificial recharge of water.

### 5.9.1. Causes of change in levels of water table

The change in levels of water table in an unconfined aquifer is basically due to changes in storage and is caused by the following factors.

**(i) Secular and seasonal variations:** Continuous pumping more than the amount of recharge over a period of several years or more can produce long period fluctuation or secular variation. This time of withdrawal may be necessary to cater to the need of increased population and also increased industrial and irrigational needs. Many water tables also show a seasonal fluctuation due to decreased or increased rainfall, pumpage, irrigational needs etc.

**(ii) Relationship with stream flow:** When a stream channel comes in direct contact with the water table, the stream can recharge the ground water or can receive discharge from the ground water. The stream is known as either influent or effluent accordingly. This can change the level of ground water.

(iii) **Fluctuation due to evapotranspiration:** Unconfined aquifers with shallow ground water tables can lose large amount of water due to evaporation as well as transpiration. The evaporation of ground water in the summer causes deepening of the water table.

(iv) **Fluctuation due to atmospheric pressure:** The change in the atmospheric pressure has least influence on the water table but in case of piezometric surface, it has a greater influence.

(v) **Fluctuation due to ocean tides and earthquakes:** Tides in the ocean affect the level of water in the coastal aquifers. As the sea level rises, the level of the water table also goes up.

Due to earthquake, the water level may have sudden rise or fall. Due to earthquake there may be change in the discharge of springs, appearance of new springs, eruption of water etc. causing fluctuations in the water table.

The level of the water table can be controlled by managing the pumpage, artificial recharge, conjunctive use of surface and ground water resources etc. This can be achieved by creating consciousness and awareness among the people.

## 5.10. SAMPLE QUESTIONS

### 5.10.1. Long Questions

(i) Describe the vertical zonation of groundwater. Add a note on hydrologic cycle.

(ii) Describe porosity and permeability of rocks. Describe how permeability can be deduced from Darcy's law.

(iii) What is an aquifer? With neat sketches describe different types of aquifers.

### 5.10.2. Write short notes on:

(i) Advantages of groundwater
(ii) Hydrologic cycle
(iii) Water table
(iv) Aquifer
(v) Aquiclude
(vi) Vertical zonation of groundwater
(vii) Zone of saturation
(viii) Zone of aeration
(ix) Porosity
(x) Permeability
(xi) Groundwater
(xii) Darcy'slaw

### 5.10.3. Write your answer using a few short sentences

(i) What is porosity?
(ii) What is groundwater?
(iii) Define water table
(iv) Mention Darcy's law
(v) What is an aquifer?
(vi) What is an aquiclude?
(vii) What is permeability?
(viii) What are the four phases of hydrologic cycle?

### 5.10.4. Distinguish between the following pairs

(Answers should be within 3-5 sentences).

(i) Aquifer and aquiclude
(ii) Porosity and permeability
(iii) Primary porosity and secondary porosity
(iv)Zone of aeration and zone of saturation
(v) Ground water and vadose water

### 5.10.5. Fill in the blanks with suitable word / words.

(i) Water that is associated with magmatic or magma related processes are known as ___________.

(ii) The subsurface water which occurs in the zone of aeration is known as ___.

(iii) The main source of ground water is _____________.

(iv) Ground water occurs in the zone of _____.

(v) The porosity which is developed at the time of formation of the rock is known as _______.

(vi) The geological materials which are porous and permeable are known as _____.

(vii) Water table separates the zone of saturation from the zone of _________.

(viii) Out of clay, silt, shale and sand the material showing maximum permeability is _____________.

**Answers**

| | | | |
|---|---|---|---|
| (i) | Juvenile water | (v) | Primary porosity |
| (ii) | Vadose water | (vi) | Aquifers |
| (iii) | Precipitation | (vii) | Aeration |
| (iv) | Saturation | (viii) | Sand |

**5.10.6. Choose the correct answer out of the four options given for each question.**

(i) A rock which is porous and impermeable is called

(a) Aquifer (b) Aquitard (c) Aquifuse (d) Aquiclude

(ii) The water that is entrapped in sedimentary rocks during their formation is called

(a) Connate water (b) Juvenile water (c) Vadose water (d) Meteoric water

(iii) Out of the following rocks which one is a good aquifer?

(a) Sand (b) Clay (c) Silt (d) Shale

(iv) The ground water zone where pore spaces are completely saturated with water is known as

(a) Zone of aeration (b) Zone of saturation (c) Zone of subsurface water

(d) Zone of internal water

(v) The surface separating the zone of saturation from the zone of aeration is called

(a) Piezometric surface (b) Water table (c) Mean sea surface (d) None of these

(vi) The water movement property of a rock is given by

(a) Permeability (b) Porosity (c) Specific yield (d) Specific retention

(vii) The linear law of movement of water was given by

(a) White (b) Linnaeus (c) Darcy (d) Weber

(viii)The perched water lies in the

(a) Zone of aeration (b) Zone of saturation (c) Zone of internal water

(d) None of these

**Answers**

| | | | |
|---|---|---|---|
| (i) | Aquiclude | (v) | Water table |
| (ii) | Connate water | (vi) | Permeability |
| (iii) | Sand | (vii) | Darcy |
| (iv) | Zone of saturation | (viii) | Zone of aeration |

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# CHAPTER – 6

# ENGINEERING GEOLOGY

## 6.1. IMPORTANCE OF GEOLOGY IN CIVIL ENGINEERING

The safety, stability and life of an engineering project is dependent on the efficiency of both the civil engineers and geologists. Their role in reducing the cost of a particular project is also important. Most of the civil engineering constructions have their foundations on geological formations for which, safe geological condition is essential for the safety, stability and life span of the structure. Besides, some engineering structures require huge amount of construction materials. The geological knowledge of such materials includes information on their occurrence, composition, durability, reaction with water and other properties. The construction materials are used as building stones, road materials and concrete aggregates.

The engineering construction where the application of geology is required can be outlined as follows:

(i) Design and construction of dams, bridges, buildings, roadways, railways, runways etc.

(ii) Finding out the alignment of a tunnel route along favourable sites.

(iii) Lying out of roads and railways along favourable alignment in hilly areas and in militarily strategic locations.

(iv) Suggesting plans for maintaining stability of slopes along mountainous regions and open cast mines.

(v) Suggesting mining plan and method of execution in underground mines.

(vi) Suggesting locations of construction materials in the vicinity of the construction site.

(vii) Suggesting alternate sites for engineering construction if the site is geologically adverse. However, if there is no alternate site for construction, suggestion can be made about suitable remedial measures.

(viii) Suggesting virgin sources of water supply especially from ground water resources in case of establishment of township, very large industrial establishment, irrigation etc. Besides, study of depth of water table and piezometric surface are of paramount importance in engineering constructions.

Since any large scale engineering construction requires a strong foot hold i.e. the foundation and /or abutment and huge amount of construction material, study of surface and sub-surfaces geological conditions of the area and that of the area in the vicinity is a prerequisite. The importance of geology in engineering constructions was realised in the last half of the twentieth century and was vigorously practised in several developed countries and some developing countries. Earlier it was not done due to economic considerations but later on it was realised that detailed geological studies of a particular site requires only 1.0 to 5.0% of the total project cost and sometimes even less than that. There are instances of failure of the structures due to improper geological studies at the site of engineering construction in the past. Some of the structures that failed due to lack of adequate geological knowledge are given below:

(i) Failure of St. Frances dam of California, Lafayatte dam of California, Austin dam of Texas etc.

(ii) Failure of Jerome reservoir of Idaho, Hondo reservoir of New Mexico.

(iii) Collapse of bridge near Cornwall in Canada

Before starting a major engineering project, it is required to prepare a detailed geological report comprising of surface and sub-surface geological studies and preparing geological maps, profiles, sections etc. The sub-surface geological conditions can also be prepared by computer softwares. The geological studies required for a proposed engineering site are given below:

### 6.1.1. Lithology

Study of rock types with respect to their texture, microstructure, mineral composition, degree of compactness, type of sorting, chemical composition, reaction with water and saline water (in case of marine engineering structures), reaction with gases from vehicles (in case of tunnels), presence of detrimental minerals in the rocks etc. Study of rock types on the surface and along selected bore holes are also necessary.

### 6.1.2. Structure

Presence of small scale and large scale structure are the most important geological study of a proposed site because, their presence can make a site unsuitable unless suitable remedial measures are undertaken. The structures which make the rocks weak are:

**(i)** **Fold:** Particularly at the closure region of anticlinal and synclinal folds.

**(ii)** **Fault:** May or may not be accompanied by shear zones, mylonitisation, brecciation etc. rendering the site a weaker zone. If the fault is active, no engineering construction should be made in the vicinity.

**(iii)** **Foliation:** Presence of schistosity in the rock, make them weak for engineering construction and has to be pre-treated.

**(iv)** **Joints:** Joints which occur as close spaced planes render the rock incompetent and unsuitable and remedial measures have to be undertaken before starting a construction.

**(v)** **Attitude of beds:** The dip and strike of the bed lying on the surface and subsurface should be studied.

### 6.1.3. Geomorphology

The topography and type of landform should be studied as component of geological informatory. Many valleys and hill slopes are bordered by unstable slopes which are to be stabilised. Some areas like alluvial plains, buried river channels, river terraces have to be properly evaluated and reported. The thickness of the alluvial region is to be studied since the foundation becomes unstable if located in these unconsolidated materials.

### 6.1.4. Stratigraphy

The stratigraphic succession of the lithounits and their age relationship has to be properly established since rocks of different ages behave differently causing instability to the structure.

### 6.1.5. Ground water

The depth of the water table in case of unconfined aquifer and piezometric surface in case of confined aquifer has to be studied since the structures lying below these surfaces like tunnels are likely to be affected due to inflow of water. Suitable arrangements of the draining away of the water can be made.

### 6.1.6. Earthquakes and neotectonic activity

Earthquakes of larger magnitude are detrimental to the safety and stability of structure. Hence record of the earthquakes in the proposed site and record of any neotectonic activity can be monitored and the design has to be planned to make the structure aseismic. Besides, position of the structures in the earthquake belts and the magnitude of the shock likely to affect should be evaluated properly.

### 6.1.7. Snow line

The snow line in case of high altitude areas should be assessed from the previous records and the site should be proposed in the altitudes below the snow line.

### 6.1.8. Landslide

The land slide prone areas in the vicinity of an engineering construction should be mapped and the slopes should be maintained accordingly to prevent landslides.

## 6.2. GEOLOGICAL CONSIDERATIONS OF DAMS

### 6.2.1. Definition

A dam can be defined as a huge massive barrier consisting of masonry, concrete or earth built across river valley to store large quantities of water (reservoir) behind. A dam which is constructed to serve more than one purpose is called *multipurpose dam* (Hirakud in Odisha, the longest earth-cum-gravity dam in the world).

The dams are constructed for more than one purpose as mentioned below:

**(i)** **Flood control:** By preventing flow of excess water in the river valley and storing it in the reservoir.

**(ii)** **Power generation:** A height difference is created between the water level in the upstream side and that in the downstream side. This allows the movement of water at a high speed in the turbine and helps in generation of electricity.

**(iii)** **Irrigation:** Water stored in the upstream side is used for irrigation throughout the year through canal system.

**(iv)** Supply of water for domestic use and use in different industries.

**(v)** **Pisciculture:** Fishes are being cultured in the large reservoir area.

**(vi)** **Recreation:** Water in the reservoir is utilized for creation of fountains in the park located just at the downstream side (e.g. Brundaban garden near Krishnarajsagar dam in Karnataka). Facilities for water park can also be created.

**(vii)** To check the entery of sediment from the reservoir to down-stream side.

**6.2.2. Type of Dams**

On the basis of the materials used, dam can be classified into four types.

**(i) Earth dams:** These are constructed mainly by soil or earth which may be covered by a blanket of hard rocks. .

**(ii) Rock-fill dams:** The entire dam is constructed by boulders and pebbles of rocks.

**(iii) Concrete dam:** This dam is constructed with concrete or masonry aggregates. It is built when the force of water in the river valley is very high.

**(iv) Composite dams:** These dams are constructed partly with masonry or concrete at least near the spill way and the main dam position (across the river channel) and partly with earth or unconsolidated materials available in the vicinity. These are suitable for wide and flat valleys.

The concrete dams can be classified into three different types on the basis of their structural design such as (i) Gravity dam, (ii) Buttress dam and (iii) Arch dam.

**(i) Gravity dam:** The cross section of a gravity dam is roughly *trapezoidal* which is nearly triangular (Fig. 6.1 a and b). It is a massive structure, which stands by its own weight. A part of the dam is made hollow to facilitate location of the turbines and other power generation units. Generally a sound foundation is required for the construction of a gravity dam. The strength of the foundation rock also controls the height of the gravity dam. Examples of gravity dam are (a) Bhakra dam in Punjab (260 m) (b) Rihand dam in Uttar Pradesh (75 m) (c) Mettur dam in Tamilnadu (138 m).

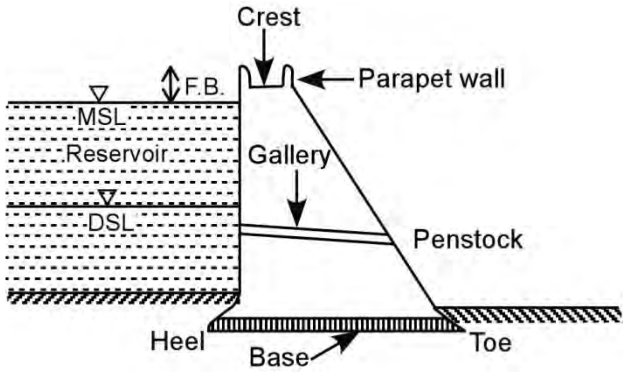



**Fig.6.1 (a): Cross section of a gravity dam along the river. (F.B. – Free boat, M.S.L. – Maximum storage level, D.S.L. – Dead storage level)**

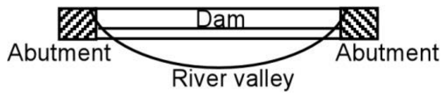



**Fig.6.1(b): Cross section of a gravity dam across the river**

The chief parts of a gravity dam are Crest, Parapet wall, F.B., MSL, Reservoir, DSL, Gallery, Heel, Base, Toe, Penstock, Dam Abutment, River valley abutment.

**Crest:** It is the top of the dam. In many cases it is used as a road way.

**Parapet walls:** These are two low protective walls on either side of the crest.

**Abutment:** It is the sloping side of the valley on which the dam is built or is keyed.

**Free board:** It is the distance between the maximum storage level in the reservoir and the top of the dam.

**Heel:** It is the upstream position of the dam where it touches the foundation.

**Toe:** It is the downstream position of the dam in contact with the foundation.

**Dead Storage level (DSL):** It is the level of permanent storage below which water will not be withdrawn.

**Maximum storage Level (MSL):** It is the level above which, the dam becomes unsafe.

**Spill way:** These are passages to discharge excess water in the reservoir. The spill way is made up of concrete.

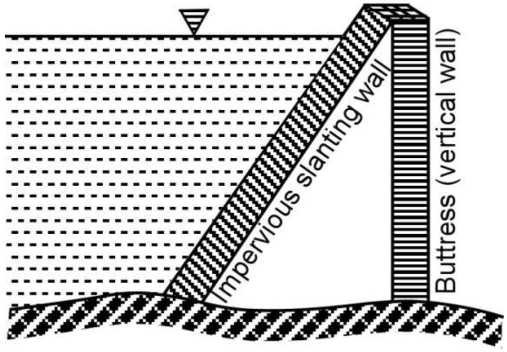
**Gallery:** This is horizontal to gently sloping tunnel-like passage within the dam wall with drains in the floor for seepage water. This passage permits entrance for inspection and movement of the equipments.

**Penstock:** These are passages for water from the reservoir to the downstream side to the Power house for moving the turbine and generating electricity.

**(ii) Buttress Dams**: These are modified gravity dams which require less amount of concrete than the gravity dams. Buttress dam is composed of a slanting impervious deck (Fig. 6.2) sloping upstream and vertical walls called buttresses and are made up of reinforced concrete. The concrete requirement for these dams is less than 60% of the solid gravity dams. The buttress dams are usually constructed on a good foundation rock. Because these are susceptible to wear and tear, these are preferred in areas where construction materials are scarce and expensive.

**Examples of Buttress Dam:** Roseland dam, France (131m) Fusino dam, Italy (78m)

**(iii) Arch dams:** These are concrete structures, curved in plan, convex up stream (Fig. 6.3). In case of these dams, the reservoir water pressure is transmitted to the abutments by arch action. Hence very strong abutment rocks are required for the construction of arch dams. Arch dams are best suited for narrow deep valleys or „V" shaped valley or gorges. Weak foundation rocks can afford the construction of an arch dam.



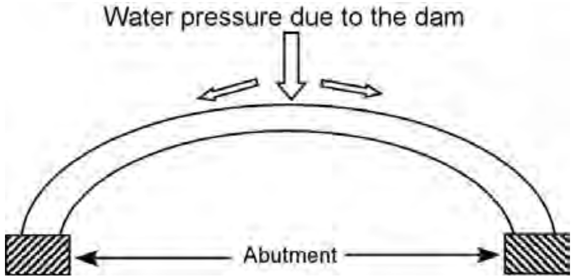




**Fig. 6.2. Side view of a buttress dam**

**Fig. 6.3. Plan view of an arch dam**

The arch dams are of different types as described below:

**(i) Single arch dam:** It consists of a single curved structure across the entire valley with the ends firmly attached to the abutments.

**Example:** Mauvosin Dam, Switzerland (260 m), Idduki Dam, Kerala, India (171m)

**(ii) Multiple arch dam:** It consists of a number of small arches and is suitable for fairly wide valleys.

**Example:** Bartlett dam, Arizona, USA (95 m), Karadj dam, Iran (120 m)

**(iii) Arch-gravity dam:** In this case the gravity dam is arched (convex) towards the upstream side. In this type of dam both the abutment and foundation should be strong enough to withstand the pressure of water and load of the dam.

Example: Boulder dam, Arizona, USA (243 m), Cadore dam, Italy (107 m)

## 6.3. SUITABLE CONDITIONS FOR CONSTRUCTION

A dam is always accompanied by a reservoir in its upstream side. Hence the suitability or otherwise of a particular site has to be taken into account for both the reservoir and the dam.

### 6.3.1 Suitability of reservoir site

The following geological considerations should be taken into account to decide the suitability of a particular site for construction of reservoir.

**(i) Large catchment area:** The area of catchment should be sufficiently large for inflow of huge amount of water for storage in the reservoir. Since the water collected in the rainy season is utilized throughout the year for power generation and irrigation, the reservoir must have a large volume of water.

**(ii) Closed basin:** The reservoir must be a closed one from all sides except the areas of inflow. As far as practicable it should have natural barriers so that cost of construction is minimized. If the natural barriers are not existent or connected, artificial short dams are constructed to make the site a closed one.

**(iii) Water tight nature of the reservoir:** Unless the barriers preventing the flow of water are water tight, there may be loss of water at the periphery or through the porous and permeable bed rocks.

The nature of the rocks such as the mineralogical composition, nature of sorting, texture, compactness of the constituent grains, nature of reaction with water, weathering etc. determine the water tightness of the basin. The rocks should be massive, compact and the constituent minerals should not be susceptible to chemical action specifically with water. Hence the rock types should be evaluated properly before recommending the site for reservoir.

Presence of structural features in the rocks like folds, faults, joints, schistosity, vesicular cavities, lava tunnels, caverns etc. make the massive and compact rocks porous and permeable causing seepage of water through them. Orientation of the bedding planes, shear zones etc. with respect to dam axis is very important since loss of large volume of water takes place through them.

A geological map of the area should be prepared encompassing the lithological and structural disposition in detail. This can guide the engineers to decide the suitability / unsuitability of the site and possible remedial measures.

The position of the water table with respect to the reservoir is also important because, if the water table lies deeper, there is possibility of more seepage of water from the reservoir unless the rocks are nonporous and impermeable.

**(iv) Silt accumulation:** The life span of a reservoir and its capability to store water is reduced when silt is accumulated in the reservoir in huge quantity. Presence of silt in the upstream side of the dam also puts an additional pressure on the dam. The siltation in the reservoir is dependent on the nature of rock types in the catchment area such as their chemical and mineralogical composition, texture, structure, weathering characteristics, rate of decomposition, vegetation cover, force of water on them etc. In addition to the above, the amount of silt carried to the main river through the tributaries should be properly evaluated before the site is recommended for construction of the dam and reservoir.

**(v) Submergence of mineral matter, habitats agricultural land and other places of interest:** The area likely to be submerged under water should be mapped properly to evaluate the mineral deposits present. Since it becomes difficult to exploit mineral deposits submerged under water, their proper evaluation prior to the recommendation is necessary.

In addition to the above, the habitats, agricultural lands, places of archaeological interest etc. should be studied properly before the site is allowed to submerge under water of the reservoir.

### 6.3.2 Suitability of the dam site

The geological considerations to infer the suitability / unsuitability of the site for construction of the dam include the following:

(i) Study of physiography
(ii) Study of lithology
(iii) Study of structures and tectonics
(iv) Study of stratigraphy
(v) Study of action of pressure
(vi) Study of action of water
(vii) Study of depth of weathering and nature of filling
(viii) Study of seismicity
(ix) Study of availability of raw material
(x) Study of ground water conditions

**(i) Physiography:** The physiography of a river valley and its surrounding areas is studied with the help of toposheets, aerial photographs, satellite imageries aided by direct field surveys. The depth of the unconsolidated sediments lying above the bed rocks is to be studied properly since its thickness, that controls the dam construction considerably, varies to a considerable extent. Other physiography related features which need proper evaluation are:

(a) shape and size of the river valley
(b) its stage of development
(c) stability of valley slopes
(d) potential areas of erosion
(e) presence of buried river valleys

A suitable site for the dam is a narrow river valley with large reservoir area towards upstream side. A site along downstream part of two or more rivers or tributaries is more favourable. Valley sections cut through massive rocks instead of loose debris is an ideal site.

**(ii) Lithology:** A geological map of the proposed dam site and areas in its vicinity depicting the rock types should be prepared. The subsurface lithology should also be studied by drilling bore holes at selected points. The texture, mineralogical composition etc. are to be assessed in detail.

The rocks present at the abutments and foundations should be able to withstand the expected static and dynamic pressures. The rocks exposed at the dam site should be resistant to chemical action, erosion and other disintegrating actions of water.

Granitic and other plutonic igneous rocks are usually hard, strong, tough and has high modulus of elasticity when fresh. These are capable of withstanding the pressure at the dam site but presence of weathered zones, joints, cracks, fissures, shear zones etc make them weak. Volcanic rocks are characterised by vesicles, lava tunnels, columnar joints, cracks and fissures making them porous and permeable. The competence of sandstones at the dam site depends on type of cementing material i.e. siliceous and ferruginous cement making a rock stronger where as calcareous cement and argillaceous matrix making them weaker. Differential weathering of the sandstones with interbedded shale units make them unsuitable. The shales have low modulus of elasticity, differential settling property and are easily scoured out as a result of which it is not suitable for foundation and abutment of dams unless preventive measures are undertaken. Limestones are suitable when massive but occurrence of bedding, joints (close spaced), cavities etc. allow percolation of water making the openings larger in due course of time causing problems at the site. The metamorphic rocks like granulites and some gneisses are suitable rocks at the dam site but schists, slates etc. are weak rocks needing treatment.

**(iii) Structure:** Presence of structural features like folds, faults, shear zones, schistosity, joints etc. and their attitude affects the strength of the rocks and stability of the engineering structure to a considerable extent. A rock, highly competent with respect to texture, mineralogical composition, compactness etc., can become unsuitable when the above structures are present is them. The geological map with lithology plotted with structures can guide the engineers to plan for a safe and stable structure. Different considerations with respect to geological structures are described below.

**(a) Attitude of the beds:** Dams on horizontal beds (Fig. 6.4) are relatively safe because the foundation can take up the load pressure which is at right angle to the bedding planes is stronger in compression. However, if the foundation rocks are porous and permeable water from the reservoir may seep and flow downstream. If the dam site is composed of thin bedded sedimentary rock with shale as a component, care must be taken by thoroughly studying the individual beds since thrust of the water also plays the same role.

Vertical beds (Fig. 6.5) can take up the load of the dam rather safely and under certain favourable conditions, there may not be large scale seepage of water from the reservoir to the downstream side. The safety factor increases, if the heel of a dam rests on a thick, compact and impermeable bed.

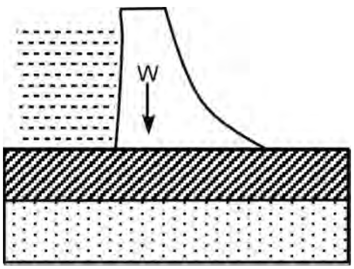



**Fig. 6.4: Dam on horizontal beds**

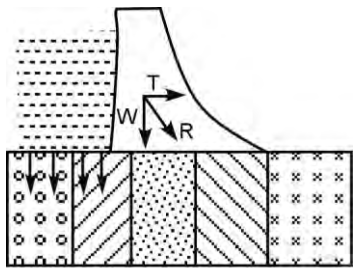



**Fig. 6.5: Dam on vertical beds**

The beds lying at the foundation can dip either towards upstream side or towards downstream side at variable angles. When beds dip towards downstream at low angles (<20°) (Fig. 6.6), water in the reservoir seeps through the bedding planes or through the permeable beds into the downstream. The horizontal thrust of water and differential erosion act against the safety of the structure in such a situation. This condition is an adverse condition. When the beds dip towards downstream at high angles (Fig. 6.7), the same adverse condition prevails but the beds behave as bearing piles and depending on the position of the resultant force, may act for the stability of the structure.

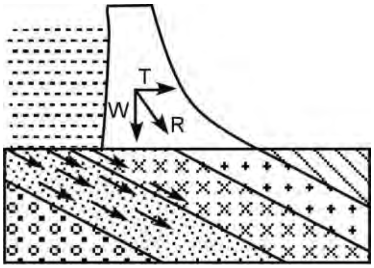



**Fig. 6.6: Dam resting on beds exhibiting gentle downstream slope**

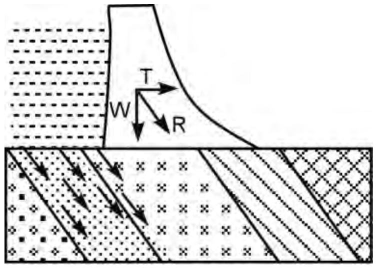



**Fig. 6.7: Dam resting on beds exhibiting steep downstream slope**

In case of beds with a gently upstream dip (Fig. 6.8), the safety of the dam is very good because the resultant force on the dam lies more or less perpendicular to the bedding plane and no seepage of water is possible to the down steam side.

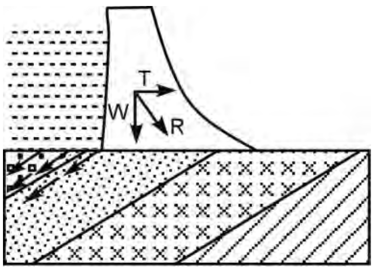



**Fig. 6.8: Dam resting on beds exhibiting gentle upstream slope**

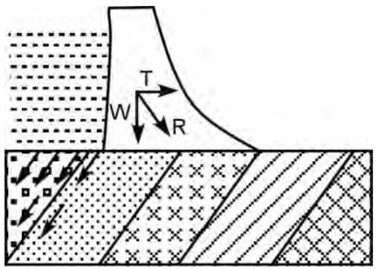



**Fig. 6.9: Dam resting on beds exhibiting steep upstream slope**

In this case presence of a geological structure becomes advantageous. However, in cases of beds with high upstream dip (Fig. 6.9), there is neither any uplift pressure nor there is leakage of water. But it is relatively less advantageous than the previous one since the bedding may not be exactly perpendicular to the resultant force on the dam.

**(b) Folds:** Dams can be constructed on rocks which may be regionally deformed with development of different types of folds and varying attitude of their limbs and axial planes. If the regional fold pattern consists of a series of synclines and anticlines, the safety and stability depends on the attitude of the limbs (Fig. 6.10). However, along the fold closure regions, the rocks are fractured with development of axial plane foliations and closely spaced fractures (No. b). These structures make the rocks weak and highly permeable and if a dam is constructed on them, pretreatment of the weak zone is a prerequisite.

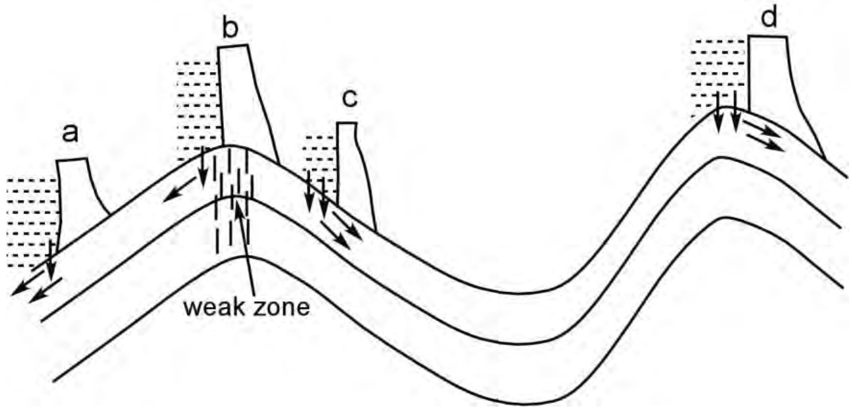



**Fig.6.10: Effects of folds on dams. At 'a' and 'b' occurrences of folds are advantageous as water cannot escape to downstream side. However, at 'b' because of weaker zone at closure of the fold, the condition may be adverse which has to be taken care of. At 'c' and 'd' occurrences of folds are disadvantageous as water escape to the downstream side.**

**(c) Faults:** The faults affecting the rocks near the dam site (Fig. 6.11) or in the river valley may be open fissures or filled up with secondary mineralization. The fault zone along or across the fault zone may be sheared, crushed or mylonitised with development of a weaker zone. If the fault present is active, there may be relative displacement of the faulted blocks on either side of the fault. Presence of faults in the foundation and abutment of the dam make them weak to withstand the load of the structure and thrust of water. Faults present in the downstream side without any active tectonic activity may not cause any problem but faults present in the upstream side with slope towards downstream side may act as the channel ways for escape of water.

The faults which are relatively of recent origin should be studied properly to know their age and relative movement of the faulted blocks. If the site has an active fault in the vicinity, the area should be avoided for the construction of the dam. The position of the fault and its extension can be known accurately by remote sensing studies followed by field checks and subsurface studies.

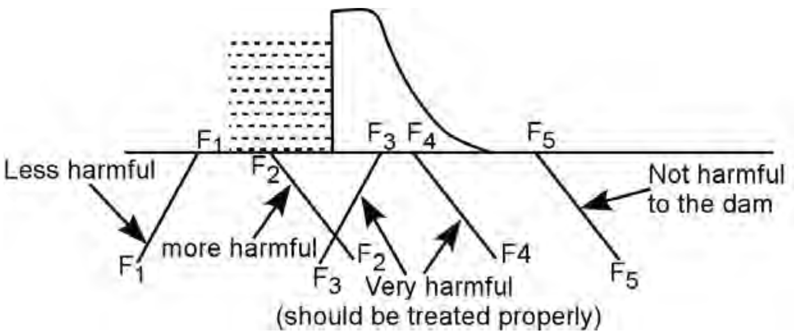



**Fig.6.11: Effects of faults on dam**

**(d) Joints:** Joints are present almost in all types of rocks and commonly in sets. Some joints are very closely spaced. Presence of joints in the rocks reduces the strength to a considerable extent. Some joints are present below the weathered rocks making the massive rocks porous and permeable. To make such rocks more competent, pretreatment of the foundation and abutment is necessary.

Schistosity, rock cleavage and other planar structures present in the rocks make the rocks weaker. These also act as channel ways for the movement of water. Hence, rocks affected by such structural disturbances should be treated at par with rocks affected by other structures.

**(iv) Stratigraphy:** The stratigraphic position of the lithounits present in an area should be ascertained properly. It is seen that rocks of contrasting ages behave differently with respect to their strength. Therefore, rocks of different ages should be treated differently to make them behave like a single monolithic unit. The stratigraphic succession of the lithounits and their correlation with regional units should be conducted at the foundation of dams.

**(v) Action of pressure on the dam and its foundation:** Different forces acting on the dam can be broadly classified into two types, horizontal and vertical. The horizontal pressure on the dam is due to the velocity of water and the sediment carried by it. The vertical pressure is due to a number of factors such as (a) weight of the dam, (b) weight of water column in the reservoir, (c) weight of the silt accumulated in the reservoir, (d) force of buoyancy due to partial submergence of the dam, (e) pore water pressure due to water in the pores and (vi) uplift pressure due to the difference in the heights of water level between upstream and downstream sides of the dam.

Horizontal and vertical forces acting on a dam can be combined into a resultant force (Fig. 6.12) which depends on the magnitude of both the forces. If the direction of the resultant force is perpendicular to the bedding as in case of beds dipping upstream at low angles, the site is very safe. However if the direction of the resultant force is along the same direction of the bedding, there is possibility of sliding and seepage of water.

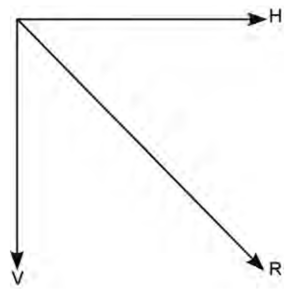



**Fig.6.12: Forces acting on a dam**
**(V = Vertical force, H = Horizontal force and R = Resultant force)**

Therefore, different forces acting on the dam and the foundation rocks should be assessed properly.

**Action of water:** The foundation of the dam, part of the dam itself and part of the abutment is submerged under water continuously for years together. Hence study of action of water on the rocks is of paramount importance at the dam site. The water has three fold action on the foundation rocks as given below:

**(a) Corrosive action of water:** Since water is a universal solvent it sets in chemical action with the foundation rocks. Some parts of the rocks are either dissolved in water or a part of the rocks reacts with water forming weathered products. In both the cases the foundation becomes weak.

**(b) Lubrication of the dry rock:** Due to lubrication of the rocks, there is decrease in dry-coefficient of friction. When a clayey rock like shale is present in between the formations, lubrication may lead to failure. When rocks get wet, plasticity changes causing problems in the safety of the dams.

**(c) Erosional and depositional action of the streams:** The erosional action by the stream may lead to scouring of the river bed when water is allowed to pass through the dam openings. Streams that feed the reservoir may bring a lot of alluvium / silt into the reservoir area causing additional pressure.

**(vi) Study of depth of weathering and nature of filling:** Due to weathering almost all the rock types are adversely affected with decrease in their strength, durability, compactness, toughness etc. The weathered product is either a very fine-grained product of chemical weathering or a coarse-grained product of mechanical weathering. Weathering of rocks at foundation and abutment is a very common phenomenon. Continued periods of weathering leads to accumulation of a thick mantle over the sound bed rock. Moreover river valleys are the places of accumulation of loose unconsolidated materials which are sometimes loosely stratified and composed of clay, silt, sand, gravel, boulders etc. Since the foundation and abutments of the dam should have a sound bed rock, it is necessary to ascertain the depth of weathering as well as nature of the fillings of the valley floors.

**(vii) Study of seismicity:** When an area is affected by the intensity of earthquakes of more than five in the Richter scale, the stability of the dam is affected. Therefore the seismicity of the area of the proposed dam site should be studied from the past records, earthquake zonation belts or from the data of seismographic stations. Many earthquakes are due to very high and impounding load of the water column in the reservoir and load of the superstructure. Hence, behaviour of the rocks due to expected vertical pressure and horizontal thrust should be experimentally ascertained to see that the earthquake is not reservoir-induced. In India, Koyna dam is considered as one that might have induced earthquake in that region where no earthquake is likely to come.

The effect of the earthquake is more on the earth dams rather than gravity concrete dams. Hence, in earthquake prone areas, earth dams should be avoided.

**(viii)Availability of raw materials:** The geological studies of the area around the dam site can help in finding out sufficient building materials of suitable characters i.e. size, hardness, toughness, weathering characteristics etc. The availability of the materials or the lack of it can control the type of dam to be constructed. If the construction materials like rock aggregates, sand, cement etc. are available in plenty, a gravity concrete dam is recommended. The choice of a buttress or arch dam can be made if the construction materials are scantily available in the vicinity and some other conditions like „V‟-shaped narrow valley with good abutment conditions and good foundation conditions respectively. In case of non-availability of the stone fragments for concrete aggregates, an earth dam can be suggested.

**(ix) Groundwater conditions:** If the water table lies above the water level in the reservoir, there may not be any serious problem due to leakage but if the water table lies below, then large amount of water from the reservoir may percolate into the groundwater zone.

## 6.4. GEOLOGICAL REPORT OF SOME INDIAN DAMS

The reports of the geological studies conducted at two most important sites of India are described below:

### 6.4.1. Hirakud dam, Sambalpur district, Odisha

It is constructed across Mahanadi River and situated at a distance of 14 km from Sambalpur. It is a 4.8 km long composite dam i.e. earth - cum - concrete dam with two concrete sections (1.2 km total length) constructed at the spill way and at the power house area. The height of the dam is 58.5 m from the base of the excavation.

The rock types at the dam site can be classified into 4 groups.

(a) Low grade metamorphic rocks such as quartzite, phyllite belonging to Chhatishgarh Group.
(b) Granites, granite gneisses, amphibolites etc.

(c) Silicified gneisses and schists

(d) Alluvium of recent age

The strike of the bedding is roughly NW - SE with high dips. The rocks are affected by shear zones making them weak and permeable. The weaker zones at the foundation necessitated grouting.

The depth of weathering varies from almost zero to 13-14 m. The thickness of the loose unconsolidated deposits varies from zero to 6 m. The right dyke of the reservoir is provided by Chandildungri hills and artificially constructed portions. The right side of the reservoir is provided by a number small hills interconnected with small dams at the gaps. Construction material was available in plenty in the nearby areas in form of coarse and fine aggregates both for the earth dam and concrete dam. A large reservoir was created behind the dam.

### 6.4.2. Bhakra-Nangal project, Punjab

This project has been constructed on the river Satlej downstream of Bhakra village. This project consists of 518 m long and 226 m high concrete straight gravity dam. The reservoir area is about 166 sq. km known as Gobind Sagar.

The Bhakra dam is located on thick sandstone beds with silt intercalations belonging to Siwalik Group. Claystone beds with approximate thickness of 30 m and 76 m occur in the upstream and downstream sides of the dam respectively. A claystone bed occurs in the central part of the dam which is faulted.

The rocks strike NW-SE slightly oblique to the dam axis with high dip (70°) downstream. The rocks are affected by joints, shear zones and fault making them weak. The shear zones range in thickness from 15 cm to 150 cm with dip varying from 15° to 55° in a downstream direction and occur in the abutments.

The lithology and structures were the greatest hurdles in the construction of the dam. The upstream claystone and other claystones become incompetent when submerged under water. The bedding planes, shear zones, fault zones were likely to lead differential settlement rendering the foundation unstable. In order to prevent siltation and expected squeezing, the clay stones were excavated and back-filled by concrete up to a depth of 58 m below the river bed. A 15 m concrete slab was provided connecting the heel of the dam with the sandstone to withstand part of the load. The shear zones, fault zones were also excavated and back filled with concrete. To increase the modulus of elasticity and make them monolithic, the entire foundation was grouted with cement up to a depth of 15 m.

Since the dam is being constructed in the seismically active zone, seismographs have been installed at the dam to study the microtremors and any other major seismic disturbances. Besides, stress-meters, strain-meters and joint-meters are also installed at variation positions of the foundation and dam to study any possible defect.

The geological studies could make it possible the construction of a dam even in the most difficult and toughest terrain.

## 6.5. GEOLOGICAL CONSIDERATION OF BRIDGE

### 6.5.1. Definition

It is defined as a structure connecting two sides of a river valley and depression providing communication across it.

Bridges are most important part of the roads and railways and constructed to connect localities which are separated by natural depressions like valleys, gorges and river channels etc. In many projects for bridge sites, there is no choice for alternative sites and hence the engineer has to design the structure based on sound geological knowledge on the site.

### 6.5.2. Parts of a bridge

A bridge (Fig. 6.13) is divided into two broad parts i.e. super structure and substructure.

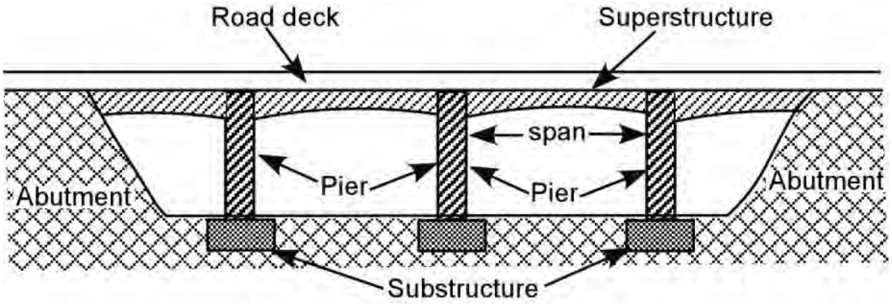



**Fig. 6.13: Bridge**

**Super structure:** It consists of that part of the bridge which rests on the piers and abutments and on which traffic moves.

**Substructure:** It consists of abutments, piers, foundation etc. It connects the superstructure to the ground surface.

A brief description of the different parts of a bridge is given below:

**Abutment:** These are structures which link the superstructure to the ground at both sides of its ends.

**Road deck or bridge deck:** These are masonry or concrete surface carrying the load of the traffic and distributing it to the main beams.

**Pier:** These are masonry or RCC column with rectangular, oval, circular or elliptical cross section erected from the foundation or abutment and support the superstructure.

### 6.5.3. Types of bridges

Depending on the design of construction and materials used, bridges can be classified into the following types.

**(i) Single span bridge:** When the bridge is supported by abutments at its two sides and there are no piers in between, it is known as single span bridge. The superstructure is supported by the abutments only. Narrow and deep river valleys having strong abutment rocks can afford for such a bridge.

**(ii) Multispan bridge**: In this type of bridge, there are several piers and hence several spans in between consecutive piers. These bridges are built in the river valleys which are very wide.

**(iii) Suspension bridge:** This bridge is suspended with the help of cables over two strong terminal support having steel towers at two ends. These bridges are suitable in case of narrow and deep river valley (Bridge joining Howrah railway station and Kolkata). In the suspension bridge the ends of the cables are firmly fixed in the hard rock or massive concrete wall on either side of the valley.

**(iv) Arch bridge:** It consists of an arched structure resting on two abutments at its two sides. Because of the arching, the load is transformed to the abutments.

**(v) Rigid frame bridge:** In this type of bridge all the parts are built with a rigid frame so that the whole unit acts as a monolith. The arch and rigid frame bridges are constructed on narrow river valleys.

The above bridge types are stationary in nature. In addition to this, some bridges are movable bridges in the sense that, the spans are movable and made up of steel sections. These types of bridges are suitable for water ways that accommodate shipping.

The piers of a bridge are very important structures since they are subjected to various forces. The forces which act on the piers are:

(i) Vertical load due to weight of the bridge and the traffic which moves on it.
(ii) Horizontal thrust due to running water, moving ice, loose material carried by water, wind forces etc.
(iii) Inclined load due to arching in the superstructure and inclined tension in case of arch bridge and suspension bridge respectively.
(iv) Seismic and tectonic force.
(v) Scouring action of rivers.

These loads are transmitted to the foundation and abutment through the piers. Hence stability of any bridge depends on the geological characteristics of the foundation and abutment materials.

### 6.5.4. Problems at the bridge site

The important problems at the bridge site leading to failure of the structure are given below.

(i) Erosion of the piers and walls if water flows in the river valley with high velocity.

(ii) Deep scouring - when velocity of the water is high and softer rocks form the basement.

(iii) Wash out due to flood current - caused by torrential rain or flash floods.

(iv) Wash out of the abutments.

(v) Differential settlement of the piers - This happens when rocks of differing geological ages and characters are present below the piers.

(vi) Earthquake effects - This causes tilting of the piers leading to collapse of the superstructure.

(vii) Tectonic effects - Presence of active faults even in the sound bed rock profile causes collapse of the structure.

These problems are more or less related to geological parameters and hence have to be attended to before the site is recommended for construction of the bridge.

### 6.5.5. Geological considerations at the bridge site

The geological considerations at the bridge site include the following:

(i) Sound rock profile underneath the floor and wall of the natural depression.

(ii) Lithology of the foundation and abutment and their strength.

(iii) Geological structures present.

(iv) Study of the erosive action of the running water if the bridge is constructed across a river channel. This includes.

(a) Nature of the river i.e. degrading or aggrading.

(b) Positions of elevations and depressions.

(c) Nature of the river course and possibility of its change.

(v) Landslides in the area

(vi) Seismicity of the area

Detailed description of each of the above parameters is given below:

**(i) Sound rock profile:** The valleys across which bridges are constructed are usually occupied by loose, unconsolidated and weathered rock debris, soil or alluvium. The walls of the valleys are also weathered to certain extent. The piers and abutments of bridges should not rest on such materials. To know the depth of the bed rock, it is essential to find out the thickness of the overburden along the floor and at the walls of the valley. The information of the rock profile can be obtained by drilling the subsurface formations particularly along the central line of the proposed bridge.

The ancient glacial valleys, river channels etc. may be concealed underneath the depressions and may create problems unless their depths are not properly ascertained. Presence of huge stray boulders in the unconsolidated rocks may be misleading because loose materials may also be present below such boulders. It is essential to ascertain the continuity / discontinuity of such boulders with the bed rock.

The thickness of the overburden decides the amount of overburden to be removed and, thus, decides the effective height of the piers. In some cases, the thickness of the loose unconsolidated materials may be very large and it becomes uneconomical to reach the bed rock. In such case pile-foundation is used which consists of piles driven through the loose materials to the bed rock.

**(ii) Lithology of the foundation and abutment:** Stability of a bridge depends on the nature of rock types on which the piers and abutments are constructed. The rocks should have sufficient strength to withstand the load and these should be sufficiently durable to resist the effects of wear and tear and chemical action of the running water.

The massive crystalline rocks of igneous and metamorphic origin are suitable foundation and abutment rocks unless affected by fissures, joints, shear zones, fault planes, vesicles etc. Compact and thick beds of sandstone, conglomerate, breccia, bedded sedimentary rocks, sandstones with shale intercalations are unsuitable. Sedimentary rocks with calcareous cement, carbonate rocks like limestone, marble etc. are originally stable but chemical action with water make them cavernous and weak.

**(iii) Geological structures:** The geological structures present in the foundation and abutment rocks are most important consideration for the selection of a bridge site.

(a) Presence of minor structures such as cracks, fissures, joints (widely spaced) etc. do not affect the stability of a bridge because they can support the load. Presence of closely spaced joint planes, shear zones etc. are likely to affect the strength of the rocks and so have to be grouted or plugged with concrete.

(b) River valleys may be the place of ancient fault zones but since there is no likely movement of formations on either side it cannot be taken as an adverse situation. Presence of active and young faults at any bridge site should be regarded as an adverse condition and such sites should be avoided as far as practicable.

(c) Faults also separate rocks of different strengths on either side of it. In such cases, differential settlements may crop in resulting in failure of the structure. In such cases, the relatively weaker zones may be grouted to bring the strength same as that of the stronger ones.

(d) Bedded, foliated and jointed rocks particularly those dipping into the river at lesser angle than the natural slope at one side of the valley are dangerous because they tend to slide and cave in. The movement of the traffic and sudden increase of load may lead to failure of the rocks.

(e) If a bridge is aligned across the strike of the country rocks, different rock types differing in their strengths are exposed along the foundation. In such cases a detailed study of the foundation under each pier should be made.

**(iv) Study of erosive action of running water:** The erosive action of the running water is responsible for scouring. This is also influenced by roughness of the river bed, uniformity of the channel, nature of rocks in the river bed and the amount of suspended matter in the flowing water. The nature of the river at the bridge site i.e. whether degrading or aggrading should be found out and in case of degrading river, a grout curtain should be provided at the valley floor. In some cases, the river changes its course and affects the areas adjacent to the bridge site. The lithology and structures present govern the change of the river course. Bridges which are constructed across rivers with heavy flow from torrential rains are affected by erosive action of running water. The degrading or aggrading nature of the river can be known from the stage of the river i.e. youthful, mature, old etc. The youthful rivers which scour and excavate valley floors rapidly also wear and tear the abutments and piers. The piers of the bridge block a part of the river channel as a result of which the running water moves in a relatively higher velocity in the space between piers. In case of mature and old rivers, the geological work is more of aggradation than degradation and hence is not problematic. Some river valleys are subjected to periodic floods which submerge the superstructure and the roads connecting it. In such cases the anticipated flow must be calculated and steps should be taken to see that the bridge and the roads are not submerged.

**(v) Landslides of the area:** When the bridge is constructed across the valley with steep slopes, the site particularly the superstructure and the roads immediately lying in the proximity may get affected by landslides. Bedded and jointed rocks dipping into the river valley become unstable when heavy traffic moves on the bridge. Such unstable slopes are also easily affected by landslides. To avoid the land slides, the slopes should be suitably maintained and sometimes other preventive measures have to be undertaken.

**(vi) Seismicity of the area:** The earthquake produces certain movement of the ground which depends on intensity of the shock and nature of the ground. The effect of the earthquake becomes more when the piers are placed on the softer foundation and abutments are in the vicinity of active faults. The effect of the earthquake is the tilting of the piers, landslides along the valley slopes and ultimate collapse of the structure. Hence the seismicity of the area should be properly assessed and the bridge should be designed accordingly.

To ensure a suitable bridge site with safety, stability and economic considerations, it is necessary to have a through geological investigation along the bridge alignment both in the abutment and foundation. This can be accomplished by reconnaissance survey, remote sensing studies, geological mapping, subsurface geological studies, seismicity studies etc.

## 6.6. GEOLOGICAL CONSIDERATIONS OF TUNNEL

A tunnel is a horizontal to near horizontal subsurface excavation opened to the ground surface at both of its ends. In contrast to tunnel, drift is a horizontal to near horizontal excavation opened at one end; shaft is a vertical or subvertical excavation opened to the surface at top only.

**6.6.1. Uses of tunnels:** Tunnels are constructed underneath the surface of the earth with one or more than one specific purposes, which are given below.

(i) **For laying roads and railways:** To provide short and convenient route across the natural obstacles such as a hill or mountain, tunnels are constructed for roads and railway lines.

(ii) **For underground passages:** In thickly populated cities, tunnels are constructed to provide additional routes for quick and safe transport.

(iii) **For underground mining**: For recovery of economic mineral deposits, tunnels are constructed for approaching them.

(iv) Tunnels are constructed for water supply and sewage disposal.

(v) For production of electricity, water of a reservoir is diverted for obtaining a suitable height (head) through tunnels. Water of a river is also diverted through diversion tunnels if some engineering construction is made across the river.

**6.6.2. Parts of a tunnel:** The different parts of a tunnel (Fig.6.14) are described below.

(a) **Crown or roof:** The arched top of a tunnel

(b) **Wall:** Two vertical sides of a tunnel

(c) **Spring line:** The line along which the crown meets the walls

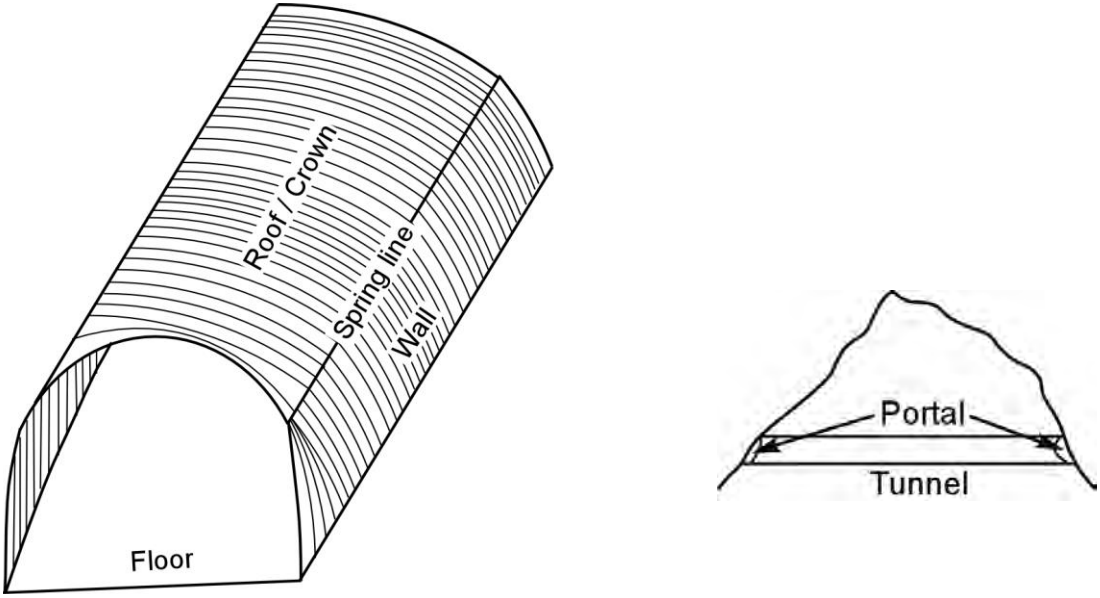



**Fig.6.14: Tunnel**

(d) **Floor:** Bottom of the tunnel on which railways and roads are laid

(e) **Portal:** The surface entrance of the tunnel

(f) **Perimeter or pay line:** The tunnel bore boundary

(g) **Overbreak:** Shattering of rock beyond perimeter / pay line due to blasting

### 6.6.3. Geological considerations for successful tunneling

The safety, success and economy of tunneling depend on various geological conditions at the tunnel site. Hence before a site is selected for tunnel route, it is necessary to study the geological conditions. These conditions are:

(i) Lithology

(ii) Geological structures

(iii) Groundwater condition

(iv) Snow line

(v) Seismicity of the area

(vi) Possibility of landslides

(vii) Geomorphology of the area

(viii) Weathering of the rocks

**(i) Lithology:** Since tunnels pass through rocks of various types along its path, the hardness and toughness of the rocks are of paramount importance. The competent rocks which are hard, strong and massive are relatively safer for tunneling but the rate of tunneling will be low with more cost. The incompetent rocks, on the other hand, are loose or soft are easily tunneled with less cost but are unstable and require lining. The porosity and permeability should not be very high to allow leakage of water into the tunnel either from ground water or surface water sources. The rocks should not react with the water with its dissolving action and also should not react with the gases from automobiles.

The general characteristics of different rocks for tunnel alignment are described as follows:

**(a) Igneous rocks:** The plutonic and hypabyssal rocks like granite, syenite, diorite, gabbro, dolerite etc are massive, hard, tough, durable and impervious and can be excavated with difficulty. The cost of tunneling may be high, but they do not need protective lining. Volcanic rocks, on the other hand are also competent in spite of having vesicles and amygdules and are suitable for tunneling. However, presence of ground water within the interconnected vesicles makes them somewhat less suitable.

**(b) Sedimentary rocks:** Tunneling through thick bedded, well cemented siliceous and ferruginous sandstones are relatively safe and better suited for tunneling. These rocks can be easily cut and may not require lining. Poorly cemented, thin bedded and argillaceous sandstones are relatively weak and so are undesirable. Shales and siltstones can be easily excavated but there may be overbreaks and shattering at the time of tunneling. Moreover, they require linings to make them stable. Among carbonate rocks, dolomitic limestones are harder and more durable than limestones. Presence of impurities makes the limestone and other carbonate rocks weak. Since the carbonate rocks are highly prone to chemical weathering, solution cavities may develop in them which go on increasing in their volume. Hence these rocks are generally unsuitable for the purpose.

Unconsolidated sediments like gravel, loose soil and alluvium can be excavated easily but tunnels constructed through these rocks need strong lining for their safety and stability.

**(c) Metamorphic rocks:** Among the metamorphic rocks, granulites and compact gneisses can be excavated with great difficulty and are more competent while rocks like schists, phyllites and slates are relatively soft and are not ideal rocks for tunnel construction since these are susceptible to higher degree of chemical action even with water.

**(ii) Geological structures:** Presence of structures along a tunnel site determines both tunneling conditions and also the stability of the tunnel. Presence of geological structures in the rocks may create ground water problems. The common geological structures which affect the suitability of a tunnel site are folds, faults, joints, shear zones, vesicles etc. Besides dip of the beds and orientation of the bedding planes are also important aspects to be studied.

**(a) Dip of the beds:** If the dips of the beds are zero i.e. when the beds are horizontal, the roof, wall and floor of the tunnel meet same rock types throughout its length and the pressure on both the walls is same. In case of inclined beds, pressure on one wall is higher than the other wall. Ground water percolation is more on the wall than the other requiring grouting to seal off water percolation.

**(b) Orientation of the bedding plane:** As discussed earlier, when a tunnel is driven through a series of horizontal beds, same rocks are met throughout its alignment. If the rocks are strong enough, no lining may be necessary. On the contrary, if it meets weak and incompetent rocks, unsafe condition prevail throughout its length requiring precautionary measures and so involves huge cost. If a tunnel is to be driven across the strike of the horizontal beds, the tunnel has to pass through rocks of different composition as a result of which the tunneling conditions vary from place to place along the entire length of the tunnel. The pressure on both the tunnel walls is uniform.

Tunnels driven along the dip direction of the inclined beds, same rocks are met throughout its length and its stability is determined by the strength of the rocks forming the roof of the tunnel. The most adverse situation is seen in case of tunnels driven through inclined strata because one wall receives more pressure than the other leading to inequilibrium on the walls. In these cases, either the sites should be rejected or should be dug out and backfilled with concrete.

**(c) Fold:** In an inclined fold, pressure acts away from the crest and tension joints may be developed along the anticlines. Similarly in case of syncline fold, pressure acts towards the trough. In case of tunnels driven along the anticlinal or synclinal fold axis, the pressure on the walls will be uniform. However, ground water percolation will be minimum in case of anticlinal fold but maximum in case of synclinal fold.

If the tunnel is driven across the anticline or syncline, it meets different rock types along its length with nonuniform pressure on the roof throughout its alignment. There will also be profuse leakage of water if the rocks are porous and permeable. Usually tunnels driven across the anticlinal and synclinal fold axis are adverse. Moreover, the crest and trough regions of the folds are highly fractured and so should be avoided as far as practicable.

**(d) Fault:** Tunnels in the sites of the active faults should always be avoided. If the tunnel cut across the fault zones or shear zones, sufficient preventive measures has to be taken by way of grouting the weak zones. However, tunnels constructed away from the inactive faults in the footwall or hanging wall sides may not be taken as adverse action.

**(e) Joints and cracks:** Joints and irregular fractures or cracks are invariably present in the rocks and affect their strength. Presence of closely-spaced joints are harmful for the stability of a tunnel, although it can be excavated easily. There is danger of percolation of both surface water and ground water into the tunnel and there is possibility of falling down of jointed blocks from the roof and walls if the weak zones are not sealed off.

**(f) Foliation and schistosity planes:** These planes are usually present in the metamorphic rocks and make these rocks weak and incompetent. Tunnels driven through foliated and schistose rocks may face problems of surface and ground water percolation into the tunnels. Tunnel construction may be easily accomplished but they need to be provided with protective lining.

**(iii) Ground water condition:** Percolation of subsurface water or groundwater through the pore spaces like joints, fault planes, shear zones, fractures, foliation planes, solution cavities etc is problematic in case of tunnel site. If the water table is situated above the tunnel alignment with porous and permeable rocks lying at the site, there will be huge percolation of water. The porous and permeable zones along the tunnel route should either be sealed off to prevent percolation of ground water or drains should be provided for flow of water out of the tunnel.

Impervious rocks like granite, syenite, diorite, gabbro, granulites, quartzites, shales etc do not allow seepage of ground water if they are devoid of structural features. Sandstones, well cemented conglomerates are semiporous allowing limited percolation of ground water. Unconsolidated rocks like sand, gravel, boulder, cavernous limestone etc are the most problematic rocks with respect to ground water. The porous and permeable rocks should either be grouted or be backfilled with concrete after removing them from the walls and roof of the tunnel.

**(iv) Snow line:** In the high altitude regions affected by snow fall, the tunnel portals should not be closed by snow fall causing dislocation of the railway and road traffic. Prior survey should be conducted to demarcate the snow line and tunnel route should preferably be suggested below the snow line.

**(v) Seismicity of the area:** An area affected by seismicity of higher degree should not have a tunnel because at the time of earthquake, the tunnel route may be affected by rock fall or dislocation of route causing damage to human life and property. If the alignment along a high seismic zone becomes indispensable, the intensity and magnitude of the earthquake from the previous history should be evaluated and sufficient precautionary measures must be undertaken

**(vi) Possibility of landslides:** Landslides are function of lithology, slope and rainfall. Landslides along an unstable slope may affect the tunnel route specifically at its portals. Transport of men and material may get seriously affected by landslides. Hence, study of landslides from the previous history and management of slopes become necessary in such sites.

**(vii) Geomorphology of the area:** Geomorphologic features such as presence of streams, spring, altitude and extent of overburden are important in case of tunnel route alignment. Proper evaluation of the geomorphological features and physiography should be undertaken in the area of study.

**(viii) Weathering characteristics**: The weathering condition of the rocks at the tunnel site should be properly studied. Some rocks are more susceptible to weathering than the other rocks. Carbonate rocks like limestone, dolomite etc are highly prone to weathering with development of solution cavities. The degree of weathering may be increased in due course of time making the rocks weak and incompetent. Hence weathering characteristics of the rocks at a tunnel site should be properly evaluated.

In addition to the geological investigations, some engineering investigations have to be carried out. These are:

(a) Determination of strength of rocks to withstand overlying load.
(b) Rock loads that will be met after excavation.
(c) Stand up time of the rocks.
(d) Excavation: The method of excavation includes the following steps:
(e) Drilling: making small diameter holes
(f) Blasting: filling up drill holes with explosives and then igniting
(g) Degassing: Removal of the gases from the area of blasting
(h) Demucking: Removal of the loose materials after blasting
(i) Supporting: Temporary or permanent support to make the walls and roof durable.

### 6.6.4. Problems encountered during tunneling

The problems faced during tunnel construction are:

(i) Over break, (ii) Caving (iii) Flowing ground (iv) Squeezing ground

**(i) Over break:** It is the shattering of the rock beyond the proposed perimeter or pay line. It is the function of the type and physical conditions of the rocks. It is also governed by effects of blasting and joint pattern. This can be reduced by adopting drilling pattern, smooth blasting, use of rock bolts etc.

**(ii) Caving:** Excessive moisture content in the soft and unconsolidated sediments may make the sediments move out its place inside the tunnel

**(iii) Flowing ground:** Presence of entrapped water under high hydrostatic pressure may move into the tunnel when the pressure is released. This gives a dynamic component to the problem which can be solved by providing good drainage from excavation, refrigeration of the impounded water and providing an umbrella of suitable materials (forepoling) over the walls and roof of the tunnel hole.

**(iv) Squeezing ground:** It consists of materials that contain a large amount of clay. Such material flows into the tunnel plastically. The problem can be sorted out either by dewatering the mass or providing a grout curtain.

### 6.6.5: Tunnels of India

(i) Tunnel constructed in Beas – Satluz project: This is in Mandi district of Himachal Pradesh consisting of two tunnels of 1 Km length and utilized for diverting water for hydroelectricity generation.

(ii) Between Hazaribag and Gaya a number of tunnels are constructed across the hills of Chotnagpur plateau for movement of railways.

(iii) Between Jammu and Kashmir, a tunnel is constructed (Jawahar tunnel) through Pir Panjal mountain range at a height of 2175 m for a length of 2440 m.

## 6.7. ENGINEERING PROPERTIES OF ROCKS

To a geologist, rocks are aggregates of minerals but to an engineer the rock signifies firm and coherent or consolidated substances that can not normally be excavated by manual methods. Since the rocks are used for or involved in construction of all engineering structures such as dams, tunnels, bridges, pavements, walls, airport runways, sea walls etc, it is important to know the physical and chemical characteristics of these rocks. The physico-chemical properties are dependent on their texture, structure, mineralogy, mode of origin and weathering characteristics. The enginrreing properties of the rocks can be classified under the following heads.

(i) Properties depending on the nature of constituent grains

(a)Specific gravity (b) Density

(ii) Properties related to void ratio

(a) Porosity (b)Void ratio (c)Moisture content (d)Degree of saturation (e)Permeability

(iii) Properties related to the nature of bonding

(a) Swelling characteristics (swelling coefficient)

(iv) Properties related to resistant to external forces

(a)Elasticity (b)Plasticity (c)Elasto-plastic nature (d)Strength of rock (e)Hardness (f) Toughness (g) Heat resistance

### (i) Properties depending on the nature of constituent grains

**(a) Specific gravity:** It is defined as the ratio of the weight of a specific volume of the rock to the weight of the same volume of water

$$\text{Thus, Specific gravity } (G) = \frac{\text{Weight of a specific volume of the rock}}{\text{Weight of the same volume of water}}$$

The specific gravity of the rocks are of two types: True specific gravity and Apparent specific gravity

**True specific gravity:** It is the specific gravity of the solids present in the rock

Thus, true specific gravity $(G_s) = \dfrac{\text{Weight of the solids in rock}}{\text{Weight of water of equal volume to that of solid}}$

$\Rightarrow (G_s) = \dfrac{W_s}{V_s \times \gamma_w}$ where: $W_s$ = Weight of solids, $V_s$= Volume of solids and $\gamma_w$= Unit weight of water

**Apparent specific gravity:** Depending on the degree of saturation of the voids, it is of two types. When the voids are completely filled up with water, the specific gravity is known as apparent specific gravity (Gb′) and when the voids are dry, it is called apparent dry specific gravity (Gb)

Thus $(Gb') = \dfrac{W_s + V_v\gamma_w}{V \times \gamma_w} = \dfrac{\text{Weight of the saturated rock}}{\text{Weight of equal volume of water}}$; $Gb = \dfrac{W_s}{V \times \gamma_w}$

Where: $W_s$ = Weight of solid, $V_v$ = Volume of water in void, $\gamma_s$= Unit weight of water and V = Total volume of rock

**(b) Density:** It is the mass per unit volume of a substance. A part of the rock may have solids and a part may have voids which may be partially or completely filled with water. Accordingly the density may be dry density or saturated density.

Dry density $(\gamma_{dry}) = \dfrac{\text{Weight of oven dried rock}}{\text{Unit volume of dry rock}}$

Saturated density $(\gamma_{Sat}) = \dfrac{\text{Weight of weight rock}}{\text{Unit volume of rock}}$

Bulk density refers to the weight per unit volume of a rock with natural moisture content wherein the pore spaces are partly filled with water. From the civil engineering considerations "Bulk density" is usually considered since the strength and thermal conductivity are influenced by it. The bulk density of some common rocks is given below.

| Rock type | Bulk density | Rock type | Bulk density |
|---|---|---|---|
| Granite | 2500 - 2700 | Basalt | 2900 |
| Dense limestone | 1800 - 2400 | sand | 1450 - 1650 |
| Sandstone | 2600 | | |

**(ii) Properties related to void ratio:**

**(a) Porosity:** It is the ratio of the volume of the voids to the total volume of the rocks and expressed in percentage.

Hence porosity = $\frac{V_v}{V} \times 100$, $V_v$=volume of voids and V = Total volume of rock

If the rock has interlocking texture, angular grains of different sizes, good cementation and good compaction, then the porosity will be less. On the other hand, rounded shape, well sorting, poor cementation and less compaction will increase the porosity values. Secondary factors like chemical action, leaching of soluble constituents, development of joints, faults etc increase the porosity of rocks.

**(b) Void ratio:** It is defined as the ratio of volume of voids to the volume of solids

Thus void ratio = $\frac{V_v}{V_s} = \frac{V_v}{V-V_v}$, where $V_v$=volume of voids, $V_s$ = volume of solids and V = Total volume of rock

**(c) Moisture content:** The voids present in a rock may be completely saturated with water or sometimes partially saturated. The amount of water present is expressed as the moisture content which is the ratio of the weight of water in the voids to that of weight of dry solids expressed in percentage

The moisture content, $M = \frac{W_w}{W_s}$, where, $W_w$ = weight of water in voids and $W_s$ = weight of solids

**(d) Degree of saturation:** It is defined as the ratio of the volume of water in the voids to the total volume of voids expressed in percentage. Thus degree of saturation

$Ds = \frac{V_w}{V_v}$, where, $V_w$ = volume of water in voids and $V_v$ = volume of voids

When the voids are completely saturated with water $V_w = V_v$ and hence the saturation is 100%.

**(e) Permeability:** Permeability of a porous media such as rock or sediment refers to its fluid conductivity, its capacity to transport fluids or the ease of movement of fluid in the medium. The characters of the openings control the flow of the fluid but not the volume of the water occupying the pore spaces. It is dependent on the pore size, pore shapes and their interconnections. Permeability is determined by applying Darcy"s law which states that "the flow rate through porous media is directly proportional to the head loss and inversely proportional to the length of the flow path".

Thus, flow rate, $V \alpha \frac{H}{L}$ where, H = head loss and L = length of flow path

$$\Rightarrow V = K \times \frac{H}{L} = K . I$$

Where K = Constant i.e. coefficient of permeability and I = hydraulic gradient

In a quantity sense $K = \frac{Q}{IA}$, where, Q = amount of water and A = cross sectional area

Thus coefficient of permeability can be defined as the quantity of water flowing through a unit cross sectional area under unit hydraulic gradient.
The permeability of a rock depends on the texture, structure, mineralogy and genesis. Permeability determines the seepage through the engineering structures, uplift pressures compressibility, consolidation, shearing resistance etc. Hence, it is important to determine the permeability prior to the use of the rocks for engineering structures.

**(iii) Properties related to the nature of bonding**

Swelling characteristics: The swelling characteristics of a rock are dependent on the texture of the rocks and their mineral and chemical composition. Interlocking and crystalline textures are not affected by swelling but rocks with poorly cemented textures swell to a large extent and sometimes disintegrate. Moisture content accelerates the swelling. The swelling characteristics are defined by swelling coefficient, which is the ratio of the change in length after moistened to the original length.

The swelling coefficient, $E_s = \frac{dl}{L}$, where dl=change in length after moistened and L= original length

The rocks can be classified into three types based on their swelling characteristics. These are:

Rocks with no measurable swelling in saturated environment

Measurable swelling in saturated environment

Large scale swelling with disintegration

**(iv) Properties related to resistant to external forces**

The elastic, plastic and elasto-plastic behaviors of the rocks are to be determined based on stress-strain relationship after addition or removal of external forces. The elastic bodies possess recoverable strain whereas plastic bodies possess nonrecoverable or plastic strain.

The stress-strain characteristics of different bodies are represented by some modulii such as modulus of elasticity and poisson‟s ratio.

Modulus of elasticity: It is the ratio of stress to strain

Poisson‟s ratio: It is the ratio of lateral strain to longitudinal strain.

The modulus of elasticity and poisson‟s ratio of some common rocks are given below:

| Rock | Modulus of elasticity in psi | Poisson‟s ratio |
|---|---|---|
| Granite | 4545000 - 8700000 | 0.15 – 0.24 |
| Marble | 7250000 - 10150000 | 0.25 – 0.38 |
| Limestone | 4350000 - 8700000 | 0.16 – 0.23 |

The elastic, plastic and elasto-plastic behaviors of the rocks are to be determined before their use in the engineering structures to avoid failure of the structure.

**(v) Strength of rocks:**

To determine whether the rocks present at a engineering site are competent or not, the strength of the rocks need to be determined. These are: (a) Compressive strength, (b) Tensile strength and (c) Shear strength.

Compressive strength is that strength or the stress required to break a loaded sample that is unconfined at the sides. Shear strength is the resistance to shear failure. Shear strength is defined as the shear stress which causes the failure of the body along a shear plane. Tensile strength is the stress necessary to break the sample by a simple experiment where a circular disc like sample is loaded diametrically till failure occurs.

**(a) Compressive strength (or crushing strength):** It may be described as the maximum load per unit area which a rock can withstand undergoing failure.

Thus, $C = \frac{A}{P}$, where, C = Compressive strength, A = Area of cross section and P = Load at failure

It is determined by making standard test specimens of cubes or cylinders of a length: diameter ratio of 2 or 2.5. Load is applied axially on the cubes after placing it on the base plate of a universal testing machine till the first crack appears in the specimen.

The factors which affect the compressive strength or crushing strength of the rocks are degree of weathering, porosity, water content, permeability, chemical and mineralogical composition, texture, structure etc.

The compressive strengths of some common rocks are given below:

| Rock | Compressing strength in Kg/cm$^2$ | |
|---|---|---|
| | Range | Average |
| Granite | 370 - 3790 | 1480 |
| Sandstone | 110 – 2520 | 740 |
| Limestone | 60 - 3600 | 960 |
| Quartzite | 260 - 3200 | 2020 |
| Marble | 310 - 2620 | 1020 |

**(b) Shear strength:** Shear strength which is the resistance to shear failure is defined as the shear stress which causes the failure of the body along a shear plane.

Shear strength can be determined in triaxial compression test by finding out cohesion (c), angle of internal friction (θ) and normal stress acting perpendicular to the shear plane for a particular loading condition. Then from the Mohr"s diagram, the required values are obtained to find out the shearing stress.

Thus, shearing stress $\tau = c + \sigma \tan\theta$

Where, $\tau$ = cohesion, $\sigma$= Normal stress acting perpendicular to the shear plane and $\theta$ = Angle of friction

The shear strengths of some common rocks are given below:

| Rock | Shear strength in $Kg/cm^2$ | Rock | Shear strength in $Kg/cm^2$ |
|---|---|---|---|
| Granite | 150 - 300 | Marble | 100 – 300 |
| Sandstone | 50 – 150 | Slate | 150 - 250 |
| Limestone | 100 - 200 | | |

**(c)Tensile strength:** It is the tensile stress necessary to break a sample by a simple experiment where a circular disc like sample is loaded diametrically till failure occurs along the diametrical plane of the specimen.

Thus Tensile strength, $T = \frac{2l}{\pi dt}$ where, l=load applied, d=diameter of the sample and t = thickness of the disc

The tensile strength of some common rocks is given below

| Rock | Tensile strength in $Kg/cm^2$ | Rock | Tensile strength in $Kg/cm^2$ |
|---|---|---|---|
| Granite | 32 - 50 | Marble | 100 – 60 |
| Sandstone | 10 – 30 | Shale | 250 |
| Limestone | 30 - 200 | Marble | 30 - 90 |

**(d) Hardness:** It is the resistance to stretching or abrasion. During the movement of heavy vehicles on road made up of rocks, the hard ones can withstand to frictional action of the vehicles whereas the less hard ones are scratched or abraded bringing damage. Hardness or abrasion resistance is measured by “Abrasion testing machine”. Differential abrasion is detrimental to the rocks used for pavements or other structures. Dense, monomineralic and uniformly textured rocks undergo uniform abrasion, whereas coarse-grained rocks having different minerals produce pitted or honey-comb-like appearance.

**(e)Toughness:** It is the resistance of a material to breaking. When rocks are used for runways in airports and other structures where sudden heavy load is imparted, this property is essential to be studied. This is studied by “Impact testing machine”.

Heat resistance: Most rocks are seriously damaged by heat, if the temperature reaches more than 850°C. Rocks used in the engineering constructions like roads, runways etc gain frictional heat and other structures may get heat from other sources. Hence, heat resistance characteristics of the rocks should be studied before an engineering construction is planned using these materials.

## 6.8. SOIL

### 6.8.1. Definition of Soil

Soil is the unconsolidated rock material that overlies the bed rock at the ground surface ranging in thickness from a few centimetres to several metres and frequently mixed with decomposed organic matter.

According to a geologist, soil is defined as the upper weathered layer of the solid earth's crust and derived from the parent rocks by slow process of weathering accompanied by the growth and influence of living organisms. According to a civil engineer, soils are defined as all granular earth materials which cannot be called as hard rocks. As such, sand, clay, silt, boulders, pebbles etc. and all unconsolidated materials irrespective of their utility and derivation are called soil.

It is one of the most vital earth resources which sustains life on the surface of the earth.

### 6.8.2. Origin of soil

Soils are produced due to disintegration and decomposition of the parent rocks followed by transport by geological agents such as wind, running water, glaciers, sea waves etc. The chief processes of soil formation are a set of processes which include erosion, transportation and deposition. Since a number of factors are responsible for the formation of the soil, its characteristics are also governed by them. The factors of soil formation are: (a) climate (b) topography and drainage (c) vegetation and (d) parent materials.

**(a) Climate:** Temperature changes and precipitation are some of the important climatic factors for soil formation. Hot climate favour mechanical weathering where as warm climate favours chemical decomposition. High precipitation helps in the formation of clay minerals and increase in the organic materials.

**(b) Topography and drainage:** Flat topography of an area helps in the chemical process because of continued exposure of the rocks to chemical action by water. The transportation of the weathered material can be accelerated when there is a slope. This also helps in the continued weathering when fresh rocks are exposed to the weathering agents. If the drainage of the underground rocks is good, chemical substances are washed away. In case of poor drainage conditions, the chemical substances including the organic materials are accumulated in the soil.

**(c) Vegetation:** It contributes organic (humus) content to the soil in the areas which have high vegetation growth particularly areas of good rainfall. They sometimes help in the mechanical breakdown of rock masses.

**(d) Parent materials:** Variation in composition and texture of the parent rocks give rise to varieties of soil with various textures, Rocks with coarse-grained minerals such as granite, pegmatite, sandstone etc. at shallow depths give rise to coarse-grained soils. On the other hand, fine grained rocks such as dolomite, basalt, shale, limestone etc. produce fine grained soils.

### 6.8.3. Types of soil

On the basis of their place of occurrence with respect to their parent rocks, soils can be classified into two types. (a) Residual soil (b) Transported soil.

**(i)** **Residual soil:** These are otherwise known as *in situ* soil and are genetically related to the underlying rocks and derived from them. After their formation, there is no transportation but they remain at the place of its formation. The thickness of the residual soil varies from place to place and depends on the physical and chemical characters of the parent rocks. These soils have undergone chemical dissolution and leaching. Some of the important types of residual soils are:

(a) **Red soil:** Formed due to degradation of older granites and gneisses and contain quartz, mica and kaolinite. The red colouration is due to presence of iron oxide. These are rich in potash and do not contain salt and carbonate. These are moderately fertile.

(b) **Black soils:** Formed from basalts and are argillaceous with montmorillonite. These are fine grained, porous and swell when wet. These are fertile soils. The black colour is due to Ti, Fe and partly due to carbon and organic matter.

(c) **Lateritic soil:** These are concretionary clay like soils and are produced due to residual weathering of granite, gneisses, basalts, shale etc. under humid tropical climate with good drainage. They consist of hydrated oxides of Fe, Al, Mn, Ti, silica, montmorillonite and kaolinite.

**(ii)** **Transported soils:** After formation, these soils are transported from the places of their origin to suitable localities by agents like wind, running water, glacier etc. The soils are named differently depending on the transporting agents involved as given below:

(a) **Eolian soil:** The agent is the wind and the materials can be blown with very high velocity. These are of two types i.e. dune soil (sandy) and loess (clayey) There are devoid of organic matter.

(b) **Glacial soil:** The agent is the glacier. These can be classified into till, moraine etc.

(c) **Alluvial soil:** These soils are transported by running water and consist of gravel, sand, silt, clay etc. Organic matter mayor may not be present in them.

(d) **Lacustrine soil:** It is formed in bottom of lakes.

(e) **Marine soil:** Produced in the sea and ocean floors or at the beach due to action of marine currents.

### 6.8.4. Soil profile

Vertical section of a soil displays sequence of changes both physical and chemical from the surface up to the bed rock. It is known as soil profile which also shows the nature and sequence of various layers as products of rock weathering in various stages. Broadly soil of fine grained nature grades downwards into loose broken rock debris called the 'sub soil' which grades into solid parent rock. In a vertical section of soils, there are several parallel zones or horizons of soil having contrasting characteristics, which indicate various stages of formation.

The topmost layer of a soil profile is known as "A-horizon" which occurs at the surface. This layer has a lot of accumulation of organic matter and the composition is modified by the plant action and humus. There is leaching of soluble matters in significant amount from this horizon. The next layer is known as "B-horizon" which is enriched in soluble components from top layer. The next layer is known as "C-horizon" which consists of broken rock fragments of larger size. The mineralogical composition of these three layers is quite different from that of the bed rock in case of "transported soil" but in case of "residual soil", the mineralogy is similar and related. .

## 6.9. SOIL EROSION

Soil erosion can be defined as the process of removal of the fertile top soil with thickness varying from fraction of a cm to 15 cm by wind and running water.

Soil is a very important natural resource which sustains agriculture, forest growth, ground water storage, growth of natural grass etc. without which survival of the animals and plants will be at stake. Weathering of the rocks (both mechanical and chemical) of all types can produce soil at the upper surface. These are frequently mixed with organic matter and humus with or without stratification. Soil is formed by a cyclic process whereby after soil formation / deposition on the top surface, removal of soil takes place by different agents of transportation exposing the fresh surface to undergo weathering with next cycle of soil formation.

Removal of soil by natural agents is a relatively slow process since for replacement of 3 to 5 cm of top soil, it takes almost 500 to 1000 years. However, interaction of man with natural processes since time immemorial and excessive exploitation and mismanagement of natural resources like land, water, soil etc. have led to higher rate of soil erosion.

### 6.9.1. Causes of soil erosion

Soil erosion takes place due to one or more of the causes mentioned below.

(i) Deforestation either by cutting down wood or forest fire make the soil barren. The root of the plants which firmly hold the soil at its base is destroyed by deforestation causing soil erosion by different agents especially running water and wind.

(ii) If cultivation is undertaken along the inclined hill slopes, surface runoff makes the soil move down the slope causing soil erosion. (Ex- Podu cultivation in Odisha)

(iii) Grass lands provide a binding force to the soil preventing soil erosion. However, excessive grazing destroys the grass land and loosens the soil causing soil erosion.

(iv) Excessive ploughing removes the plants from the top surface. If the land is kept barren for some days specifically during rainy season, soil erosion takes place by running water. Wind also carries away a part of the soil, if the land is kept barren for some days.

### 6.9.2. Types of soil erosion

The most important agents of soil erosion are running water and wind. In addition to these, other agents like ground water, moving ice, sea waves also play certain role in soil erosion.

**(i) Erosion by wind:** In the arid and semi arid regions and in the areas where the soils are dry, loose and light, the effect of wind erosion is maximum. The lighter particles are carried to longer distances while heavier particles move to short distances. In coastal areas, soil erosion takes place both by wind and sea waves.

**(ii) Erosion by running water:** Running water is mostly received from the rainfall. It moves in various parts of the land surface carrying solid with them from higher level to lower level. These are finally transported to nallas, streamlets, streams, rivers, lakes, sea and ocean etc. If the land surface is not protected by vegetation, running water takes away all the top soil making the land degraded.
Erosion by running water takes place, by the following processes:

**(iii) Sheet washing:** During periods of heavy rain fall, the soil grains of an area are made loose and if there is some slope, the thin layers of the top soil float away.

The damage may not be realised in a spectacular manner but with every heavy shower the cream of the top layer is uniformly skimmed off. As a result of this type of erosion the productivity of the land is gradually reduced since the nutrients are washed away. This type of erosion has transformed many fertile lands into barren lands. Huge amount of soil is washed away into the water bodies like lakes, seas, oceans along with water. In case of loose soil, a single heavy downpour can remove 2 to 3 cm thick top soil.

The rate of soil erosion is dependent on the factors like: (a) Intensity of rainfall (b) Velocity of rain drops (c) Inclination of the slope (d) Compactness of the soil (e) Soil conservation practices adopted (f) Size of the soil particles.

**(iv) Gully Erosion:** In the thick soil and weathered horizons „V‟ or „U‟ shaped gullys and channels are formed by running water first as narrow and small ones. Gradually the gullys and channels are widened and their depth increases sometimes reaching more than 10 cm deep. The process goes on year after year cutting the fertile lands into small blocks known as „bad lands‟ making them unsuitable for cultivation.

**(v) Stream erosion:** In the mature and old stage of the stream, river etc. the river banks, river beds and flood plains are eroded away both at normal times and during time of floods. The alluvial deposits which are very fertile get eroded year after year. The erosion of the banks is a common phenomenon in case of meandering rivers where the concave part gets easily eroded away unless preventive measures are taken.

### 6.9.3. Harmful effects of soil erosion

Soil erosion has affected the life of the people since time immemorial. Mismanagement of land and water resources is responsible for destruction of many ancient civilisations. The harmful effects of soil erosion are given below.

(i) The fertile top soil is eroded away. Thus, the yield of the crops becomes less due to loss of nutrient.

(ii) Gullies, channels and badlands are formed reducing the fertile areas for cultivation.

(iii) Huge amount of silt is accumulated in the reservoirs, canals and larger water bodies reducing their water bearing capacity.

(iv) The reduction of water bearing capacity in the reservoirs is responsible for causing floods.

(v) The ground water table is affected because the surface water doesn‟t get chance to seep through the soil.

(vi) Because of washing away of the soil, surface water gets polluted.

(vii) The mountain roads along the slopes may get flooded with soil and water dislocating traffic.

(viii) The soil eroded by wind are carried to certain distance and they damage the agricultural land, human settlements, crops etc.

(ix) Sea waves erode the coastal areas and sometimes affect highways, railways, buildings, human settlement etc.

## 6.10. SOIL CONSERVATION

Soil conservation is defined as the processes or practices undertaken to control the soil erosion and maintain soil fertility. It can be accomplished in two ways.

(i) Reducing soil erosion; (ii) Maintaining soil fertility

**(i) Reducing soil erosion:** Soil erosion cannot be prevented altogether but its intensity can be reduced to a considerable extent. The different measures to reduce the soil erosion are described below.

**(a) Afforestation:** In the areas affected by severe deforestation, immediate measures should be undertaken for afforestation practices by planting trees and taking step to maintain them.

Areas demarcated for pasture land should be planted with permanent grass to check soil erosion. Sheet erosion can be prevented by providing suitable cover crops during rainy season.

Sloping lands beyond a particular limit of slope, should not be allowed for cultivation. Steeper slopes should be allowed for development of either pasture land or forests.

Ploughing or tilling of lands along contour levels result in development of furrows across the slope which can check immediate flow of water and hence check soil erosion.

**(b) Contour irrigation:** Trenches or channels and bunds (terraces, ridges, embankment) constructed along the contours and across the slopes can check the flow of water. The water can also be collected and can be utilised in some other fields by providing suitable channels. The process subdivides and reduces the length of the slope and change the slope if a number of these structures are provided in succession.

**(c) Contour cropping:** Crops are planted along contours across the slope which results in formation of miniature terraces. This helps in holding the rain water and minimising the rate of flow of surface runoff.

**(d) Strip farming:** Farming of grass alternately with cash crops along the slopes can check the soil erosion to certain extent.

**(e) Controlled grazing:** Overgrazing by cattle results in loosening of soil that facilitates erosion. This can be minimised if the cattle are allowed to graze the grass land to a limited extent.

**(f) Providing check dams:** Small check dams made up of concrete, wood, steel, earth etc. should be constructed at topographically suitable places across nalas, streamlets, tributaries, stream channels etc. so that a fair amount of water is stored at the upstream side reducing soil erosion in the downstream side. The water stored in the small reservoirs can be utilised for irrigation and other purposes during non-rainy seasons. This is also very useful in checking flow of silt along the rivers into the large reservoirs constructed near the dams.

**(g) Checking of forest fires:** Fires cause large scale destruction of forests which in turn is responsible for soil erosion. Hence it is necessary to check the forest fire.

(**h) Educating people:** The land owners and farmers should be educated about the adverse effects of soil erosion and advantages of soil conservation. They should also be educated about the different methods of soil conservation practices. The NGOs, Government organisations and planners should do the needful to check the menace of soil erosion.

**(i) Preventing coastal erosion:** The coastal erosion can be prevented by construction of effective barriers to prevent sea Waves reaching areas more prone to erosion. These include break waters, jetties, sea walls etc. The coastal erosion can also be prevented by planting suitable tress at the coast lines and restoring beaches by depositing sand.

**(j) Preventing wind erosion:** The effects of wind erosion can be minimised by construction of retaining wall across the prevailing wind directions and planting dense trees in rows across the wind direction.

**(ii) Maintaining soil fertility:** Due to soil erosion the top soil which is rich in plant nutrients in eroded away. The soil becomes less fertile and the productivity is decreased considerably. Hence soil conservation practices should also aim at maintaining soil fertility in addition to checking the soil erosion. Some of the practices to be adopted are described below:

**(a) Rotation of crops:** Harvesting of same type of crop year after year results in impoverishment of the soil in nutrients and decrease in the production. Roots of a particular type of crop may not hold the soil firmly causing soil erosion but roots of some other plants may hold the soil preventing soil erosion. Hence to maintain the soil fertility and to prevent soil erosion, the crops should be rotated:

**(b) Addition of fertilizers and manures:** The fertility of the soil can be maintained by adding proper and right type of fertilizer and manures. Organic manures are more preferable over the fertilizers used now-a-days.

It may be kept in mind that soil erosion is a continuous process and it is going to happen because of the erosive action of the denudational agents such as running water, wind etc. However, with some preventing measures and adopting soil conservation practices, the evil effects of the soil erosion can be minimised.

## 6.11. SAMPLE QUESTIONS

### 6.11.1. Long type questions

(i) Describe the importance of geology in civil engineering constructions.

(ii) Describe the geological considerations in the selection of a suitable dam site.

(iii) Describe the geological considerations in the selection of a bridge site.

(iv) Describe the geological considerations in the selection of a tunnel site.

(v) Give an account of engineering properties of rocks.

(vi) What is soil erosion? Describe different processes of soil erosion.

(vii) Describe the causes of soil erosion and methods to prevent soil erosion.

(viii) Describe how soil conservation can be done.

### 6.11.2. Write short notes on (Answer within 3- 5 sentences)

| | | | | | |
|---|---|---|---|---|---|
| (i) | Gravity dam | (v) | Buttress dam | (ix) | Grouting |
| (ii) | Arch dam | (vi) | Parts of a bridge | (x) | Porosity |
| (iii) | Soil conservation | (vii) | Soil erosion | (xi) | Permeability |
| (iv) | Sheet washing | (viii) | Gully erosion | (xii) | Compressive strength |

### 6.11.3. Answer the following questions in one sentence

| | | | |
|---|---|---|---|
| (i) | What is a dam? | (v) | What is sheet erosion? |
| (ii) | What is abutment of a dam? | (vi) | Name two measures of soil conservation? |
| (iii) | What is soil erosion? | (vii) | What is portal of a tunnel? |
| (iv) | What is pier of a bridge? | (viii) | What is void ratio? |

### 6.11.4. Fill in the blanks with suitable word / words.

(i) The passage to discharge excess water in the reservoir is known as ________.

(ii) A modified gravity dam which requires less amount of concrete and has a slanting deck is known as ____________.

(iii) The dam which is best suited for narrow deep valleys with strong abutment rocks is _____________.

(iv) The horizontal pressure on the dams is mostly due to __________ .

(v) The part of the bridge which is erected from the foundation or abutment to support the superstructures is known as ____________ .

(vi) The weak foundation rocks treated by forceful injection of cement .and sand is known as ______________ .

(vii) Dams resting on beds exhibiting gentle downstream slope is not for dam construction. ___________ .

**Answers:** (i) Spill way (ii) Buttress dam (iii) Arch dam (iv) Velocity of water (v) Pier (vi) Grouting (vii) Suitable

**6.11.5. Choose the correct answer out of the four choices given.**

(i) The type of dam preferred where the river section is wide and the foundation is unsound is (a) Gravity dam (b) Buttress dam (c) Arch dam (d) None of these

(ii) The downstream portion of the dam in contact with the foundation is known as (a) Heel (b) Toe (c) Crest (d) Free board

(iii) The dams which are constructed in narrow river valleys with strong abutmen1 rocks are Buttress dam (b) Arch dam (c) Earth dam (d) None of the above

(iv) The most important agent / agents of soil erosion are (a) Wind only (b) Wind and running water (c) Running water only (d) Static water

(v) Dam resting on beds exhibiting gentle downstream slope is Suitable (b) Unsuitable (c) Ideal (d) None of these

**Answers:** (i) Gravity dam (ii) Toe (iii) Arch dam (iv) Wind and running water (v) Unsuitable

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# CHAPTER – 7

# STRATIGRAPHY

## 7.1. DEFINITION AND SCOPE

Stratigraphy is that part of Historical Geology which deals with the inorganic aspects i.e. the formation of rocks in geologic time (the organic aspect is known as palaeontology.)

Stratigraphy deals with the classification and description of rocks in a chronological order from the oldest to the youngest as they ware formed on the earth‟s surface i.e. development of the earth‟s rocky framework or lithosphere through successive geologic ages. The word „Stratigraphy‟ has been derived from the Latin word „Sternere‟ meaning to spread which refers to the planar units of rocks.

It is inferred that straigraphy deals with time (geochronometry) and rock (lithostratigraphy) which are the fundamental entities of geological time scale. Besides one more units (biostratigraphy) is added which deals with fossils. The principles of stratigraphy were worked out primarily on sedimentary rocks, but they may be useful in the study of layered igneous rocks as well as ash falls, lava flows and of metamorphic rocks which display the original sedimentary character.

The sedimentary rocks are easily put in order as one sits on the older and may have fossils in them. But the igneous and metamorphic rocks are somewhat complicated and many parameters are involved in studying them. The three broad rock groups, forming in one time-period, are interrelated with each other in space and time and when all these rock groups are studied in terms of their chronology, the stratigraphy of the region is evolved.

The stratigraphy is based on three phases:

(i) Description of strata as they occur in sequence in local areas - the basic data.

(ii) Correlation of these local sections - determination of their mutual time relations and their place in the standard scale that forms the framework of Historial Geology - Time Scale.

(iii) Interpretation of stratigraphic record, both rocks and their contained fossils (if any, in terms of past history of earth).

## 7.2. PRINCIPLES OF STRATIGRAPHY

Charles Lyell in his book "Fundamentals of Geology" indicated that the great changes on earth‟s surface take place not as a result of catastrophy but due to slow and steady geological processes which are operating even today. This is called the concept of "UNIFORMITARIANISM" which means past geological process are explained in terms of contemporary processes which can be observed and recorded at present. James Hutton in visualising the above concept pronounced that "PRESENT IS KEY TO PAST"

The earth had recorded all the things chrongically from its inception. Nicolaus Steno, a Danish physician while studing the rock strata of northern put forth four laws mentioned below:

(i) Law of original horizontality: In undeformed sedimentary sequence, the strata developed are either horizontal or almost parallel to earth surface.

(ii) Law of stratigraphic superposition: In an undisturbed sedimentary sequence, the rock layers are laid down from bottom to top i.e. the oldest would occur at the base while the youngest bed would be at the top.

(iii) Law of cross-cutting relationship: In case of fault and igneous dykes or other intrusions which cut through the country rocks, the intrusions are always younger than the affected rocks.

(iv) Law of faunal succession: The fossils found in any undisturbed sedimentary sequence always maintain a chronogical order in which they appeared on the earth, evolved and / or disappeared. If the rocks of different locations possess similar in situ fossils, then the sedimentary rocks are of same geological age.

Lithology, fossil content and order of superposition are the three main aspects for study of stratigraphy of any region.

### 7.2.1. Lithology

The mineralogy and other characters of rocks (lithology) continue to be same over certain distance normally because of their sedimentary nature. The lithology may vary with distance. Several individual beds constitute a litho-unit and characters of the beds are individual to them and each has almost the same characters along their spread in space. When such is the case, the beds are termed as formation (with a local name). Thus, Kamthi sandstone (Lower Gondwana near Nagpur) is different in age and location from Jabbi sandstone (Permian of Himalayan area) even though their lithological similarity may not be in doubt. But lithological similarity (mineralogical, physical and other special features) is also of good help in correlation of similar / same rock in different parts of one geological unit. For example, banded-hematite-chert of Gua, Khandadhar or Joda are correlatable as one and the same in time and space.

### 7.2.2. Fossil content

Each formation has not only specific petrological characters, but also specific forms of life of that time. When some animals live long they are less important as index-fossils. Species with short life-range are good time indicators of the formation of rocks in which they are found. Stromatolites of certain types indicate Vindhyan age of the associated rocks.

Fossil assemblage means a group of fossils which existed in a particular time within a geographic space having similar environmental conditions for persistence of life and formation of rocks. Thus, deep sea rock fossils are different from their coastal, estuarine or riverine counterparts. Therefore, in studying fauna and flora of areas, lithological as well as environmental situations (facies) also get considered as well.

**7.2.3. Order of superposition**

A geological formation rests on another and is overlain by still another one. So naturally the bottom-most is the oldest and the upper-most is the youngest. This is true for these three in both time and space. Again in each formation, the part that rests on one is younger to the latter. One formation, however, may be missed because of many reasons. When this missing part really does not exist (not deposited or eroded) it is called an unconformity. Without any visible break in deposition and existence of parallelism of two formations with a gap of sedimentation, is a disconformity. Non-deposition feature between an igneous body and a formation results in a nonconformity. (West of Keonjhar town in Odisha on the eastern hill slope, Singhbhum granite (eroded) is found to underlie Dhanjori sandstone forming a nonconformity. The unconformity may show (a) different disposition of the two beds (angular), (b) intervention of a conglomerate horizon with pebbles of underlying rock(s) or by other features. This conglomerate is different from autoclastic ones produced by shearing. When the overlying formation spreads beyond the limit of the lower one it is said to „overlap‟ the lower one and when this overlapping formation gets detached from its original or forms simultaneously in another nearby place it is termed as an „outlier‟. These, however, don‟t create hindrances causing any change in the order of superposition of the strata. When folded, they form „windows‟ and „nappes‟ as found in the Himalayas.

Rocks on the earth‟s crust undergo constant changes by structural as well as tectonic forces and get weathered forming new chemical set-up. Igneous rocks intrude into them and cause rise of geo-isotherms to metamorphose them. This goes on and on and in the Precambrian period and because of the time involved, complexities are obviously the maximum. The earth-scientist has to unravel all the geological information based on available evidences.

## 7.3. STRATIGRAPHIC UNITS

The following three are fundamental stratigraphic units. (i) Rock Unit, (ii) Time Unit and (iii) Time-Rock Unit.

**7.3.1. Rock Unit:** The rock unit is a mappable assemblage of strata observable in the field. The fundamental unit is a "Formation". Two or more formations when combined, form a „Group‟ and groups combine form a „Supergroup‟. The "Gondwana Supergroup", for example, is divisible into Lower and Upper Gondwana groups. The "Lower Gondwana Group" is divisible into a number of groups out of which one is "Damuda Group". The "Damuda Group" includes four formations and "Barakar Formation" is one such that is divisible into ten members each of which is divisible into sandstone, shale and coal beds. The criteria of distinction are lithological characters and presence of unconformities.

**7.3.2. Time Unit:** The time unit is a continuous unit and may be defined as segment of geologic time characterized by major hiatus, geological events and appearance or disappearance of important organisms. The biggest unit is Eon which is divided into smaller rank terms as era, periods, epochs and ages.

**7.3.3. Time-Rock Unit:** It is defined as assemblage of strata deposited during a distinct time-unit. The biggest unit is "Erathem", which is divided into smaller rank terms like „System", „Series", „Stage" and „Zone".

## 7.4. GEOLOGICAL TIME-SCALE

The rock sequence can be called as conformable only when its layers have been formed without any time gap or interruption. But in nature, there are long gaps in the formations of rock layers due to removal of strata by geological processes or non deposition. These are called unconformities. On regional scale these are the natural boundaries for division of time. These unconformities indicate smaller or larger time span or gap in rock sequence. The former is called time value and latter is hiatus.

Based on the world wide geological survey, the geoscientists have correlated and plotted the sequence of rocks that have been formed continuously through out the duration of the geological history of the earth and have constructed an intact vertical geological column. This column consists of a composite record of of the earth in achronogical order. The vertical geological column, in combination with sequential arrangenment of geologic time units comprises the „Geological time scale".

The Geological Time Scale is a reference scale of earth" history whose major units are Eons, Eras, Periods and Epochs. The geological time scale were constructed long before the radioactive dating methods basing on palaeontological records. When absolutes dates of radioactive methods have been deduced the earlier scale was modified. It is observed that there is no major changein time scale.

In the scale the ages of the rocks is given in million years written as m.y. or Ma. The former denotes time span or duration of the event in millions of years, and latter expresses the age in millions of years.

The Geological time scale begins with the formation of earth‟s independent existence as a planet which coincides with 4600 million years before present. Then onwards the earth‟ history was sub divided in to two parts basis on their fossil content. These are called Cryptozoic or Pre Cambrian eon and Phanerozoic eon. Phenrozoic denotes presence of forms of life with preservable hard parts. The primitive life of Archaeozoic and Proterozoic did not contain hard part and therefore earlier referred as Azoic absence of life. On palaeontological record the eons can be subdivide in to five eras namely Archaean, Proterozoic, Palaeozoic, Mesozoic, and Cenozoic. The names have been derived from Greek words Archeos meaning oldest, Proteros older, paleo early Mesoz intermediate and Cainos new and endings of each name Zoics meaning life.

The cryptozoic eon is called Precambrian eon because it represents that part of geological time older than the Cambrian Period, the oldest period of Palaeozoic era which also marks the beginning of invertebrates.

The Phanerozoic eon has been divided in to three eras namelyPalaeozoic, Mesozoic and Cenozoic.

The Palaeozoic era is divided in to five periods namely Cambrian, Ordovician, Silurian Devonian, Carboniferrous and Permian. The Mesozoic era is divided in to three periods: Triassic, Jurassic and Cretaceous and Cenozoic in to Tertiary and Quaternary Periods.

The Tertiary Period is divided in to five epoch namely Palaeocene, Eocene, Oligocene, Miocene and Pliocene. The Quaternary Period is Pleistocene Holocene and recent.

The geological formations have been studied in different parts of the world and in international meetings and publications, geologists argue on different points and have come to the conclusions about the rocks. They are arranged into certain major groups and the terms indicate stages of developments of organisms. The Azoic, for example, is devoid of life, while the Proterozoic shows the presence of primitive life without bones and hence absence of any well preserved fossils. In Palaeozoic time good fossil evidences start showing up, followed by plants, larger animals and so on till the Recent time. This has been described in Table 7.1.

The stratigraphy of the entire litho-sequence of the world is divided broadly into two i.e. Precambrian (earlier than Cambrian) and post-Cambrian (Cambrian and younger rocks). The former involves huge time frame (8 times more than latter), high grade of metamorphism and structural deformation and is almost unfossiliferous in total contrast to the latter. The Precambrians take more than ≈3,000 million years (m.y.) to form in contrast to approximately 500 m.y. for the later. The age of the first crust is yet to be exactly understood or estimated and at present we don"t go into the controversy. It may be much older and vary between 4,600 m.y. to 7,200 m.y. This age-dating is done by radioactive minerals based on their half-life periods.

## Table 7.1: The Geologic time scale

| Eon | Era | Period | Epoch | Duration (Ma) | Time since beginning (Ma) | Important events |
|---|---|---|---|---|---|---|
| Phanerozoic | Cenozoic | Quaternary | Holocene | 0.01 | 0.01 | Present living animals |
| | | | Pleistocene | 1.6 | 1.61 | Death of many mammals during glaciation; Man appeared |
| | | Tertiary | Pliocene | 3.7 | 5.3 | Mammals, flowering plants and Mollusca |
| | | | Miocene | 18.4 | 23.7 | |
| | | | Oligocene | 12.9 | 36.6 | |
| | | | Eocene | 21.2 | 57.8 | |
| | | | Palaeocene | 8.6 | 66.4 | |
| | Mesozoic | Cretaceous | | 78 | 144±5 | Giant reptiles and ammonites disappeared at the end. |
| | | Jurassic | | 64 | 208±18 | Numerous flowering plants, abundant Ammonites, first birds; |
| | | Triassic | | 37 | 245±20 | Ammonites, reptiles and Amphibians plenty; Arid climate |
| | Paleozoic | Permian | | 41 | 286±12 | Trlobites disappeared at the end |
| | | Carboniferous | | 74 | 360±30 | Many non-flowering plants, first reptile appears |
| | | Devonian | | 48 | 408±12 | Abundance of Corals, Brachiopoda |
| | | Silurian | | 30 | 438±12 | Graptolite disappear, first fish, first land plants |
| | | Ordovician | | 67 | 505±32 | Plenty of Trilobites and Graptolites |
| | | Cambrian | | 65 | 570±28 | Abundance of Trilobites |
| Proterozoic | Late (Neoproterozoic) | | | 330 | 900 | Soft-bodied animals and plants |
| | Middle (Mesoproterozoic) | | | 700 | 1600 | |
| | Early (Palaeoproterozoic) | | | 900 | 2500 | |
| Archean (Azoic) | Late | | | 500 | 3000 | Soft-bodied animals and plants (less abundant) |
| | Middle | | | 400 | 3400 | Lifeless |
| | Early | | | 600 | 4000 | |

The Precambrians are older to post-cambrian rocks with a big time-gap of no deposition forming the „Eparchean unconformity‟. From 500 to 2,500 m.y., all these rocks formed come under Proterozoic group and beyond that are usually igneous rocks and / or only narrow, shallow and deformed basin deposits considered as deposits of Archaean or Azoic age. Soft-bodied life-forms and primordial plants are, at times, traced in Proterozoics.

Thus, based on the sequence of formation and incoming of intrusions etc the stratigraphic orders of rocks are presented. Lithology, fossil content and order of superposition are the three main aspects for study of stratigraphy of any region.

## 7.5. PRECAMBRIAN ROCKS OF INDIAN PENINSULA

The Precambrian rocks, as the name implies, are grouped as Azoic and Proterozoic; the former also is named as Archean (by J. D. Dana, 1872) meaning at that point of time about all rocks older to Cambrian. Later it was divided into the two groups as mentioned above; the latter having primitive organisms as fossils (ill-preserved because of no hard part) while the Azoics show no fossils at all. This is partly due to fact that unicellular bodies started coming up during early Proterozoic time that has been assigned an age of ≈ 2,500 m. y.; this date is approximate and is brought forth by rationalizing world radioactive age data. The earth, based on those data, was inferred to have been formed about 4,600 m.y. ago and by about 3,600 - 3,700 m.y. oldest rocks of the earth‟s crust started forming possibly as primodial granites. Series of later intrusive made them more complex and metamorphosed them into gneisses and crystalline schists. These are named as „Shields‟ meaning the core-rocks of the land masses which were most stable to any change. These shields apparently had undergone only vertical movements (epirogenic). The world has about a dozen areas of such complex rocks of which peninsular India is one and Singhbhum-Keonjhar granitic complex is one of the oldest in the eastern part of the Peninsular India.

The Archeans show no evidence of life and are mostly igneous acidic and basic (flows of basalts) rocks with narrow and shallow basins of sediments. Greenstone, para-schists and para-amphibolites, garnet-mica schists, granite gneisses and trondhjemitic gneisses are the main litho-types in this group. Below them no rock is known to exist and even these rocks are also rarely found except in some localities of complex litho-characters. They are regarded as Basement complex or Fundamental gneiss which are ortho-and para-schists and gneisses.

These Archean rocks are found from Cape Comorin up to the Ganges in Bihar, in Bundelkhand and Madhya Pradesh and up to north of Rajasthan. In the Western Ghats it is restricted because of the Deccan Traps that mantles a huge area of peninsula. They are also present in the northeastern part of the country. These are described in the following paragraphs.

### 7.5.1. Andhra Pradesh

The western part of the State shows Dharwarian rocks (quartzites, mica schists and ferruginous quartzite) up to Karimnagar and Warangal trending roughly N-S. Pink and grey gneisses occupy the region further east. While the grey one is Peninsular gneiss, the pink one is intrusive and is probably equivalent to Bellary gneiss. Felsite and porphyry dykes intrude into them and auriferous quartz veins occur in these Dharwarian rocks.

Nepheline syenite with corundum and excellent zircon crystals occur as intrusive in Khammam area. Nellore region witnessed four types of gneisses. Two of them, being schistose, are likely to be paragneisses while the other two are igneous in origin and King named one as Carnatic gneiss, which is considered akin to Peninsular gneiss. The other, a pinkish one is younger and is intrusive. Pegmatite and quartz veins intrude them. In western part, basalts metamorphosed to amphibolite (Kandra volcanics), are found in schistose rocks.

**7.5.2. Tamilnadu**

Occupied essentially by Peninsular gneiss, charnockites and intervening schistose rocks the regional folds here are found to plunge northward. While Madurai and Tiruchirapalli have Peninsular gneisses and pink granite, Coimbatore and Salem have banded hematite / magnetite quartzite (meta sedimentary).

The Chalk hills of Salem are ultrabasic while Sheveroy and Palni hills show khondalites at the top and charnockite at a lower horizon. Anorthosite, as a layered sequence, is found at Sittampundi and runs beyond Suryapatti. Indianite (a plagioclase with $An_{80}$-$An_{100}$) is found here with anorthosite. This metamorphic sequence is gravity-layered and contains aluminous-chromites. Near Tiruchirapalli a funnel shaped anorthositic intrusion is found. Also intrusives are exposed as alkaline rocks of nepheline syenite and its variations around Sivamalai. Along the lineament, west of the Eastern Ghats Supergroup (EGSG) are exposed series of anorthosite, alkali-syenitic and diamond-bearing lamproitic rocks up to north Odisha. Of late many lamproites are found in western Odisha occasionally with diamonds. More prospecting is needed for winning diamond from this lineament controlled region.

**7.5.3. Jeypore - Bastar**

West of Koraput district beyond the above lineament (discussed as Crookshank"s fault) are granites, gneisses, greenstones and charnockites with dolerite dykes, those are partly older and also younger to the Bengpal and Sukma groups of rocks indicating several phases of intrusion. Their line of separation is not yet quite certain. While Sukmas show higher grade of metamorphism, the Bengpals have some basaltic flow inside them and the Bailadila Iron Ore Group overlie them. Chatterjee (1961) has done detailed studies on the Bailadila sequence that shows two metamorphically different Banded iron formations (BIFs) the lesser one above the other. The supra-BIF contains an excellent iron ore deposit that was responsible for the railway line construction from Bailadila to Visakhapatnam for export of ore.

### 7.5.4. Chhatisgarh and Madhya Pradesh

To the west of Odisha is the Chatishgarh State where Raipur / Chatishgarh Group of rocks, with quartzite, phyllite etc and banded hematite quartzite of Dhalli-Rajhara ridge are exposed. Overlain by volcanic agglomerates and intruded by granite, these rocks form Chilpighat sequence that, westward, gets bifurcated forming Nagpur-Chhindwara unit (Sausars) in the north and Nagpur-Bhandara unit (Sakoli) to its south. But eastward they tend to taper out. The Gangpurs of Odisha are considered their equivalent. The old Sonawani series, when mapped continuously, were found to merge with the Sausar rocks. The Sausars dip southward while the Sakolis dip northward forming a basin-like structure whose axial zone seems to be faulted. While the Sausars are manganese-rich and are metamorphosed to amphibolite facies, the Sakolis have undergone lower grade of metamorphism and contain low grade iron ores. The details of geological studies by Sarkar and Bhattacharjee reveal briefly three divisions for Sakolis viz. Amgaon, Nandgaon and Khairagarh (from 1630 to 600 m.y.) in ascending order.

Dongargarh granite records 710-2,000 m.y. age. The Sausar Group, well exposed in Bilaspur-Balaghat sector, is studied in good details because of the Mn-ore content. A somewhat accepted stratigraphy of the Sausar is presented in Table 7.2.

**Table 7.2 - Stratigraphy of the Sausar Group**

| Sequence | | Rock types |
|---|---|---|
| Minor intrusions | - | Smaller granites and pegmatites |
| Granite intrusive | - | Ortho-gneiss |
| | Intrusive contact | |
| Bichua Formation | - | Dolomite marble, wollastonite-grossularite rich calc-granulite |
| Junewani Formation | - | High grade para-metamorphites (Al-rich) (widespread but lenticular bodies) |
| Chorbaoli Formation | - | High grade para-metamorphites (Si-rich) |
| Mansar Formation | - | Mica-phyllites and Mn-rich horizons |
| Lohangi Formation | | |
| (a) Lohangi | - | With three divisions of calcic, silicic and Al-richhorizons |
| (b) Utiketa | | |
| (c) Kadbikhera | | |
| Sitasaongi Formation | - | To the east as schistose felspathic grit<br>To the west passes laterally into Lohangi |
| ~~~~~~~~~~~~~~~~~~~~~~~~ | Unconformity | ~~~~~~~~~~~~~~~~~~~~~~~~~~~ |
| Tirodi gneiss | | Biotite gneiss |
| ~~~~~~~~~~~~~~~~~~~~~~~~ | Unconformity | ~~~~~~~~~~~~~~~~~~~~~~~~~~~ |
| Metamorphic rocks | | Hypersthene granite gneiss, Hornblende gneiss etc |

This belt is famous in India for manganese ores and the belt runs from Balaghat to Chindwara, a distance over 200 km with 25 km width. The area is completely folded and faulted where even nappes are developed with variable southward plunge. Due to overthrusting, inversion of stratigraphy is not uncommon. Chilpighat and Sonawani are considered parts of Sausars.

Manganese ores are traced in three horizons and the ore-bearing rock is named as gondite, the name coming from the „Gond" tribe in whose area these rocks are beautifully developed. Metamorphism has resulted in the formation of a host of manganese-bearing minerals; more than twenty of which are found in the ore bodies. The Sausars give a geochronologic age between 864 to 984 m.y. Absolute age dating is likely to revolutionise the idea about the stratigraphy of these rocks in the central part of the country.

A part of the Deccan trap separates these rocks from the northerly lying group of middle-grade metamorphic rocks of Jabalpur with occasional manganese and iron ore patches. They resemble the rocks of Gangpur Group.

Deccan traps cover the part between the Champaner Group and the rocks of Madhya Pradesh. Heron, while mapping in Rajsthan, found these Champaner rocks equivalent to the Aravallis; but these need further confirmations. Pavagad hill, the outlier of Deccan trap, lies above these rocks near Shivrajpur manganese area that belongs to Champaners (≡ Sausars ?).

**7.5.5. Rajsthan**

The geology of Rajasthan has been somewhat well-studied because of its mineral wealth and vegetation-poor topography leading to the desertic conditions. Here exposures have been excellently traced for mapping. Azoics and Proterozoics prevail in this region where more than three periods of meta-sediments were deposited and were subjected to almost equal number of periods of deformation along NNE-SSW axis running from Delhi to the Gulf of Cambay. Exposed in the Aravalli hills as a synclinorium, rocks of Delhi Supergroup superpose over the Aravallis almost along the same axis. It may incidentally be said that the Aravalli hills are oldest true mountains of the country and compare well with those of the world. To its east is the subparallel Boundary fault delimiting the eastward extension of this basin. The major groups of the rocks of Rajsthan are given in Table 7.3.

**Table 7.3 - Precambrian stratigraphy of Rajsthan**

| |
|---|
| Igneous suites of Malani |
| Delhi Group |
| Raialo Group |
| Aravalli Group |
| Banded gneissic complex and Bundelkhand gneiss |

While the Aravallis are taken as equivalent of the Dharwars and contains metapelites essentially, the Delhis, with its 6,000 m thick sequence lie above the Raialos. Erinpura, Jalor-Siwana and Idar granites are possible equivalents of the Malani suite of igneous rocks of Rajasthan and occur beyond in NNE direction.

The Bundelkhand gneiss and Banded gneissic complex (BGC) have definite parts of sediments, which were granitised and, as such, this is a complex rock group exposed in Berach river valley. This zone, with Bundelkhand gneiss (BGC), Berach and Rajsthan granites are complicated and challenging as their gradation to one another or their intrusion history is not fully understood. The metasomatic (granitised) nature of a larger part of Bundelkhand granite is, however, never in question.

The Gwalior Group is considered equivalent to the Aravallis while the Mewar region has ferruginous sandstone/chert below Khardeola grits.

The Aravalli rocks are intruded by aplo-granites as lit-par-lit intrusive around Udaipur. Ultrabasics also intrude them. Nepheline syenite cuts them across as intrusion at Kishangarh where theralite and camptonite are also available in addition to sodalite (blue in colour) and cancrinite (yellow) bearing syenite-pegmatite. For information, it may be said that the pegmatites of this blue-yellow and white coloured mineral from Kishangarh is completely taken away by geology students and others because of its sheer beauty. Controversy on the line of emplacement of this rock however, exists.

Makrana marble, the famous marble of India is available from Raialo series at Markana and Ras from a field of 80 × 2 km stretch.

The much-talked Bundelkhand granite is exposed as a large southern semi-circular side. Its northern side is irregular. It stretches over 320 km (E-W) with a width of 200 km (N-S) and shows varied characters from pink and grey colours to schistose and gneissose structures. With xenoliths and inclusions, it indicates its essential igneous character in patches and pockets and metasomatic appearance on a large scale. Sarkar, in 1964, has dated (K-Ar) the biotites from its inclusions to be of 2500 m.y. Thus, it may be younger-phase equivalent of Singhbhum granite.

### 7.5.6. West Bengal

The western part of Bengal shows granite gneiss etc. in Midnapur district known as Bengal gneiss. It is equivalent to the Peninsular Gneiss of South India. These rocks continue northward and borders the Bengal anorthosite exposed south of Raniganj (also south of Damodar river) wherein the primary (magmatic) foliation of felspars of anorthosite being parallel around the border zone are protoclastically granulated. The inclusion of Bengal gneiss in anorthosite and veins of anorthosite in Bengal gneiss indicate a confirmed nature of intrusion of this monomineralic rock in this petrologic and structural environment. Chatterjee considers it as a differentiation product of gabbroic magma. Its relationship with the Banpur, Chilika, Sonepur, Samal and Mayurbhanj anorthosite is yet to be established. But nevertheless, they are all intrusions along lineaments between Indo-Gangetic plain and Eastern Ghats mobile belt.

### 7.5.7. North-East India

The entire region of India covering east and north of Bangladesh is discussed here. Assam, Arunachal Pradesh, Nagaland, Manipur, Mizonim, Tripura and Meghalaya are included in this region.

The Archaeans apparently continue below Bengal basin and Bangladesh (Ganges and Brahmaputra River valleys) and form the Assam plateau. It consists of Garo, Khasi and Jaintia hills and beyond. The area as a whole is covered by gneisses, granites and schists of varying degrees of metamorphism. The granites are porphyritic or fine-grained while the gneisses often contain sillimanite. Nongstoin in Khasi hills has sillimanite deposits which are massive in nature. Above the gneisses is the Shillong Group with quartzite, conglomerate, phyllite etc. with occasional carbon phyllite and banded hematite-quartzite. In parts of Goalpara these BIF rocks are also found. The Garo and Mikir hills show similar rocks.

The Shillong Group is intruded by Khasi greenstones and both are folded together suggesting the Precambrian nature of the basic rocks. Mylliem granite stands separate as an intrusive and forms bosses and stocks. It is coarse microcline granite and is later to Khasi greenstone.

Inside the granite and greisses are pyroxene granulite types of rocks resembling chornockite. These and the Nongstoin sillimanite deposit, common to Eastern Ghats rocks, lead to infer the extension of Eastern Ghats rocks (khondalite and charnockite) to Assam region, running below the Gangetic - Brahmaputra alluvium.

Dolerites cut the granites and vesicular basic flows (Sylhet traps) of Upper Cretaceous in age (= Rajmahals ?), are found at the top. In the far NE-area, the Himalayas form the Assamese arc when the east-north-easterly sediments swerve to south and WSW to form Arakan and Pegu Yoma hill ranges of Burma.

### 7.5.8. The Precambrian Rocks of Extra-peninsula

The Azoic and Proterozoic rocks in Himalayan region pervade all through its axial length but are identified and discussed or studied in a few places only. Gansser has made an all-round attempt on Himalayan geology with good success.

From NW Himalayas (From Gilgit) through Nepal and up to Sikkim, Precambrian rocks are traced. In Kashmir and Hazara area they are called Salkhalas (slate, phyllite, quartzite, carbonaceous-schist and marble) and are folded along with the Post-Cambrian rocks during Himalayan folding and faulted by the low angle thrust as is the case in that part of northern India. D. N. Wadia, a pioneer to study Himalayan geology, suggests these Salkhalas to be homotaxial with the Jutoghs of Simla-gneisses exposed in Zanskar, Dhauladhar and Pir Panjal ranges.

These gneisses and the Salkhalas are cut by gabbro, pyroxenite, granites and pegmatites and are considered as rocks of central gneisses in which pre - and post - Tertiary granites also exist.

Dogra slates are found to succeed the Salkhalas and are overlain by fossil-bearing Cambrian of Kashmir. In Punjab they are called Attok slates.

Jutogh Group is treated as equivalent to the Chail Group with slates, limestones and mica - schists. Chor granite, on Char hills, is the core-rock in some recumbent folds with overthrusted Chail Group and is distinctly intrusive with clear contact minerals.

The Chails are thrusted over Blainis and Simla slates and at Chakrata are thrusted over Deoban limestone and Mandhali Group of Precambrian age.

In Garhwal zone the story repeats and over-folding with pressure from north has produced recumbent folds which get thrusted over less metamorphosed southerly occurring sedimentary rocks. The correlation of autochthonous zones with the para-autochthonous, naturally has to be vague and sometime only inferential. To the east, these rocks are said to resemble the Dalings of Sikkim-Darjeeling region.

The Dalings grade into Darjeeling Group, the former contains copper. These two show inversion of metamorphism with depth and high grade metamorphic rocks are available over low grade ores; this forces the geologists working there to separate them by a thrust. They both are thrust over the Gondwanas further south. The Everest region, with limestone, represents both these rocks.

There are common features between Dalings and Salkhalas, although in detail they have their own characters.

Gansser has worked on the Bhutan and East Himalayan region as well. The Wadia Institute of Himalayan Geology works on the geology of the region.

The Salkhalas of Kashmir-Hazara, Jutogh and Chails of Simla, central gneisses of Gahrwal and Kumaon, Dalings and Darjeelings of Nepal-Sikkim and gneisses and some schists of Assain Himalayas are broadly equivalent to each other and to the Dharwars of Peninsular India. All the Precambrian and Archaean rocks have undergone the drastic deformations and orogenic movement of the Tethys-Himalayas during rise of the mountain in Tertiary time. They present, as a result, a set-up of very complicated structures of folding, faulting, thrusting post-thrust-superposed and later folding, later thrusting etc. to make the study of Himalayan rocks very difficult but nevertheless, very challenging as well.

## 7.5.9. ARCHEAN ROCKS OF KARNATAKA

The Archean rocks of south India are best developed in Mysore and adjoining parts of Karnataka, which are generally named as Dharwar Supergroup of rocks. The area is made up mainly of gneisses and schists intruded by granites. The rocks are folded and thrusted and show a NNW-SSE to NW-SE trend. Tectonically this part of the Peninsular shield is known as Dharwar craton. This craton is separated from the higher granulite terrain of southern and eastern part (Kerala and Tamilnadu) by a tectonic boundary. On the west it is boarded by Arabian Sea and its northern part is concealed by Proterozoic sediments.

The Dharwar Supergroup of rocks was first studied by R. Bruce Foote in the eighties of ninetieth century. In 1915 these of rocks ware described by W. F.

Smeeth. According to him the Dharwars were regarded as the oldest formation of Mysore area and contain the rocks like ortho-gneisses and ortho-schists which have neen produced due to metamorphism of preceding igneous country rocks. He classified the Dharwars into Lower hornblendic division and Upper chloritic division.

After a detailed study, B. Rama Rao has given a classification of Dharwars and associated rocks in 1940, which is based on lithology and structure. The outline of the succession proposed by Rama Rao is given in the Table 7.4. Taking into account of the geographical position of the rocks, Rama Rao classified the Dharwara into five zones. These are

(a) The easternmost zone: This zone is also known as Kolar schist belt. It is about 64 km long with maximum width of about 6 km. This belt is made up of mostly hornblendic rocks and is traversed by quartz vein and reefs containing gold.
(b) The east-central zone: This zone is composed of granulites, gneisses and schists of variable composition.
(c) The central zone: It is made up of limestones, ferruginous rocks and metamorphosed igneous rocks.
(d) West-central zone: This zone is composed of banded manganeferous and ferruginous rocks.
(e) The westernmost zone: This zone consists of mainly hornblende schist within which thin bands of hematite-quartzite are found.

Later on Swaminath et al (1981) had given a stratigraphic succession of Dharwars. According to them Archeans of Karnataka are divisible into an older -

**Table 7.4: Stratigraphy of the Dharwar Supergroup according to B. Rama Rao**

| | |
|---|---|
| Intrusives | Felsite and perphyry dykes<br>Closepet granite<br>Charnockites<br>Norite dykes<br>Hornblendic dykes<br>Peninsular gneiss<br>Champion gneiss |
| - - - - - - - Unconformity - - - - - - - - - - - | |
| Upper Dharwar | Cherty, ferruginous and calcareous silts and clays. Impure quartzite, conglomerates are also seen. |
| Middle Dharwar | Metamorphosed granitic rocks with gneissic structure form the upper part of the subdivision. The lower part is made up of micaceous gneisses, schistose conglomerates, banded green stone with amphibole. |
| Lower Dharwar | Highly crushed micaceous quartz schist and gneisses form the upper part of the subdivision. The lower part of the subdivision is made up of hornblende schist, green stone and flows of basic composition. |
| - - - - - - - Base not known - - - - - - - - - | |

Sargur Group and younger Dharwar Supergroup separated from each other by some unclassified gneissic rocks. The classification as suggested by them is given in Table 7.5. The important intrusives which intruded into the Dharwar Supergroup rocks are Champion gneiss, Peninsular gneiss, Charnockites and Closepet granite.

**Champion gneiss:** Near Kolar schist belt sheared grey gneiss is exposed, that is possibly younger to Dharwars but older than Peninsular gneiss and forms stocks and bosses of granite and porphyry. Some other igneous rocks like keratophyre, rhyolites and quartz-porphyries are considered equivalent to them.

**Table 7.5: Stratigraphy of the Dharwar Supergroup according to Swaminathan et al. (1981)**

| | |
|---|---|
| | Felsite and porphyry dyke |
| | Closepet granite |
| | Chitaldurg granite |
| | --------- Unconformity ------------- |
| Dharwar Supergroup | Ranibannur Group |
| | Chitaldurg Group |
| | --- Unconformity ------ |
| | Bababudan Group |
| | --------- Unconformity ------------- |
| | Peninsular gneissic complex |
| | Sargur Group |
| | --------- Base not known ------------ |

**Peninsular gneiss:** This is widespread in Karnataka and South India which intrude into the schistose rocks. Granite, granodiorite, gneissose granites and banded gneisses, showing signs of intrusion, belong to this group. Apparently they form a gamut of intrusive rocks within a time period and have all mixed up to give rise to composite gneisses, migmatites and have granitised older crystallines followed by intrusive granites with related aplite and quartz vein. Thus, a granite series may be thought of when one studies these rocks. This suite of rocks may itself contain granites related in time and space forming a kindred with consanguineous relationship.

**Charnockites:** The rocks of this Formation are plentily present in south India. This rock, with orthopyroxene (hypersthene) as a must, is of granitic composition with a granulitic texture, was first described by Sir Thomas Holland, who named the rock in honour of Job Charnock, the founder of Calcutta (now Kolkata), whose tombstone was made from this rock brought from Mt. Thomas hill of present Chennai city. This rock, he showed, forms a petrographic kindred along with other ultrabasic to acid varieties exposed in a petrographic province. Since Holland‟s publication on this Formation by Geological Survey of India, many workers described it from other parts of southern and also parts of northern Hemisphere. Excellent summary of these rocks are made by Quensel (1951), Pichamuthu (1953), Howie (1964) etc. Later Subramanian (1959) redefined the terms of. charnockite and charnockite series. In Odisha this rock is excellently exposed in south Odisha. According to Howie (1964) charnockite is a plutonic igneous rock, which has undergone recrystallisation in solid state by plutonic metamorphism. Holland‟s basic division is formed by pyroxene granulites, which is related to the base of khondalites and is generally unrelated to charnockite and the acid division of charnockite formation forms an igneous suite from charnockitic magma. Charnockitisation, like granitisation, is a process that produces charnockitised charnockite from basic to acid sediments as found by Ghosh (1948) from the south and Chatterjee (1955) from Mayurakshi river valley in eastern India. Leptynite is considered a rock that is recrystallised khondalite (granitised). The association of charnockite with Eastern Ghats rocks is a prominent feature both as intrusive and as metasomatic ones and also in Nilgiri, Anamalai, Sheveroy and Palni hills in Kerala. Rama Rao (1945) was also of the opinion of. „chamockitisation‟ as a process of charnockite formation from noncharnockitic rocks.

**Closepet granite:** This is a pinkish granite suite of rocks intruding into the Dharwarian rocks of Karnataka and is younger to Peninsular gneiss. It runs across Mysore and veered westward from its N-S disposition and maintains a width of about 18 to 24 km. According to Radhakrishnan this is a metasomatic granite becoming magmatic towards the centre. The country rocks are intruded by this granite. The Na-feldspars in this rock have been microc1inised. This granite is trondhjemite to granodiorite in composition and cuts through the regional metamorphic rocks those get less intense metamorphosed northward and become green schists.

**Structural features:** Three phases of deformation are marked in the eastern sector of Sargur and Dharwars. The first phase exhibits small scale tight to isoclinal folds, which was followed, by a second phase of deformation marked by large-scale upright isoclinals folds having N-S striking axial planes. The third phase is identified by some folds having NE-SW to N-S striking axial plane. In Bababudan belt the strike of the axial plane is E-W. In the western sector the general structure is anticlinal flanked by two synclines on either side with variation in plunge.

**Metamorphism:** There is an overall progressive metamorphism from south to north. The high grade Sargurs exhibit an amphibolite to granulite facies of metamorphism but the Dharwars broadly exhibits a greenschist to amphibolites facies.

**Economic minerals:** By the presence of N-S fault, Dharwars are divided into two parts. The eastern side is known as Bababudan Group and is famous for iron ore deposits. The western side is named as Chitaldurg Group, is famous for gold deposits, the important gold fields being Kolar gold field, Hutti gold field, Rampur gold field etc.

## 7.5.10. ARCHEANS OF ODISHA AND JHARKHAND

### 7.5.10.1. Eastern Ghats Supergroup

**(i) Geological setting:** The rocks of Eastern Ghats Supergroup form a discontinuous mountain chain parallel to the east coast of India. Continuous exposures are found to extend from Bejawada of Andhra Pradesh in the south up to Dhenkanal district of Odisha in NE-SW direction and then the strike changes NW-SE ultimately merging with the Bay of Bengal. In other parts, the rocks are found as isolated outcrops extending up to Srilanka.

**(ii) Regional structure:** The regional structure of Eastern Ghats Supergroup has not yet been worked out in detail, but local works indicate that the entire sequence represents a highly folded and faulted succession confirming to polyphase deformation history. Probably it was uplifted during post-Cuddapah time. The western margin of the Eastern Ghats possibly represents a great boundary fault running in NE-SW direction parallel with the strike of Eastern Ghats rocks.

Stratigraphy: The stratigraphy of the Eastern Ghats Supergroup is given in Table 7.6.

**(iii) Lithology**

**Khondalite Group:** This group is constituted of khondalite, quartzite, leptynite (garnetiferous quartzite) and calc-granulite. The khondalite is a metamorphic rock composed of quartz, orthoclase, plagioclase, garnet, sillimanite and traces of graphite. Khondalite is found in Kalahandi and Jeypore of Odisha and parts of Andhra Pradesh and locally termed as Kailas gneiss and Bejawada gneiss. According to Fermer, khondalite was formed by metamorphism of argillaceous sediments under deep seated katamorphic conditions as indicated by the presence of garnet and sillimanite.

**Charnockite Group:** Charnockites are special type of rock containing quartz, feldspar and essentially hypersthene and range from acid to basic varieties. The origin of the charnockites is controversial and igneous, metasedimentary and metasomatic views have been assigned by different researchers.

**Intrusions:** Granite, anorthosite, nepheline syenite, pegmatite and quartz reefs have intruded into rocks of Eastern Ghats Supergroup.

**Economic minerals:** The economic mineral resources associated with the Eastern Ghats Supergroup are manganese, bauxite, graphite, mica, quatz, feldspar, limestone etc.

**Table 7.6: Stratigraphy of the Eastern Ghats Supergroup**

Pegmatites

Nepheline syenite

Anorthosite

Charnockite Group (Acid-, intermediate- and basic-charnockites)

Khondalite Group (Khondalite, quartzite, leptynite and calc-granulite with graphite, bauxite and manganese deposits)

~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~

Older Metamorphic Group

**7.5.10.2. Iron Ore Supergroup**

**(i) Geological setting:** Because of huge iron ore association, the Archean meta-sedimentary rocks developed around Singhbhum district of Jharkhand, Keonjhar, Sundargarh, Jajpur and Mayurbhanj districts of Odisha are termed as Iron ore Supergroup. The geology of the area is interesting because of its structural complexity, stratigraphy, economic mineralization and tectonic history. The area has been extensively studied in detail by Jones, Dunn and Dey, Saha and Sarkar, Banerjee and Acharya et al. The area is represented by two distinctly different facies, the southern part marked by an unmetamorphosed facies and the northern part by a metamorphosed facies separated by a shear zone known as Singhbhum copper thrust that runs in an initial E-W direction and then N-S for a distance of more than 160 kms.
~~~~~~~~~~~~~~~~~

**(ii) Structure:** The area is tectonically highly disturbed and marked by the presence of thrust zones, folds of different generations, faults, joints etc.

**Thrust zone:** The major thrust zone, known as Singhbhum Copper Thrust, extends from Porhat in the west through Chakradharpur, Amda, Rakha mines and Mosabani into Mayurbhanj district of Odisha for a distance of about 160 kms. It runs in an E-W direction in the western part and takes a turn to NW-SE and N-S direction in the eastern part. The rocks are highly sheared and mylonitised along this thrust zone. The Arkasoni soda granite has been emplaced and copper mineralization has taken place along this thrust zone. Two smaller thrust zones are found further north along the northern boarder of the Dalma outcrop and another still further north along the boundary of Chhotanagapur granite gneiss. All the three thrust zones converge near Goilkera where the rocks are tightly folded.

**Geanticline:** To the north of Singhbhum Copper Thrust the rocks of Iron Ore Supergroup are folded in form of a geanticlines and the thrust zone marks the overfolded limb of the geanticlines. In this part the Iron Ore Supergroup is represented by the Chaibasa stage constituted of high grade metamorphic rocks. This is classified as Singhbhum Group by Saha and Sarkar and Dunn and Dey.

**Syncline:** South of the thrust zone, the Iron Ore Supergroup is folded in form of a synclinorium. This is composed of BHQ, BHJ, shales and phyllites which are least metamorphosed.

The rocks south of the thrust zone are sheared, mylonitised and probably belong to Singhbhum Group.

### (iii) Stratigraphy

The stratigraphy of the Iron Ore Supergroup was first of all established by H. C. Jones and subsequently revised by J. A. Dunn and A. K. Dey as well by A. K. Saha and S. N. Sarkar.

**Jones' Stratigraphy:** Jones recognized two different groups of rocks, viz. Older metamorphics and Iron Ore Series (presently named as Iron Ore Group) separated by an unconformity, the former forming the basement of the Iron Ore Series. His stratigraphy is given in Table 7.7.

**Table 7.7: Stratigraphy of Iron Ore Supergroup according to Jones**

| | |
|---|---|
| Intrusives: Dolerite, granite and ultrabasics | |
| IRON ORE SERIES | Basic lava flow |
| | Upper shale |
| | BHQ and BHJ |
| | Lower shale |
| | Purple and grey limestones (local) |
| | Basal conglomerate and sandstones |
| - - - - - - - - - - - - -Unconformity- - - - - - - - - - - - - | |
| Older metamorphic Group: Quartzites, Quartz-mica-hornblende-chlorite schist | |

**Dunn and Dey's Stratigraphy:** According to Dunn and Dey

(a) The older metamorphics of Jone forms a part of the Iron Ore Series and not the basement.

(b) Iron Ore Series is divisible into Chaibasa Stage and constituted of high grade metamorphic rocks and Iron Ore Stage constituted of low grade metamorphic rocks like BHQ, BHJ, shale, phyllite etc.

(c) The Iron Ore Series is unconformably overlain by a group of sedimentary and volcanic association termed as Dhanjori sandstones and volcanic.

(d) The conglomerates, sandstones and limestones are younger than Iron Ore Series equivalent to the Cuddapahs and named as Kolhan Series of Proterozoic age.

(e) The stratigraphy proposed by Dunn and Dey is given in Table 7.8.

**Table 7.8: Stratigraphy of Iron Ore Supergroup according to Dunn and Dey**

| | |
|---|---|
| Kolhan Series | Limestones |
| | Conglomerates and sandstones |
| | ~~~~~~~~~~ Unconformity ~~~~~~~~~ |
| | Newer dolerite |
| | Singhbhum granite |
| | Arkasoni soda granite |
| | Chhotnagpur granite gneiss |
| | Dalma and Dhanjhori lavas |
| | Dhanjori sandstones |
| | ~~~~~~~~~~ Unconformity ~~~~~~~~~ |
| Iron ore Series | Iron ore stage - BHQ, BHJ, shales and phyllites (Unmetamorphosed) |
| | Chaibasa stage - Quartzite, Quartz - mica - hornblende - chlorite schist, Garnet - kyanite schist (High grade metamorphic facies) |

**Saha and Sarkar's stratigraphy**

On the basis of intrusive, structural and palaeocurrent studies supplemented by K-Ar, Rb-Sr and Pb isotopic age data, Saha and Sarkar have established the presence of three distinct orogenic cycles with closing dates at 3200, 2950 and 1600 my. The stratigraphic succession with correlation is given in Table 7.9.

**Table 7.9: Stratigraphy of Iron Ore Group according to Saha and Sarkar**

| South of Copper belt thrust zone in Singhbhum, Mayurbhanj, Keonjhar | North of Copper belt thrust zone in Singhbhum |
|---|---|
| Kolhan Group (1500 - 1600 my) { Limestones<br>Conglomerates, Sandstones | |
| ~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~ | |
| Newer Dolerite<br>Mayurbhanj Granite (2000 - 2100 my)<br>Gabbro - Anortosite<br>Ultramafic intrusives | Arkasoni soda granite<br>Chakradharpur granite gneiss<br>Kuilapal granite |
| ~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~ | |
| Dhanjori Group { Jagannathpur - (Dhanjori -) Simlipal lavas<br>Quartzites and Conglomerates | Dalma lavas with intertrappeans<br>Reworked lava conglomerates |
| ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ Unconformity | ~~~~~~~~~~~~~~~~~~~~~ |
| Singhbhum Group { Dalbhum Formation<br>Chaibasa Formation | |
| ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ Unconformity | ~~~~~~~~~~~~~~~~~~~~~ |
| Singhbhum Granite (2950 my) | |
| ——— Iron ore Orogeny ——— | |
| Iron Ore Group \| Upper lava Formation<br>Upper phyllite Formation<br>Banded Iron Formation<br>Lower lava Formation<br>Sandstones and conglomerates | |
| ~~~~~~~~~~~~ Unconformity ~~~~~~~~~~ | |
| Older metamorphic gneiss (3200 my) | |
| ——— Older metamorphic Orogeny ——— | |
| Older metamorphic Group (3300 my) | |
| Granitic basement (> 3300 my) | |

## A.K. Banerji's Stratigraphy

Banerji recognized two distinct iron ore groups in the area. The BHQ and BHJ formations of Mayurbhanj were considered as older and were named as Gorumahisani Group. These were intruded by Singhbhum granite. The BHQ and BHJ formations of horse-shoe syncline (Keonjhar – Sundargarh – Singhbhum) and those of Gandhamardan hill ranges of Keonjhar were regarded as younger and named as Noamundi Group. The stratigraphy given by Banergi is presented in Table 7.10.

**Table 7.10: Stratigraphy of Iron Ore Supergroup according to A. K. Banergi**

Newer Dolerite
Kolhan Group
~~~~ Unconformity ~~~~~~
Naomundi Group
Dhanjori (Simlipal) Quartzite and Lava
Singhbhum Granite
Gorumahisani Group
~~~~ Unconformity ~~~~~~
Basement not seen

The Singhbhum granite, in contrast, is replete with dolerite dykes of different dimensions. Mainly doleritic to basaltic in composition, they, however, are thick-bodied and show magmatic differentiation to norite, picrite and perkinite. The whole of SGC is traversed by these dolerite dykes striking NNE-SSW and secondarily also along NNW-SSE direction, the widest being around 700 m at Palasponga (in Keonjhar district); this is considered as one of the longest dykes of the country. The Amjori sill of Simlipal in Mayurbhanj is a well differentiated one and is considered to be equivalent of the dolerite of SGC. It may be mentioned here that these dolerite dykes are equivalent to those of Dhanjori and Dalma traps and also to Keonjhar trap exposed west of Suakati up to Brahmani river in Western Odisha (Acharya, 2005). In Indian Science Congress (2000) and in SGAT- Keynote address Acharya suggested on entirely different stratigraphy and three groups of BIF were put together in the BIF-Supergroup, this has been given in Table 7.11. Jones and Krishnan mentioned about one BIF only, which is really the youngest (BIF-3).

Kolhan sandstone and shales overlie the eroded Singhbhum granite in the Railway cutting at Chaibasa with an unconformity. They extend southward in Deo-river section showing the typical jasper fragments-containing-conglomerate at its base. Dipping west, the basin gets deeper and produces limestone used in cement factory. In Deo river an excellent section is available off Mungra village where inclusions of BIF - rock are seen in the granite whose age has recently been found by Paul to be around 3050 m. y. This makes the geology interesting as these blocks of inclusion then cannot be from the northern tip of BIF-3 (Noamundi) lying hardly 15 km south (as was previously suggested) but must have been from an older BIF (possibly BIF-l) whose age is likely to be around 3050 m. y. With more age-data this problem can be tackled by future workers on regional geology. But undoubtedly this has brought in a changed concept about the blocks of inclusion in Singgbhum granite and their structures.

**(iii) Lithology**

**Iron Ore Group:** The Iron Ore Group is developed south of the main thrust zone and constituted of conglomerates, sandstones, BHQ, BHJ, shales, phyllites and lavaflows. The BHQ and BHJ horizon is about 300 m thick and forms isoclinally folded ridges capped by hematite. In addition to massive and compact hematite -

## Table 7.11: Stratigraphy of Iron Ore Supergroup according to S. N. Acharya

Kolhan Basin — Kolhan deposits

~~~~~ Unconformity ~~~~~~

**Joda - Koira Basin (BIF - 3 basin)**

- **Upper pelites**: Volcanics, ultrabasic dykes, (Clastics and mixed shales) Ferruginous shales and banded shales with all variations
- **BIF - 3**: Banded hematite chert / jasper / and iron ore bodies and their variations
- **Lower pelites**: Stromatolitic dolostones / limestone, ferruginous shales (irregular); Banded shale Banded manganese formations (BMnF) banded Mn - ore minerals and shale ores within this Variegated shales, tuffs and tuffaceous shale / phyllite

~~~~ Unconformity (and Disconformity) ~~~~~

**Dhanjori Group**

- Keonjhar - Nuakot lavas
- Dalma and Dhanjori lavas of Krishnan '68 (with intertrappeans)
- Sills and dykes (Palasponga) in Dhanjori and SGC (= Newer dolerite)
- $B_2$ folding (of Daitari basin)
- Dhanjori ( = Kansa quartzite) ferruginous-phyllites, conglomerate (bouldary locally) Ca 2300 - 2400 Ma

~~~ Unconformity, Disconformity and angular unconformity with BIF-2 and non-conformity with SG ~~~

Daitari - Tomka Basin (BIF - 2 basin)

~~~ Unconformity (and non-conformity) ultrabasics, granite and shear zone ~~~~~~

Malayagiri - Gorumahisani basin (BIF - I basin)

~~~~~~~~ Non-conformity ~~~~~~~

**PRE-IOSG PRECAMBRIAN**

- Singhbhum Granite = Keonjhar Granite = Bonai Granite + some more granites in SW area (Phase -I and II) (older to BIF - I) — C 3.3. Ga
- Tonalite gneiss (OMTG) — C 3.4 - 3.5 Ga
- Mica schist, fuchsite quartzite, Para-amphibolite, Hornblende-schist etc — C 4.0 Ga
~~~~~~~~

ore, in places porous, biscuity or finely crystalline powery ore named as „blue dust" are also found. The shales are manganiferous and contain pockets of manganese ores, mined at Jamda - Koira valley and Joda. This group is intruded by Singhbhum granite.

**Singhbhum Group:** It is well developed north of the thrust zone. The lower Chaibasa formation of Dunn and Dey is composed of low to high grade metamorphic rocks such as quartz-mica-hornblende-chlorite schist. At places the schistose rock contains garnet, staurolite, kyanite etc. The upper Dhalbhum Formation is composed of phyllites. This group is intruded by Kuilpal granite, Chakradharpur granite gneiss and Arkasoni soda granite.

**Dhanjori Group:** This group unconformably overlies the Singhbhum Group and constituted of conglomerates, sandstones and lavaflows. It is found in both sides of the thrust zone. South of the thrust zone the lavaflows are termed as Jagannathpur lava and Dhanjori (Simlipal) lava. North of the thrust zone, these are termed as Dalma lava. The Jagannathpur volcanics are intruded by ultramafic intrusive, gabbro, Mayurbhanj granite and Newer dolerite.

**Kolhan Group:** It is of Proterozoic age and equivalent to the Cuddapah Supergroup of the type area in Andhra Pradesh. It is constituted of conglomerates, sandstones, shale and cement grade limestone.

**Economic mineral resource:** The Iron Ore Supergroup and associated rocks constitute a store house of vast quantity of both metallic and non-metallic minerals.

The metallic minerals are iron ore, manganese ore, copper ore, chromite and non-metallic minerals are china clay, steatite, asbestos, apatite and kyanite. The iron ores occur with BHJ succession capping the hills. The manganese ores occur as pockets and lenses within the shales and mined near Koira, Jamda and Joda. The copper mineralization has taken place along the Singhbhum copper thrust and mined at Mosabani, Rakha and Badia mines. Chromite is found near Roroburu in association with ultrabasic rocks. The kyanite deposit is located at Lapsaburu and china clay deposits are produced by weathering of the feldspathic granites in many parts in Singhbhum, Keonjhar and Mayurbhanj districts.

**7.5.9.3. GANGPUR GROUP**

A group of metasedimentary rocks exposed in the western part of Sundargarh district of Odisha was first studied and named as Gangpur Series by M. S. Krishnan. The rocks occur west of the Iron Ore syncline and are younger than the Iron Ore Supergroup.

Krishnan considered this sequence to be an anticlinorium with its axis running in NE-SW direction. The structure is closed towards east and obscured by granitic intrusive in the west. A shearzone has been recognized by Krishnan at the top of the succession along which the Raghunathpalli conglomerate has suffered intense shearing. However, Kanungo and Mahalik, on the basis of detailed structural analysis opined that the anticlinorium of Krishnan is in fact a synclinorium comprising a rock sequence younger than the Iron Ore Supergroup. The succession of the Gangpur Group as proposed by Kanungo and Mahalik has been given in Table 7.12.

On the basis of lithological similarities, the Gangpur Group has been correlated with the Chilpighat Group exposed at about 120 kilometres to the west of Gangpur area. Manganese ores associated with gondites as well as limestone and dolomites are the economic minerals associated with Gangpur Group.

**Table 7.12: Stratigraphic succession of Gangpur Group**

| | | |
|---|---|---|
| Gangpur Group | Ghorijhar Formation - | Staurolite and garnet schists, calc schists, quartzites and conglomerates |
| | Kumarmunda Formation - | Carbonaceous quartzites, dolomite quartzites and phyllites |
| | Birmitrapur Formation - | Limestones, dolomites, quartzites and phyllites |
| | Laingar Formation - | Phyllites, carbonaceous slates and quartzites |
| | Raghunathpalli Formation - | Conglomerates, quartzites and slates |
| | ~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~ | |
| | Iron Ore Supergroup | |

## 7.6. THE CUDDAPAH SUPERGROUP

### 7.6.1. Introduction

The Archaean rocks were intensely folded and faulted and were intruded by many granite rocks towards the end of the deformation. The end of this intense stage of deformation and consequent intrusions was considered as the end of the Archaean time and for a long period there was neither any deposition of rocks nor tectonic or intrusive activities took place and the rocks, already existing were denuded and weathered; this resulted in the creation of a time of non-deposition and is known as "Eparchaean unconformity". This is considered a very important one in the world stratigraphy because above it are deposited the Precambrians which are divided into two Supergroups i.e. Cuddapah and Vindhyan by name. They are intermediate between Archaeans and Cambrians and were regarded as "Puranas" a term later not found to be accepted. The Vindhyans are younger than the Cuddapahs.

### 7.6.2. The Cuddapah Basin (Andhra Pradesh)

The Cuddapah basin forms a crescent shaped outcrop (Fig. 7.1) one whose concave side is in its east. It is 340 km long with Singareni coal field in its north while the Nagari hillock (off Chennai) delimits it in the south. With a width of 145 km, it forms in an area of about 42,000 sq km.

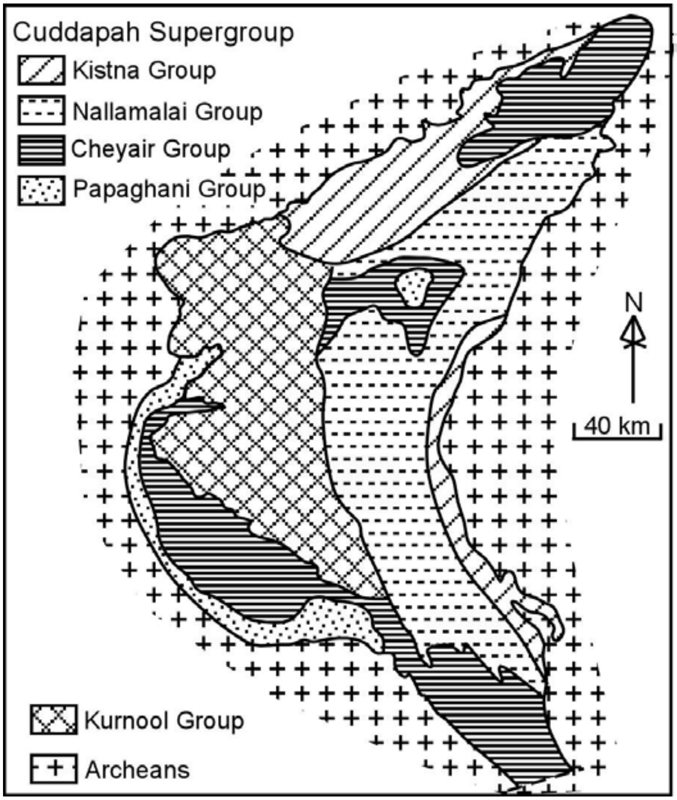


Fig. 7.1: The Cuddapah basin

The upturned and weathered edges of the gneisses and schistose rocks of Archaean age form its base and earlier Proterozoic rocks are missing here. Hence this forms a long time-period of non-depositions here as well after which Cuddapahs were formed. This "Eparchaean Unconformity" - as it is known is very profound as is already mentioned. The Cuddapah sediments dip eastward and have a basal conglomerate that suggests a land mass in the west that supplied sediments into the basin. The western side is more folded but the eastern side is more metamorphosed and has the maximum depth with 4,000 m of sediments. Evidences go in favour of a possible eastern extension of the sediments that existed.

In the south-west of the basin are the basaltic rocks (sills) and tuffs. Similarly in the north-east, lead-zinc deposits are found associated with granitic rocks.

King studied these rocks about 150 years back and established a stratigraphic succession. Some geochronologic studies indicate a 1,500 m. y. for its basal rocks. Table 7.13 shows the stratigraphic succession published by King and later modified.

One finds four unconformities among the major divisions but the most importanf one is below Nallamalai Group. Each Group overlaps the former but the Kishna overlaps all up to the basal gneisses. The fluctuation of depth is remarkable as evidenced from quartzite to limestone. Each time the cyclothemic concept of sedimentation is maintained. The basin slowly becomes deeper east ward.

**7.6.2.1. Papaghni Group:** Exposed in the west, the Gulcheru quartzite has conglomerate, grit and sandstone resting over Archaean basement unconformably. The Vempelle shale and limestone shows flaggy limestone and exhibit features which look like algal structures. Traps intrude into the upper part.

**7.6.2.2 Cheyair Group:** Named after Cheyair river the lower Pulivendla Quartzite has quartzite and conglomerate (pebbles from Papaghni rocks). Near Kalahasti, (eastern side) the rocks are crushed by faulting.

The Tadpatri shales has shale and limestone with chert and jasper that is intruded by basic sills.

**Table 7.13 - Stratigraphy of Cuddapah Supergroup**

| | |
|---|---|
| Kishna Group | Srisailam quartzite |
| (600 m) | Kolamnala shale |
| | Irlakonda quartzite |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | |
| Nallamalai Group | Cumbum shale |
| (1000 m) | Bairenkonda quartzite |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | |
| Cheyair Group | Tadpatri shale (Pulampet) |
| (3300 m) | Pulivendla (Nagri) quartzite |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | |
| Papaghni Group | Vempalli shale and limestone |
| (1400 m) | Gulcheru quartzite |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | |
| Archaeans | Gneisses and schists |

**7.6.2.3 Nallamalai Group:** Named after Nallamalai hills the rocks occupy largest area, and form slight unconformity with the Cheyairs. They are intensely folded with Cumbum Shales in the axial zones.

**7.6.2.4. Kishna Group:** Unconformably over the Nallamalais, they lie over gneisses while Irlakonda Quartzite forms a plateau. Kolamnala Shale is traced in the valley and Srisailam Quartzite, forming a northerly plateau, is named after the temple.

The Vempalle limestones are intruded by basic sills of variable thickness (up to 30 m) and occupy southwestern part of the basin. They are basic in nature and contain quartz and even olivine at times.

These basic rocks have certain resemblance with dolerites of Singhbhum granite complex.

In certain areas like Ceded, barite deposits are found associated with these sills. Asbestos are also traced at times. The Cuddapah rocks are famous as building materials.

## 7.7. THE VINDHYAN SUPERGROUP

After the folding and erosion of the Cuddapah rocks a time-gap was naturally there for the initiation of the next phase of sedimentary system and when it started it formed the existing plateau-like sandstone expansions with low dip and covering about 1,00,000 sq km on the surface.

Vindhyan rocks rest either on Cuddapahs or on older rocks and the unconformity is very prominent. Between the Groups one encounters conglomerates as well.

The Vindhyans are exposed north of Narmada river in Bundelkhand and Malwa region. From Dehri-on-sone to Hoshangabad and from Chitorgarh (Rajasthan) to Gwalior the Vindhyans are spread over on the periphery of Bundelkhand granite. In the Sone valley the lower Vindhyans are exposed but the upper Vindhyans are traced more commonly forming scarp lands. These rocks are positively less deformed than the Cuddapahs and not uncommonly, they rest, as told before, on them as well.

In Suket shales in Central India Fermoria (a relative of primitive Brachiopod - *Acrothele*) had been reported. Its organic nature is, however, challenged by some workers and even its plant and animal nature is debatable. Presence of stromatolite and other fossils in Semris and Kaimurs was also not confirmed and on the whole absence of trilobites is considered as the most vital point to relegate this part of the Vindhyan to Precambrians. However, confirmed evidences of carbonaceous matters in the Dehri-on-Sone area are available and, thus, one may think that „life" in some form started at this stage during the Vindhyan sedimentation.

The Vindhyan rocks have been statigraphically classified to have four groups as follows:

| | **Group** | **Rock type** | **Thickness in m** |
|---|---|---|---|
| | Bhander | Mainly calcareous | 1000 |
| Upper | Rewa | Mainly arenaceous | 2000 |
| | Kaimur | Mainly arenaceous | 400 |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | | | |
| Lower | Semri | Mainly calcareous | 1300 |

The subdivisions of the Vindhyans are given in Table 7.14. The lower Vindhyan (Semris) are well-exposed in the Sone-valley and the succession is given from that region. At Karauli and Chitor its equivalents are traceable. The Glauconite bed and Tirohan limestone of Karauli are important units because of glauconite and special structure features (breccia due to solution) and the story is somewhat similar for Nimbahera shales and Suket shales south of Chitor that attains a thickness of about 300 m.

**Table 7.14 - Subdivisions of the Vindhyans**

| | | |
|---|---|---|
| | | Upper Bhander sandstones |
| Bhander | | Sirbu shales |
| Group | | Lower Bhander sandstones |
| | | Bhander limestone |
| | | Ganurgarh shale |
| ~~~~~~~~~ Diamond bearing conglomerate in unconformity ~~~~~~~~~~~~~~ | | |
| | | Upper Rewa sandstone |
| Rewa | | Jhiri shales |
| Group | | Lower Rewa sandstone |
| | | Panna shales |
| ~~~~~~~~~ Diamond bearing conglomerate in unconformity ~~~~~~~~~~~~~~ | | |
| | | Dhandraul quartzite |
| Kaimur | Upper | Scarp sandstone and conglomerate |
| Group | | Bijaygarh shale |
| | Lower | Upper quartzite and sandstone |
| | | Susnai breccia |
| | | Lower quartzite and shale |
| ~~~~~~~~~ Diamond bearing conglomerate in unconformity ~~~~~~~~~~~~~~ | | |
| | Rohtas Formation | Alternating shale and limestone |
| | Khenjua Formation | Glauconitic member |
| Semri | | Fawn Limestone |
| Group | | Olive Shale |
| | Porcellanite Formation | Porcellanite Shales with other silicified rocks |
| | | Kajrahat Limestone |
| | Basal Formation | Basal Conglomerate |

The Upper Vindhyans consisting of Kaimurs, Rewas and Bhanders consist mainly of sandstones and shales with subordinate limestones. The former forms plateaux south of Bundelkhand granite.

The Kaimurs are well-exposed in the Sone valley and contain two bands of quartzite with grit and conglomerate. Porcellanites are interbeded with the flagstones occurring above the quartzite; these flagstones show very good ripple marks, sun-cracks which suggest top and bottom characters of rocks. The Susnai breccia is epiclastic in nature and indicates a sedimentational break. But the base is put below the lower quartzite.

The Susnai breccia is overlain by silicified quartzite and being very hard with a low dip, forms a conspicuous scarp. These topographic features are common in sedimentary rocks with low dip and alternating hard and soft rock associations as is normal for the Vindhyans. It gets accentuated especially when strike-faults occur in the rock. The Bijaigarh Shales are carbonaceous and pyritiferous indicating reducing condition of deposition in the sedimentary mileau and lenses of vitrain (a coal type) are occasionally found. The pyrite horizon is thickened to more than a metre around Amjhor area off Dehri-on-Sone and is being mined for production of sulphur and sulphuric acid as it contains about 40 % of sulphur.

The Rewa Group overlies the Kaimurs with a diamond-bearing conglomerate in between. The position of the conglomerate is sometimes confusing as different geologists had opined differently about it. More detailed field work may be needed to come to a solution of the real stratigraphic position and status of the conglomerate.

The Bhander Group is also separated from the underlying Rewas by another diamond-bearing conglomerate. The Bhander sandstone is typically red coloured with streaks and dots of white. They are thick and yield good blocks for building purpose. The limestone grades into shale. The Sirbu shales appear to be similar to salt-pseudomorph shales of Salt Range.

The Vindhyans are thickest in the south and west (≈ 3300 m). The margins show good exposures of sandstone which form scarp topography or plateaux for the Vindhyans in general. They are thought to be lying below Indogangetic alluvium; in the west they get separated from Aravallis by the thrust along which a part of the Chambal river flows. The Kurnools in the Cuddapah basin are considered as Vindhyans which have equivalents also in the Himalayas.

The economic minerals and rocks of Vindhyan Supergroup make the sequence important for search and exploration. The diamond, sourced from Majhgawan, off Panna region in the north and Wajrakarur of A. P. in the south, are confined to the Kimberlite rock-type. The lineament west of the Eastern Ghats Supergroup is the probable corridor along which these rocks are supposed to be intruding as found at many places in Odisha. Similar rocks are found close to this lineament east of Jaipur to Sambalpur. These Kimberlite - pipes are of Kaimur and / or Pre-Kaimur age.

Pyrite, limestone and building stones are the other materials of economic considerations of the Vindhyans. Red Fort, Fatepur Sikri and other constructions during Mughal period were made by Vindhyan sandstone.

Decomposed sandstone, with removal of felspathic and other undesirable components, give excellent glass sand near Allahbad. On further careful separation of these materials optical glass-grade sand of quartzite may be found.

## 7.8. GONDWANA SUPERGROUP

### 7.8.1. Introduction

The term “Gondwana” was given to a group of rocks by Medlicot in the year 1872 after an ancient tribe "Gond" of Madhya Pradesh where these rocks were studied for the first time. Later on, the name Gondwana was extended to similar rocks occurring in other parts of the world. Indian peninsula witnessed a period of non-deposition after the deformation and upliftment of the Vindhyan rocks which continued upto Upper Paleozoic time i.e. Upper Carboniferous. During this time, spectacular channges occurred in the distribution of land and sea in the globe in addition to the mountain building episodes. In this period a large undivided landmass known as “Gondwanaland” existed comprising of present day India, Australia, South America, Antarctica, Africa and Madagascar. The similarities of floral and faunal assemblages, sedimentation history, climate, lithology etc. in addition to jig-saw fitting of their margins indicate their close connections. The sequence which started in Upper Carboniferous time continued upto Lower Cretaceous with a long sedimentation history of about 180 million years. Although the sedimentation started with a glacial deposit at the base, lacustrine and fluviatile deposits are most prevalent in the 6,000 to 7,000 metre thick Gondwana succession.

### 7.8.2. Distribution of Gondwana Rocks in India

The sequence of Gondwana rocks are named differently. It was named as Gondwana system, Gondwana Group etc. but because of their very big sedimentation history, subdivisions with clearcut differences in climatic, floral and lithological factors, this is named as “Gondwana Supergroup”. This supergroup of rocks is further subdivided into different groups, formations etc.

The Gondwana sediments in India in most cases are deposited in faulted troughs or grabens. The three river valley grabens where Gondwana rocks are located are:

(a) Narmada - Son - Damodar graben trending roughly east - west.

(b) Mahanadi graben trending roughly NW - SE

(c) Godavari graben - Trending roughly NW - SE

In addition to these three, Gondwana rocks also occur in the following areas.

(a) Himalayan foot hills of Kashmir and Assam

(b) Rajmahal area of Bihar

(c) Detached outcrops in Rewa, Saurastra, Kutch, Phulbani (Odisha), Chennai, Ongole, Trichinopoly etc.

The distribution of Gondwana rocks, in India is given in (Fig. 7.2).

### 7.8.3. Classification of the Gondwana Supergroup

The classification of Gondwana Supergroup is a subject of controversy. The two fold classification was proposed by Oldham (1893), Cotter (1917), Fox (1931), Krishnan, Robinson (1967) and others. According to them, the whole sequence is divided into Lower and Upper Gondwana. The Lower Gondwana rocks, with age ranging of Upper Carboniferous to Lower Tsiassic, are characterised by the presence of *Glossopteris* flora with pteridospherms, cordaitales, equisetales, spenophyllales etc. The Upper Gondwana rocks ranging in age from Upper Triassic to Lower Cretaceous and are characterised by the presence of *Ptilophyllum* flora with more evolved group of plants like ferns, cycads, conrifers etc. According to some workers, the Lower Gondwanas are separated from the Upper Gondwanas by an unconformity. Change in climatic conditions is also cited as the reason for distinct floral assemblages in both the periods.

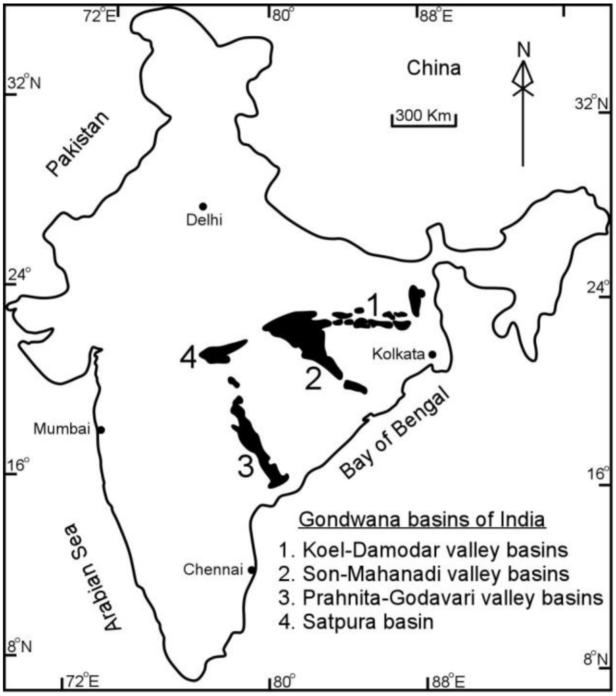


**Fig. 7.2: Gondwana basins of India**

The three fold classification subdividing the Gondwana sequence into Lower, Middle and Upper Gondwana was proposed by Feistmantel (1880), Vredenberg (1910), Wadia (1926) and others. Their classifications are based on climatic differences and floral and faunal characteristics. The Lower Gondwana rocks were formed under a warm and humid climate and host a number of coal seams. The Middle Gondwana rocks were formed under warm and dry climatic conditions prevailed during Triassic age. The Upper Gondwana sediments were deposited again under a warm and humid climate. Since there is similarity of the upper part of the Lower Gondwana with that of the lower part of Upper Gondwana, the third division i.e. Middle Gondwana is incorporated between the Lower and Upper Gondwana sequences by the proposers of threefold classification.

### 7.8.4. Climate during the Gondwana Period

Gondwana sequence starts with a glacial deposit at the base. Presence of tillite, boulder bed, striated pavements indicate glacial climate during the begining of the Gondwana sedimentation. The movement of the glaciers was in a northerly to north-westerly direction in Godavari valley whereas in the Damodar valley region it was in a southerly direction.

The glacial climate in the Indian Peninsula was followed by humid sub-tropical climate, with deposition of coaliferous sediments in the swamps by streams. The sedimentary rocks include a thick repetitive sequence of sandstone, shale with numerous coal seams. This warm humid climate was followed by a dry, warm, arid climate with deposition of a thick sequence of iron stone shales. The dry climate is responsible for disappearance of Glossopteris flora which was characteristic of the Lower Gondwana rocks. The dry climate of the Lower Triassic period was again followed by mild temperate and wet climatic conditions which favoured floral assemblages like *Ptilophyllum* flora.

### 7.8.5 Succession of the Gondwana Supergroup

The Gondwana sequence is separated from the Archaean / Proterozoic rocks by an unconfarmity at the base. The subdivision of the Gondwana Supergoup rocks of India with their age is given in Table 7.15.

**Table 7.15 - Stratigraphic succession of the rocks belonging to Gondwana Supergroup**

| Subdivision | Group | Formation | Age |
|---|---|---|---|
| | | Umia | Lower Cretaceous |
| | Jabalpur | Jabalpur | Upper Jurassic |
| | | Chaugan | |
| Upper Gondwana | Rajmahal | Kota | Middle Jurassic |
| | | Rajmahal | Lower Jurassic |
| | Mahadeva | Maleri | Upper Triassic |
| | | Panchmari | Upper Triassic |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | | | |
| | Panchet | Panchet | Lower Triassic |
| | | Raniganj | Upper Permian |
| Upper Gondwana | Damuda | Barren Measures | Middle Permian |
| | | Barakar | Lower Permian |
| | | Karharbari | Lower Permian |
| | Talchir | Talchir | Upper Carboniferous |

**7.8.5.1. Talchir Formation:** This was first described from Talcher area of Odisha. This formation comprises a basal Boulder Bed, overlain by greenish sandstone and shale sequence. The formation is characterised by Lower Gondwana fossils like *Glossopteris indica, Gangamopteris cyclopteroides, Vertebraria indica,* *Noeggerathiopsis hislopi* etc. This group lies unconformably on the Precambrian rocks. The Boulder bed also known as Talchir Tillite is a typical glacial and fluvio-glacial deposit. It comprises well rounded pebbles and boulders set in a fine grained matrix. The thickness of the Boulder Bed varies from 15 to 60 m. The boulders are composed of gneises, granites, quartzite, slate, amphibolite etc. which are suggested to be derived from basement rocks. Evidences of glacial transport are smoothened, striated and polished boulders; polished and grooved glacial pavements at the base of the Talchir sedimentation. The Talchir Formation is made up of predominantly greenish shales also known as needle shales and a few associated bands of sandstones containing unaltered grains of feldspar. The upper most part contains mainly sandstone and siltstone-shale- mudstone horizons. The thickness of the Talchir formation varies form 150 to 300 m.

**7.8.5.2. Damuda Group:** This group rests conformably on the Talchir Formation with distinct lithological assemblages. The nomenclature of this group is from the Damodar river (earlier spelt as Damuda river) flowing in the southern parts of Rajmahal hills and Ranchi plateau. The Damuda Group is characterised by very thick cyclic sedimentation of more than 500 m comprising of conglomerate, sandstone and shale (sometimes carbonaceous). The thickness of the coal seams varies considerably from a few cm to more than 40 m, but these are usually less than 5m thick.

The Damuda Group has been subdivided into four formations on the basis of difference in lithology, fossil content, climatic factors etc. viz.

(a) Karharbari Formation (b) Barakar Formation

(c) Barren Measures Formation and (d) Raniganj Formation

Karharbari Formation is the basal member of the Damuda Group followed by Barakar, Barren Measures and Raniganj formations. With change over of the glacial climate to warm humid climate, nature of sedimentation also changed. There is general decrease in grain size and thickness of cross-bedded units of the sedimentary rocks from the Karharbari sequence upwards. The maturity of the sediment increased upwards. A description of the individual formations is given below.

**(a) Karharbari Formation:** It consists of sandstone, grit, conglomerate, shales and coal seams. The rocks of this formation contain sediments of the Talchir Formation indicating the fact that at least a part of the sediments are derived from the Talchir Formation. The sandstones of this group contain angular to subangular particles of quartz and feldspar indicating their lesser distance of transport. The formation is characterised by *Gondwanidium-Buriadia* mega-floral assemblage.

**(b) Barakar Formation:** This formation lies over the Karharbari Formation with an unconformity at the base. It contains cyclic succession of conglomerate, grit, sandstone, shales and coal seams. The thickness of this formation in Raniganj area is about 1700 m but, very less (less then 100m) in Godavari basin. The formation is named after the Barakar river. It contains a number of coal seams and is the most important coal-bearing horizon of Lower Gondwanas. Some of the important coal seams like Korba and Kargali seams are more than 30 m thick. The coal seams are so frequent that, their thickness is almost one ninth of the total thickness of the Barakar sediments. The conglomerates of the Barakar Formation contain pebbles of granite and quartzites of Precambrian age. The sandstones are coarse- to medium-grained, light in colour and are characterised by current bedding structure. Their feldspar content is relatively high but are usually kaolinised. This formation also contains fairly large china clay deposits.

**(c) Barren Measures Formation:** The rocks of the Barakar Formation are overlain by sandstones, carbonaceous shales with nodules of clay iron stones. In eastern India, this formation is represented by reddish and brownish coloured shales which is also known as "Ironstone shale Formation". This formation is devoid of coal seams but in some areas like Raniganj coal field area, workable deposits of sideritic iron ore is present; this is known as Kulti Formation and Motur Formation in Narmada valley.

**(d) Raniganj Formation:** The rocks of this formation overlie the Barren Measures Formation which is about 1000 m thick. This formation is composed of sandstone, shales and coal seams. The sandstones are relatively fine grained than those of the sandstones of Barakar Formation. This formation is characteristically developed in the Raniganj coal field area and is of Upper Permian age containing characteristic Lower Gondwana fossils. The Raniganj Formation is correlated with Kamthi Formation of the Godavari graben that contains red and grey argillaceous sandstones and conglomenates interstratifed with shales.

**7.8.5.3. Panchet Formation:** This formation is named after Panchet hills in Manbhum region and is well developed in Raniganj coalfield area. It lies over the Damuda Group with an unconformity at the base. The thickness of this formation varies from 250 to 700 m and is devoid of coal. It is constituted of alternating beds of coarse-grained, feldspathic, micaceous and cross bedded sandstones, thin bedded green shales and bedded variegated clays. The greenish, buff and brownish sandstones and shales in the lower part are overlain by greyish, micaceous and feldspathic sandstones and shales in the upper part. The colour of the sandstone indicates their deposition in an arid and dry climatic condition. The Panchet formation is characterised by *Glossopteris, Schizoneura* etc. and represents the topmost horizon of the Lower Gondwanas of India. Presence of vertebrate fauna indicates its Triassic age.

**7.8.5.4. Mahadeva Group:** This group is named after the Mahadeva Hills near Panchmari where the Lower Gondwana rocks are overlain unconformably by thick succession of sandstone, clay and conglomerate. This group is subdivided into two formations, viz. Panchmari and Maleri.

The Panchmari Formation attains a thickness of about 750 m and comprises of red and buff sandstones with red clays at the base and top. Hematitic clay and veins of ferruginous matter are also present. The Panchmari Formation is devoid of carbonaceous matter but clay layers contain leaf impressions. The Durgapur beds, Dubrajpur sandstones and other Supra-Panchet rocks of Damodar valley are considered equivalent to the Panchmari Formation.

The Maleri Formation is exposed in the Pranhita - Godavari valley along a NW - SE belt and composed of red clays and subordinate amounts of calcareous sandsotnes. Fossils are preserved in the red clay beds.

**7.8.5.5 Rajmahal Formation:** The type area of the Rajmahal Formation occurs at the head of the Ganges delta near the border of Bihar and Bengal. This group is further subdivided into two units i.e. Rajmahal and Kota.

The Rajmahal Formation is exposed in the Rajmahal hill area of Bihar and West Bengal. It is composed mostly of basic lava flows with a thickness of about 450 to 600 m. These lava flows are intercalated with carbonaceous shales, sandstones, clays etc. These sedimentary units, which are known as intertrappeans, range in thickness from 1.5 to 6 m and contain a number of plant fossils. The lava flows are both massive and vescicular and contain minerals like plagioelase (labradorite), pyroxene (augite), iron oxides, primary glass (no crystallisation) and some secondary minerals. Presence of plant fossils in the intertrappeans indicate a Jurassic age for this formation.

The Rajmahal Formation is succeeded by the Kota Formation which is characteristically present in the Godavari valley area and attains a thickness of about 650 m. It is made up of sandstones and grits alongwith thin seams of coal and bands of limestone and clay.

**7.8.5.6. Jabalpur Formation:** The Jabalpur Formation which is exposed in the Satpura area is subdivided into basal Chaugan beds and Jabalpur Formation lying above it. The Chaugan beds consist of white and light coloured clays, shales and massive soft sandstones. Some of the shales are carbonaceous and contain thin bands of coal which are uneconomic.

The Jabalpur Formation is composed of light coloured clays, carbonaceous shales and massive and friable sandstones. The Chaugan beds and Jabalpur Formation are Middle to Upper Jurassic in age.

The uppermost division of the Upper Gondwanas is developed in Kutch area of Gujurat and these are interstratified with marine sediments. This formation consists of "Barren sandstones" belonging to Early Cretaceous age.

**7.8.6. Gondwanas of the Himalayan Region**

The equivalents of Lower Gondwana sequences of the Peninsula are exposed in the Darjeeling district of West Bengal, Rangit valley of Sikkim and

Siang district of Arunachal Pradesh. In the Darjeeling and Sikkim areas, the Gondwana sequence starts with a basal pebble slate Formation comprising of pebbly to gritty slates, lithic wakes, quartzites, argillites, volcanoclasts, mars etc.

This is overlain by Damuda Group comprising of pyritiferous and carbonaceous shale, silt stone, calcareous sandstone and feldspathic wacke. These rocks contain abundant floral assemblage such as *Glossopteris indica,* G. *communis, G.damudica, Gangamopteris cyclopteroides, Vertebraria indica, Phyllotheca sp.* and *Schizoneura sp.*

**7.8.7. Gondwana rocks of Odisha**

In Odisha, Gondwana rocks occupy an area of about 1,200 $km^2$ and are exposed in the following area.

| **Basin / Area** | **District** | **Age** |
|---|---|---|
| Talcher Basin | Angul / Dhenkanal | Upper Carbonifeous to Triassic |
| Ib-river Basin | Sambalpur, Jharsuguda, Sundargarh | Upper Carbonifeous to Triassic |

In addition to these two major basins, Gondwana rocks occur at Katrangia area of Phulbani district, Gaisilat and Salebhatta area of Bolangir district, Athmallik area of Angul-Boudh districts, Athgarh area of Cuttack, Khurdha districts and Chhatrapur area of Ganjam district. The stratigraphic succession of Gondwana rocks in Odisha is given in Table 7.16.

**7.8.8. Fossils present in different stratigraphic horizons**

The typical fossils present in different stratigraphic units of the Gondwana Supergroup are given below:

**(a) Talchir Formation:** Plant fossils: *Glossopteris indica, Gangamopteris cyclopteroides, Vertebraria indica, Noeggerathiopsis hislopi*. Seed ferns, monosaccates and disaccates trilete and monolete micropores.

**Table 7.16 - Stratigraphy of Gondwana rocks of Odisha**

| Age | Group | Formation | Lithology | Area |
|---|---|---|---|---|
| Lr. Cretaceous | Upper Gondwana | Athgarh | Conglomerate, Shale, Sandstone | Atgarh basin |
| Lr. to Middle Triassic | Middle Gondwana | Kamthi | Conglomenate, Ferruginous sandstone, red shales | Ib river Basin Talcher Basin |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | | | | |
| Upper Permian | | Raniganj | Sandstone, siltstone, clay, coal | Ib river basin |
| Middle Permian | Lower Gondwana (Damuda Group) | Barren Measures | Sandstone, shale, clay, Ironstone shale | Ib river basin Talcher basin |
| Lower Permian | | Barakar | Conglomenate, sandstone shale, fire clay coal | Talcher, Ib river, Athmallik, Katringia, Gaisilat |
| Lower Permian | | Karhabari | Conglomenate, sandstones shale, fire clay coal | Talcher, Ib river, Gaisilat |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | | | | |
| Up. Carboniferous | | Talchir | Boulder bed, green shale, sandstone | Talcher, Ib river, Gaisilat |
| ~~~~~~~~~~~~~~~~~~~~~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~ | | | | |
| Precambrian - Gneisses, amphibolites, granites etc | | | | |

Animal fossils: Annelid tracks, foot prints of the toed animals.

**(b) Karharbari Fonmition:** *Glossopteris indica* and other species, *Gangamopteris cyclopteroides* and other species, *Vertebraria indica, Noeggerathiopsis hislopi* and other species, *Neuropteridium (Gondwanidium) validum, Schizoneura gondwanesis, Buriadia heterophylla* etc.

**(c) Barakar Formation:** *Glossopteris indica* and other species, *Gangamopteris cyclopteriodes, Sphenopteris, Schizoneura gondwanesis, Phyllotheca, Noeggerathiopsis hislopi, Dadoxylon indicum, Taeniopieris, Spenophyllum speciosum, Walkomiella, Pseudoctenis, Barakaria* etc.

**(d) Barren Measures Formation:** *Glossopteris indica, Glossopteris conspicua, Gangamopteris cyclopteroides, Noeggerathiopsis hislopi, Cyclodendron* etc.

**(e) Raniganj Formation:** *Glossopteris indica* and some other species, *Gangamopteris whittiana, Vertebraria indica* and some other species, *Sphenopteris, Pecopteris, Noeggerathiopsis hislopi, Taeniopteris, Schizoneura gondwanensis, phyllotheca indica* etc.

**(f) Panchet Formation:**

Flora: *Glossopteris sp, Schizoneura sp, Pecopteris sp, Cyclopteris sp, Samorpsis sp, Taeniopteris sp*

Vertebrate: Fishes, amphibians, reptiles, thecodont.

Invertebrate: *Esthiids, Cyzicus, Estheriella* and insect remains.

**(g) Maleri Formation:** Fishes; *Paradapedon, Phytosaurian* and other reptiles, Amphibians, Coprolites, Unionids, Fossil tree trunk.

**(h) Rajmahal Formation:** *Ptilophyllum acutifolium, Otozamites bengalensis, Dictyozamites, Taeniopteris spatulata, Nilsonnia, Equisetites rajamahalensis, Lycopodites, Marattiopsis, Cladophlebis denticulata, Gleichenites, Elatocaldus; Podozamites.*

**(i) Kota Formation:** *Ptilophyllum acutifolium, Taeniopteris spatulata, Elatocladus, Araucarites, Fishes - Lepidotns, Tetragonolepis* etc.

**(j) Chaugan Beds:** *Taeniopteris spatulata, Nilssonia, Dictyozamites, Pagiophyllum.*

**(h) Jabalpur Formation:** *Ptilophyllum acutifolium, Otozamites, Elatocladus, Plagiophyllum, Brachyphyllum, Araucarites, Cladophlebis.*

**(i) Umia Formation:** *Pelecypods - Trigona, Plant fossils - Ptilophyllum, Cladophlebis, Elatocladus, Araucarites etc.*

### 7.8.9. Igneous rocks in the Gondwanas

The coal fields of India such as Stapura, Son-Damodar, Assam are traversed by dikes and sills of dolerites, basalts etc. Some of these dikes are affected by faults where as others are found along the faults. The intrusives of Satpura and Rewa areas are equivalent of Deccan Traps but those of Damodar valley and Assam are equivalent to Rajmahal age (precursor of Deccan trap?).

In the coal field areas of Damodar valley, Giridih and Gondwana rocks of Darjeeling foot hills, dikes and sill of mica - peridotite, lamprophyre (mica rich ultrabasic rocks containing olivine, calcite, dolomite, bronze coloured mica and apatite) intrude into coal seams or intrude along junction of sandstone and coal seams. Because of this, the coal has been devolatilised and converted into a kind of coke called *jhama.*

The igneous intrusives are comparatively rare in the Gondwana rocks of Godavari and Mahanadi valleys.

### 7.8.10 Economic minerals in the Gondwanas

The Gondwana rocks contain coal, clay (fire clay, fuller's earth, bentonite) and iron ores. The sandstone are also utilized as building stones.

**(a) Coal**

Coal deposits of the Godwanas are found in Damuda group i.e. in Karharbari. Barakar and Raniganj formations. Coal seams are also associated with Kota, Jabalpur, Chikiala and Umia formations, but their thickness is much less and the grade is inferior.

Most important coal seams in India are found in the Barakar Formations. Coal seams in Raniganj Formation are found in Raniganj, Jharia and Bokaro coal field areas. Coal is usually banded with dull and bright coal bands. There are more than 57 Gondwana coalfields in India out of which Odisha has two only. The major Gondwana coalfields of India are given below:

**Damodar valley area**

(1) Jharia (2) Raniganj (3) Bokaro (4) Chandrapura (5) South Karanpura (6) North Karanpura.

**Godavari valley area**

(1) Singareni (2) Kamaram (3) Lingala (4) Kothogudem.

**Odisha**

(1) Talcher (2) Ib - valley areas

**Sone valley area**

(1) Singrauli (2) Umaria

**Wardha valley**

(1) Chanda (2) Warora (3) Ballarpur

**Chhatisgarh**

(1) Jhilimili (2) Bisrampur (3) Lakhanpur (4) Korba

**Hazaribag**

(1) Giridih (2) Itkhori

**(b) Clay deposits**

Various clay deposits are associated with the Gondwana rocks. The coal seams of the Gondwanas especially those associated with the Barakar Formation contain clay deposits. These fire clay deposits are being mined for manufacture of refractory bricks. Fuller‟s earth.is mined at Jabalpur and Katri areas. Bentonitic clays are mined from Upper Gondwana rocks in Tamilnadu. White clay and moulding sand are mined from Rajmahal Hills. In Odisha, fire clay is being mined at Talbasta area of Khurda district.

**(c) Iron Ore**

Sideritic iron ore and their oxidized products occur in the Iron stone shales of Barren Measures Formation. These are mined in Raniganj coal field areas. Similar occurrences are also found in Auranga and Hutar coal fields. Sandstones of Kamthi and Mahadeva formations also contain pockets of limonitic iron ore and both yellow and red coloured ochres.

**(d) Building stones**

The sandstones of Karharbari, Barakar, Raniganj, Kamthi and Panchmari formations are used as building materials for construction of walls and floors of the buildings. Atgarh sandstones of Odisha are used for beautiful carvings and were utilized in the temples of Puri, Bhubaneswar and Konark. A number of caves in Athgarh sandstone were built in the Khandagiri area near Bhubaneswar.

## 7.9. GEOLOGY OF ODISHA

### 7.9.1. Introduction

The state of Odisha lies in the south-eastern part of India bordered by West Bengal and Jharkhand states in the north, Chattishgarh in the west while Andhra Pradesh is to the south. To the east is the Bay of Bengal that gives a coast-line of about 480 km for Odisha along Baleswar, Bhadrak, Kendrapara, Jagatsinghpur, Puri to Ganjam districts. The Chilka lake, the pride of India, as the largest lagoon of the country, lies south of Puri and north-east of Ganjam districts between Bhusandapur and Talo Huma. The eastern and central parts of all these districts are covered by alluvium that exhibits evidence of „neotectonism". Below the alluvium at different depths and at different places are rocks of „Eastern Ghats Supergroup (EGSG)" with charnockite, khondalite, quartzite, calc-granulite and granitic rocks. But the Iron Ore Supergroup (IOSG) rocks are not much known to exist this way in the northern part of the alluvium tract possibly due to structural configuration. The western parts of all these districts are covered by rocks of Precambrian age. At Baleswar and Puri, Tertiary deposits exist with fossils of Ostrea, crabs etc. Holocene and subrecent deposits occur on hill slopes as talus and unconsolidated sediments.

Brahmani and Mahanadi rivers are jointly responsible physiographically to separate Orissa into two main geological regions

1. Iron Ore Supergroup (IOSG) region in the north

2. Eastern Ghats Supergroup (EGSG) region in the south and rocks of Gondwana Supergroup with coal deposits, come in the middle. The first two Supergroups come somewhat in juxtaposition along east-west running Sukinda thrust (chromite occurrences related to it ?) which is the northern boundary fault of Gondwana basin (graben); the southern boundary passes roughly east-west north of Khurda town, south of Bhubaneswar. The Eastern Ghats Supergroup apparently (?) ends up against the Sukinda thrust, although some workers opine its extension further north below Iron are Supergroup to be exposed near north of Samal area. The northern extension of Iron are Supergroup, somewhat limited to Singhbhum copper thrust that runs also east-west from Duarpuram up to Baharagora turning southward east of copper mine of Jharkhand at Mosabani, is up to Kesarpur in Mayurbhanj (copper reported) and beyond up to at least west of Dukura off Baripada along the base of Simlipal hills. Here boudinised sheared quartzite same as that of Rakhamines are discontinuously traced between Bangiriposi and Dukura where galena and other mineral occurrence are reported. Both these thrusts in the north and south of Iron ore Supergroup are mineral producing zones.

More important than these two in size are the two subparallel NNE-SSW trending lineaments which separate the alluvial tract and the rolling topography of Bolangir - Kalahandi region (west Odisha) from the middle mountainous tract. The eastern lineament controls the eastern configuration of India considerably; the western one delimits the extension of Eastern Ghats Supergroup rocks further west of Tel-Mahanadi confluence. Gandhamardan hill, in Bolangir, is an outlier of Eastern Ghats Supergroup. These two broadly control the structural, geomorphic and petrologic evolution of this part of India. When expanded, they become extensional features of world tectonics regionalized around Indian subcontinent and Euro-Asian plate with Tethys Sea in between. More on these aspects will be discussed in higher levels of study.

Geology, essentially a field science especially in this country, good field work is needed to know detailed regional geology set-up. Without good field work geology is never well understood. Maps are prepared, based on plottings of data collected from the field on toposheets, which becomes the base of the future geologic studies. Rocks and their attitudes are plotted and, thus, a map, prepared this way, is the base data for any region. It can be done on different scales for different purposes.

Rivers flow along natural slopes of the land and curve their own beds on rocks that show both the third dimension and the characters of rocks. Hence, river valleys are good places to start field work. Alluvium-filled river beds do not show hard rocks frequently and the alluvium is considered as „mantle" over the pre-existing older rocks. The Odishan rivers show younger Quaternary alluvium in the deltas.

Valentine Ball is the one who has done pioneering work on the geology of Odisha. In 1876 he wrote on the Naraj sandstone and the intrusive. No earlier publications are known to exist. At Naraj the Mahanadi enters into the deltaic stage; around this place also passes the eastern lineament mentioned above. Ball also described about the hot spring at Atri near Khordha. Walker in 1904, mentioned about a rock in Kalahandi, which he named as khondalite after Khond-clan of Kalahandi, in whose area it is excellently developed. It is an important rock of the Eastern Ghats Supergroup. Stronalite in Alpine rocks are considered to be similar to Khondalite. Geological Survey of India published a book on Geology of Odisha and the mineral riches but covered only the then six districts as the feudatory states (then not in Odisha) were not studied by them. These were the storehouse of many minerals. Pramath Nath Bose in the first decade of last century traced iron ore in Mayurbhanj district based on which TISCO was started in 1911. Local studies were made by the then existing kings in their kingdoms and other interested parties made such endeavours in different areas. The first report on the Geology of the present state of Odisha was possibly the one published in the „Gazetteers of Odisha" in the nineties of the last century (printed in 1982). The Society of Geoscientists and Allied Technologists, Bhubaneswar has produced a volume on „Geology and mineral resources" that was later revised and reprinted in 2006.

Details of the geology and challenges putforth by the rocks and minerals are not discussed so far anywhere because of various reasons they were to be very brief. This latest publication has also been reduced down drastically as the students are new to the subject and the subject is constrained by „mark" in the syllabus of courses of studies. The author expects a more detailed descriptive volume within two years so that these students can get more in-depth-study-materials on different aspects of the geology of Odisha for research and factual improvement.

**7.9.2. Physical Geology and Physiography**

A physical map of Odisha shows three contrasting regions with their own characters. They are (1) Eastern Coastal Plain, (2) Middle Upland and Plateau, (3) Western undulating and rolling plain.

As already mentioned, the two mega-lineaments separate these three divisions physically. Their brief descriptions are given below.

**7.9.2.1. Eastern Coastal Plain:** This starts in the north from south of Digha (tourist spot of West Bengal) and runs upto south of Ganjam without break. The rivers dumped their detritus east of the Eastern megalineament that has produced a few parallel step-faults with throw to the east and shows many complicated structural pattern as proved by geophysical studies from time to time, khondalites and charnockites, forming hills are in-liers in the delta (Ex-Dhauli, Assia and many more). Assia hill is the eastern most known exposure of EGSG from where the trend of the strike swerves westward and runs upto and beyond Tel-Mohanadi confluence in Bolangir ditrict.

West of the Barmes zone the sea wind creates a zone of sandy ridges and valleys: The „Red Soil" on the back of the sand dunes has 15-18% of heavy minerals. Rao and Acharya studied their behaviour around Gopalpur.

A peculiar feature noted in the delta is the tendency of a dextral turning of the river branches and with time have even flowed south-westward! The lagoon status of Chilika is due to sand bars blocking the seaconnection. These bars often cut now by the Chilika development authorities have allowed to maintain the own status of Chilika as a lagoon and fishes including dolphins have come and keep coming into the lake. Kalijai island is an extension of Khondalite from the landmass into the lake, while Chadeihaga hill is an anorthosite spot and Mamu-Bhanja hills are the same anorthosite confirmining the presence of the eastern mega-lineament. Chilika was of bigger size and is now silted from the north and Daya river cannot any more reach to dump its own sediment in the lake. The average depth of the lake is hardly four metres.

**7.9.2.2. Middle upland and plateau:** The middle part of Odisha is covered by hills, mountains and plateaux. The highest peak is at Koraput and the next one is Meghasini in Simlipal. The Precambrian metamorphic rocks of sedimentary parentage produce the hills while granite rocks produce the plateaux and rolling valleys; the volcanics produce flat-topped hills in Keonjhar. The same hill types (flat on top) are found around Koraput and they are mostly by Khondalites and known as „mesas‟ (Bauxite deposits occur on them). The forest of Odisha is confined to this region and naturally are less inhabited.

**7.9.2.3. Western undulating and rolling plain:** West of Crookshank‟s fault is this region that exhibits more than one granite. To its west are N - S trending Vindhyan rocks dipping west which have created a scarp-topography with a "trellies" drainage while the hill tract in the mid-upland has a dendritic one.

**7.9.3. Study of Geology**

The study of geology leads to search, identify and know the rocks, associated mineral deposits and soils. Water is one that demands special attention and „environment‟ is becoming an important aspect of study in geology. This is for immediate societal need. One can know many aspects of the past in terms of billions of years. With good geological knowledge one can understand about minerals which are found in different rocks in different areas. Minerals are assets for any country and that is why geology is an excellent subject to develop the society materialistically. Coupled with laboratory study, this subject brings in information about potential wealth of any nation and this is equally true for India without jeopardising the environmental conditions.

The geology of Odisha has now been studied with certain thoroughness by the Geological Survey of India and its Regional office at Bhubaneswar. The entire state has been mapped on a 1 cm toposheet scale (1 cm = 1 km scale). The Directorates of Geology and Mining, Orissa Mining Corporation, Central Ground Water Board, IMMT (formerly RRL), Universities and individuals give the input more and more and situation has improved considerably to appreciate the geology in a better way.

The rocks of this state mostly belong to the Precambrian age. One finds gaps in the status of litho-deposition with time as will be seen in stratigraphic table.

Odisha claims to have one of the oldest rocks of the earth at Champua which is a variant of the granites of Keonjhar and Singhbhum. Rocks don"t follow administrative boundaries and as such the granites are found both in Singhbhum and Kenojhar districts and so also are the sedimentaries. They form a complex with variations in them in time and space. The sediments formed in valleys are metamorphosed to fuchsite-quartzite, mica-schist, hornblende-schist, etc. and may be equivalent to the Sargurs of Kamataka; the latter are considered to be the oldest metasediments of India. As in this region the oldest Indian granites are available (Singhbhum granite complex - SGC), the sedimentaries around it / them are likely to be one of the oldest sediments as well. Due to non-existence of any work and literature of geology, Odisha is normally referred to as "Singhbhum-Odisha-Craton" etc. The former, is a district of Jharkhand while the latter is a State. This incongruity is slowly being lifted and "Singhbhum - Keonjhar Craton" is replacing the previous term.

The sequence of rocks has been documented in the Gazzetteers of Odisha (1990). Below is given sequence of the rocks in a broad way. Only a few important places have been described in some details.

The descriptions of IOSG and EGSG have here been separately made. Their age-relationship is not discussed here. It is the opinion of the author that rocks of the Eastern Ghats Supergroup are older than that of the Iron ore Supergroup although, at times, an opposite picture seemingly crops up.

### 7.9.4. Broad Stratigraphy of Odisha

**Post Cambrian**

Laterite

Tuff-deposits (from volcaneous of the world)

Younger alluvium

Older alluvium

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Baripada beds

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Basic lava flows

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Gondwana Rocks

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

**Precambrian**

Vindhyan S.G.

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Kolhan Group

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Gangpur Group and its equivalents

Basic intrusives and traps

Ultrabasic intrusion

Granites

Hybabyssal intrusives (dolerite and quartz porphyry)

Iron Ore Supergroup and its equivalent

Older metamorphics and their equivalents around the granite

Basement granite complex

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~~

Other intrusions (anorthosite, nepheline-syenite, carbonatite etc.)

Granite intrusions (in time and space)

~~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~~

Eastern Ghats Supergroup

Older granite gneisses (Basement later anatexised and granitised)

It has already been discussed that the geology of north Odisha is entirely different from that of the south in all aspects. As such it is proper to discuss the geology of Odisha in two parts essentially.

**7.9.4.1. North Odisha (Precambrian):** Because of the mineral riches, this part has been visited by geologists frequently; this resulted in discovering ore deposits like that of Joda, Gorumahisani iron ore deposits, Kuanr Bauxite (off Keonjhar) or Kansa-Saruabil chromite deposits and other aspects of geology were naturally studied as well. This has brought to light that there are three iron-ore basins in time. Forty years back this thinking was not there. Problems of Mahagiri quartzite, south of chromite deposit of Sukinda, remain unsolved as to its time of formation.

Similarly river capture of Mahanadi by Tel river, of a misfit valley off Tikra Nala etc. need more attention as they are of great importance. All these make the Odishan geology very interesting.

The map (Fig. 7.3) broadly shows that Singhbhum granite and the Keonjhar granite (SKGC) are one and the same which are one of the oldest rocks of the country forming a platform around which Precambrain sediments have formed and got metamorphosed because of the magmatic heat and pressure due to later repeated intrusions. These metasediments, considered as part of the early sediments of the earth, are correlatable with the Sargurs of Kamataka; these are thought to be the oldest in the country as mentioned earlier.

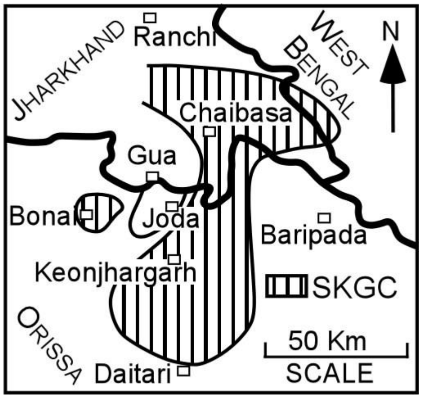


Fig. 7.3: Singhbhum – Keonjhar granite complex

Rafts and inclusions are more frequent in the peripheral parts of the granite because of their higher altitude (thereby lesser erosion) of the magmatic rocks. The Dhanjori quartzite shows direction of flow of water (from current bedding studies) in all directions suggesting a higher landmass of granite east of Keonjhargarh town and studies on granite exhumation can also be done.

The three banded iron formations (BIFs) in Odisha bring in rocks of about 2,000 m.y. of age together into one supergroup. The Joda-Koira iron ore basin is an intracratonic (faulted) basin between Keonjhar and Bonai granites. These faults trend in the same way as the dolerites those intrude Keonjhar granites. The entire North Odisha has three to four dykes-sets of different time periods. Palasponga dyke, the longest known dyke of the country (width ≈ ¾ km) is considered the feeder of the trap rock lying west of Gandmardan hill off Suakati. This trap is a product of fissure eruption; no central eruption features have been found inside the trap area. When the unexposed rocks below the trap can be studied, many new mineral occurrences and more geological informations will be available.

East of Keonjhar granite complex is the Similipal hill with alternating quartzite (metasediment) and volcanic flow and the duo form a Cauldronlike basin. Iyengar has done extensive studies on them. Tulsi Dongr, in old Koraput district has similar sequential features and outcrops. These two need comparative studies on their genesis. The Joda-Koira iron ore basin has the best grade ore in Odisha and the total tonnage is yet to be fully known. Jones in 1934, mapped the area and later Acharya, Sarangi, Sahoo, Singh and many others have worked on these rocks. The sediments are:

(a) Upper shale (Pinkish and Whitish)

(b) Banded Hematite Quartzite also chert / jasper (B.H.Q.-as it is called)

(c) Lower shale (variegated)

BHQ, being very hard forms the hills giving a "U" shape and because of its shape, Jones named it as "Horse Shoe" basin. The iron ore occurs above, inside and below BHQ and is of excellent grade. The lower-shale contains manganese deposits mostly along fault zones. Later weathering processes have upgraded the deposits. This is the youngest basin of iron ore and forms a northward plunging syncline whose axis has been crossfolded giving opposite and different directions of plunge.

Grade-wise estimation of iron ore (hematite) is yet to be completed and different mines have done their estimaties for their own requirements.

South of Harichandanpur (S. of Ghatagaon) is the Daitari- Tomka sedimentary basin that has Daitari iron ore deposit. The simple stratigraphy of Daitari basin is as follows:

Dhanjori Quartzite

Basal Conglomerate

~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Chromite-bearing utrabasic and related rocks.

Upper Shale

BHQ

Lower shale and Phyllite

~~~~~~~~~~~~~~~~~~Unconformity ~~~~~~~~~~~~~~~~~~

Base - Eroded granite.

Four ultrabasic have entered into these rocks including the chromite bearing peridotite of Sukinda.

The rocks of the basin have undergone three periods of deformation that has resulted in co-axial superposed folding and each period showing synchrorous cross-folding. Talpada valley is an excellent location for learning of both stratigraphic and structural mapping. The ore is somewhat lower in grade than that of the Joda-Koira area. Standing at Saruabil, one can see, to its north, the southern tip of the Daitari deposit and the crusher site east of it on the hill top. The entire basin is intruded also by dolerite possibly of an older age than the ones cross-cutting the SGC. The Dhanjori quartzite at Kansa runs westward, gets folded and reaches western part of Keonjhargarh town. The unconformity plane described in structural geology (Fig. 8.17 a, b, c) is situated here and is a classic one. This is not of Kolhan age which is younger to rocks of Joda-Koira-basin (BIF-3). Acharya has termed the BHQs of Odisha as 1,2 & 3 depending on their stratigraphic age (BIF = banded iron formation). Daitari stands as No.2 while stratigraphically below exists BIF-1 that runs from Malayagiri to Gorumahisani touching Kamakshyanagar, Sukinda, Andapur, Badam and Suleipat. Mahagiri Range is a single quartzite unit that is younger to BIF-1 with a basal conglomerate and older (?) to chromite bearing peridotite that is considered to intrude (?) the quartzite in its northern slope. BIF-l, is highly metamorphosed and shows minerals from chlorite to sillimanite facies but does not contain any iron ore (hematite) deposit worth mentioning.

In northern Odisha there are many individual sedimentary basins and these show variable degrees of metamorphism. The Darjing Group of rocks, Deogarh Group, East-Similipal sequence and West-Anandapur rocks demand more studies as they individually claim to possibly have the status of being considered as Precambrian meta-sediments forming „Groups". This study will offer plenty of new findings to conceive of a more detailed geology of this state with newer sedimentary groups.

**7.9.4.2. Gangpur Basin:** A separate basin of Precambrian depositions, west of Joda-Koira iron ore basin, exists in the Sundargarh district (erstwhile Gangpur

State) and it was mapped and described by Krishnan. The basin runs E - W and the rocks maintain the same strike but closes east of Rourkela township. The western extension of the basin is obscured by granites. The hill-range south of Rourkela township is its southern border with the basal conglomerate (partly autoclastic). Mahalik has worked on this region and regards this part of the basin as a syncline (based on top-bottom features) in contrast to Krishnan‟s anticlinal theory. The stratigraphic succession of the Gangpur Group is given in Table 7.12.

The rocks lower in the stratigraphy are flaggy, while the marbles are good for blast-furnace. These gondites, a manganese ore-bearing sedimentary rock (well-developed in the Gond-tribe-area in Madhya Pradesh) is economical for manganese mining and contains minerals like blanfordite, rhodonite, winchite etc. in form of ores in quartz-spessartite rocks. These rocks are regarded as the eastern equivalent of the rocks of Sausar Supergroup and geochronologically records a 980-990 m.y. of age.

The Darjing Group comes in between this and BIF-3 (youngest).

Lead and Zinc deposits of certain value occurs west of Sundargarh town at Sargipalli. These are epigenetic and are confined to the shear zones.

There are rocks between Bonai and Barkot which are not yet considered in the study and, thus, the North-Odisha geology offers many a challenges to be solved by the geologists. Economic considerations have forced geologist to work in some detail in some selected regions although many problems remain yet unsolved.

**7.9.4.3. South Odisha (Precambraian):** It has already been mentioned that rocks of IOSG dominates the north (north of Sukinda thrust) while the southern part of the state shows rocks of E.G.SG and their variations. In between lies the Gondwana rocks in the graben whose southern boundary fault passes south of the Bhubaneswar city and 0.75 km north of Khordha town (not clearly identifiable because of alluvium). The principle of age-dating cannot be fully used for these rocks and as such general principles for young-old relationship have to be applied to appreciate their interrelationship.

These rocks, including charnockite, khondalite and calc-granulite are continually exposed from mid-Odisha upto Sri Lanka and have undergone similar grade of metamorphism (the highest). Different granites have intruded into them (not yet numbered) and either are co-folded or have their own style of variations. Often porphyroblast of 30-32 cm size (Rayagada-Bhawanipatna Zone) are found as of post-kinematic origin while folded blasto-porphyries are not uncommon either. The rocks show few clastic sedimentary characters although banding and rare currentbedding exist (Dash). Normal bedded characters are noted among quartzite (silcrete), khondalite (alcrete) and calc-granulite (calcrete) which form the so called sedimentary sequence fully and uniformly metamorphosed from Brahmani river to Sri Lanka and, as such, are considered to be products of Kata zone metamorphim. Such uniformity in metamorphism is not traced in IOSG rocks. The petrographic characters are simple with constancy of the presence of hypersthene in granulitic rocks of granitic composition (charnockite). Khondalite has sillimanite, quartz, felspar, garnet, ± graphite and accessory minerals (apatite, zircon etc). Calcite, dolomite and ferro-magnesian minerals (hornblende, augite etc) are present in calc-granulite with typical granulitic texture. These suggest a simpler chemical composition of rocks (and so earlier age to those of IOSG ?).

Khondalite is usually weathered and iron from garnets provides a reddish hue to the rock. Two hand specimans of this rock rarely have similar appearance. Possibly it is derived from early Precambrian tuff-like material (tuff are extremely variable in their composition, texture and general appearance) added by some weathered products of the then pre-existing landmass (Vredenberg). These three form a cyclothem. Pre-existing (?) charnockitic rocks have variations from ultrabasic to acidic type and intrusion-like exposures do also exist. Ghosh and Chatterjee have described the charnockites as a special product of a process of „Charnockitisation" which may broadly be taken as a special type of metasomatism. Job Charnock, the founder of Calcutta, (now Kolkata), after whom the rock has been named and for whose tombstone this rock was brought from Mt. Thomas Hill, off Chennai (old Madras city), was studied by Holland in 1900, who for the first time showed its special characters.

The charnockite-khondalite duo is almost inseparable in Odisha"s context and the former lies below the latter and this relationship always holds good. A trip from Berhampur to Rayagada via Taptapani and Kailashkotaghat shows this relationship to be uniformly constant. In some road-turning at Kailashkotaghat one sees clearly their mutual-gradational character made prominent by metamorphism bringing to the mind the concept of earliest volcanism and dust-settling to account for these two rocks after partial mixing of sediment followed by high grade metamorphism. The rocks of E.G.S.G. are more often than not, extensively folded along with their axes and create difficulty in fieldmapping. They are usually high dipping (with naturally high fold-plunges) and are intruded by series of granites. While at Tulsidongr there are four later granites (one of them is tin-mineral-bearing) at Thuamal-Rampur orbicular granite (?) is also found and off Angul rapakivi-granite has been recorded. The pegmatites along the western fault-line shows galena (Saintala), atomic minerals all around and excellent beryl crystals from south of Tel-Mahanadi junction. The Ampani sequence needs detailed investigations below which is Joypatna granite and a host of other granites are around.

Along the two mega-lineaments (described earlier) and their subsidiaries occur anorthosites (Chilika, Banpur, Sonepur, Turkel & Mayurbhanj) and Nepheline syenites (Miaskite at Koraput, Rairakhol (or Redhakhol) and Samal). Around Umpavalli off Sunki is a huge body of carbonatite that is being worked at present for cement production. The latest finding of basalt (Panda) above a Khondalite-hill west off Chilika made a reconfirmation of the existence of an east-mega-lineament (already discussed) that passed NNE-SSW, east of the railway line. This basaltic lava is so far a single case of surface basaltic exposure whose characters agree with that of Naraj, Rajmahal, Rajmahendri and the ones available from 1000 m below Bay of Bengal. It is surmised that along this megalineament erupted basalt of Pre-Decan Trap age whose easterly outcrop were at Rajmahal, Naraj and Rajmahendry. To this the Chilika exposure added a lustre giving a further confirmation acting as another prop to the eastern limit of the Deccan trap at least in time and space. Manganese ores, graphite and atomic minerals are the important products of the EGSG. While carbonatite is used for cement making, khondalite is extensively used for making wall panelling and containers for water food etc.

### 7.9.4.4. Vindhyan Rocks

The youngest in the Precambrian sequence of Odishan geology is the Vindhyan rocks in the western and south-western part of Odisha. Stromatolite in them is the evidence of early fossils in these rocks and their characters confuse the bedding feature in rocks at certain places. Caves are known to occur in these limestones (Ex-Gupteswar). These limestones run for kilometers without break and have low dip; their shale and sandstone counter parts make the scarp topography. Conglomorates in Vindhyans contain diamond and at any place in this sector this costly mineral may be prospected especially when these rocks are closed to the Sambalpur-Jeypore-diamond corridor.

### 7.9.4.5. Gondwana Supergroup

Odisha does not record the depositions of Palaeo-mesozoic rocks anywhere except the Gondwana deposits. As mentioned earlier, these rocks are found in the middle part of the state and runs from Bhubaneswar in the east to beyond Sambalpur in the west. The entire city of Bhubaneswar with Khandagiri and Udayagiri stands on upper Gondwana (Athagarh sandstone) and the east of the city is the eastern limit of exposures of these rocks. The NNE-SSW trending lineament (refer physiography) passes east of Naraj from where the delta of Mahanadi starts and below the alluvium is the Gondwana rocks followed by charnockite that persists upto certain distance beyond Choudwar.

Talchir formation, the oldest sequence of Gondwana rocks, offers evidences of the then glaciation. Parekh, Pandya and others have studied the rocks around Angul-Talcher region (Lower Gondwanas). Mudstone, siltstone and greenish sandstone occupy the lower part and undecomposed feldspar in sandstone suggest non-decomposition of rocks (covered by glacier and hence no decomposition). The glaciation is further evidenced by striated boulders of the Boulder bed (a few cms to 0.5 m size of the striations) and also tillite. Paul and others recorded drumlins and other features from this area.

Intrusive into these sandstone (upper) is found to the west of Naraj IB below Sidheswar peak. Acharya and others have opined on this igneous structure as a bysmalith-cum-sill below Sidheswar peak. Sills and dykes at Mundali around the canal are traced after the construction of the canal system. Valentine Ball described the geology of this region for the first time in 1875-76. A recent landslide (40 years back) has broken up the alluvial flat and the sandstone wall west of the lB. Plant fossils (*Glossopteris*, *Vertebraria* etc) are available from these rocks and are identified by Patra. Vertebrate fossils were collected from Handappa (off Rairakhol) by Indian Statistical Institute, Kolkata. Gondwana rocks are discovered in a narrow basin off Phulbani at Katrinjia. It is surmised that the Godavari (A.P.), Talchir (Odisha) and Bihar basins were not physically continuous. Now they are regarded as three independent basins produced by the process of grabenisation.

**7.9.4.6. Tertiary and Quaternary Rocks**

Jurassic time saw in Odisha the end of Gondwana sedimentation. Cretaceous period witnessed the sill (Mundali & Sidheswar) and this is the harbinger of the Deccan traps of India in Odishan sector.

Tertiary rocks are confined to narrow basins (produced as fall-outs of eastern mega-lineament ?) and consist of limestone, shale and sandstone. The fossil-content of these sediments makes this famous and Mahulia (5 km off

Baripada along Budhabalanga river downstream) has been visited by scholars from G.S.I and Calcutta University. Nirmal Bose, Abani Chowdhury, Dharani Sen and a host of others have enriched our knowledge on these calcareous rocks and fossils (ostrea, crabs, elphidium, shark teeth, vertebrates and molluscs and many more). At Satpautia, Mukuramatia and Badsahi these rocks have been exposed and ultimately get linked with its Balasore counterpart where fish fossils were collected (Hora). The wells of the Pradeep and Swarup Nivas of Baripada High School and the bathing-ghat of the palace at Budhabalang river were locations of fossils as well. At Kuliana and beyond Sirsa these fossil-containing rocks exist. Bore holes at Astia for the river bridge indicated the extension of the rock west of Mahulia and P. Acharya, on checking the fossils of the rocks upto 45 m depth, introduced M. Mohanti for detailed work who established the marine condition of deposition of these Mio-Pliocene sediments.

Older and younger alluvium stretched from Balasore to Ganjam in the eastern part of the state. The older is found cut by the younger in river-sections. The alluvium mantle is above Precambrian and Gondwana rocks. The river-valleys are mostly along faults as bore hole indicates charnockite and other metamorphites on banks (not on river beds). Mahanadi, Brahmani and Baitarini form the „Tri-delta" that has dumped sediments into the sea causing land projections. Abandoned meanders and river valleys, shifting shore line, wind-borne sand dunes, red soils, placers etc are features of the deltaic tract. Excessive draw of ground water causing incursion of salinity water into fresh water zones cause problems for the societal need of water. Ground water management must be taught from school stage where ignorance and carelessness have created problem"s to find fresh water in an erstwhile place of fresh water. In Bhubaneswar city the acuteness is to be felt soon.

Present day volcanic ash falls everywhere but get concentrated along eroded hill-slopes. Its texture and non-mixing nature differentiate it from other sediments. With time they are named as ash-beds (or lenses) depending on the quantum of supply. It is of interest to know that a good part of the Precambrian shale /phyllites are really ash beds. The Joda-Koira iron ore basin has plenty of such rocks of older age.

Different aspects of the Geology of India have been very briefly described and discussed here. It is far from being complete. It is hoped that the students will learn more and more when they reach the higher classes and can critically discuss topics of different facts of Geology of Odisha.

## 7.10. SAMPLE QUESTIONS

### 1. Long answer type questions

(i) Give general stratigraphic sequence adopted everywhere in the world and the broad reason why it is accepted by all.

(ii) How do you correlate rocks of the Precambrian age?

(iii) What are stratigraphic principles? Show how a lithosequence is described based on this.

(iv) Two sequences of rocks are exposed at two different places and one does not see them continuous physically. How can they be correlated if they are really one and the same?

(v) Describe and discuss the Dharawar Supergroup.

(vi) Describe and discuss the Cuddapah Supergroup.

(vii) Describe and discuss the Vindhyan Supergroup.

(viii) Describe the stratigraphic sequence of any Precambrian sequence of Odisha.

(ix) Which aspects of geology of Odisha, you think, are very interesting and why?

(x) Discuss and describe the Post-Cambrian geology of Odisha.

(xi) Discuss and describe the Precambrian geology of Odisha.

(xii) Give the stratigraphic account of the Gondwana rocks of India.

(xiii) Describe the stratigraphy of the Gondwanas with respect to their distribution in India, stratigraphic succession, lithology and economic mineral deposits.

**2. Write short notes on**

(i) Economic mineral deposits associated with the Gondwana rocks.

(ii) Glassification of the Gondwana rocks of India.

(iii) Fossil content of the Gondwana rocks of India.

**3. Answer in 3 to 5 sentences**

(i) How the rocks of Cuddapah and Vindhyan Supergroups are separated from each other?

(ii) A part of the Peninsular India lithologically may be correlated with those of Bundelkhand and Rajasthan. Do you agree?

(iii) Gondwanaland

(iv) Ptilophyllum flora

**4. Answer in one sentence.**

(i) Climate of the Upper Gondwana.

(ii) Floral assemblages of the Lower Gondwana.

**5. Choose the correct answer.**

(i) The geological time range of the Gondwanas is

(a) Upper Triassic to Lower Cretaceous

(b) Upper Carboniferous to Lower Cretaceous

(c) Lower Permian to Middle Jurassic

(d) Upper Carboniferos to Upper Jurassic

(ii) The lowermost unit of the Damuda Group is

(a) Raniganj Formation (c) Karharbari Formation

(b) Mahadeva Formation (d) Barakar Formation

(iii) The Upper Gondwanas are characterized by

(a) Ptilopyllum flora (b) Glossopteris flora

(c) Gangamopteris flora (d) Dichroidium flora

(iv) The type of clay deposits associated with Gondwana rocks are

(a) China clay (b) Fire clay (c) Kaolin clay (d) None of the above

**6. Fill in the blanks**

The Lower Gondwanas are characterized by ________ flora.

(ii) The Lower Gondwana coal fields are mostly confined to ________ Group.

**Answer to short question Nos.5 and 6.**

5. i (b) (ii) c (iii) a (iv) b

6. (i) Glossopteris (ii) Barakar

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# CHAPTER – 8

# STRUCTURAL GEOLOGY

## 8.1. INTRODUCTION

Structural geology is a branch of geology dealing with external shape of the rocks, their internal pattern either of primary (in igneous or sedimentary rocks) or secondary characters in metamorphic rocks. The diastrophic movement or deformation also causes various types of impressions. Even under microscopic studies, different styles of aggregation or grouping of minerals come under structural behaviour. Hence, structural geology is the study of architecture of rocks resulted from deformation. Structural geology is a major branch of geological studies. It is of interest to note that non-diastrophic causes producing features on rocks are also considered as structures but classified as non-diastrophic.

Thus, broadly it may be said that structural geology deals with the descriptive evaluation and meaning of the features produced by any force or otherwise (diastrophic or non-diastrophic) in rocks and their changes in time. Tectonics and tectonic geology are terms that many consider to be synonymous with structural geology. But structural geology is concerned primarily with the geometry of the rocks whereas tectonics deals with forces and movements that produced the structures. The movements that affect solid rocks result from forces within the earth, causing folds, faults, joints and foliation. It is of interest to know that many geomorphic features are the outcome of structural ones directly or indirectly. Horst, graben, slopes etc. are structural features and are smoothened later by weathering.

## 8.2. WHERE STRUCTURAL FEATURES ARE FOUND?

Structures are observed on rock-exposures, which mean any visible rock surface for certain distance (either big or small). When studied continuously on these exposures, certain features take shape which, when geologically analysed, are known as „structural features‟. With geological analysis, it is possible to know the direction of horizontal extension (strike) of rocks and their inclination/penetration into earth‟s surface (dip) (Fig. 8.1). Strike and Dip express the attitude of the rocks.

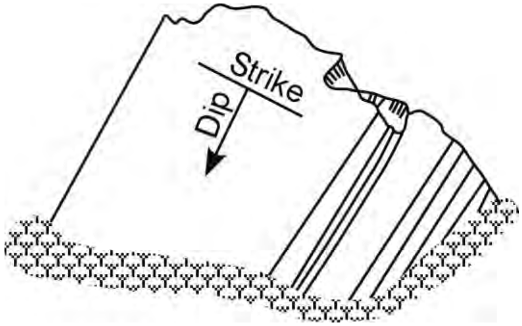
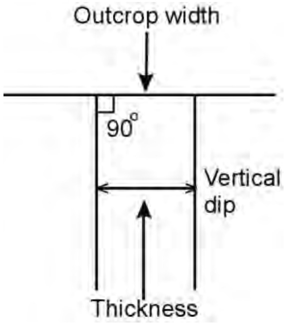


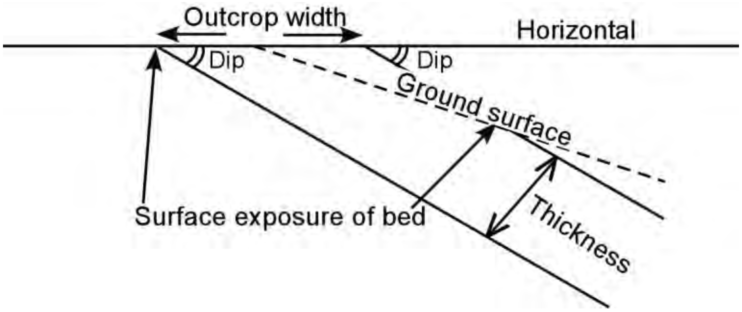

**Fig. 8.1: Strike and dip**

Strike can be defined as the direction of the line formed by the intersection of any planar feature and the horizontal plane. Dip is the amount of inclination with respect to the horizontal plane and it is measured in a vertical plane lying at right angles to the strike of the bedding. Hence the attitude of a bed can be expressed by specifying the direction of strike and the direction and amount of dip. The dip is further classified as: True dip and (b) Apparent dip.

True dip is the maximum amount of slope along a line perpendicular to the strike. In other words, it is the maximum amount of inclination with respect to the horizontal plane.

Apparent dip, on the other hand, is the angle measured in any direction other than perpendicular to strike direction. The apparent dip of any bed towards any direction is always less than its true dip. Hence a bed has only one true dip and „n‟ number of apparent dips. Thus, dip of a bed may be from 0°-90° (horizontal to vertical) and can never be more than 90° because the sense of direction then changes. Therefore, strike remaining the same, the dip may change in amount (0-90°) and in direction (on a vertical plane perpendicular to the strike direction) (Figs. 8.2 a, b). For example, the dip of a horizontal bed is 0° and that of a vertical bed is 90°.




**Figs. 8.2a: Dip of vertical bed** **Figs. 8.2b: Dip of inclined bed**

Dip and strike can be measured with the help of a Brunton compass or Clinometer compass.

By plotting the data of the attitude of exposures of the planar features of the rocks on a toposheet, it is possible to prepare a geological map that gives mutual position of rocks on a topographic map. Because of weathering and superficial cover any rock on the earth"s surface is never fully or perfectly exposed; it rather crops out in a discontinuous way separated by vegetation or soil below which it occurs. These occurrences (outcrops) go a long way to assist in better understanding of the structural behaviour of the rocks. Therefore, the outcrops are treated as continuous when their detached parts are traced in the field.

## 8.3. PRIMARY AND SECONDARY PLANAR AND LINEAR FEATURES

The role of topography comes in a big way in shaping the outcrop patterns and styles of exposures of individual rocks and especially it is so for the sedimentary rocks. A geological map can then be produced which is the horizontal projection of geological features, which are observed during the field survey (Fig. 8.3) can be mapped and produced on the required scale.

The structural features may be very big (can‟t be seen fully in one look) to very small (microscopic) and are accordingly known as „macroscopic‟ and „microscopic‟. The intermediate (most commonly found) is termed „mesocopic‟ whose scale may be considered as between a few cm and a run of hundred or so metres.

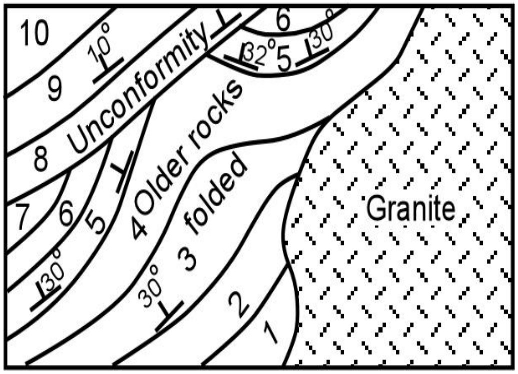



**Fig.8.3: A geological map**

A fold of about two km wide cannot be seen at one glance and soil, vegetation and slope etc may block the visibility. These are inferred to exist by plotting on a paper of structural (data) elements collected in the field. Structural features, known as elements, are found in rocks and a hand specimen can show them convincingly in most of the cases in the field. Therefore, continuous breaking of rocks during field work is an absolute must because a fresh surface is thereby exposed while breaking a rock (with a geological hammer). When weathered, mossed or disfigured surfaces are removed first to get fresh rocks.

When the structural elements are in the nature of a plane, they are known as planar features (bedding, cleavage, joints, schistosity, gneissosity etc.) On these planes develop certain line-like elements known (as a group) as linear features or lineations. Mutually parallel to each other or group-wise, rough parallelism exists within them. These structural elements are present in all parallel sections of the rock and are then considered as „penetrative‟ in contrast to „non-penetrative‟ structures like joint or fault. They exist after certain gaps and are not found everywhere in the rock like the penetrative elements. Planar structures are mutually parallel or nearly so. Lamination, bedding, schistosity or gneissosity, cleavage etc. come in this category (Fig. 8.4). They are considered as S-planes (a German term accepted world over) and are named numerically one after the other depending on their sequence of origin as $S_0$, $S_1$, $S_2$…etc. Linear elements are related to these S-planes and are grouped, related to different S-planes having a genetic relationship between them (Figs. 8.5, a-d).

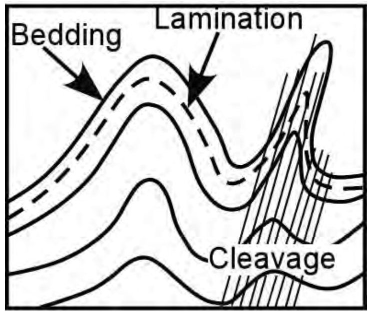
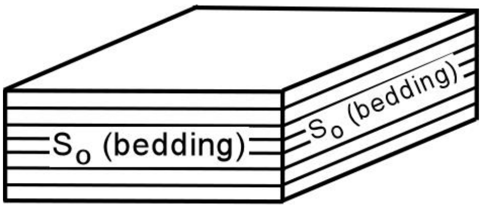
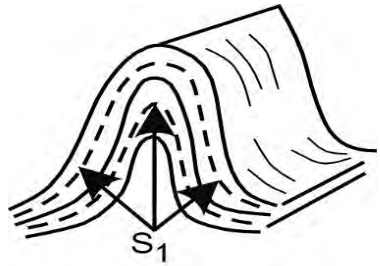



**Fig.8.4: Bedding and cleavage**




**(a)**

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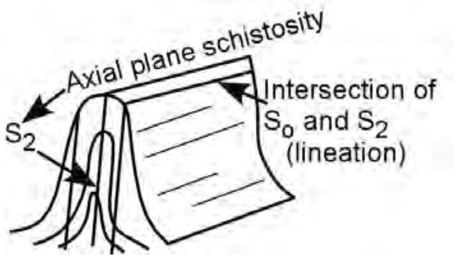
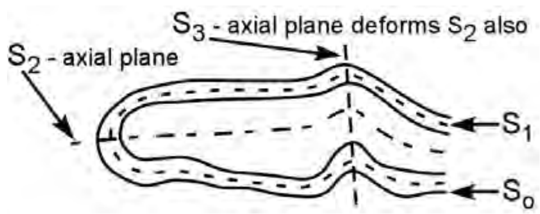



**(c)**




**(d)**

**Figs. 8.5 (a-d): Bedding and development of later S-planes in chronological sequence based on folding and S-plane development.**

Sedimentary rock-structures, developed during deposition, are considered as primary features as they have co-genetic relationship with those rocks. Banding produced by magmatic settling of minerals producing rocks or ore deposits are also considered primary as it is also a planar feature. (Banding by metamorphism is imprinted and is secondary). In the primary category, features like current bedding (cross-stratification), slump structures and all penecontemporaneous deformation features (produced by deformation during formations) are included. (Figs. 8.6 a-e)

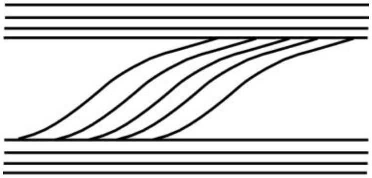


**Fig.8.6a: Current bedding whose foreset is not cut-off or truncated. Not used for top – bottom knowledge**

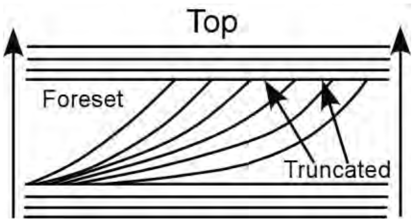



**Fig.8.6b: Foreset is truncated by top set and hence top side is indicated.**

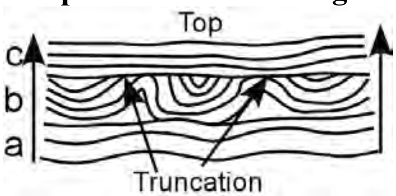



**Fig.8.6c: Features cut by top horizontal layer**

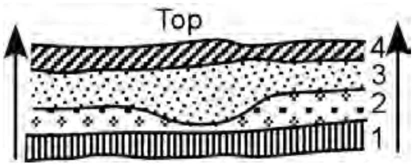



**Fig.8.6d: Top of bed 2 is cut and filled by bed 3**

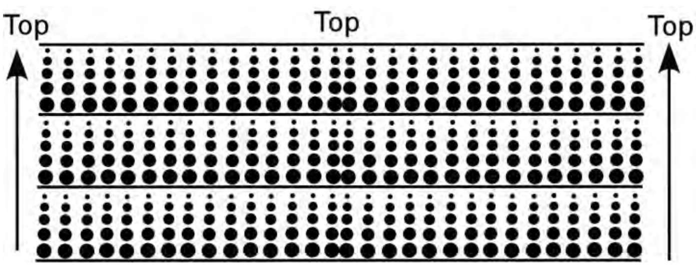



**Fig.8.6e: Graded bedding indicating normal stratigraphy – young upward**

Continuous process of sedimentation results in formation of parallel strata and can be said to be conformable. Somewhat irregular and angular beds by quick deposition under same process are termed as cross-stratification (current bedding) (Figs. 8.6 a-b). On the other hand a thick conformable sequence of rocks (say thousands of metres) may become oblique to another set of somewhat equally thick and conformable beds. This oblique nature is regarded as unconformity (Figs. 8.7 a-d) and these two sets of rocks are considered unconformable. Between them a gap of time of non-deposition or break in deposition exists. Unconformities may have different forms as seen in the (Figs. 8.7 a-d) figures. Thus, the following types of unconformity may develop.

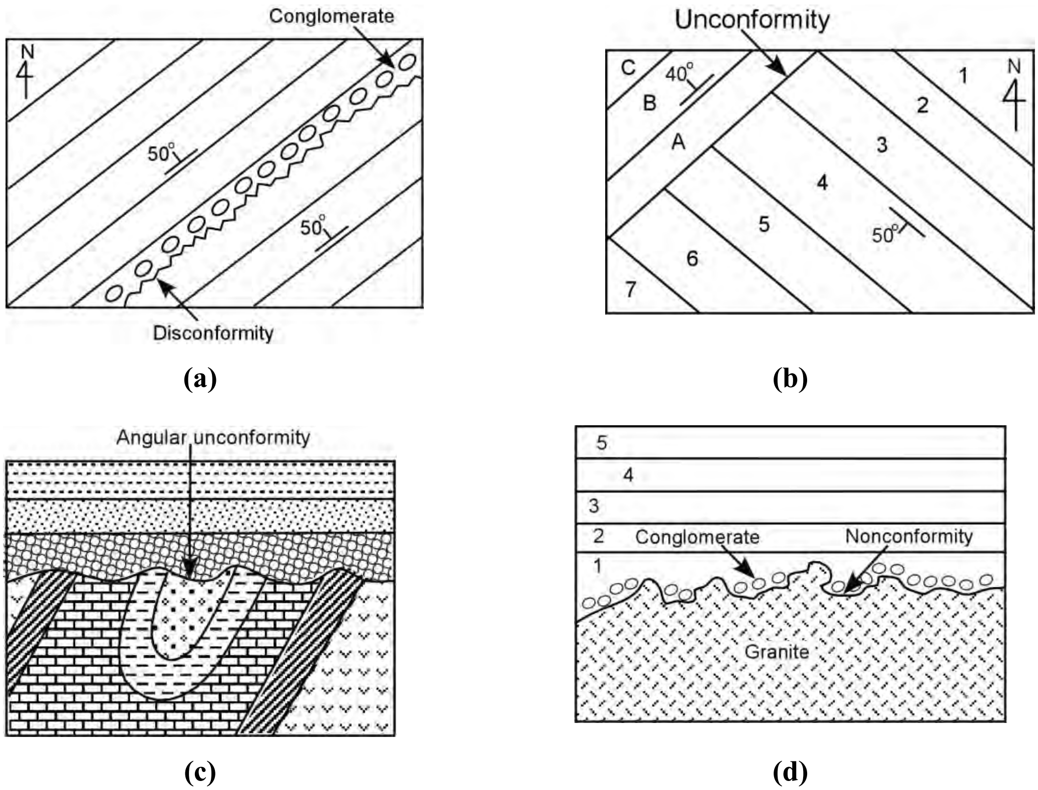



**Fig.8.7: Different types of unconformities; (a) Disconformity (Plan), (b) Angular unconformity (Plan), (c) Angular unconformity (Section) and (d) Nonconformity (Section)**

(i) Two sets of conformable strata separated by a thick conglomerate. (Fig. 8.7a)
(ii) Two sequences of sedimentary rocks having different attitudes (result of different degrees of deformation. (Fig. 8.7b and c)
(iii) A set of conformable sedimentary rocks overlying an intrusive rock like granite. (Fig. 8.7d)
(iv) A set of conformable rocks overlying an older (pre-existing) weathered igneous rock.

As is mentioned above, an unconformity thus, means a break or gap in any form of continuity of geologic history of the region where the rocks are spread. A cycle of geologic history, therefore, exists that normally is regarded with a beginning of sedimentation of beds forming sedimentary strata of variable thickness, their deformation with production of folds, faults (with related elements both penetrative and non-penetrative) developed in them, eruption of lava from the interior of the earth into the basin of deposition, moving of sediments into deeper levels of the basin of earth‟s crust (sedimentation subsidence), granite / other rock intrusion/s followed by metamorphism of these rocks. Almost as a rule, basinal depression, igneous intrusion/s, metamorphism due to changes of temperature and pressure are simultaneous along with diastrophism which controls and somewhat is controlled as well by this cyclic earth‟s evolution that has gone into the evolutional history of earth‟s crust since its inception about say 4,500 million years ago. The phenomena of weathering are there when the rocks are exposed to surface atmosphere, heat and rain water bringing in physical and chemical changes on the rocks of the earth‟s surface (studied in geomorphology).

The two episodes of earth‟s history, thus, evolved, is separated by a time gap and depositional break and an unconformity results between them. The structural elements of the older sequence show more effects of deformation and metamorphism imprinted on them in contrast to the younger one. Studying them indicates their separate characters (primarily imprinted and secondarily imbibed) which assist in distinguishing the separate units.

This process goes on somewhat the following way: A bed forms inside a basin (of variable sizes in terms of say tens of kilometers) produced as a depression on the surface of the earth by diastrophism. This bed is either horizontally or sub-horizontally (rarely >20°) spread inside the basin and during diastrophism, the bed gets tilted to one side and, with more pressure from one or opposing sides, gets folded and with still higher force, faulted. The tilt is known as „dip" that shows its inclination to one azimuthal direction and the bed obviously extends in a direction perpendicular to it.

A set of beds, when dips uniformly, makes a homocline. A bed may be upright vertical or, with more intense deformation, may be oppositely dipping (when its natural top in limbs is opposite to each other) causing problems for field geologists. They should, therefore, know about top and bottom characters of rocks (see sedimentary rocks, a few are given here). When walking along dip-direction of a bed one observes a similar rock dipping in the opposite direction, he should think in terms of a fold.

This subject of geology is a field science where evidences in support of a statement are collected from nature especially when structural, geomorphic, weathering phenomena etc. are needed to be observed. Emphasis is, therefore, given here to identify structural elements in the field and their interpretation for multiple purposes.

## 8.4. TYPES OF STRUCTURAL FEATURES

Diastrophism often leads to various structural disturbances in rocks. In the field there are plenty of such examples in different areas especially in folded Precambrian and other younger rocks. Very large (> km) to very small scale

(< cm) folds, are found. As is already known, it is produced by crumpling and buckling of primary layers as found in the outcrops.

Structural geology deals with the attitude of primary surfaces (bedding plane etc.), layers, foliations etc. One can imagine the bedding-plane of sedimentary rock as the most important one, which is considered to have been formed quietly inside water and hence horizontal in initial stages of formation. Other original surfaces are top and bottom planes of lava flows or contact planes of sills and dykes and other related primary features.

The earth‟s crust on being subjected to pressure will bend or break. This depends on the physical characters of the rocks. As a result, folds or faults are produced depending on the total effect of pressure and the rock types. The geometry of these features can be studied to establish the structural pattern or style and more than one period of such features can be linked in time and space.

Folds and faults are divided into two different groups. Competence of rocks to pressure is very important for the intensity of pressure of rocks.

The structural features broadly can be grouped as follows.

(i) Fold - Feature where a surface bends normally in continuity without break.

(ii) Cleavage - They are closely set parting planes which develop during folding of certain types ($S_1$, $S_2$ etc.)

(iii) Linear Structures - These features have only one dimension for development. They are produced essentially on pre-existing S-planes and are considered to develop during the process of development of that plane and on earlier plane as well.

(iv) Fault - As told before, it is a non-penetrative planar feature which makes the primary surface displaced to lose continuity. Thrusts are faults of special type and related to folding when one limb moves over the other along the thrust plane.

(vi) Joints - These are fractures produced on rocks, closely set or otherwise, by which the primary surfaces get affected but not displaced. These features are described below.

### 8.4.1. FOLDS

Rocks can be folded and are observed in the field as crumples or buckles of primary layers in outcrops. When the scale is large, folds are recognized by swing of structure of beds, by beds dipping in opposite directions or by repetition of the same bed along the traverse-line.

The bending of rock strata due to compressional forces acting tangentially or horizontally towards a common point or plane from opposite direction is known as folding. Folds are flexures or wavy undulations formed in the earth"s crust and consist of crests (arches) and troughs in alternate manner. They are best displayed by sedimentary rocks. The size of the folds may vary between kilometres and metres or centimetres.

**(i) Different parts of fold are:**

(a) Limb or Flank – These are the sides of a fold. An individual fold unit contains two limbs.

(b) Axial plane – It is an imaginary plane which divides a fold into two equal halves.

(c) Hinge – The line along which a change in the amount and/or direction of dip takes place is known as the hinge line and on many folds this coincides with the position of maximum curvature.

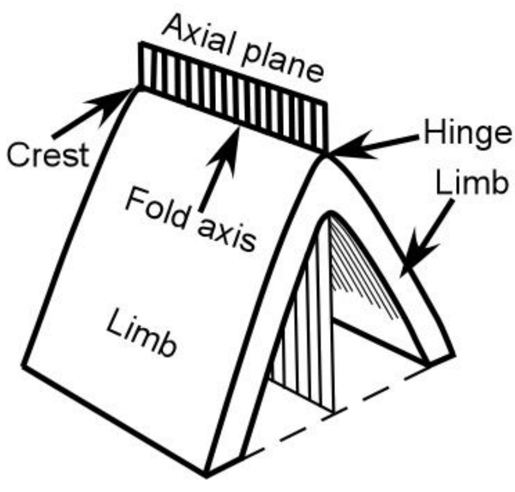



**Fig.8.8: Parts of a fold**

The area adjacent to the hinge line is known as hinge area or nose of the fold.

(d) Axis – In any fold, the line of intersection of the axial plane with the upper and lower surface of any of the constituent beds is known as its axis. Like the axial plane, the axis of the fold may be horizontal, vertical or inclined.

(e) Crests and Troughs – The highest points in an uparched fold is known as crest and lowest points in a downward bend is known as trough. The wavy undulations or folds contain a series of crests and troughs.

(f) Crestal plane – There is a separate crest for each fold. The imaginary plane or surface by all the crests in a series of fold is known as the crestal plane.

(g) Trough plane – Similarly, the plane containing the lowest part of folds is called the trough plane.

**8.4.2. Types of Folds**

(a) Antiform – Any upwardly convex fold is termed as an antiform. In this folds both the limbs dip away from each other. The age relation between the upper and lower set of beds is not established.

(b) Synform – Any upwardly concave fold is known as a synform. In this fold both the limbs dip towards each other. In this case also, the age relation between the upper and lower set of beds is not established.

(c) Anticline – These folds (Fig.8.9a) are convex upwards and the limbs dip away from each other. In anticlines the older rocks occur at the centre of curvature of the fold.

(d) Syncline – Synclines (Fig.8.9b) are concave upwards and the limbs dip towards each other. In synclines the younger rocks occur at the centre of curvature of the fold.

(e) Anticlinorium – If minor or secondary folds are developed in an anticlinal fold, the fold is known as an anticlinorium. It consists of a number of small anticlines and synclines.

(f) Synclinorium – Similarly, if minor or secondary folds are developed in a synclinal fold, the fold is known as a synclinorium. It consists of a number of small anticlines and synclines.

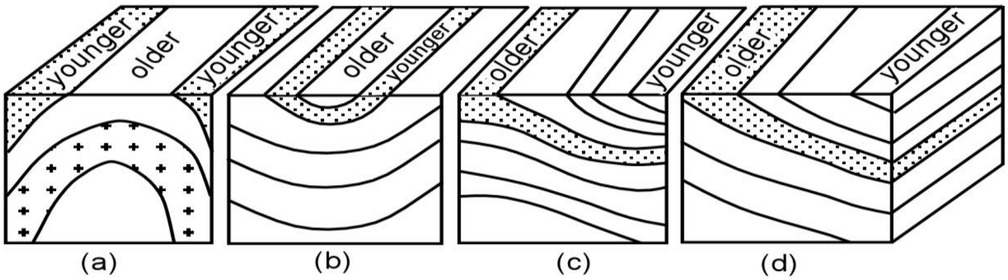



**Fig.8.9: (a) Anticline, (b) Syncline, (c) Monocline and (d) Homocline**

(g) Monocline – In a monocline (Fig.8.9c) the rock beds lying at two different levels are separated by a limb with steep inclination. It is formed due to the vertical movements. Monoclines are also known as anticlinal bend.

(h) Structural terrace – In this case a dipping bed shows local flattening and again follows the original trend of dip. These are also known as synclinal bend or structural bench.

(i) Symmetrical fold – In a symmetrical fold the axial plane is essentially vertical and bisects the fold. It is also known as normal or upright fold. Both the limbs have the same amount of dip. Symmetrical folds may occur either as anticlines or synclines.

(j) Asymmetrical fold – The axial plane is inclined in asymmetrical fold and the limbs dip at unequal angles in opposite directions. Both asymmetrical anticlines and synclines are found in nature.

(k) Overturned folds – In overturned folds the axial plane is inclined and both limbs dip in the same direction, usually at different angles. One of the limbs (overturned or reversed limb) comes to occupy the present position after having suffered a rotation through more than 90°. The other limb is known as normal limb.

(l) Isoclinal fold – It is a type of overturned fold in which the two limbs are parallel and dipping at equal amounts. Isoclinal folds are of three types: (a) Inclined Isoclinal fold ( axial plane is inclined), (b) Vertical Isoclinal fold (axial plane is vertical) and (c) Recumbent Isoclinal fold ( axial plane is horizontal )

(m) Recumbent fold – It is an overturned fold, in which the axial plane is essentially more or less horizontal. The upper limb is known as the normal limb and usually thicker than the lower inverted limb. The sharp bend which joins both the limbs is known as arch bend. The innermost part of the fold is made up of crystalline core. The subsidiary or secondary folds developed in the normal limb of a recumbent fold are known as digitations. The zone from which it originates is known as root zone. The base of the fold may or may not be traceable.

(n) Homocline: The term homocline (Fig.8.9d) is applied to strata that dip in one direction at a relatively uniform angle. Many homoclines represent limbs of folds.

### 8.4.3. FAULTS

A fault is a fracture in the earth‟s crust along which there is displacement of rocks on one side in relation to those of the other. The slip is always relative and not absolute for one side and can be in any direction, vertical or horizontal or in any other direction between the two.

The surface of discontinuation is the fault plane, a group of them making it a fault zone. The fault-plane may be vertical, inclined or curved. Like any plane it has dip and strike. The block above the fault-plane is the hanging wall where as the block below the fault plane is the footwall. The fault plane when intersects the ground surface is termed as fault-line. If this fault-line is straight the fault is vertical, if curved, it is inclined.

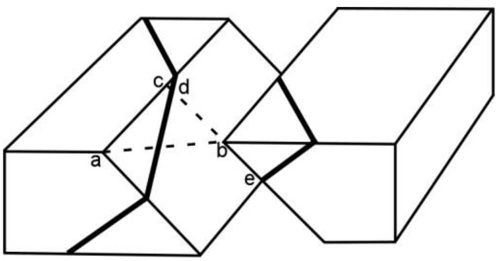
One of the dislocated blocks of the fault appears to have been shifted downwards in comparison with the adjoining block lying on the other side of the fault plane. The block which moves downward is known as down-thrown side while the other block is known as up-thrown side.

The different fault terminology can be described as follows:

(a) Strike – It is the trend of a horizontal line in the plane of the fault (ac in Fig.8.10A).

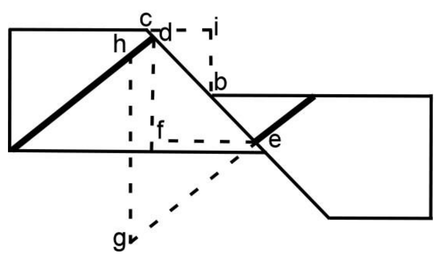
(b) Dip – It is the angle between any horizontal surface and fault plane and it is measured in a vertical plane that strikes at right angles to the fault.

(c) Hade – It is the complimentary angle of dip (i.e. Hade + Dip = 90°) or in other words, it is the angle formed by the fault plane and the vertical plane that strikes parallel to the fault.




**(a)**

**Fig. 8.10a: Heavy black layer is disrupted stratum. a-b is net slip, a-c is strike slip, c-b is dip slip.**




**(b)**

**Fig. 8.10b: Vertical cross section perpendicular to strike of the fault. d-f is throw, f-e is heave.**

(d) Throw and Heave – The vertical component of the displacement of the up-thrown and down-thrown block is known as throw (df in Fig.8.10B). The horizontal component of the displacement is known as heave (fe in Fig.8.10B).

(e) Slip – It indicates the relative displacement of the adjacent points and is measured on the fault plane. Net slip (ab in Fig.8.10A) is the total displacement and is measured in terms of the distance and the angle it makes with some line in the fault plane. Strike slip (ac in Fig.8.10A) is the component of net slip parallel to the strike of the fault. Dip slip (db in Fig.8.10A) is the component of the net slip parallel to the dip direction of the fault plane.

**8.4.4. Classification of faults:** Faults can be classified on the basis of their geometry or genesis.

**(A) Geometrical classification of faults:** The geometrical classification can be made on the basis of criteria like rake of net slip, attitude of fault plane relative to attitude of beds, fault pattern and dip amount of fault.

**(i) Classification of faults on the basis of rake of net slip**

On this basis, faults can be classified as strike-slip, dip-slip and diagonal-slip faults.

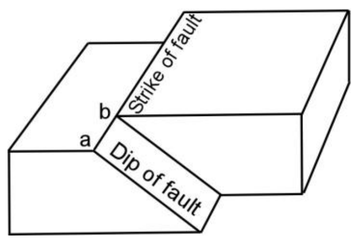


**Fig.8.11. Strike-slip fault**

**(a) Strike-slip fault:** It is a fault in which the net slip is parallel to the strike of the fault. There is no dip-slip component (Fig.8.11).

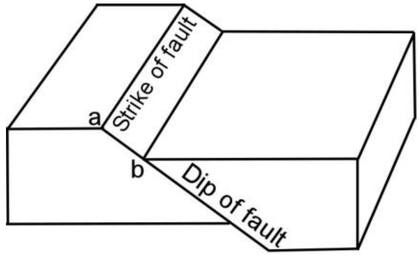



**Fig.8.12. Dip-slip fault**

**(b) Dip-slip fault:** In this fault, the net-slip is up or down the dip of the fault. There is no strike-slip component (Fig.8.12).

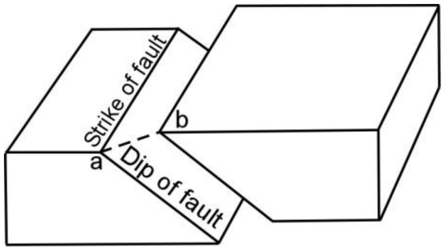



**Fig.8.13. Diagonal-slip fault**

**(c) Diagonal-slip fault:** The net slip is diagonally up or down the fault plane and there is both strike-slip and dip-slip components (Fig.8.13).

**(ii) Classification of faults on the basis of attitude of fault plane relative to the attitude of adjacent beds**

On this basis, faults can be classified as strike fault, dip fault, bedding fault, longitudinal fault, transverse fault etc.

**(a) Strike fault:** The strike of the fault is essentially parallel to the strike of the adjacent rocks (Fig.8.14).

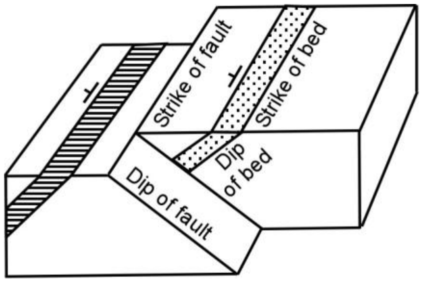



**Fig.8.14. Strike fault**

**(b) Dip fault:** The strike of the fault is essentially parallel to the dip direction of the adjacent rocks (Fig.8.15).

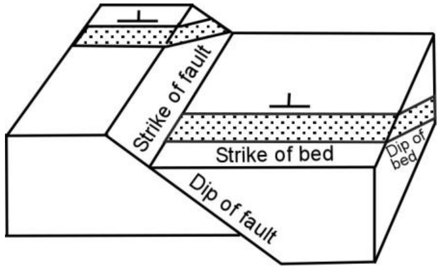



**Fig.8.15. Dip fault**

**(c) Oblique fault:** The fault has strike oblique to the strike of the adjacent rocks (Fig.8.16).

**(d) Bedding fault:** It is a variety of strike fault in which the strike is parallel to the bedding of adjacent rocks.

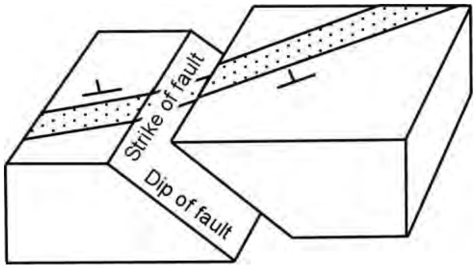



**Fig.8.16. Oblique fault**

**(e) Longitudinal fault:** These faults strike parallel to the strike of the regional structure.

**(f) Transverse fault:** These faults strike perpendicularly or diagonally to the strike of the regional structure.

**(iii) Classification based on fault pattern**

On this basis, the faults are classified on maps or in a cross section. Some of these faults are described below.

**(a) Parallel fault:** The faults which occur as a single set having same strike and dip. The strike remaining same, the dips may vary giving rise to faults of two or more sets (Fig.8.17).

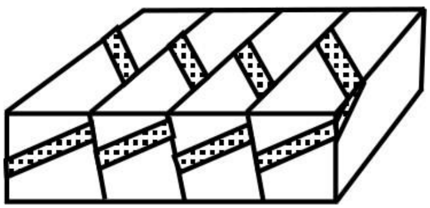


**Fig.8.17. Parallel fault**

**(b) En echelon faults:** These are relatively short faults overlapping each other (Fig.8.18).

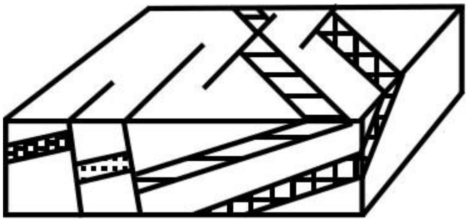


**Fig.8.18. En echelon faults**

**(c) Peripheral faults:** These are arcuate faults which are sometimes circular also enclosing a part or whole of circular area (Fig.8.19).

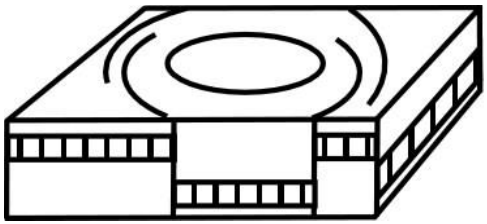


**Fig.8.19. Peripheral faults**

**(d) Radial faults:** These faults radiate out from a common centre (Fig.8.20).

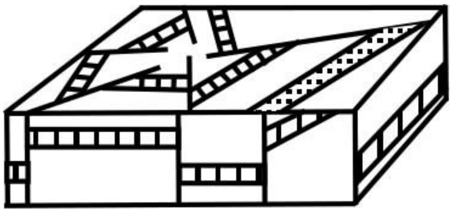


**Fig.8.20. Radial faults**

**(iv) Classification based on value of dip of a fault**

The angle of dip of fault is sometimes used to classify faults.

**(a) High angle faults:** In these faults the dip is more than 45°.

**(b) Low angle faults:** The dip in these faults is less than 45°.

**(B) Genetic classification**

On the basis of origin, the faults can be classified as normal fault, thrust fault and strike slip fault.

**(i) Normal fault:** It is a fault in which the hanging wall has gone down relative to the foot wall. Sometimes the term "gravity fault" is used for this type of fault.

**(ii) Thrust fault:** It is a fault in which the hanging wall has moved up relative to the foot wall. There are three types of thrust faults.

**(a) Reverse fault:** It is a thrust fault in which the dip is more than 45°.

**(b) Thrust:** In this case the dip is less than 45°.

**(c) Overthrust:** In this case the dip is very less i.e. less than 10°, but the net slip is very large.

**(iii) Strike-slip fault:** These faults are otherwise known as wrench faults. As described earlier, these faults are those in which the displacement is parallel to the strike of the fault (Fig. 8.11).

In addition to the faults described above, there are other structures related to the faults. Horst and grabens are two such terms which are associated with normal faults.

**Horst:** It is a raised block bounded by steep normal faults on both sides (Fig.8.21a). It is generally very long compared to its width.

**Graben:** It is a block lowered relative to the blocks on either side and is bounded by steep normal faults on both sides (Fig.8.21b). It is also relatively long compared to its width.

In their occurrence horsts are generally associated with grabens. Horsts and grabens of large scale are known respectively as block mountains and rift valleys.

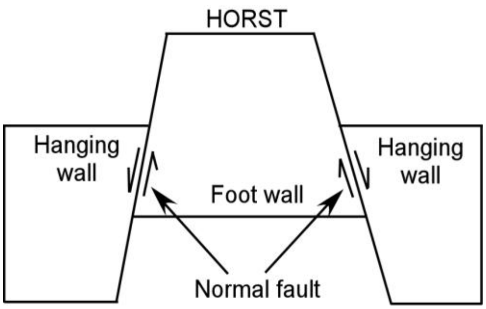



**Fig. 8.21 (a): Horst**

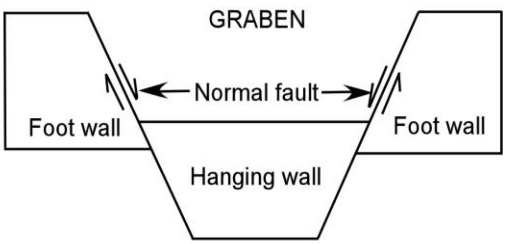



**Fig. 8.21b: Graben**

**8.4.5. Criteria for recognition of faults:** The following points should be searched in the field to confirm the presence of faults. They are

(a) Discontinuity of structures: Sudden ending of strata against a different rock.

(b) Repetition of beds / strata: This may be either result of faulting, folding, unconformity etc.

(c) Omission of bed / strata: This may be result of faulting or any other criteria. etc.

(a) Fault-plane characters: This include slickenslides, mylonites, fault gauges etc. Slickensides are striations (line-like feature) on the polished surfaces of the fault-plane resulting from friction of rocks along the fault-plane. Slickensides show the direction of movement. Coarse slickensides are named as flutings (several inches deep). Several directions may be indicated by slickenside based on movement direction in different times. Drag exists on rocks and, this bending shows movement-direction as well. Along fault-plane the rocks get broken irregularly and it is known as breccias found along the plane of displacement and the groundmass is a fine-grained rock-mass in which these blocks are embedded. When stress grinds the rock to powdery form it is known as mylonite, (micro-breccia) and with more stress, ultra-mylonite develops and results in the formation of pseudotachylite (glassy - no crystalline base).

(b) Silicification and other mineralization: Along the fault plane solutions of minerals move and get deposited in the space available in the plane based on pressure and temperature conditions. Often the country rock gets replaced by the minerals those crystallize back from the solution. Silica forms quartz veins and bands. This vein quartz is usually the most common criteria for identification of faulting.

(c) Change in sedimentary facies: From the basin margin, the rocks change in character, as one goes deeper into the basin, thus, changing in its name as well.

For example, sandstone is inter-fingered with shale, which at greater depth, gradually changes to limestone. When a fault is there, sandstone may be found in contact with limestone and one infers this to be due to a low-inclination fault. In areas of over-thrusting, this is frequent. In the Himalayas and Alps and in other areas of over-thrusting, this feature is rather commonplace.

(d) Physiographic contrasts: Faults occur in nature and the topography as well as the rocks makes the faults prominent or otherwise. A resistant bed, when gets faulted, forms a discontinuation of a ridge or slope.

(e) Scarp: A scarp may form that produces a topo-slope of varying angle and height along the fault-plane. With erosion, its sharpness gets reduced. Again a scarp may not always indicate a fault when differential weathering is prominent. In both the cases waterfall / rapid, however, may be produced.

Thus, one has to find out more than two or three evidences to suggest the presence of a fault.

Any folded terrain shows a number of folds and faults of different dimensions. In the field one observes topography as the first unit of study because its nature is observed even from a distance. Study of rocks, folds etc. come later. Hence a good understanding of fault in relation to topography makes one‟s job easier.

If there are more than one set of faults, their age, with reference to each other, can be known. A dyke, being displaced, may be affected by a fault while a later one (younger to a fault) will cut the fault and pass to the other side. (Fig. 8.22) This is the general principle in structural studies of age of faults.

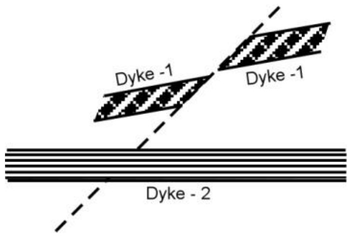



**Fig.8.22: Relative age of dyke and fault**

## 8.5. JOINTS

A joint is a plane that separates a once-continuous-rock-unit into two parts. Along the joint-plane there is no movement and that is how it is different from a fault. They are produced by stress within the rock-mass and are quite frequent in rocks. Outcrops rarely are jointless. Often they are mutually parallel and are then known as a joint-set. Joints, perpendicular to each other, also exist.

Joints are planes of weakness and hence solutions enter along the planes to dissolve the existing minerals in rocks or re-precipitate them when conditions are favourable. Master-joints are prominent ones, often cutting a set of rocks and control the exposure pattern. They are often termed also as diaclases when they form large crack like features.

Shrinkage cracks are not tectonic and are the outcome of shrinking of rock causing space specially found in sedimentary rock and resemble sun-cracks. Usually they are confined to single bed but, with sedimentarily formed younger rocks they almost try to create a replica of their own when the time comes.

Contraction joints produce columnar jointing in basalts and the columns are perpendicular to the base. Sheet-jointing is almost sub-parallel to the surface and is possibly due to the stress that results due to unloading especially in granite rocks of homogenous composition. Exfoliation or onion-weathering is the outcome of curvi-planar joints on homogenous rock mass. Conjugate joint system and its oblique equivalents produce many special geomorphic features like „tors‟ in granite topography. They are excellently developed in Devon and Cornwall (England). In Odisha, development of such features towards south of Berhampur and around Seetabeeinchi off Keonjhar town are also seen. When joints develop due to tectonic causes, longitudinal joints, (parallel to fold trend), cross joints (perpendicular to the fold-axis) and oblique joints develop (Fig. 8.23). In different horizons different joint-type is not impossible. They form as the outcome of the -

reaction of stress on rocks differentially. Like faults, the joints are considered as non-penetrative structure by structural geologists. As with other features, joints are to be analysed along with them for a total answer of their development and genesis with reference to the deformation style.

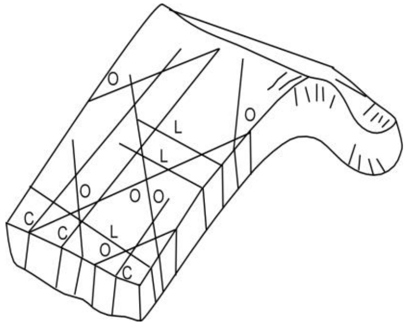



**Fig.8.23: Joints in rocks; L – Longitudinal joint, C – Cross joint and O – Oblique joint**

## 8.6. UNCONFORMITIES

An unconformity is defined as a surface of erosion or non-deposition separating younger strata from the older rocks. Thus, unconformity is a feature with respect to time when a process of any action stops, again to begin after a pause. The unconformity has several stages of development such as (a) formation of older rocks (b) upliftment and erosion of the older rocks and (c) deposition of the younger strata.

Unconformity of two sets of sediments, is different from that of sediments intruded by plutons and like-wise. Hence an unconformity broadly is regarded as a plane of non-deposition or erosion (in geological sense). With different types of rocks (igneous, sedimentary and metamorphic) the expression will be different. In geological sense it may be described as follows:

After an older rock is formed, it is followed by uplift and sub-aerial erosion. This is the period when there is non-deposition. This is followed by deposition of younger rocks. Eruption of basalts may come in after certain amount of erosion of this rock. This locality may have two unconformities, one above the oldest rock and the second above the later stage of sediments (eroded).

### 8.6.1. Types of unconformity

There are various kinds of unconformity (Figs. 8.7a-d). The most important ones are:

(a) Angular unconformity: In this case the two sides of the plane are not parallel either in a section or on a map. It is of interest to note that sedimentary rocks normally are tilted to one side at some angle due to deformation. Erosion acts on the surface of it. After the cessation of erosion, deposition takes place and conglomerate, sandstone and shale beds are formed as a normal sedimentary sequence. If the age of the rocks can be known the time of the development of unconformity can be decided.

Examples: At Rebna-Palaspal (15 km north of Daitari iron ore deposit) the hills west of the stream shows tilted Daitari iron-formation rocks overlain by sub-horizontal sandstone of Dhanjori age forming the peaks of the hills.

(b) Disconformity (or Parallel unconformity): In this case the rocks on both sides of the unconformity are parallel. Volcanic and /or sedimentary rocks (with or without conglomerate) are involved in the process. A disconformity normally covers a large area and represents a considerable interval of time.

(c) Nonconformity (or Heterolithic unconformity): In this type of unconformity the older formation is made up of essentially plutonic rocks and it is overlain either by sedimentary rocks or lava flows.

(d) Local unconformity: It is is also known as Non-depositional unconformity and is similar to disconformity. However, it is local in extent and hence the name. The period of non-deposition is very short and the age difference between the overlying and underlying beds is very less.

### 8.6.2. Recognition of unconformities in the field

The best way to find an unconformity is to search for it on a mesoscopic scale i.e., in road or railway cuttings, in a tunnel, on a stream section and the like. The non-existence of parallelism on both sides as found in case of angular unconformity is the best identifying point. Of course faults do show this feature at times.

(a) Angular unconformity: It shows lower deformed and tilted rocks overlain by relatively horizontal sedimentary beds. There may or may not be a basal conglomerate horizon separating the two set of beds. The unconformity plane covers a part of the lower beds. The strike and dip of both the sets are different.

(b) Disconformity: In older and younger set of beds, the dip is almost at the same angle. There may be sharp contrast in colour between the rocks above and below the disconformity surface. The surface of disconformity may be wavy with a conglomerate horizon separating the older rocks from the younger. Fossil record sometimes helps to distinguish older rocks from the younger rocks.

(c) Nonconformity: The nonconformity surface represents an intrusive rock lying below with sedimentary strata lying above. The rocks above the nonconformity may contain pebbles or boulders of igneous rocks that lie below.

Examples: In Daitari basin one observes an excellent disconformity between Daitari iron-formation rocks and Dhanjori sandstone with a thick (~20 - 25 m) boulder conglomerate below the Dhanjori sandstone off Raighati. This runs for a considerable distance. Dip of rocks of both sides is almost the same. The conglomerate is not autoclastic.

In search of a nonconformity one has to find a plutonic body (granite, gabbros, etc.) above which will be sedimentary / volcanic sequence / rock. A beautiful example is found between eroded granite and Kolhan sandstone towards south of Chaibasa (Jharkhand) on the walls of the railway-cutting below the southern bridge. The granite is eroded and sandstone is deposited above it sub-horizontally (Fig. 8.24 a, b and c).

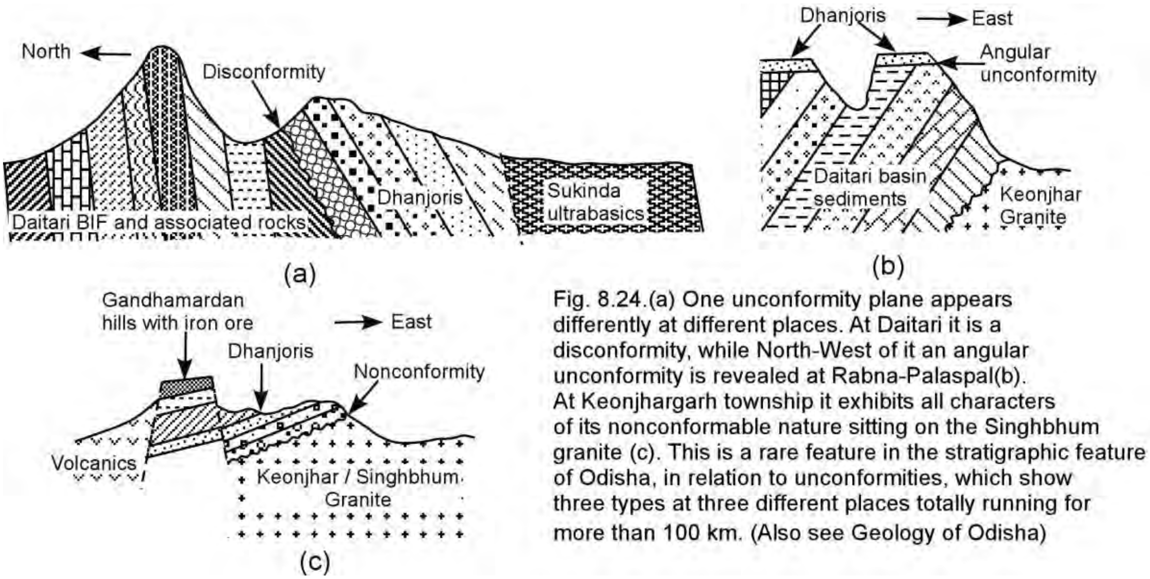



Fig. 8.24.(a) One unconformity plane appears differently at different places. At Daitari it is a disconformity, while North-West of it an angular unconformity is revealed at Rabna-Palaspal(b). At Keonjhargarh township it exhibits all characters of its nonconformable nature sitting on the Singhbhum granite (c). This is a rare feature in the stratigraphic feature of Odisha, in relation to unconformities, which show three types at three different places totally running for more than 100 km. (Also see Geology of Odisha)

One unconformity plane appears differently in different places. At Daitari it is a disconformity while north-west of it, an angular unconformity is revealed at Rebnapalaspal. West of Keonjhargarh township it exhibits all characters of its nonconformable nature lying on the granite. This is a rare stratigraphic feature in relation to unconformity; a single plane shows three types of features of unconformity at three different places covering a distance of more than 100 kms. It is an important structure that plays a vital role in the study of Geology of Odisha.

## 8.7. SAMPLE QUESTIONS

### 8.7.1. Long answer type questions

(i) Discuss the relationship of dip and strike of rocks with diagrams.

(ii) What is a fold? Describe different parts of fold with neat sketches.

(iii) What are fold types? Explain with diagrams.

(iv) What are antiform and synform? How are they distinguished?

(v) What are planar and linear structures? How are they applied to understand the structures of an area?

(vi) What is a fault? What are the different types of faults?

(vii) Describe the geometry of a fault.

(viii) What are river valleys? How are they formed? Give examples.

(ix) In one diagram can you explain fold, fault and unconformity? How?

(x) How do you identify a fault in the field?

(xi) In your field work days if you see a hill running E- W suddenly disappears, what may be the reason of its disappearance?

(xii) What are unconformities in stratigraphy? Give examples of 2 to 3 of this feature from Odisha.

### 8.7.2. Briefly describe the following (within two or three sentences)

(i) Dip and strike

(ii) Slickenside

(iii) Hanging wall

(iv) Recumbent fold

(v) Symmetrical fold

(vi) Plunging and non-plunging folds

(vii) Lineation in axial plane of fold

(viii) Unconformity and its types

(ix) Horst and Graben

(x) Angular Unconformity

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