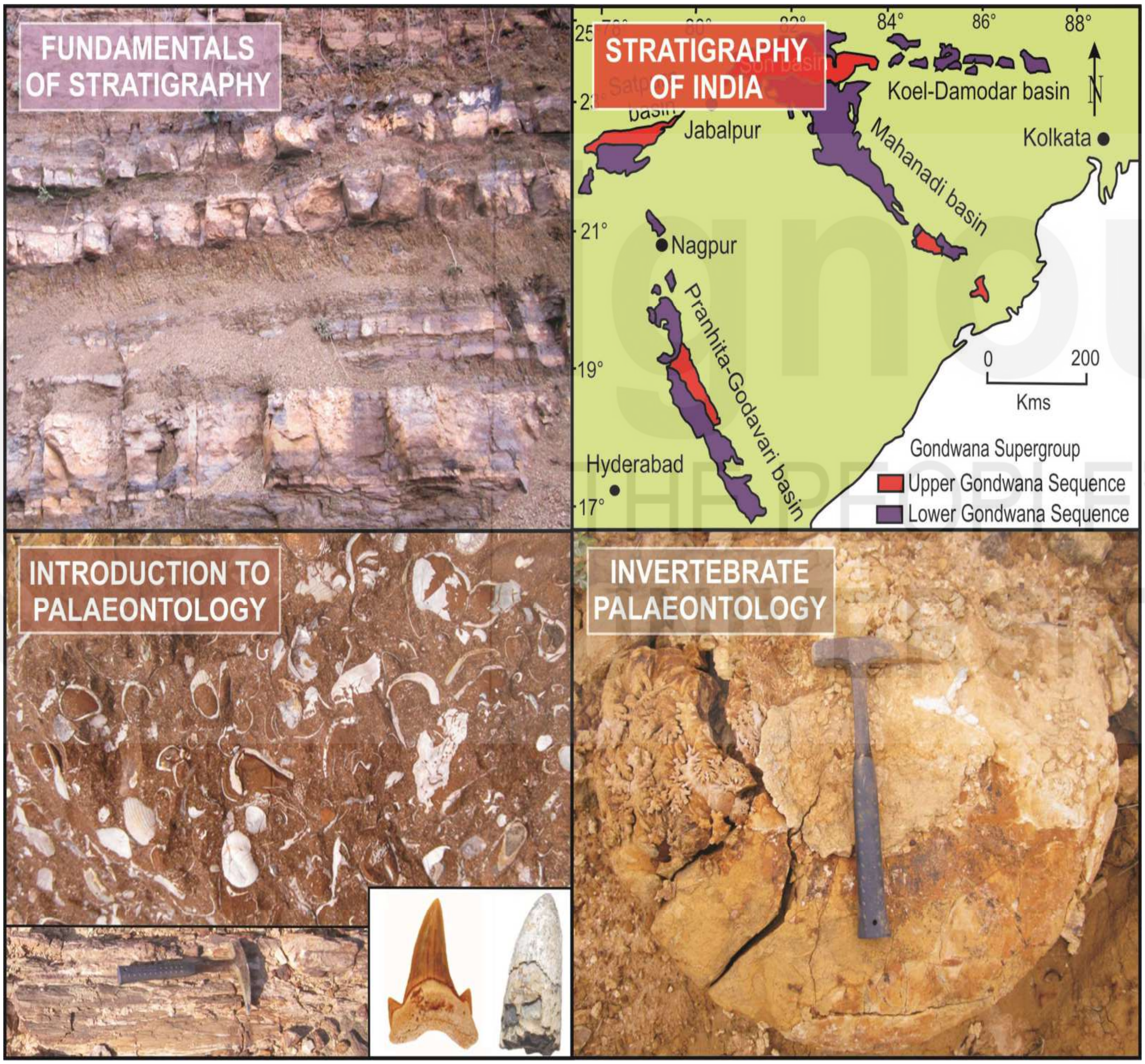
Indira Gandhi National Open University
School of Sciences

BGYCT-137
STRATIGRAPHY AND PALAEONTOLOGY



Stratigraphy

Volume 1

"शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्गगत विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।"

— इन्दिरा गांधी

"Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances."

- Indira Gandhi

Indira Gandhi National Open University
School of Sciences

BGYCT-137
STRATIGRAPHY AND PALAEONTOLOGY

Volume

1

STRATIGRAPHY

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BGYCT-137: STRATIGRAPHY AND PALAEONTOLOGY	
Block 1	**Fundamentals of Stratigraphy**
Unit 1	Principles of Stratigraphy
Unit 2	Stratigraphic Classification
Unit 3	Physiography of India
Block 2	**Stratigraphy of India**
Unit 4	Precambrian of India
Unit 5	Palaeozoic of India
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List of audio/video materials related to this course

1. **Evolution of Himalaya**

   Link: https://www.youtube.com/watch?v=gVGZKqrjVZY

2. **Himalaya – an overview**

   Link: https://www.youtube.com/watch?v=vK5Cglisa1Y

3. **Fossils in Himalaya**

   Link: https://www.youtube.com/watch?v=sLUqzsz1E80

4. **Application of Palaeontology**

   Link: https://www.youtube.com/watch?v=YbDXz8dZDWY

5. **Science of Palaeontology (Fossils and Fossilization)**

   Link: https://www.youtube.com/watch?v=XEN6q5CCJCU

6. **Deccan Volcanism and Mass Extinction at K/T Boundary**

   Link: https://www.youtube.com/watch?v=cxifXuAnSPE

7. **Age and duration of Deccan Volcanism**

   Link: https://www.youtube.com/watch?v=rodlNJOA-r8

8. **Deccan volcanism: an inside story**

   Link: https://www.youtube.com/watch?v=1a3glcg0oGs

Development of audio/video programmes is a continuous process. For recent materials pertaining to the course you may visit YouTube page of the School of Sciences, IGNOU.

Alternatively, you can visit eGyankosh website at

http://egyankosh.ac.in/handle/123456789/36575

BGYCT-137: STRATIGRAPHY AND PALAEONTOLOGY

The scientific study of strata and prehistoric life is stratigraphy and palaeontology. Both these branches are considered to be the oldest and fundamental branches of geology that document the historical, geological and biological events of the Earth. Stratigraphy, primarily, concerns with the systematic arrangement of layered (stratified) rocks and is based on the law of superposition. This law states that in a normal rock sequence, the youngest layer occurs at the top and the oldest layer lies at the bottom of the sequence. Prior to 1960, the lithostratigraphy and biostratigraphy were the two techniques available for studying the stratigraphy. However, after the beginning of 1960, stratigraphy witnessed dramatic changes and several modern techniques emerged for its study. Currently, geologists are using lithostratigraphy and biostratigraphy in conjunction with modern techniques like magnetic, event, sequence, chemical and facies stratigraphy in order to better understand the history of life and Earth.

Palaeontology, the study of fossils, aids the stratigraphy. It is a geological clock, which helps to document origin and evolution of life on the Earth. Fossils are found mostly in sedimentary rocks. Therefore, palaeontology also helps to determine the times in Earth history when and where the beds containing the fossils were deposited. It provides a record of past life, where it is inferred that with the passage of time, many old life forms were replaced by newer and more complex forms. Life was not uniform throughout the geological history. Hence, each era or period of geological past is marked by the dominance of a particular organic group like invertebrates, vertebrates or plants. Presently, each type of life form is living in a particular type of environment likes terrestrial, freshwater or marine. In order to understand various aspects of strata and fossils, it is assumed that the scientific laws, geological processes and forces operating today were also operating in the past. This simple principle referred as the Principle of uniformitarianism, which states that present is the key to the past. It is a fundamental base for the study of stratigraphy and palaeontology.

This course provides a broad introduction to stratigraphy and palaeontology by means of two distinct volumes. Each volume comprises of two blocks. **Volume 1** contains first two blocks which deal with the fundamentals of stratigraphy and stratigraphy of India. **Volume 2** comprises the last two blocks that deal with various aspects of palaeontology.

Block 1 deal with the fundamentals of stratigraphy. In this block, you will learn about principles of stratigraphy, stratigraphic classification and correlation, and significance of stratigraphy. This block also gives a glimpse about the physiography and stratigraphy of India.

Block 2 deals with stratigraphy of India. The block will acquaint you with the main stratigraphic supergroups or groups of India belonging to different geologic time such as Precambrian, Palaeozoic, Mesozoic and Cenozoic, and occur in various parts of the country.

Block 3provides insights into basic principles of palaeontology. In this block, you will learn about fossils, their types, modes of preservation and significances. It will, also educate you about the evolutionary histories of horses.You would also learn the plant fossils, their modes of preservation, classification and major groups of Gondwana plant fossils.

Block 4 describes major groups of invertebrate fossils. You will learn general introduction, taxonomy, morphology and geological history of corals, brachiopods, molluscs, trilobites and echinoderms in this block.

Expected Learning Outcomes

After studying this course, you should be able to:

- ❖ define stratigraphy and palaeontology;
- ❖ describe basic principles of stratigraphy and palaeontology;
- ❖ discuss various stratigraphic classifications and their units;
- ❖ outline the physiographic divisions and stratigraphic units of India;
- ❖ discuss the fossils and major groups of fossils;
- ❖ describe the morphology, systematics and geological history of major groups of invertebrate fossils;
- ❖ explain the evolutionary histories of horses; and
- ❖ discuss major groups of plant fossils.

We hope that you would enjoy reading the self-learning material.

VOLUME 1: STRATIGRAPHY

Stratigraphy is a branch of Geology, which deals with the study of rock layers (strata), their sequence and relationship with each other. Stratigraphy provides simple principles used to interpret geologic events; hence, it is also known as Historical Geology. Stratigraphy of India refers to the understanding of the sequential arrangement of its rock record from Archaean to Holocene. Rock record constitutes all type of rocks including igneous, sedimentary and metamorphic, occur in an area or in a country.

Palaeontology, the study of fossils, aids the stratigraphy. It may be defined as the science which deals with the fossilized remains of plants and animals of past geological ages preserved in the sedimentary rocks constituting of earth's crust. Strictly speaking it includes palaeozoology and palaeobotany, but the term is not infrequently used as a synonym of the former. The plants and animals are represented as fossils in the sedimentary rock-beds at definite times during the geologic past and hence have importance and chronological significance.

Volume 1 comprises of 2 blocks. In this volume you will learn about principles of stratigraphy, stratigraphic classification and correlation, and significance of stratigraphy and about the physiography and stratigraphy of India. The volume will also acquaint you with the main stratigraphic supergroups or groups of India belonging to different geologic time such as Precambrian, Palaeozoic, Mesozoic and Cenozoic, which occur in various parts of the country.

The first two blocks deal with the fundamentals of stratigraphy and stratigraphy of India.

Block 1- Fundamentals of Stratigraphy: The block comprises of three units. In this block, you will learn about principles of stratigraphy, stratigraphic classification and correlation, and significance of stratigraphy. This block also gives a glimpse about the physiography and stratigraphy of India.

Block 2 - Stratigraphy of India: The block comprises of five units. The block will acquaint you with the main stratigraphic supergroups or groups of India belonging to different geologic time such as Precambrian, Palaeozoic, Mesozoic and Cenozoic, and occur in various parts of the country.

Expected Learning Outcomes

After studying this volume, you should be able to:

- ❖ describe basic principles and importance of stratigraphy;
- ❖ discuss standard geological time scale;
- ❖ discuss the physiographic divisions and stratigraphic units of India.
- ❖ describe the stratigraphy and economic importance of the major Precambrian Supergroups of Peninsular India;
- ❖ explain the stratigraphic classification and economic importance of the Gondwana Supergroup and the Deccan Traps.

Wishing you success in this endeavour!!

Indira Gandhi National Open University
School of Sciences

BGYCT-137
STRATIGRAPHY AND PALAEONTOLOGY

Block

1

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BLOCK 1: FUNDAMENTALS OF STRATIGRAPHY

The science of sediments and strata is stratigraphy. Stratigraphy is, perhaps, the earliest branch of geology and is fundamental to all geological studies. It dates back to the time, when human beings started to observe and record the nature of Earth's natural processes. The main aim of stratigraphy involves the subdivision of sequences of rock strata into mappable units for determining their time relationships and correlating units of the sequence within rock strata or elsewhere. Therefore, all aspects of stratigraphic studies start from the rocks themselves. In fact, it provides invaluable tools, which allows reconstruction of the sequence of events of Earth's history and the evolution of life on Earth.

This is the first block of the course. It will give you a basic understanding of the stratigraphic principles and classification as well as an outline of stratigraphy of India. In this block, several diagrams and illustrations have been included to stimulate your interest.

This block deals with fundamentals of stratigraphy. In this block, you will be introduced to the basic principles and classification of stratigraphy. It comprises three units in all.

Unit 1 deals with the basic principles of stratigraphy. In this unit, you will learn about principles of stratigraphy, stratigraphic contacts, unconformities and importance of stratigraphy. You will also learn the standard geological time scale and collection of data for stratigraphic studies.

Unit 2 deals with the stratigraphic classification. You will learn lithostratigraphic, biostratigraphic and chronostratigraphic classifications in this unit. In addition, you will also learn various methods of stratigraphic correlation and its significance in stratigraphy.

Unit 3 deals with the physiography and stratigraphy of India. For the understanding of stratigraphy of India, knowledge of physiography of India is essential. In this unit, you will learn the physiographic divisions of India. It will also give a brief overview of stratigraphic units of India.

Expected Learning Outcomes

After studying this block, you should be able to:

❖ define stratigraphy;

❖ describe basic principles and importance of stratigraphy;

❖ discuss standard geological time scale;

❖ elaborate the litho-, bio- and chronostratigraphic classifications; and

❖ recognise the physiographic divisions and stratigraphic units of India.

In order to evaluate your learning while reading the self-learning material of this block, we have provided self-assessment exercises under the caption "Self Assessment Questions (SAQ)" at a few places and at the end "Terminal Questions" in all units of the block, which invariably end with answers to the questions, set in these exercises. You should attempt the exercises yourself and not be tempted to look up the answers given under the caption "Answers" beforehand. It should be noted that the check your progress is provided as study tools to help you keep on the right track as you read the units. You have been provided with the links of audio video materials related to this course. They are blended with the self-learning material. You are instructed to watch/listen these audio video programmes and answer the questions given after "terminal question".

We advise that as you read the units, jot down important points in the space provided in the margins of each page. In fact, broad margins in the booklet are provided for you to write your notes on. Make your notes as you work through the materials. This will help you prepare for the term end examination (TEE) and also in assimilating the content.

Your feedback pertaining to this block will help us undertake maintenance and timely revision of the block. Send your feedback to us to the address given below or e-mail to omkarverma@ignou.ac.in or kakoligogoi@ignou.ac.in:

The Course Coordinator BGYCT-137

Discipline of Geology

School of Sciences

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We hope that you would enjoy reading the self-learning material.

Wishing you success and all the best in this endeavour!!

UNIT 1

PRINCIPLES OF STRATIGRAPHY

Structure

1.1 INTRODUCTION

You already know that the Earth's surface is composed of rocks and soil. Most of these rocks were formed by a slow process of deposition of sediments carried by rivers and streams into oceans and other water bodies such as rivers, lakes, etc. This process has been going on for millions of years. In due course of time, the soft sediment got consolidated into stratified (layered) hard rocks. These rock bodies constitute the **sedimentary rocks**. The sedimentary rocks comprise bulk of the rock cover of the Earth. In course of time, some of these rocks might get subjected to high pressure and temperature when they sink down below the Earth's surface and change in composition and structure. Metamorphic rocks may be intruded or extruded by the igneous rocks formed from molten rock matter called **magma**.

Stratigraphy constitutes the study of stratified rocks in terms of their geometric relations, compositions, origins and age relationships. Thus, it helps us to interpret the Earth's history. It is essential to understand the basic principles of stratigraphy so that you can interpret the history of how the rocks were formed and what was the kind of sediment and the type of the basin where deposition took place. Once you get familiar with the basic principles, you would be able to trace the historical evolution of Earth's surface in time.

In this unit, we will introduce you to the concepts, historical development and basic principles of stratigraphy. We will also discuss the stratigraphic contacts and unconformities, techniques for collection of stratigraphic data and importance of stratigraphy. Once you know the principles you would know how to study the rocks and how to collect them to obtain information on their formation history.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define stratigraphy;
- describe the concepts and historical development of stratigraphy;
- discuss its basic principles;
- identify stratigraphic contacts and unconformities;
- elaborate the breaks in stratigraphic record;
- list the methods of stratigraphic data collection;
- state the significance of geological time scale; and
- explain the importance of stratigraphy.

1.2 STRATIGRAPHY

In simple words, **Stratigraphy** is the study of **stratified rocks**, which are deposited layer by layer. Its study includes classification, interpretation and correlation of stratified rocks in space and time that help us interpret the geologic history of Earth. The term Stratigraphy was given by French geologist d'Orbigny in 1849. The word stratigraphy is a combination of the Latin word **Stratum** and the Greek word **Graphia**, which refersto the description of all rock bodies forming the Earth's crust and their organisation into distinctive, useful and mappable units. Let us discuss the basic concept, definition and historical development of stratigraphy.

1.2.1 Concept and Definition

Stratigraphy is a branch of Geology, which deals with the study of rock layers (strata), their sequence and relationship with each other. Stratigraphy provides simple principles used to interpret geologic events; hence, it is also known as **historical geology**.

Stratigraphic studies deal primarily with sedimentary rocks, but it may also include layered igneous rocks like lava flows. It also involves the relationship of intrusive igneous rocks with respect to the sediments.

The stratified rocks always display a record of the past geological events. Stratigraphy involves the studies directed towards the interpretation of these events. For this purpose, the sediments and sedimentary rocks are studied to know the nature of the sedimentary environment. The study also involves the examination of fossils in the rocks that have a direct bearing on the time of deposition.

Determining the nature and type of rocks or what is called **lithology** constitutes one of the important aspects of stratigraphic studies. This aspect is called **lithostratigraphy**. The other important aspect involves the study of fossils present in the rock sequence that is known as **biostratigraphy**. From biostratigraphic studies, it becomes possible to build a time sequence based on stratigraphic events that is called **chronostratigraphy**.

1.2.2 Historical Development

Stratigraphy reached the modern level of development through a series of discoveries and observations made from time to time. The foundation was laid by Nicholas Steno (Fig. 1.1a), who is regarded as the father of stratigraphy. It was Steno who proposed the law of superposition and introduced the principles of original horizontality and lateral continuity in 1669 thereby laying down the basis of stratigraphy as a science. He was followed by James Hutton (1726-1797, Fig. 1.1b), who propounded the theory of uniformitarianism which remained the basic principle of stratigraphic studies and influenced the subsequent works like those of John Playfair, William Smith and Charles Lyell.

(a) (b)

Fig. 1.1: Renowned stratigraphers: a) Nicolas Steno – founder of modern stratigraphy (Source: http://en.wikipedia.org/wiki/Nicolas)**; and b) James Hutton.** (Source: www.martinfrost.ws/html files/gazette/james_hutton)

While JohnPlayfair (1748-1819, Fig. 1.2a) popularised the Hutton's principle of uniformitarianism, it was William Smith (1769-1839, Fig. 1.2b) who first proposed the concept of layering in sedimentary rocks. He introduced the term "strata" (singular "stratum") to denote these layers thus giving a name to the science of stratigraphy that is derived from this term. Smith also published the first geological map of Great Britain. Almost simultaneously the concept of layering in sedimentary rocks and the significance of different fossils for dating strata were elaborated in France by Alexandre Brongniart (1770-1847, Fig. 1.2c). It was Charles Lyell (1797-1875, Fig. 1.2d), who published the book *Principles of Geology* wherein he elaborated on uniformitarianism and defined the significance of stratigraphic sequence.

Fig. 1.2: Renowned stratigraphers: a) John Playfair (Source: http://www.electric scotland.com/history/nation/playfair.htm)**; b) William Smith** (Source: http://en.wikipedia.org/wiki/William_Smith)**; c) Alexandre Brongniart** (source: http://en.wikipedia.org/wiki/File:Alexandre_ Brongniart.jpg)**; and d) Charles Lyell.** (Source: http://en.wikipedia.org /wiki/File:Sir_Charles_Lyell-Bt-jpg)

In recent years, stratigraphy has evolved considerably with dating of rocks through radiometric and magneto-stratigraphic techniques. Use of chemical indicators and isotopes has also revolutionised the methods and applications in stratigraphic studies. For purposes of uniformity of approach, an International Sub commission on Stratigraphic Classification has been established by the International Union of Geological Sciences (IUGS), which lays down the applications and principles from time to time depending on the new findings and discoveries.

1.3 BASIC PRINCIPLES OF STRATIGRAPHY

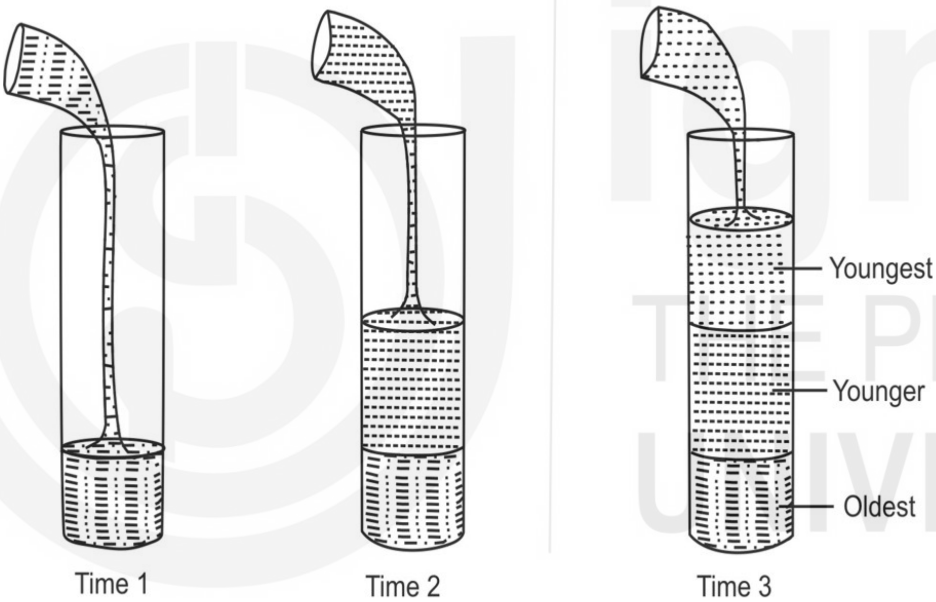
Stratigraphy is based on a set of principles that govern the processes of sedimentation. The sedimentation is a result of accumulation of rock material carried by agencies like water, wind and glaciers and deposited in a basin. The mechanism of sedimentation and accumulation of other stratified rocks like lava flows determines the principles of stratigraphic studies. There are eight basic principles or laws of stratigraphy, which are listed below:

- Order of superposition
- Original horizontality
- Lateral continuity
- Cross-cutting relationships
- Inclusions
- Unconformities
- Fossil succession
- Uniformitarianism and catastrophism

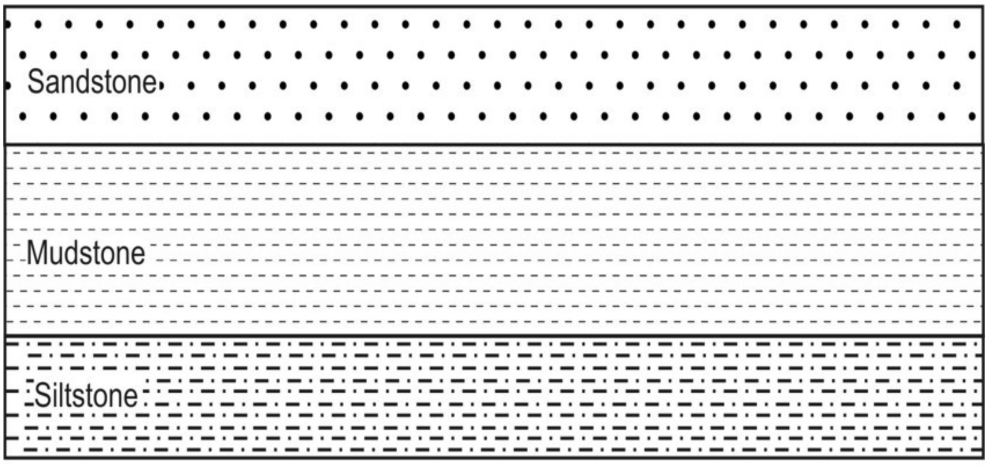
Let us discuss each principle in brief in the same order as given above.

1.3.1 Order of Superposition

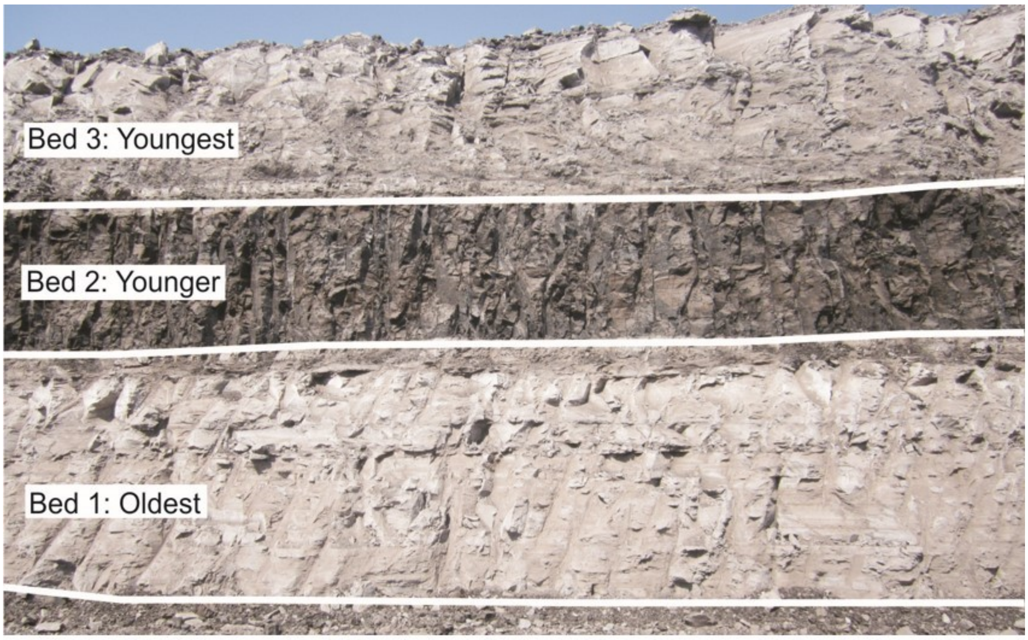
It is obvious that when sediments get deposited in a basin they go down to the bottom layer by layer. The bottom-most layer is thus the first to deposit. This process continues throughout the course of deposition as more and more sediments are deposited in the subsequent layers. Thus, in a sedimentary sequence the beds or layers at the bottom are deposited first and hence, are the oldest. The beds overlying them are younger. Accordingly, in a sedimentary sequence it is possible to determine which are the older beds and which beds are younger (Fig. 1.3). Therefore, a sedimentary sequence denotes relative time of deposition as the beds lie one upon the other. The principle is that in a sedimentary sequence, the beds are younger and younger as we go up from bottom to top. This principle is known as the **order of superposition** that constitutes one of the basic principles of stratigraphy.



(a)



(b)



(c)

Fig.1.3: Schematic presentation of order of superposition: a) Showing the model for deposition of three beds at time 1, 2, and 3; and (b-c) Showing their actual position in space with the oldest bed at the bottom and the youngest at the top. (Source: http://www.appstate.edu/~marshallst/GLY1101/lectures/12-Geologic_Time.pdf for a)

1.3.2 Original Horizontality

The sedimentary rocks occur in all dispositions, but they are rarely horizontal and most of the time they may be tilted or dipping at various angles or may even be folded. It is obvious that they could not have been deposited in that condition. Sediments in a basin are always deposited in a horizontal manner irrespective of the shape of basin. The tilting and folding are structural changes that take place after the rocks are deposited and consolidated (Fig. 1.4). So, for a study of the rocks you have to visualise their nature not in their present disposition, but assuming that they were deposited originally in a horizontal fashion. This is the principle of original horizontality.

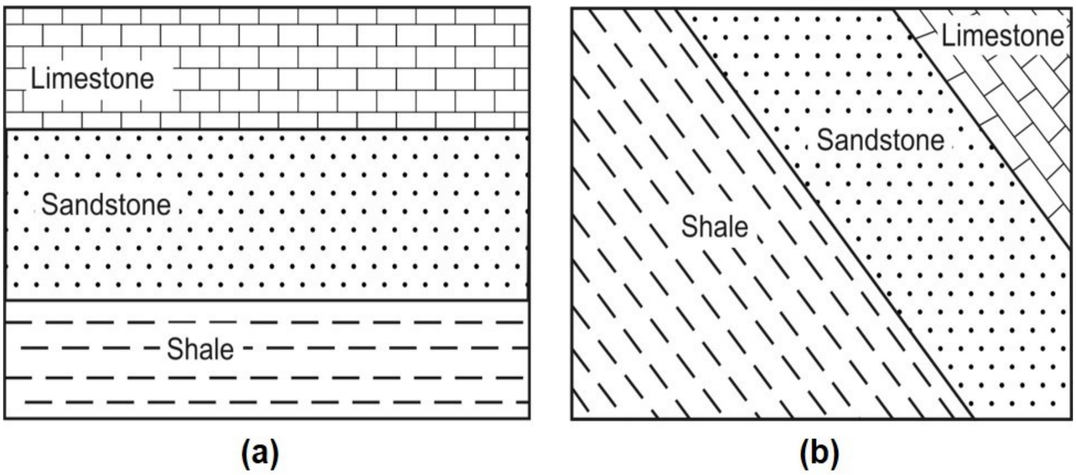


Fig. 1.4: Schematic views of original horizontality: a) Rock sequence with horizontal beds showing the principle of original horizontality, and b) Same rock sequence with inclined beds after folding or tilting.

1.3.3 Lateral Continuity

In a basin, sediments are spread in all directions during the course of deposition, but, when traced they show a lateral continuity. When we study sediments, we often find that in a valley the deposits cannot be seen. But they are exposed again across the valley as shown in Figure 1.5. This is because the subsequent erosion along the valley has removed these sediments. But, originally, they were deposited in continuity, which extends up to the limit of the basin, if sufficient amount of sediment is available.

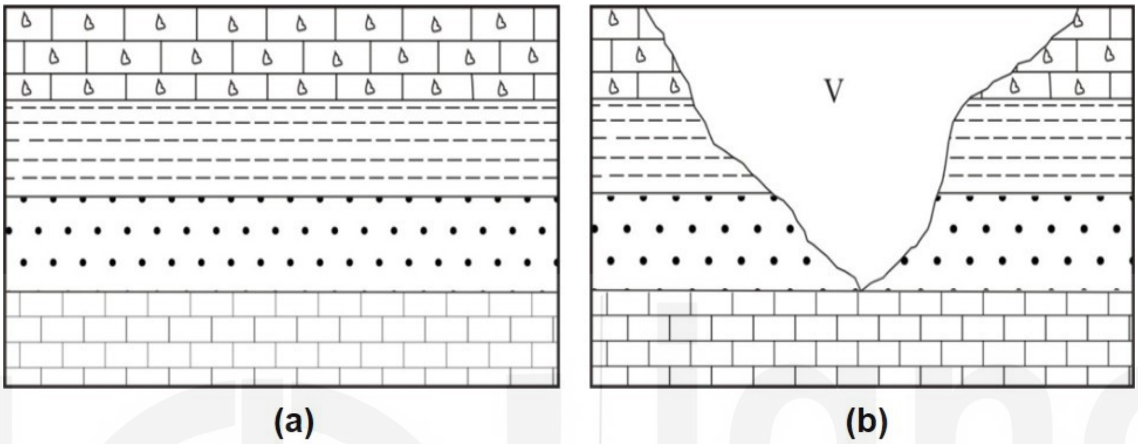


Fig.1.5: Lateral continuity among the beds: a) Original laterally continuous deposition of a rock sequence; and b) Same rock sequence showing a disturbed lateral continuity after the erosion of beds along the valley V.

1.3.4 Cross-Cutting Relationships

The basic principle of cross-cutting relationship is that when something cross cuts a sedimentary sequence, it is always younger than that sequence. In other words, all cross-cutting features are produced after the sediment is deposited. The cross-cutting feature may be a structural feature like a fault or an igneous intrusion like a dyke (Fig.1.6). It could also be a feature of erosion like a valley or a break in deposition as shown in Figure 1.5b. All these changes are brought about after the deposition has taken place.

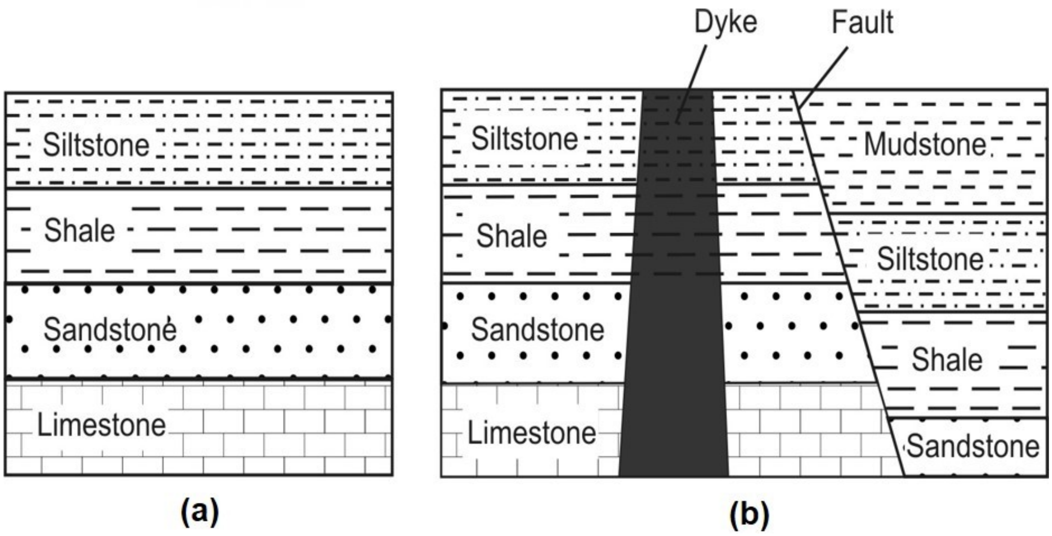


Fig. 1.6: Cross-cutting relationships: a) original sedimentary sequence; and b) same rock sequence showing the formation of cross-cutting features like dyke and fault after the deposition of the beds.

1.3.5 Inclusions

Sedimentary rocks are often made up of clasts or fragments of older rocks that are carried by river water or any other medium and deposited in a basin. After deposition, these clasts get consolidated into a rock. These clasts range in size from very fine silts to fragments of gravel and can be termed as inclusions in a sedimentary rock (Fig. 1.7a). In lava flows, there can also be some inclusions and they are known as xenoliths (Fig. 1.7b). The principle of inclusions is that they are all older than the rock in which they are deposited. This is obvious because they are derived from denudation of pre-existing rocks.

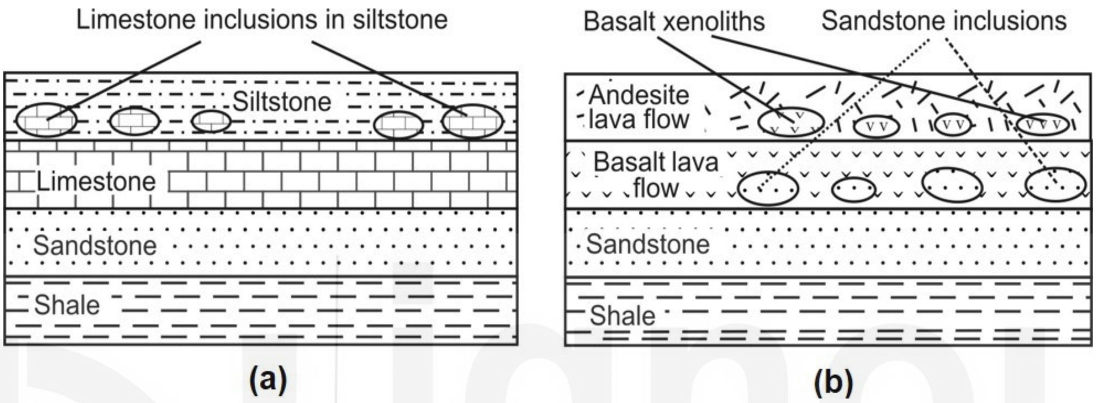


Fig. 1.7: Inclusions in rock beds: a) Limestone inclusions in siltstone bed; and b) Sandstone inclusions in basalt lava flow and basaltic xenoliths in andesite lava flow. (Source: http://www.appstate.edu/~marshallst/GLY1101/lectures/12-Geologic_Time.pdf)

1.3.6 Unconformities

When sediments are deposited continuously, they constitute a sedimentary sequence. Very often it happens that there is a break in sedimentation, which is called an **unconformity** (Fig. 1.8). The break in sedimentation can be due to the non-availability of sediment or to the filling up of the basin. Alternatively, the basin may be uplifted and hence no sedimentation can take place. The break may last for a brief period or may be long. In the former case, it may be difficult to locate an unconformity, but in long breaks, the unconformity can be located by evidences of erosion or change in the angle of inclination of beds.

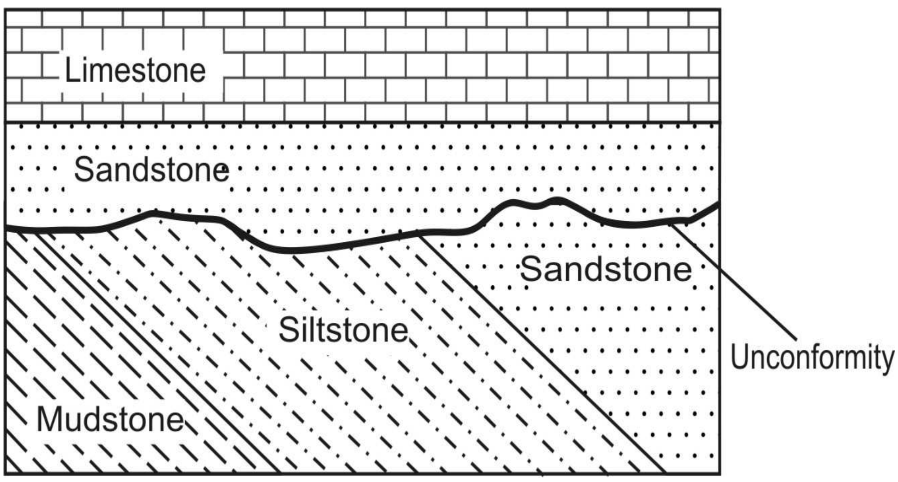


Fig. 1.8: Unconformity in sedimentary rock sequence.

1.3.7 Fossil Succession

Most sedimentary rocks bear fossils that are the remains of organisms of the past. But the type and species of organisms keep changing from time to time. As a result, the fossils are not the same in different strata. Therefore, on the basis of the type of fossils in a bed, it is possible to differentiate between the beds at different levels (Fig. 1.9). Fossils help in classifying the sequence of rocks and in establishing a succession in time of deposition.

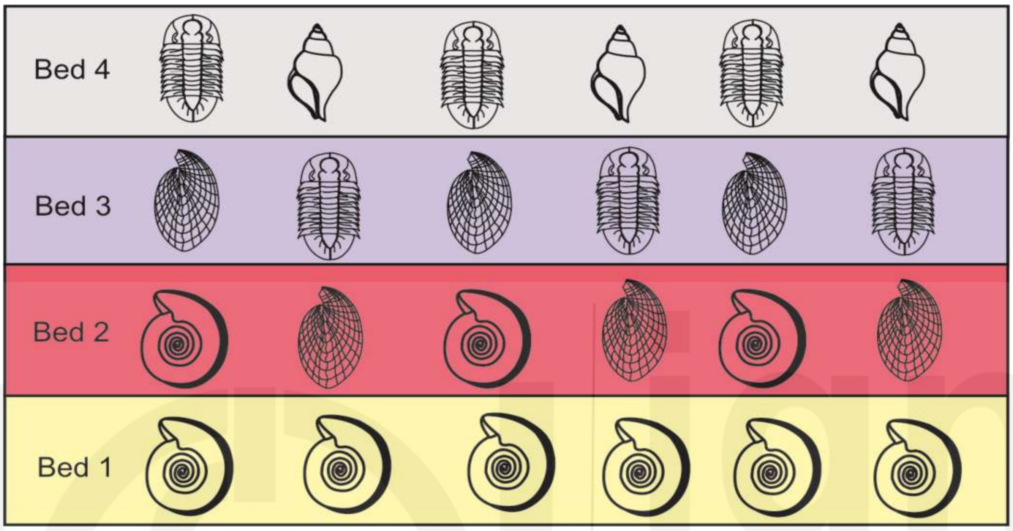


Fig. 1.9: Use of fossils in a rock sequence: Bed 1 is characterised by the presence of ammonoids; Bed 2 by ammonoids and brachiopods; Bed 3 by brachiopods and trilobites; and Bed 4 by trilobites and gastropods.

1.3.8 Uniformitarianism and Catastrophism

The principle of uniformitarianism is that the processes as operating on the Earth at present like sedimentation, erosion, etc. were the same in the past as well. These processes, over a prolonged period of time, were responsible for the changes that have taken place on the Earth. The guiding maxim for understanding the historical evolution of Earth under this principle as proposed by James Hutton is that "***study of the present is the key to the past***". Uniformitarianism is a slow process and brings about changes after a prolonged period of time. However, it has been noticed that major changes on Earth have taken place suddenly through some catastrophic events. So, Earth's history consists of long periods of gradual and uniform changes (uniformitarianism) followed by occasional short period of a catastrophic event (catastrophism). So, while both uniformitarianism and catastrophism are the operating processes in Earth's history the major changes are all a result of catastrophism.

Learners, you have learnt the concept, historical development and basic principles of Stratigraphy. Before discussing about the stratigraphic contacts and unconformities and their identification, spend few minutes to perform an exercise to check your progress.

SAQ1

a) Stratigraphy is the study of ……………………

(a) Stratified rocks (b) Igneous rocks(c) Mineral deposits (d) Plutonic rocks

b) List the main principles of stratigraphy.

c) Present is the key to the past is known as ………………………

(a) Order of superposition (b) Uniformitarianism (c) Unconformity (d) Fossil

1.4 STRATIGRAPHIC CONTACTS AND UNCONFORMITIES

The stratified rocks comprise beds of different rock types. When these beds overlie one another, in a sequence, the junction between the two constitutes a stratigraphic contact. The contact is generally vertical, but it can also be lateral when one rock type abuts against another, horizontally. These are normal types of depositional contacts, but there can be others that are intrusive or structural in nature.

1.4.1 Stratigraphic Contacts and their Identification

A stratigraphic contact is the boundary between the two rock units. In stratigraphy, a number of contacts are recognised and important ones are discussed below.

i. **Vertical Depositional Contacts**: When beds are deposited one above the other, the junction between them is known as a **vertical stratigraphic contact**. It can be conformable or unconformable. Conformable contacts indicate unbroken deposition where there are no perceptible breaks and the sequence is uninterrupted. As has been discussed in Section 1.3.2 above, the original deposition is always horizontal. But it is rare to find strata in a horizontal condition as they often get tilted subsequently due to structural deformation. A conformable sequence may be tilted or folded but the contacts remain uninterrupted.

   Vertical contacts may be **abrupt** or **gradational**. In abrupt contacts two different kinds of rocks, say sandstone and limestone are in contact, one overlying the other, along a fixed line (Fig.1.10a). While there is no break the rock changes suddenly. The gradational contacts show a gradual change upwards from one type of rock to another. For example, an underlying sandstone may slowly become calcareous with addition of calcium carbonate content and with increasing amount of calcium carbonate may eventually become a limestone. This change is not along a particular line but extended for a considerable thickness of the rock (Fig. 1.10b).

ii. **Lateral Depositional Contacts**: Laterally, the strata may extend in all directions up to the basin extremity. However, the thickness of individual strata may increase or decrease as we follow the beds laterally. A particular bed may even taper off and be replaced by another bed with a different lithology. The lateral contacts are seldom abrupt and are generally gradational (Fig.1.11).

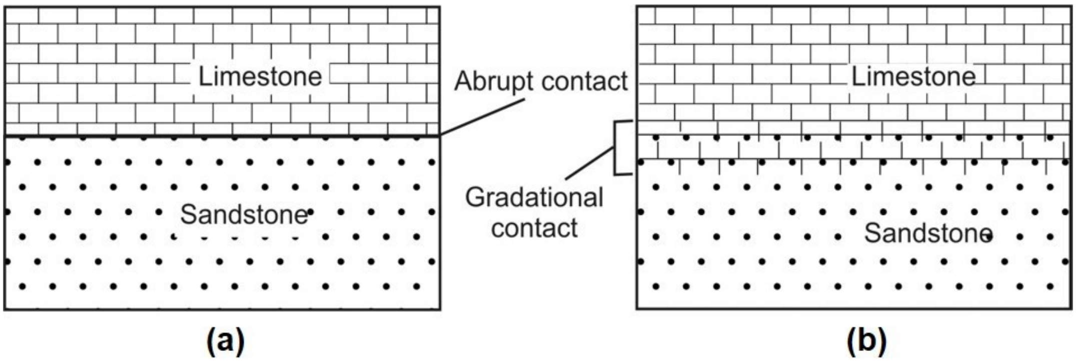


Fig.1.10: Stratigraphic contacts: a) Abrupt; and b) Gradational.

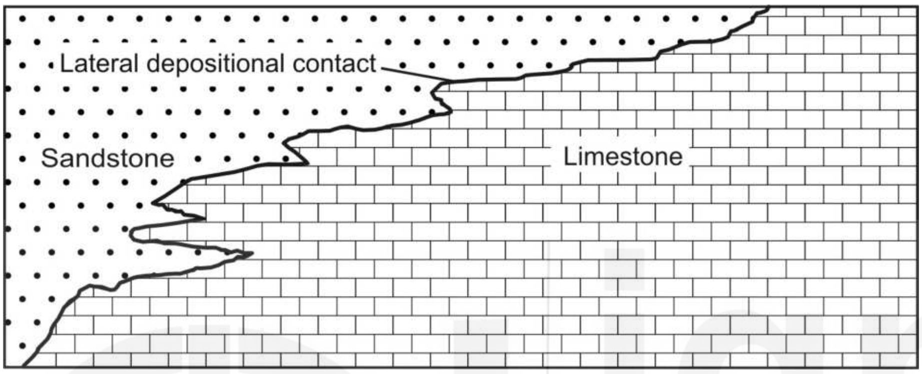


Fig. 1.11: Limestone passing laterally into sandstone showing a lateral depositional contact.

iii. **Intrusive Contacts**: Sedimentary rocks may be intruded by igneous rocks in the form of sills, dykes or batholiths. A sill is an intrusion that is parallel to the bedding plane and thereby **concordant** with the sequence of the strata. It is disposed like one of the beds of the sedimentary sequence (Fig. 1.12). A dyke cuts across the sedimentary sequence and is **discordant** with the bedding (Fig. 1.12).

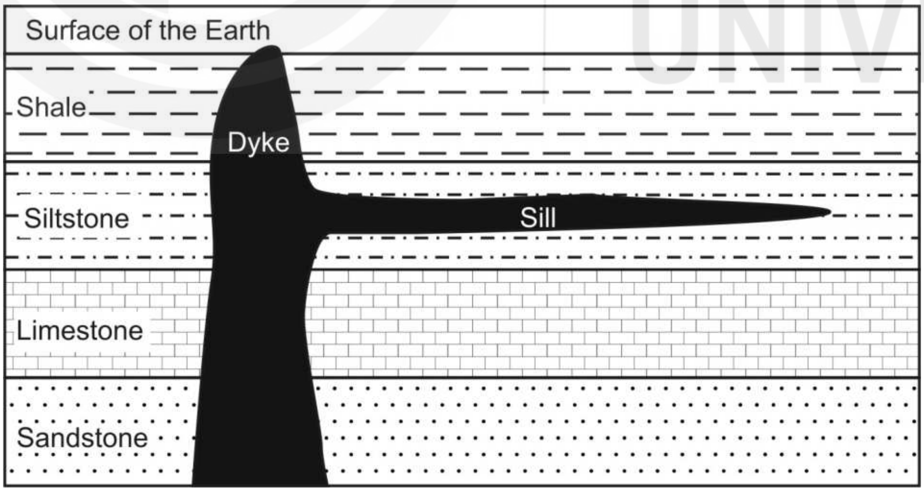


Fig. 1.12: Intrusive contacts; the discordant dyke intruding across four sedimentary beds and a concordant sill intruding along the siltstone bed.

iv. **Fault Contacts**: A sedimentary sequence may be faulted as a result of structural deformation after the deposition and consolidation of the rock. A fault disturbs the sequence of the strata along a plane that cuts across the bedding. As a result, rocks of different kinds and ages come in contact with each other along a discordant plane that may be cutting across the bedding as shown in Figure 1.13.

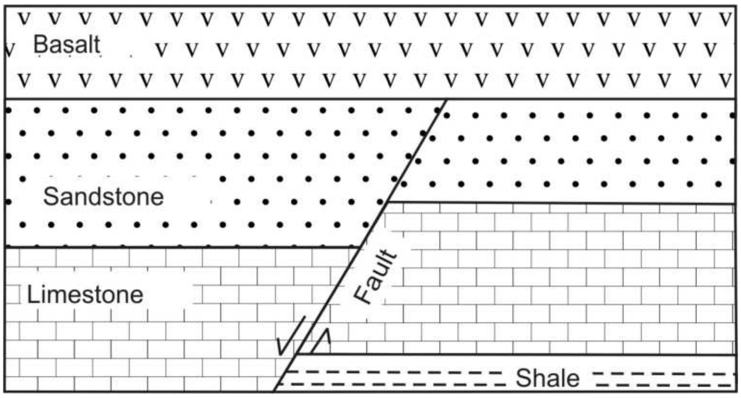


Fig. 1.13: Fault contact. Note that fault is younger than shale, limestone and sandstone but older than basalt. Half arrow symbols indicate upward and downward movement of beds.

1.4.2 Unconformities and their Identification

A break in a stratigraphic record takes place when sediment is not being deposited or when some previously deposited sediment has been removed by erosion. Such a break in stratigraphic record is called a **hiatus**. The indication of a hiatus in stratigraphic record is called an **unconformity**. In other words, an unconformity is indicative of either a break in sedimentation or a period of erosion separating the two strata. These periods can be long or short. The unconformities are of various types and generally can be easily identified. Following are some of the common types of unconformities:

i. **Angular Unconformity**: Angular unconformity is one of the most easily identifiable unconformities. In an angular unconformity, the two sets of strata are at an angle and not parallel to each other. Generally, the lower set of strata is tilted whereas the overlying set may be horizontal or tilted at a different angle. An angular unconformity is produced as a result of deformation of the older rocks during a period of uplift and non-deposition (Fig. 1.14a) and at a later stage, a younger set of sedimentary beds get deposited over the tilted older beds. These unconformities are easy to recognise in field because of the angular relationship of the two sets of strata.

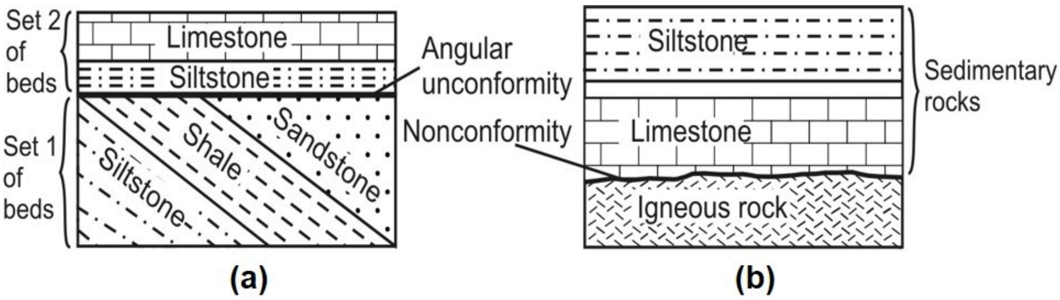


Fig. 1.14: Types of unconformity: a) Angular unconformity; and b) Nonconformity. Note the orientation of the beds.

ii. **Nonconformity**: Nonconformity is another easily identifiable unconformity. In nonconformity, an igneous or a metamorphic rock is overlain by a sedimentary rock or vice versa as shown in Fig. 1.14b. The line of contact is always an erosional surface and may represent a long hiatus. Since the two sets of rocks are totally different the nonconformity can be easily recognised.

iii. **Disconformity**: A disconformity is marked by an erosional surface but there is no angular difference between the underlying and overlying beds (Fig. 1.15). The erosion may be indicated by the presence of a pebble or boulder bed or the development of a layer of old soil called palaeosol. Disconformities are harder to recognise because there are seldom any clear indications of a break in deposition. They can be recognised either by the presence of pebble beds or palaeosols or by comparing the underlying and overlying beds in respect to the rock type or fossil content.

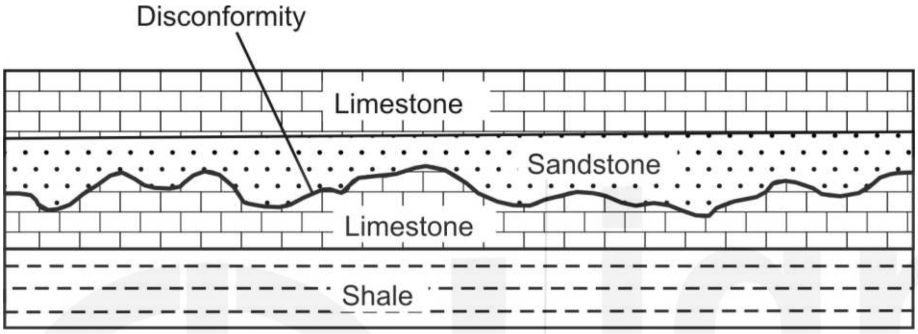


Fig. 1.15: Disconformity: marked by wavy line along which erosion has taken place.

iv. **Paraconformity**: In paraconformity, the bedding planes in lower as well as the upper set of rocks are parallel and there is no apparent break or evidence of erosion that could indicate a period of non-deposition. This type of unconformity is very difficult to recognise since it marks a period of non-deposition that has not left any evidences. The only way of recognising such an unconformity is by the fossil content in the two strata that may indicate the time span of non-deposition.

Learners, you have learnt about the stratigraphic contacts and unconformities and their identification. Before discussing about how to collect stratigraphic data, spend few minutes to perform an exercise to check your progress.

SAQ 2

a) What is the difference between an angular unconformity and a disconformity?

b) What is the difference between a sill and a dyke?

c) What is the difference between uniformitarianism and catastrophism?

1.5 HOW TO COLLECT STRATIGRAPHIC DATA?

For understanding the history and nature of a rock formation, it is necessary to collect stratigraphic data in a systematic manner so as to know how the rocks were deposited and what changes took place after their deposition. It would also be possible to know about the nature of basin in which deposition took place. Let us discuss the equipment and techniques required for collection of data.

1.5.1 Equipment Needed

For collection of stratigraphic data in the field, some simple equipment is necessary. These includes a field diary, a measuring tape, a hammer with a set of chisels, a brunton compass (or a clinometer compass), a set of pencils, a haversack, a hand lens, etc. It is preferable to carry a topographical map of the area, if available.

1.5.2 Recording the Attitude of the Beds

From the topographical map or a base map of the area we choose a point to start the study and data collection. At this point it is necessary to record the **attitude** or **dip** and **strike** of the beds. If the beds are horizontal, we need to look for a ravine, gorge or a valley. Because in a flat terrain, the sequence of beds cannot be seen as the same bedding surface and will extend throughout the area. However, if the beds are inclined and dipping, the study and data collection can be made even in a flat terrain. In a dipping terrain, it is necessary to record the direction and amount of the **true dip**. This can be done by a brunton compass or a clinometer compass. The highest value of the dip is always in the direction of the true dip.

1.5.3 Choosing a Traverse

It is necessary to choose a traverse for the study of the sequence. A traverse is a direction along which one can move and systematically collect the data. It is preferable to choose the traverse along or across the true dip. Only where it may not be possible due to some obstructions, a traverse along or across **apparent dip** may be taken. But in no case the traverse should be along strike of the beds because in that case we will be following the same bed.

While moving along the true dip we have to remember that older beds dip towards the younger beds. In this situation we are following the beds in a natural stratigraphic order from older to younger beds. If our traverse is across the dip then we are following the sequence from younger to older beds and the recording has to be made accordingly.

1.5.4 Measuring Thickness

The next important step is to measure the thickness of individual beds. If the beds are horizontal and the study is being undertaken in a ravine. The thickness of each bed can be measured directly by placing the measuring tape at right angle to the bedding plane that will give the true thickness of each bed. The same technique can be applied for dipping strata in a gorge. However, in dipping strata in a flat or sloping terrain the outcrop width of each bed is only the **apparent thickness** and not the **true thickness**. From this apparent thickness the true thickness can be calculated by applying the sine formula. For example, if the terrain is flat the true thickness can be calculated by multiplying the apparent thickness with sine of the angle of the dip (Figs. 1.16 and 1.17).

True Thickness: True thickness is the perpendicular distance between the lower and upper bedding plane of a rock formation.

Apparent Thickness: Apparent thickness is the thickness at an oblique angle to the bedding plane. In flat terrain the dipping strata display only the apparent thickness.

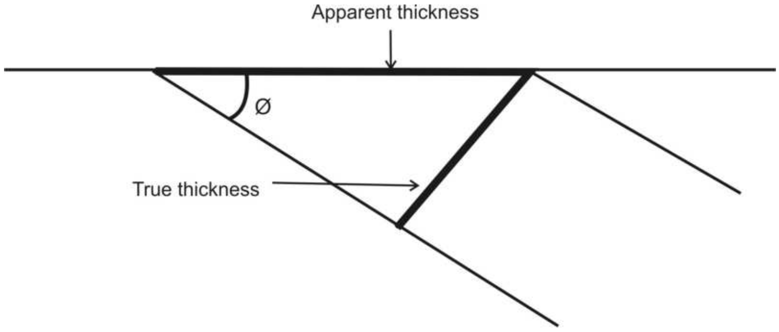


Fig. 1.16: Relation between true thickness and apparent thickness. True thickness (in this case) = Apparent thickness × Sin Ø, where Ø is the angle of dip.

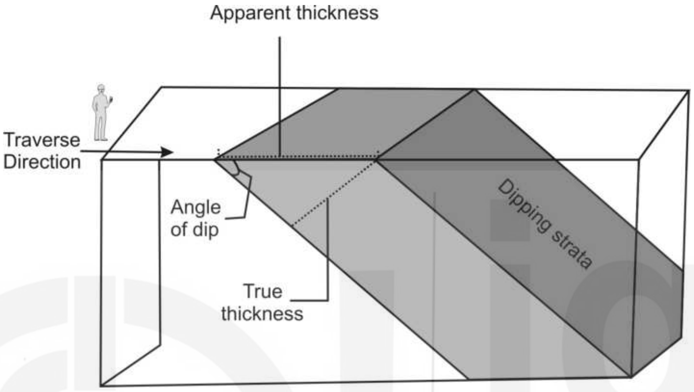


Fig. 1.17: Relation between true thickness and apparent thickness as illustrated above in three-dimensional framework.

1.5.5 Recording Lithological Characters

The lithological characters of each measured unit have to be systematically recorded in the field diary. These include the nature of the rock type (limestone, sandstone, shale or conglomerate, etc.), the nature of bedding (thin bedded, thick bedded), the **sedimentary structures** (cross-bedding, ripple marks, etc.) and any other features like colour and grain size.

1.5.6 Recording and Collecting Fossil Data

While studying the individual rock units it is necessary to look for the fossils that may be present in the rocks. The larger fossils can be seen with a naked eye or with the use of a hand lens. All the different types of fossils have to be carefully extracted with the hammer and chisel. However, the rocks may not show fossils on surface but may still contain microfossils. For that purpose, the rock samples need to be carried to the laboratory to extract and study them. It is important to properly label these samples so that it is exactly known as to from which bed a particular rock sample has been collected.

1.5.7 Preparing a Stratigraphic Column

The purpose of study and collection of data along a traverse is to prepare a stratigraphic column. A stratigraphic column depicts the interpreted sequence as it would have been deposited originally. It is always made to the scale based on the thickness of the individual beds. There is a code of hachuring to denote the different rock types. For example, the limestone is denoted by brickwork, sandstone by dots and siltstone by horizontal broken lines and dots as shown in Figure 1.18.

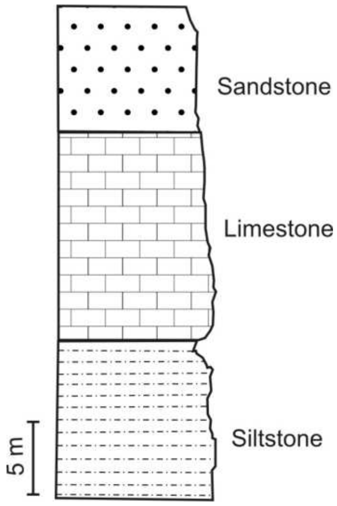


Fig. 1.18: A sample stratigraphic column with a scale (5 metres) indicating the thickness of each rock type.

1.5.8 Stratigraphic Correlation

Stratigraphic correlation is the comparison of the rock types of different traverses and equating them with one another in respect of their characters. A number of traverses are undertaken in an area from which the stratigraphic data has to be collected. For each of these traverses a stratigraphic column is prepared. When many columns are prepared, the next important function is to correlate them as shown in Figure 1.19. This is done by identifying the individual units by their lithology or fossil content or both. The thickness of each unit in different stratigraphic columns may vary and that will give the total picture of the stratigraphic setting of the basin.

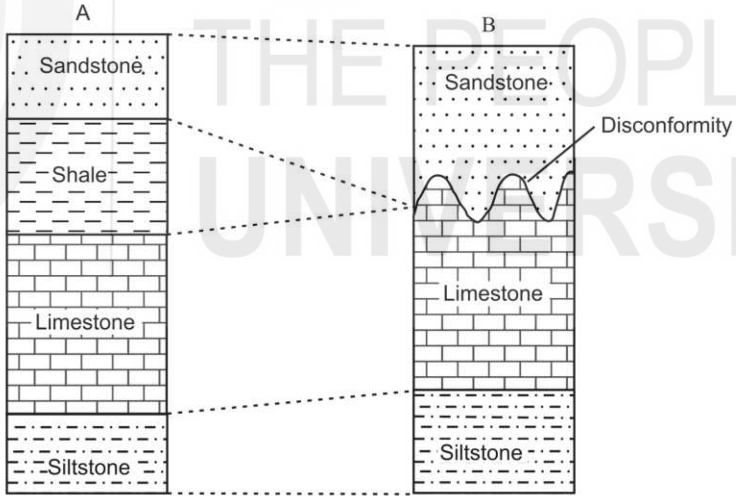


Fig. 1.19: Stratigraphic correlation; stratigraphic columns of sites A and B are correlated. It is inferred that shale bed is absent at site B and nature of contact between limestone and sandstone shows the presence of an unconformity which is a disconformity (marked by a wavy line).

1.6 IMPORTANCE OF STRATIGRAPHY

Stratigraphy is the basic branch of Geology that depicts the Earth's history through time from its consolidation to present day. It gives the distribution of land and sea at different periods of time. It also provides the data on the evolution of organisms and their diversification in space and time throughout the Earth's history. While stratigraphic studies focus primarily on sedimentary rocks, they also deal with layered igneous rocks like lava flows, metamorphic rocks and intrusive igneous rocks. Stratigraphic studies allow the classification of rocks into **mappable units** with a time control. This forms the basis of all other studies to know the Earth's history and evolution. On the economic front, it is the cornerstone in location of oil and gas and is a basic science for Petroleum Geology. Because oil and natural gas almost always occur in stratified sedimentary rocks, the process of locating petroleum reservoir traps has been facilitated significantly by the use of stratigraphic concepts and data.

In addition to providing data on the evolution of life through space and time, stratigraphy also finds application in Archaeology where the law of superposition helps in location of different stages of human cultural evolution. With the help of stratigraphy, we can know about the distribution of land and sea and other geographical information at different points of time. Together with the help of fossils, stratigraphy provides data on past climate and environment.

1.7 GEOLOGICAL TIME SCALE

You have already read that the vertical sequence in stratigraphy is indicative of time. This is because the older beds are overlain by the younger beds. In stratigraphy, the vertical sequence reflects the passage of time. On the basis of fossils, the geological time has been classified into units, which are then grouped together into larger units. The process is similar to our daily classification of time into seconds, minutes, hours and days.

Eon	Era	Period	Epoch	Absolute age
Phanerozoic eon	Cenozoic	Quaternary	Holocene	0.01 Myr
			Pleistocene	2.6 Myr
		Neogene	Pliocene	5.5 Myr
			Miocene	23 Myr
		Palaeogene	Oligocene	33.9 Myr
			Eocene	55.8 Myr
			Palaeocene	66 Myr
	Mesozoic	Cretaceous		145 Myr
		Jurassic		201 Myr
		Triassic		251 Myr
	Palaeozoic	Permian		299 Myr
		Carboniferous		359 Myr
		Devonian		416 Myr
		Silurian		444 Myr
		Ordovician		488 Myr
		Cambrian		542 Myr
Precambrian: Proterozoic eon	Neoproterozoic			1.0 Gyr
	Mesoproterozoic			1.6 Gyr
	Palaeoproterozoic			2.5 Gyr
Precambrian: Archaean eon	Neoarchaean			2.8 Gyr
	Mesoarchaean			3.2 Gyr
	Palaeoarchaean			3.6 Gyr
	Eoarchaean			3.8 Gyr
Precambrian: Hadean eon				4.56 Gyr

Fig.1.20: Geological time scale, Gyr–billion years ago and Myr–million years ago.

The only difference is that we do not use the absolute time in thousands or millions of years, but we use relative time on the basis of changes in fossil content. A geologic time scale has accordingly been prepared in which the smallest time unit is an age. A number of ages grouped together constitute an epoch, while several epochs constitute a period. Likewise, many periods together constitute an era. Eon is the largest unit comprising many eras. Thus, in descending order Eon, Era, Period, Epoch and Age are the divisions used for geological classification of time (Fig. 1.20).

Learners, you have learnt how to collect stratigraphic data, importance of stratigraphy and also learnt about geological time scale. Now, spend few minutes to perform an exercise to check your progress.

SAQ 3

a) What kind of field observations should be made while collecting the stratigraphic data?

b) Define stratigraphic correlation.

c) List the periods of Palaeozoic era.

1.8 ACTIVITY

1. Draw diagrams of abrupt and gradational types of contacts.
2. A sedimentary sequence consisting of five beds is given below (Fig. 1.21). Label the oldest and youngest beds of the sequence.

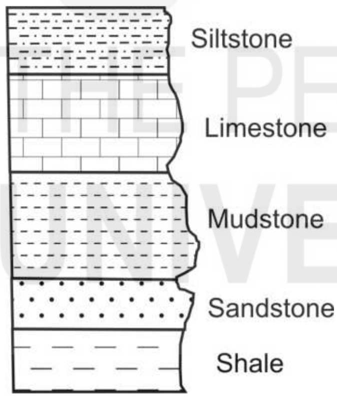


Fig. 1.21: Sedimentary sequence of five beds.

3. Arrange the following eons and eras in ascending order:

   (i) Phanerozoic eon, Archaean eon and Proterozoic eon.

   (ii) Mesozoic era, Palaeozoic era and Cenozoic era.

1.9 SUMMARY

In this unit, we have introduced you to the basic principles of stratigraphy. Let us now summarise what you have learned in this unit;

- Stratigraphy is a branch of Geology which deals with the sequence of rocks in relation to the time of their deposition.
- It focuses primarily on stratified rocks that include sedimentary rocks and lava flows. It also includes study of metamorphic and other igneous rocks in relation to the time of their formation.

- The principles on which the stratigraphic studies are based include order of superposition, original horizontality, lateral continuity, cross-cutting relationships, inclusions, unconformities, fossil succession, uniformitarianism and catastrophism.
- Stratified rocks that are continuous vertically as well as laterally have normal contacts. However, there may be breaks in deposition that constitute an unconformable contact. Likewise, the contact may be faulted or an igneous rock may produce an intrusive contact.
- The breaks in deposition or unconformities can be of various types like angular unconformity, non-conformity, disconformity, paraconformity or diastem.
- Stratigraphic studies can be undertaken with simple equipment by taking traverses, recording attitudes, measuring sections, collecting fossils and preparing a stratigraphic column.
- Stratigraphy helps in unravelling the history of the Earth and organisms through time and helps in location and exploration of minerals, notably fossil fuels.
- Time in stratigraphy is divided into eons, eras, periods epochs and ages based on important events notably in the evolution of organisms as seen from the fossil record. Thus, a standard scale is prepared that is being periodically modified. We can also determine the absolute age of some rocks by radiometric methods.

1.10 TERMINAL QUESTIONS

1. What is stratigraphy? Discuss the concept and historical development of stratigraphy.
2. Describe the various principles of stratigraphy.
3. Describe stratigraphic contacts and unconformities with the help of labelled diagrams.
4. Discuss the methods and techniques of stratigraphic data collection.
5. Write a note on importance of stratigraphy.
6. What is geological time scale?

1.11 FURTHER/ SUGGESTED READINGS

- Boggs, S. (2012) Principles of Sedimentology and Stratigraphy, Prentic Hall, New Jersey.
- Christiansen, E. H. (2014) Dynamic Earth, Jones & Bartlett Publishers, Burlington.
- Mukherjee, P. K. (1997) A text book of Geology, The World Press Pvt. Ltd., Calcutta.

1.12 ANSWERS

Self Assessment Questions

1. i) Stratified rocks.

   ii) The main principles of stratigraphy are order of superposition, original horizontality, lateral continuity, cross-cutting relationships, inclusions, unconformities, fossil succession, uniformitarianism and catastrophism.

   iii) Uniformitarianism.

2. a) In angular unconformity the two sets of beds are at an angle and not parallel whereas in disconformity the two sets of beds are parallel to one another.

   b) A sill is concordant to the bedding plane meaning thereby that it is parallel to the sedimentary beds whereas a dyke is discordant and cuts across the beds.

   c) Uniformitarianism is a slow process of change that takes place through a prolonged period of time. Catastrophism is an abrupt change brought about through some major catastrophic event.

3. a) The main field observations that need to be recorded in the field diary while collecting the stratigraphic data are attitude, thickness, lithological characters and fossils contents of beds. The nature of traverse taken should be recorded with a sketch of map of the study area.

   b) Stratigraphic correlation is the comparison of rocks in different traverses relating them to each other in respect to similarity of characters.

   c) The periods of Palaeozoic era are Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian.

Terminal Questions

1. Refer to section 1.2.
2. Refer to section 1.3
3. Refer to section 1.4.
4. Refer to section 1.5.
5. Refer to section 1.6.
6. Refer to section 1.7

UNIT 2

STRATIGRAPHIC CLASSIFICATION

Structure

2.1 INTRODUCTION

You are by now familiar with the general principles of stratigraphy and how stratigraphic studies are undertaken. It was also discussed in Unit 1 that what you have to observe in the rocks and some information was also given on how to collect and present the stratigraphic data that form the base of stratigraphic classification. In this unit, you will be introduced how rock sequences are classified so that you arrive at conclusions about their mode and time of deposition. For the study of any rock sequence, it is necessary to classify it so that it can be studied in parts with respect to its thickness and time of deposition that it indicates. The factors that need to be considered for stratigraphic classification are the rock type, its physical and chemical characters, nature of bedding and fossils it contains. From all these, the type of the basin and the time of deposition can be interpreted.

In this unit, we will discuss three basic classifications of stratigraphy, namely, lithostratigraphy, biostratigraphy and chronostratigraphy. You will also learn about the various units of classification and how we name these different units. It is important to note that for classifying the rock sequences, you should be able to identify the rock types. The most common types of sedimentary rocks are sandstone, limestone, shale and conglomerate. In addition, you should also be able to identify the breaks or unconformities in the rock sequence. The fossils present in the sequence also need to be identified. In addition, we will also discuss the methods and importance of stratigraphic correlation in this unit.

Expected Learning Outcomes

After studying this unit, you should be able to:

- ❖ define stratigraphic classification;
- ❖ describe lithostratigraphy, biostratigraphy and chronostratigraphy;
- ❖ discuss basic units of different types of stratigraphic classification;
- ❖ differentiate different types of stratigraphic classification;
- ❖ elaborate the concept and principles of stratigraphic correlation; and
- ❖ explain methods and importance of stratigraphic correlation.

2.2 PRINCIPLES AND TYPES OF STRATIGRAPHIC CLASSIFICATION

Stratigraphy involves the definition and description of rock successions from a historical point of view. It includes determination of the sequence of rocks locally and relating the same to the regional or global framework of the geological time scale. You may have become familiar with the geological time scale while studying the section 1.7 of Unit 1. You may also be familiar with the fundamental unit of stratigraphy namely the stratum (plural strata) that has given name to this branch of Earth science. To remind you the **stratum** denotes a layer of rock and such layers in a sequence are referred to as **strata**. Each stratum indicates deposition of sediment at a particular point of time. Therefore, stratigraphy has a time significance and the rock sequence constituting the strata indicates the time of deposition.

It is necessary to classify the strata into various divisions to determine the nature and time of deposition and to relate it to the geologic time scale. Therefore, stratigraphic classification includes all rocks of the Earth's crust. Each classification is based on certain stratigraphic units, in which each unit represents a single property or a set of rock properties. Since rocks have many distinctive and measurable properties, therefore, rocks may be classified according to any property. It is important to note that the stratigraphic position on change of any property does not necessarily coincide with that for any other property. As a result, the stratigraphic units based on one property generally do not match with those units which are based on a different property. Normally, it is not possible to show the distribution of all properties in the rocks by using a single set of stratigraphic units. Hence, different sets of stratigraphic units are required in order to classify the rock sequence. Thus, there are three main types of stratigraphic classification namely:

- **Lithostratigraphic**;
- **Biostratigraphic**; and
- **Chronostratigraphic** classifications.

These are based on lithology, fossil content and time of deposition, respectively. In a broad sense, all these classifications are closely related to each other because each classification represents a different property of the same rock sequence. The main aim of all stratigraphic classifications is to enhance our knowledge and understanding of rock sequences of the Earth and their history.

It is important to know that for either of these classifications, it is necessary to follow the prescribed rules and regulations as specified in the **Code of Stratigraphic Nomenclature**. When we follow all these rules and classify the sequence it becomes a formal classification. If we do not strictly follow the code then it is only an informal classification. For each unit of classification in lithostratigraphy and chronostratigraphy, we need to identify a type area and the sequence in the type area, which is known as **stratotype**. The type area is a geographic area or region where the stratotype of a stratigraphic unit is first identified. Let us discuss each classification one by one.

- **Code of Stratigraphic Nomenclature** was developed by the International Subcommission on Stratigraphic Classification (ISSC) of the International Commission on Stratigraphy (ICS) created by International Union of Geological Sciences (IUGS). It has since been accepted by most countries of the world, including India. All stratigraphic classifications follow this code to evolve a uniform and formal division of rock sequences.
- **Stratotype** is regarded as a typical of a stratigraphic unit that it defines. It is a particular section that shows all the characteristics of the stratigraphic unit. Identification of stratotypes is mandatory for all lithostratigraphic units and desirable for chronostratigraphic units but are not used for biostratigraphy.

Let us discuss the three main types of stratigraphic classification in the following subsections.

2.2.1 Lithostratigraphy

In simple words, lithostratigraphy (**litho** means rock type and **stratum+ graphia** means description of all rock bodies) may be defined as an element of stratigraphy that deals with the description, definition and naming of the rocks of the Earth based on their lithology and their stratigraphic relations. Hence, the lithostratigraphic classification is primarily based on the rock types (i.e. lithologic properties) present in a rock sequence. That is why it is also called **rock-stratigraphic classification**. Lithostratigraphic classification, basically, is the organisation of rock sequences into different units on the basis of their lithological properties and their stratigraphic relations to other rocks. It is more accurate stratigraphic classification and is fundamental to all branches of stratigraphy. In addition, lithostratigraphic units are basic units of geological mapping. In this classification, the sequence is divided on the basis of lithology whereby each rock type or a group of rock types constitutes a unit. These units are further divided or grouped together as follows:

- **Lithostratigraphic Units**

The basic hierarchy of lithostratigraphic units is given in Table 2.1.

Table 2.1: Lithostratigraphic units.

Supergroup – a combination of several associated groups
Group – a combination of two or more formations
Formation – basic unit of lithostratigraphy
Member – named lithologic subdivision of a formation
Bed – named distinctive layer in a member or formation

The arrangement of units in lithostratigraphic classification in descending order of thickness is Supergroup, Group, Formation, Member and/or Beds. However, the primary and mandatory unit of this classification is only the Formation.

- **Formation**: In lithostratigraphy, we start the classification from formation. Formation is the basic formal unit of this classification. A Formation is a homogeneous set of strata consisting of a distinct rock type or a set of rock types. It is laterally continuous and of a sufficient thickness so that it becomes a mappable unit. In Unit 1 you have already been introduced to mappable unit. Let us recapitulate, a **mappable unit** of rock sequence constitutes a rock type or a set of rock types that is sufficiently thick and continuous so that it can be recorded in a map to a scale. The homogeneity may be by way of lithological or other distinctive characters like colour or weathering characteristics or a combination of these. Talchir Formation of Damuda Group, Gondwana Supergroup is an example of Formation.
- **Member**: Each Formation may be further classified into **Members**. Hence, member constitutes a formal unit of lithostratigraphy next in rank below a formation. It possesses certain lithologic properties which distinguishes it from adjacent parts of formation. Several members may be present within a formation and each member is characterised by distinctive lithology. It is not always necessary to divide the formation into members. Depending on the purpose, some formations may be divided into members while others are not divided into members or its certain parts may be designated as members.
- **Bed**: It is the smallest formal unit of lithostratigraphy. In sedimentary sequences, there are certain distinctive layers such as key beds, marker beds, etc. of stratigraphic importance. These beds deserve their proper names and hence, they are considered as formal lithostratigraphic units. For example, the Boulder bed of the Talchir Formation is a classic example of bed.
- **Group**: A group is a combination of two or more formations, in which each Formation has common significant and diagnostic lithological properties. Damuda Group consisting of four formations (Karharbari, Barakar, Barren measures and Raniganj), belongs to the Gondwana Supergroup is an example of a Group.
- **Supergroup**: It is a combination of several associated groups or associated groups and formations, in which significant lithological properties are common. The Gondwana Supergroup is an example of a Supergroup.

The lithostratigraphic units are named on the basis of locality or geographical features such as a river or a mountain peak where a type section is exposed.

For example, Raniganj Formation named after the town Raniganj (Bardhaman District, West Bengal), where this formation is exposed, constitutes its type section. A type section and stratotype, as mentioned above, are necessary to be identified for a formation as per the Code of Stratigraphic Nomenclature. A stratotype should include the full complement of the formation. The locality or geographical feature that gives name to the formation is suffixed by unit name. For example, we can say Raniganj Formation for a rock formation consisting of a set of rock types for which Raniganj area in West Bengal is the type area. When the formation consists of a distinct rock type, we may also use the rock name as a suffix instead of the Formation like Muth Quartzite and Rohtas Limestone. For other lithostratigraphic units like Supergroup, Group and Member also the same procedure is used. The first letter of all formal stratigraphic units is capitalised.

Learners, you have learnt the principles and types of stratigraphic classification. In the above section we have discussed about lithostratigraphic classification. Before discussing about biostratigraphic and chronostratigraphic classifications, spend few minutes to perform an exercise to check your progress.

SAQ 1

a) Complete the following sentences:
   i. The factors that need to be considered for stratigraphic classification are…………………………………………………………………….
   ii. For each unit of classification, we need to identify a type area and the sequence in the type area is known as………………………….
   iii. A formation is a homogeneous set of strata consisting of a distinct rock type or a set of rock types that is laterally continuous and of a sufficient thickness so that it becomes…………….

b) Arrange the different units of lithostratigraphic classification in descending order of thickness.

2.2.2 Biostratigraphy

Biostratigraphy (**bio** means life and **stratum+ graphia** means description of all rock bodies) may be defined as an element of stratigraphy that deals with the distribution of fossils in a rock sequence and organisation of strata into distinctive units based on the fossils present in it. Biostratigraphic classification is the systematic subdivision and organization of a rock sequence into named units on the basis of fossils contained in the rocks. The basic principle of biostratigraphy is that the evolutionary changes in organisms are non-reversible and, therefore, the fossils present during a time span are characteristic only of that particular time interval and cannot repeat or replicate at any other time. Accordingly, based on the presence of characteristic fossils, the strata are divided into different **biostratigraphic zones** or **biozones.** It is important to note that biozones constitute the primary units of biostratigraphic classification.

- **Biostratigraphic Units or Biozones**

Biozones are of various types depending on the nature and distribution of fossils contained therein. However, there are four most commonly used biozones (Table 2.2).

Table 2.2: Biostratigraphic units.

1.	Range zone (also called Acrozone)
2.	Interval zone
3.	Assemblage zone (also called Cenozone)
4.	Abundance zone (also called Acme zone)

Let us discuss each biozone in brief in the same order as given above.

1. **Range Zone**: A range zone is based on the total range of a fossil form that is, the span between its first appearance and final disappearance. In a sequence, when a particular fossil appears for the first time, that level marks the beginning of this zone. The zone ends at the level of its last presence (Fig. 2.1). For fixing a range zone, only those fossils can be utilised which have a short time range and as far as possible wide geographical distribution. Such fossils are known as **index fossils**. On the basis of total ranges of such fossils, the biozones are fixed. There are two types of range zone namely – partial range zone and concurrent-range zone.

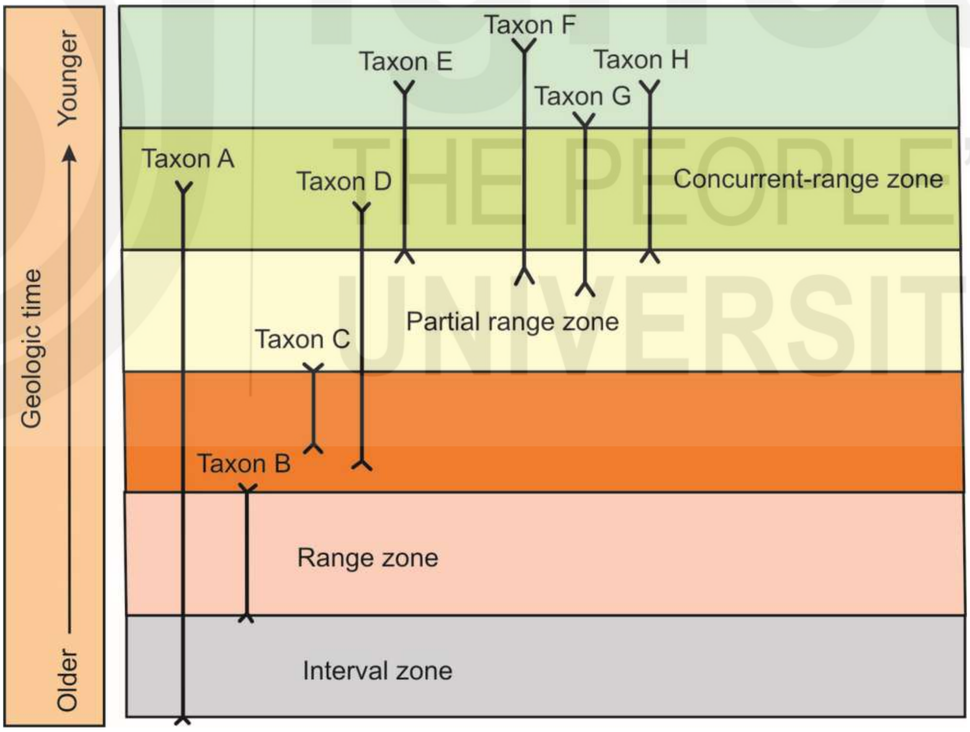


Fig. 2.1: Types of biostratigraphic zones; interval zone marked by the first appearance of taxon A and B, range zone defined by first and last appearance of taxon B, partial range zone is that part of the stratigraphic range of taxon D which starts from the end of taxon C and beginning of taxon E and concurrent-range zone defined by overlap of taxa F, G and H. Taxon is singular and taxa is plural.

A partial range zone is made within a stratigraphical range of a taxon or form in which part of its stratigraphic range lying above the range of another taxon and part of its range lying below the range of another taxon (Fig. 2.1). Concurrent-range zone includes abody of rock sequence corresponding to the overlapping stratigraphic range of two or more specified fossil taxa as shown in Figure 2.1.

2. **Interval Zone**: It contains a body of rock sequence corresponding to the interval between any two specified biological events (Fig. 2.1). For example, an interval between two extinction events and an interval between two origination events or an interval between an origination event and an extinction event.

3. **Assemblage Zone**: An assemblage zone is defined as a biozone characterised by the association of many fossil forms (usually three or more) as shown in Fig.2.2. Only on the basis of the combined association of these forms the zone can be identified and not on the presence of any single form as in the case of range zone. It is necessary for all the identified forms to be present in the strata in order to qualify for the recognition of an assemblage zone.

4. **Abundance Zone**: An abundance zone is defined as a body of strata that contains a maximum population of one or more species of fossils (Fig. 2.2). In other words, these species were at their acme or climax during that period. Abundance zones are used only for local classification and do not have widespread application. This type of classification is commonly used in oil industry for classifying local stratigraphic sections in an oil field.

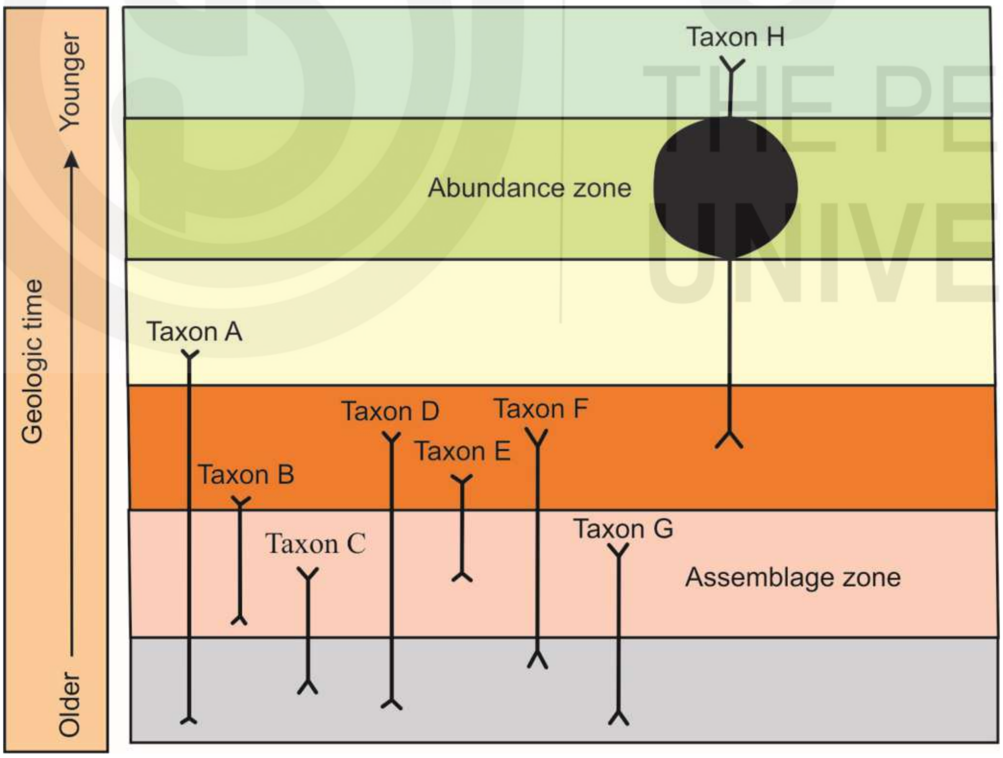


Fig. 2.2: Types of biostratigraphic zones; assemblage zone defined by presence of taxa A to G and abundance zone marked by the extraordinary population of taxon H.

It is interesting to note that sometimes in a fossiliferous sequence we have a bunch of strata that do not contain any fossils. The term **Barren Zone** is used for that unfossiliferous part of the sequence.

Note that for biostratigraphic classification, there are usually no stratotypes, but reference localities can be named. A **range zone** or **abundance zone** is named on the generic or trivial name of the index or acme species, respectively. In the case of an assemblage zone, the name can be based on the two of the assemblage forms. The examples can be *Ophiceras* Zone for a range zone, *Spiriferella raja* Zone for an abundance zone and *Tonkinella-Bailliella* Zone for an assemblage zone. The zones may be further divided into **subzones** or further into **Zonules**, the latter being the smallest biostratigraphic sub-division.

2.2.3 Chronostratigraphy

You have read that lithostratigraphy and biostratigraphy are based on the content of the strata namely lithology and fossils, respectively. The chronostratigraphy (**chrono** means time and **stratum+ graphia** means description of all rock bodies) is defined as an element of stratigraphy that deals with the relative time relations and age of rock bodies. It may be noted that chronostratigraphy is an abstract concept and is based on relative time as interpreted from biostratigraphy to a large extent. The time is not something that can be seen within the rocks, but it has to be determined from the fossil content as indicated by the biostratigraphic classification. The main aim of the chronostratigraphy is to organise the rock sequence on a global scale into chronostratigraphic units, so that all local, regional as well as global events can be related to a single standard geological scale. Thus, chronostratigraphy is mainly concerned with the age of rock sequence and their time relations. Hence, chronostratigraphic classification is considered as the organisation of rocks into units on the basis of their age or time of origin.

- **Chronostratigraphic Units**

A chronostratigraphic unit may be defined as a body of rocks that includes all rocks formed during a specific interval of geologic time and it also includes those rocks formed during that time span (Murphy and Salvador, 1999). In chronostratigraphy, the time encompassed by a biozone is termed as a **biochron** and on the basis of biochrons, the various chronostratigraphic units can be identified. Chronostratigraphic units are the fundamental working units of the geological time scale. The hierarchy of chronostratigraphic units is given in Table 2.3.

Table 2.3: Chronostratigraphicunits.

Eonothem				
	Erathem			
		System		
			Series	
				Stage

On the basis of a biochron, we determine and identify **stage** that constitutes the lowest unit of chronostratigraphy. The other units in ascending order are **series**, **system**, **erathem** and **eonothem**. These are all identified on the basis of fossil content and are of a relative nature. The order of superposition determines the sequence of the sediments and characteristic fossils of different beds that determine their relative ages.

In section 1.7 of Unit 1, you have already learnt how the geological time scale was prepared on the basis of time. You have also learnt that the time is relative time and is not measured in absolute years. Therefore, for the better understanding of chronostratigraphy, a proper knowledge of geochronology is essential. **Geochronology** is a branch of geology that deals with the dating of rock formations and geological events in years by using radioactive dating methods. Thus, geochronologic units are the subdivisions of geologic time. These are abstract units and only defined after the chronostratigraphic units. The hierarchy of geochronologic units is given in Table 2.4.

Table 2.4: Geochronologic units.

Eon				
	Era			
		Period		
			Epoch	
				Age

You have already studied in Unit1, the age in absolute years as determined by radiometric methods may be assigned to these units but that is not the basis of the classification.

It should be noted that the basic aim of chronostratigraphic and geochronologic classifications is to arrange systematically rock strata of Earth into named units (chronostratigraphic units) and corresponding to intervals of geologic time (geochronologic units). Such arrangement facilitates time correlation and age determination of rock strata and further, serves as a reference system for recording events of geologic history. In this arrangement, each chronostratigraphic unit has its corresponding geochronologic unit as shown in Table 2.5.

Table 2.5: Hierarchy of chronostratigraphic and corresponding geochronologic units.

Chronostratigraphic (time-rock) units	Example	Geochronologic (time) units	Example
Eonothem	Phanerozoic	Eon	Phanerozoic
Earthem	Mesozoic	Era	Mesozoic
System	Triassic	Period	Triassic
Series	Upper Triassic	Epoch	Late Triassic
Stage	Norian	Age	Norian

Now, let us discuss the chronostratigraphic units and their corresponding geochronologic equivalents in brief.

- **Stage**: It is a basic and lowest ranking unit of chronostratigraphy. It includes all rocks formed during a particular age. Stage can be recognised worldwide. It represents a subdivision of a series. Its corresponding geochronologic equivalent is age.
- **Series**: It is a chronostratigraphic unit ranking above a stage and below a system. An epoch is its geochronologic equivalent unit.

- **System**: It is a major rank chronostratigraphic unit. It lies above the series and below erathem, e.g. Triassic System. Period is its geochronologic equivalent unit, e.g. Triassic Period. Here the relation between these two units such as Triassic System and Triassic Period is that the rocks of the Triassic System were all deposited during the Triassic Period.
- **Erathem**: It consists of a group of systems. For example, Mesozoic erathem consists of Jurassic System, Triassic System and Cretaceous System. The geochronologic equivalent of erathem is an era. The Mesozoic era which consists of Jurassic Period, Triassic Period and Cretaceous Period, is an example of era.
- **Eonothem**: It consists of a group of erathem. It is higher in rank than an erathem. Its geochronologic equivalent is an eon. It may be noted that there are three eonothems namely Archean, Proterozoic and Phanerozoic.
- The time-rock and time divisions in the geological time scale are denoted by the same terms but the suffix indicates if it is a time-rock unit or a time unit. For example, Cambrian System denotes a time-rock division while Cambrian Period denotes time division during which those rocks were deposited.

It may be noted that age in absolute years or what is known as **geochronology**, when determined by various methods includes radioactive dating or magneto-stratigraphy. It is superimposed on the time units but their variation does not change the scale since it is not based on absolute years.

Learners, you have learnt about biostratigraphic and chronostratigraphic classifications. Before discussing about stratigraphic correlation, spend few minutes to perform an exercise to check your progress.

SAQ 2

a) Fill in the blanks:
   (i) On the presence of characteristic fossils, the strata are divided into …………… that constitute the primary units of biostratigraphic classification.
   (ii) The span between the first appearance of a fossil form and its final disappearance is known as…………………
   (iii) A biozone is characterised by the combined association of more than one fossil form is known as …………………..
   (iv) The time-rock equivalent of the time unit Epoch is…………………
   (v) The time encompassed by a biozone is called a…………………………

2.3 STRATIGRAPHIC CORRELATION

You have learnt in Section 1.5 of Unit 1, how to collect the stratigraphic data and how to construct stratigraphic columns. Once you have constructed stratigraphic columns of different sites of a wide area, then next step will be to correlate these columns. As you know the principle of lateral continuity states that rock beds can be traced across a wide area. Therefore, stratigraphic correlation i.e. connecting similar rock beds is a best means to reconstruct the geological history of an area. Let us discuss stratigraphic correlation in detail.

2.3.1 Definition and Introduction

Correlation is a procedure to indicate correspondence between geographically separated geologic units of rocks. The correspondence can be in the character and stratigraphic position of the rocks. It can be of various types like correspondence in lithology, fossil content and time of deposition. Thus, correlation is dependent on what kind of equivalence can be established according to the character of the rocks to be equated. The scope of correlation is different in different sequences and the interpretation depends on the type of correlation undertaken.

When we are looking for correspondence in lithology or lithological correlation we make use of **key beds**. Key beds are the marker beds with a characteristic lithology that may extend for considerable distances and may help in marking a stratigraphic position. Likewise an unconformity may also be used as a marker horizon like a key bed and can be of importance in lithological correlation. Biostratigraphic correlation or correlation by fossil content may be made by index fossils or a fossil assemblage as indicated in section 2.2.2 above.

2.3.2 Methods

Rock sequences can be correlated in many ways, but there are three simple and important methods, viz., lithostratigraphic, biostratigraphic and temporal correlation. Let us discuss each method of correlation in detail.

i. **Lithostratigraphic Correlation**: The methods to be applied for correlation depend on what type of correlation is needed or possible in various stratigraphic sequences. The easiest correlation is the lithostratigraphic correlation whereby similar rock units or key beds are used to determine the correspondence between two separated sequences.

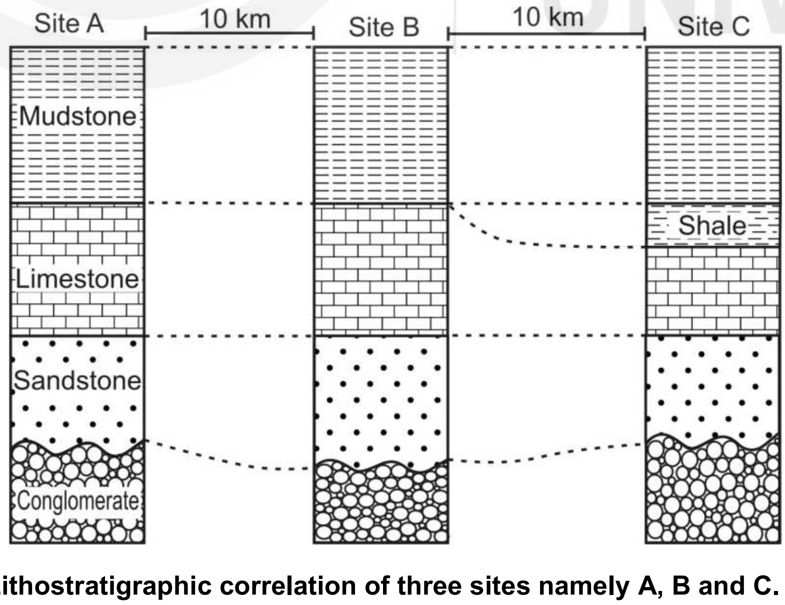


Fig. 2.3: Lithostratigraphic correlation of three sites namely A, B and C. Dotted lines indicate correlation. Note that shale bed is absent at sites A and B, but it is present at site C. Unconformity above the conglomerate bed is marked by the wavy line. The distance between site A, B and C is 10 kms.

In lithostratigraphic correlation, it is the usual practice to classify one sequence on the basis of lithology into formations and even members if possible, and to identify the key beds or marker beds and unconformities, if any. Then these marker horizons are located in the other sequences and accordingly, the correspondence between the first sequence and the second sequence is established. The correspondence may not be necessarily identical because lithological units are known to thicken or thin out or sometimes even vanish as we follow them laterally. But a general correlation is possible while registering the lateral changes.

While lithological correlation is relatively easy, it has to be understood that this correlation is only of a local nature and may not be applicable or useful for long distances. The lithological similarity can be only if the deposition has taken place in a single basin. If the basins of deposition are different then the lithological similarity may not be there nor can the same key beds exist in different basins.

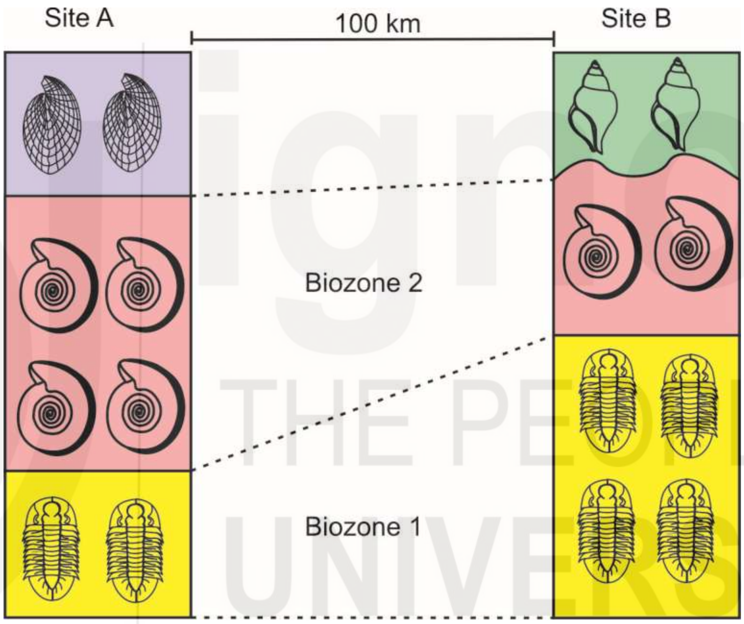


Fig. 2.4: Biostratigraphic correlation between two sites, namely, A and B. Here the beds are correlated on the basis of similar fossils. Dotted lines indicate correlation. For example in this figure, biozone 1 is characterised by the occurrence of trilobites and biozone 2 by ammonoids. Note that top of both sites has different fossils content hence they cannot be correlated and wavy line in site B indicates a depositional break (unconformity).

ii. **Biostratigraphic Correlation**: Biostratigraphic correlation is based on the fossil content of the rocks. It is more precise and accurate correlation that can be applied for long distances or even widely separated sequences that may have been deposited in different basins. In biostratigraphic correlation, index fossils or an assemblage of fossils is used. In the case of lithostratigraphy, in practice we choose a sequence and classify it on the basis of fossil content. You have already learnt how we classify a sequence on the basis of fossil content in Section 2.2.2 above. To remind you again we divide the sequence into biozones that may be either range zones, assemblage zones or abundance zones. Once such a classification is made we identify these zones in other sequences that may be widely separated. In this regard, the range zones based on index fossils are usually the best tools for biostratigraphic correlation. Index fossils may be useful within a region or may also be applicable for long distance correlation or intercontinental correlation.

Biostratigraphic correlation is also directly related to chronostratigraphic or time correlation because as biochrons are based on biozones as they indicate the relative time. However, one precaution is necessary in this correlation. The similarity of fossils or **homotaxis** in two widely separated localities does not necessarily indicate same time of deposition or **contemporaneity**. This is because the organisms that may have evolved at one place may take a long time to reach another locality and there may be some time lag of dispersal. However, since we are only dealing with relative time and not absolute time, the homotaxis need not indicate contemporaneity as the sequence will remain the same.

iii.**Temporal Correlation**: Sometimes when fossil content may be scanty and lithological similarity may not be there we choose only a key bed that may be based on some kind of a time similarity like an unconformity or some fossil horizon. From that bed upwards and downwards we build a stratigraphic column based on superposition and correlate it with the corresponding known units from an established stratigraphic sequence. This is based on the principle that overlying beds are younger and underlying beds are older and they should correspond with the beds of the known sequence.This is the temporal correlation and it may not be very accurate since it is only an approximation.

2.3.3 Need for Correlation

The concept of correlation is fundamental to stratigraphy because without correlation there can be no synthesis of geographically separated rock units. Moreover, without correlation we will have innumerable rock sections from different parts of the globe without any relationship or linkage to one another.

The scope of correlation is twofold. The main purpose of correlation is to determine the equivalence in the time of deposition so that we can establish a standard time sequence of rocks across the globe. It is only through correlation that we have been able to establish a geological time scale and we are able to place the different rock units across the globe at their proper stratigraphic positions. It is through correlation that we obtain a neat gradation of rock sequences from old to young. The distribution of fossil types around the globe has to make sense in terms of the history of the continents and a coherent pattern usually emerges through correlation. The other scope of correlation may not be related to time but may deal with geometrical relationships of rocks. In other words, this correlation is primarily based on lithology and how rock units change vertically and laterally and the relation between the two. While such a correlation has only a local value, it has significant application in oil industry where local correlation is of considerable importance.

Learners, you have learnt about stratigraphic correlation in the above section. Now, spend few minutes to perform an exercise to check your progress.

SAQ 3

a) What is correlation?

b) What are the main methods of correlation?

c) Fossil similarity is indicative of (a) homotaxis (b) contemporaneity.

d) Lithostratigraphic correlation is (a) intercontinental (b) regional (c) local.

e) The main purpose of correlation is to determine_______________.

2.4 ACTIVITY

1. Write down the lithostratigraphic divisions in descending order from the largest unit to the smallest unit.
2. List the various biozones and indicate the two most preferred biozones that help in regional correlation.
3. In the two stratigraphic columns given in Figure 2.5 below, connect the litho-units to indicate the lithostratigraphic correlation.

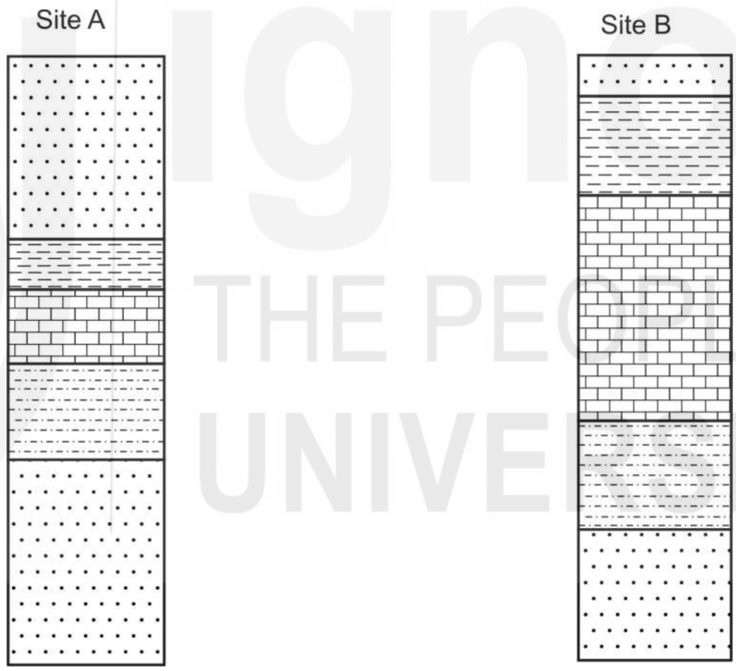


Fig. 2.5: Lithostratigraphic columns of two sites, site A and site B.

2.5 SUMMARY

In this unit, we have discussed the principles and methods of stratigraphic classification and correlation. Let us now summarise what we have learnt:

- The factors that need to be considered for stratigraphic classification are the rock type (lithology), its physical and chemical characters, nature of bedding and fossil content.
- The stratigraphic classification can be of various types depending on the nature of lithology, fossils present in the rocks and the time of deposition as interpreted from fossils.
- There are three main types of classification, namely, lithostratigraphic, biostratigraphic and chronostratigraphic classifications.

- The basic unit of lithostratigraphic classification is a Formation which is a homogeneous set of strata consisting of a distinct rock type or a set of rock types that is laterally continuous and of a sufficient thickness so that it becomes a mappable unit. Formations can be further classified into Members. Formations can also be combined into Groups and Groups into Supergroups.
- The basic unit of biostratigraphy is a Biozone. There are four primary types of biozones namely, Range zone, Interval zone, Assemblage zone and Abundance zone.
- Chronostratigraphic classification is an abstract classification based on relative time as interpreted from biostratigraphy. The basic chronostratigraphic unit is a Biochron that is based on a biozone. On the basis of chronostratigraphy the sequences can be divided into time-rock divisions and time (geochronologic) divisions. The main chronostratigrapic (time-rock) units are Eonothem, Erathem, System, Series and Stage. The main geochronologic (time) units are Eon, Era, Period, Epoch and Age.
- Correlation is a procedure to indicate correspondence between geographically separated units of rocks. It can be undertaken by lithology or fossil content. Lithological correlation is local while correlation by fossils can be regional or intercontinental. It is through correlation that a coherent pattern emerges in stratigraphy throughout the globe.

2.6 TERMINAL QUESTIONS

1. What are the main types of stratigraphic classification?
2. What are the essential requirements for defining a Formation?
3. What is a stratotype? In which classification is it mandatory?
4. What are the main types of biozones?
5. What are index fossils? What are their applications?
6. What is the relation between biostratigraphic and chronostratigraphic units?
7. List the main time units and their equivalent time-rock units.
8. What is the purpose of stratigraphic correlation?

2.7 REFERENCES

- Murphy, M.A. and Salvador, A. (1999) International Stratigraphic Guide – An abridged version. Episodes, Vol. 22, No. 4, pp. 255-271.

2.8 FURTHER/ SUGGESTED READINGS

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2.9 ANSWERS

Self Assessment Questions

1. a) i) The rock type, its physical and chemical characters, nature of bedding and Fossil content
   ii) Stratotype.
   iii) Amappable unit.
   b) Supergroup, Group, Formation, Member.

2. a) (i) Biozones.(ii) Range Zone.(iii) Assemblage Zone.(iv) Series. (v) Biochron.

3. a) Correlation is a procedure to indicate correspondence between geographically separated geologic units of rocks.
   b) Main methods of correlation are Lithostratigraphic and Biostratigraphic correlation.
   c) Homotaxis.
   d) Local.
   e) The main purpose of correlation is to determine the equivalence in the time of deposition so that we can establish a standard time sequence of rocks across the globe.

Terminal Questions

1. Refer to section 2.2.
2. Refer to sub-section 2.2.1.
3. Refer to section 2.2.
4. Refer to sub-section 2.2.2.
5. Refer to sub-section 2.2.2.
6. Refer to sub-section 2.2.3.
7. Refer to sub-section 2.2.3.
8. Refer to sub-section 2.3.3.

UNIT 3

PHYSIOGRAPHY OF INDIA

Structure

3.1 INTRODUCTION

In previous Units 1 to 2, you have learnt about the general principles of stratigraphy and the stratigraphic classifications. You have also learnt that stratigraphic principles and classifications are primarily used to establish the regional stratigraphy of any area or country that helps to know the geological history of that particular region. The work on the Indian rock sequences, which has been carried out by various workers resulted in the establishment of regional stratigraphy of India. It includes the rock sequences ranging from Precambrian to Recent occurring in all parts of country.

For the study of different stratigraphic units of India, references are usually made according to the physical and structural divisions of India such as the Peninsular region, Himalaya and Indo-

Gangetic plains. Therefore, it is necessary to introduce you to the physical and structural setting of India so that you would be able to understand where the different kinds of stratigraphic units occur.

In this unit, we will introduce you to the fundamental physical and structural divisions of India. We will also discuss the regional stratigraphy of India that has been developed as a result of stratigraphic studies undertaken on the rock sequences of this country by various geologists from time to time.

Expected Learning Outcomes

After studying this unit, you should be able to:

- ❖ discuss the physical and structural setting of India;
- ❖ describe major stratigraphic units of India;
- ❖ find coeval rocks of Archaean and Proterozoic ages in Peninsular as well as Himalayan regions; and
- ❖ explain the distribution of marine Phanerozoic rocks in Himalaya and coastal regions.

3.2 PHYSICAL AND STRUCTURAL DIVISIONS

India is a vast country; its three sides are bounded by the seawaters and the young Himalayan mountains system separates it from Asia on its fourth (northern) side. As a result, it becomes an independent entity, which is broadly known as the Indian subcontinent. India shows a huge diversity in physical and structural features as its land comprises various natural features like snow-clad folded mountains in the north, plateaus in the south and plains in between them. It may be noted that all these features have evolved over a very long geological time. For example, the Himalayan mountain system started to develop around 50 - 35 million years (Myr) before present, when the Indian plate started subducting beneath the Asia. Therefore, it is pertinent to consider that the distribution of the rocks of various ages reflect the geographic setting of different regions.

Physically, India can be divided into three broad divisions (Fig. 3.1) as listed below:

- ➢ Himalayan mountain system;
- ➢ Indo-Gangetic plains; and
- ➢ Peninsular plateau.

These three divisions are well marked, geologically very significant as they correspond to the three main structural or tectonic divisions of India. These divisions from south to north constitute the peninsular India, Indo-Gangetic plains and Himalayan mountain system. The last two are popularly referred to as extra-Peninsular region. India exposes rocks of many ages ranging from Archaean to Cenozoic in all these divisions. However, the stratigraphy of these regions is quite different. For example, the peninsular plateau comprises mostly older rocks of Precambrian (Archaean and Proterozoic) age, whereas the Himalayan region bears mostly younger rocks (Phanerozoic) that are structurally deformed. However, a large part of the Indo-Gangetic plains is covered by Recent (Holocene) alluvium.

India is characterised by a great diversity in its physical features and physiographically, divided into following divisions (Fig. 3.1):

- Himalayan mountain system;
- Indo-Gangetic plains;
- Peninsular plateau;
- Indian desert; and
- Coastal regions.

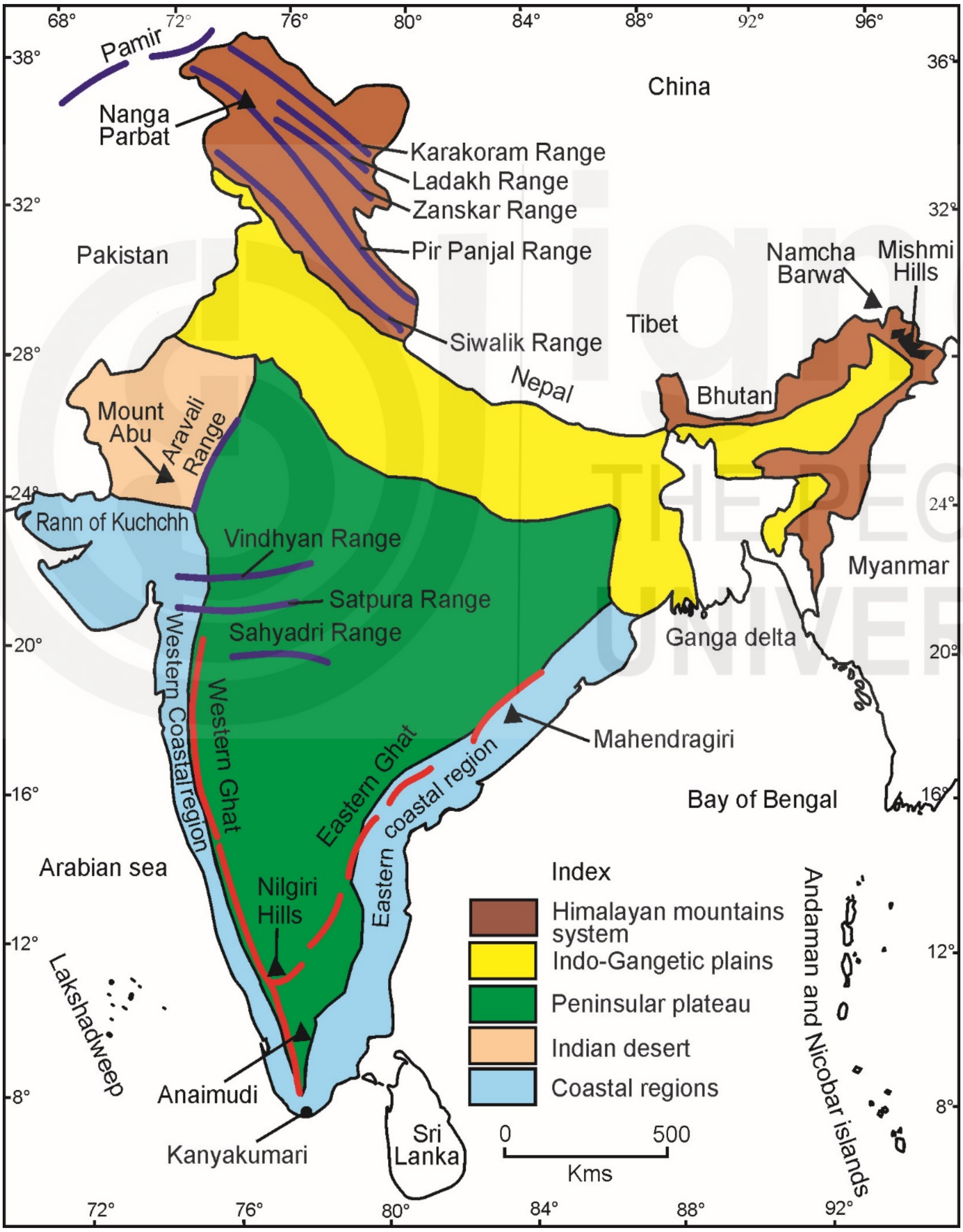

Fig. 3.1: Map showing physiographic divisions of India.

3.2.1 Himalayan Mountain System

The Himalayan range is one of the longest systems of mountain chains in the world. It extends for over 2500 km from Pamir in the west to Mishmi Hills in the east (Fig. 3.1). It bears some of the loftiest mountain peaks, including the world's highest peak, namely the Mount Everest (height 8848 m). It is an arcuate range with convexity to the south and its width ranges from 150 to 400 km. There are two major knee-bends in the range, one to the west around Nanga Parbat and the other to the east at Namcha Barwa and these are commonly referred to as **syntaxial bends**. The northern margin of the Himalaya is marked by a lineament known as **Indus-Tsangpo Suture Zone** (Fig. 3.2). While the bulk of the Himalayan range is in India, it also extends into Pakistan, Nepal, Bhutan and Tibet. Himalaya comprise a chain of parallel mountain ranges.

Topographically, Himalaya can be linearly divided into five parallel ranges from north to south, which are separated by deep valleys and plateaus (Fig. 3.2). These ranges are described below:

(i) **Trans Himalaya**: It consists of southern region of Asian plate and northernmost part of the India plate. It is located north of the Tethys Himalaya and mainly developed in the northern Ladakh (Jammu and Kashmir) and the northernmost Pakistan. Its height ranges from 3000 to 6000 m and consists of Kohistan, Shyok, Karakoram regions. The Trans Himalaya is also known as the **Tibet Himalaya** because its major portion occurs in Tibet.

(ii) **Tethys Himalaya**: It is the northernmost region extending partly into Tibetan plateau. It is given the popular geological name "**Tethys domain**" or "**Tethyan Himalayan Zone**" for want of any other suitable topographic nomenclature. It consists of a plateau region over 3000 m in height sloping gently northwards. Stratigraphically, it is composed of sedimentary rocks of almost all ages. The contact of the Tethyan and Greater Himalaya is termed as **Tethyan Thrust**.

(iii) **Greater Himalaya**: It lies to the south of the Tethys Himalaya and is the highest part of Himalaya. The Greater Himalaya is also given the Sanskrit name ***Himadri***. It bears some of the highest mountain peaks (ranging from 6000 to 8000 m) including the Mount Everest. This part is almost perpetually snow covered and constitutes the watershed for all Himalayan rivers, except Indus, Sutlej and Brahmaputra which cut across this region. The Zanskar, Ladakh and Karakoram are the main mountain ranges. Greater Himalaya is made up mainly of deformed (crystalline) metamorphic rocks. The Main Central Thrust demarcates the boundary between the Greater and Lesser Himalaya.

(iv) **Lesser Himalaya**: It lies to the south of the Greater Himalaya. Its height ranges from 1000 to 2500 m. The PirPanjal, Dhauladhar, Nag Tibba and Mahabharat are common high ranges of the Lesser Himalaya. The terrain is characterised by a complex structure consisting of superimposed thrust sheets and composed mainly of Precambrian metamorphic rocks. However, sedimentary and igneous rocks of other ages are also present. The Main Boundary Thrust demarcates the boundary between the Lesser and Outer Himalaya.

(v) **Outer Himalaya**: The southern-most part of the Himalaya is called **Outer Himalaya** or **Sub-Himalaya**. It comprises low hills less than 1000 m in height that merge finally with the Indo-Gangetic plains. Siwalik is one of the predominant ranges of this part of the Himalaya. It is composed mainly of sedimentary rocks of Cenozoic age. The boundary between the Outer Himalaya and Indo-Gangetic plains is marked by the Himalayan Frontal Fault.

From west to east, the different sectors of the Himalaya are named as Kashmir Himalaya, Himachal Himalaya, Kumaon-Garhwal Himalaya, Nepal Himalaya, Bhutan Himalaya, Assam and Arunachal Himalaya.

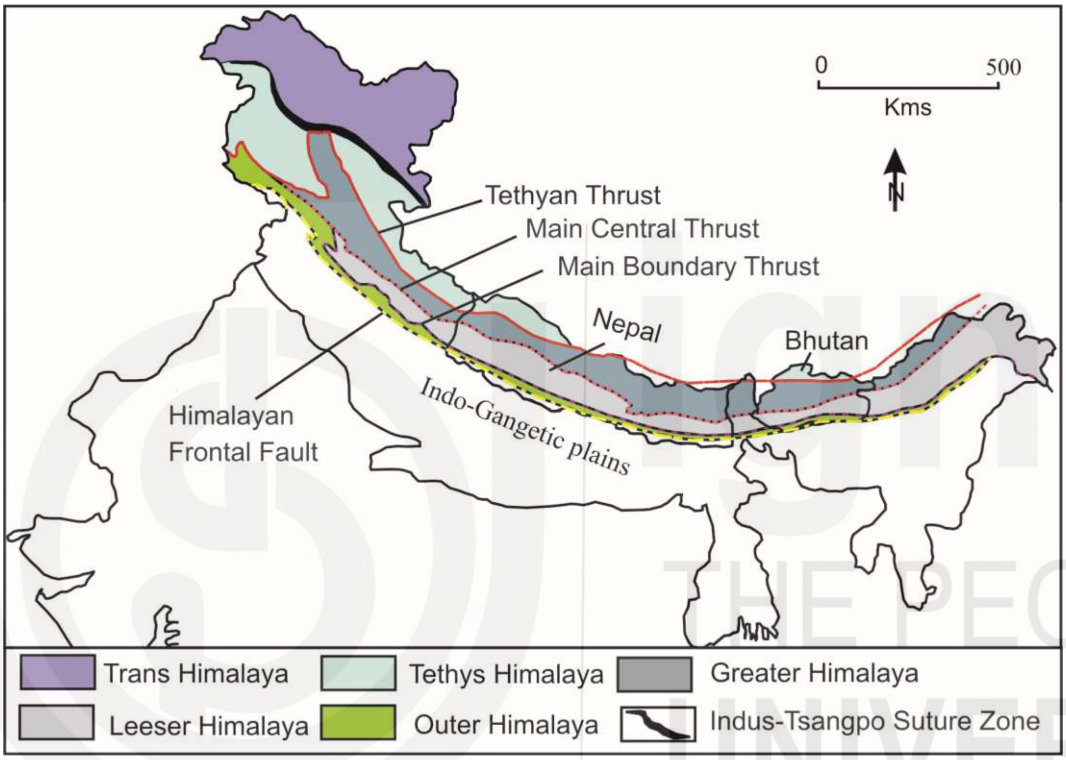

Fig. 3.2: Map showing major ranges of Himalaya. (Source: simplified after Kumar, 1988)

3.2.2 Indo-Gangetic Plains

The major part of northern and eastern India lies to the south of the Himalayan arc and comprises the Indo-Gangetic plains (Fig. 3.1). The plain comprises the sediments that are brought down and deposited by the three Himalayan river systems, namely, the Indus, Ganga and Brahmaputra along with their tributaries during the Recent (Holocene) times. The plains cover the states of Punjab, Haryana, Uttar Pradesh, Uttaranchal, Jharkhand, Bihar, West Bengal, Assam and parts of Rajasthan. They extend from east to west through which the rivers of the Indus and Ganga (also known as Ganges) systems flow. The rivers of Indus system flow towards the southwest into the Arabian Sea, while the rivers of Ganga system flow towards the south east into the Bay of Bengal. These two river systems are separated by the Aravalli mountain chain, which cuts across the plain in a north northeast – south southwest direction. The Aravalli mountain chain extends from Gujarat through Rajasthan up to Delhi. The highest point is in the Mount Abu called **Gurushikhar**, which is 1722 m high. However, the main range comprises low hills that project out from the desert sand. Aravalli mountain chain acts as a water divide between the Indus and Ganga river systems.

The Indo-Gangetic plains are a flat country comprising mainly the alluvial sediments, which are not more than 2000 m deep. It is the most fertile region of the country. It is bounded to the south by the Vindhyan mountain chain and to the southeast by the Satpura mountains, which separate it from the peninsular part of India.

3.2.3 Peninsular Plateau

The Peninsular plateau is more or less a triangular area enclosed within the low mountain ranges (Fig. 3.1). To the north, it is bounded by the Vindhyan Hills and to the northeast by the Satpura chain. The Vindhyan Hills comprise low mountains and plateaus that extend from Gujarat in the west to Bihar in the east. The average elevation is between 500and 600 m though some peaks are as high as 900 m. The Satpura range is a short chain, but higher than the Vindhyan chain, with some of its peaks are higher than 1000 m, for example Pachmarhi around 1335 m.

The Western Ghats (also known as **Sahyadri chain** in early Indian literature) and Eastern Ghats are the major mountain ranges in peninsular region of India.

- **Western Ghats**: These are a continuous chain of hills extending from South Gujarat to Kerala (Fig. 3.1). They constitute low hills of an average height of less than 1000 m though the highest peak called **Anaimudi** is 2693 m high. The height of the Western Ghats increases from north to south. Western Ghats constitute the watershed for most peninsular rivers, notably, the Godavari, Krishna and Cauvery, which flow in the easterly direction into the Bay of Bengal.
- **Eastern Ghats**: These comprise a chain of detached hills extending from Odisha to Tamil Nadu (Fig. 3.1). They constitute low hills with a maximum elevation of about 1500 m at Mahendragiri in Odisha. Eastern Ghats are also known as **Poorvadri**. They join the Western Ghats at the Nilgiri Hills.

Structurally, the Peninsular Plateau forms the India shield. A shield is, basically, a large tectonically stable area made up of crystalline igneous and metamorphic rocks of Precambrian age. The Indian shield, consisting of extensive exposures of Precambrian rocks, is a mosaic of five Archaean blocks. These blocks are largely made up of granite (igneous) as well as gneisses and migmatites (metamorphic) rocks. It is important to note that these Archaean blocks had achieved tectonic stability for a long geological time and remained unaffected by mountain building movements since the close of Precambrian. Hence these blocks are known as **cratons** and constitute the continental crust. The main cratons of the Indian Shield are the Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli, located in southern, central, eastern, northern and western peninsular India, respectively (Fig. 3.3). The east-west trending Son-Narmada-Tapti (SONATA) lineament separates the Aravalli craton from the Bastar and Singhbhum cratons (Fig. 3.3). The Aravalli craton lies north of SONATA lineament whereas the Bastar, Singhbhum and Dharwar cratons lie to its south. All these cratons are of Archaean age.

- **Dharwar Craton** is located in Karnataka and parts of Andhra Pradesh and Tamil Nadu. It comprises granite-gneiss-greenstone that has suffered orogeny at different points of time, e.g., at 3400, 3000 and 2600-2800 Myr ago.
- **Bastar Craton** is located in central India in the state of Chhattisgarh. It consists primarily of gneisses and secondarily of basic and ultrabasic rocks. It shows orogenic dates of 3500, 3000 and 2500-2600 Myr ago.
- **Singhbhum Craton** lies in the state of Jharkhand and comprises granites and gneisses associated with banded iron ore. It shows orogenic dates of 3500 and 3000-3300 Myr ago. It is also associated with basic lava flows.
- **Bundelkhand Craton** is the northernmost craton of the Indian Shield. It is located in Madhya Pradesh and parts of Uttar Pradesh. It is partly concealed under the Indo-Gangetic alluvium. It comprises mainly granitic rocks with subordinate gneisses. The orogenic dates range between 3500 and 2500 Myr ago.
- **Aravalli Craton** is separated from the Bundelkhand craton by the Vindhyan basin. It has suffered several phases of orogeny, which have a wide range of dates from 3300 Myr ago to as low as 1700 Myr ago, the last one placing this phase of orogeny (i.e., Delhi orogeny) in Proterozoic.

Interestingly, these Archaean cratons are separated from one another by the mobile or fold belts that were developed during Proterozoic times (Fig. 3.3). The boundaries of the mobile or fold belts are demarcated by shear or fault zones. A **shear zone** is a planar rock area that is under higher strain than the adjoining rocks. It ranges from a few cms to several kilometers in width. It behaves like a fault system except that the fault plane cannot be seen anywhere. Shear zones constitute important discontinuities in the rock groups. The mobile belts consist of metamorphosed Proterozoic rocks, in which gneiss, amphibolites and migmatites are dominant rock types. The main mobile belts are the Eastern Ghat Mobile Belt, Pandyan Mobile Belt, Satpura Mobile Belt, Aravalli Mobile Belt and Chhotanagpur-Singhbhum Mobile Belt.

(i) The **Eastern Ghat Mobile Belt** borders the Dharwar and Bastar cratons to the east and the Singhbhum craton to the south. The Mahanadi rift separates the Singhbhum craton from the Bastar craton. Godavari rift separates the Bastar craton from the Dharwar craton. The Chitradurga Shear Zone separates the West Dharwar craton from East Dharwar craton.

(ii) The **Pandyan Mobile Belt** lies to the south of the Dharwar craton and the Eastern Ghat Mobile Belt. A system of shear zones consisting of the Moyar Bhavani Shear Zone and Palghat Cauvery Shear Zones separate the southern boundary of the Dharwar craton from the Pandyan Mobile Belt. The Moyar Bhavani Shear Zone is located in the south of the Dharwar craton and the Palghat Cauvery Shear Zone is found in the north of the Pandyan Mobile Belt. The Pandyan Mobile Belt is also termed as Southern Granulite Terrain.

(iii) The **Satpura Mobile Belt** lies to the north of the Bastar and Singhbhum cratons separating them from the Bundhelkhand craton.

(iv) The **Aravalli Mobile Belt** lies to the west of the Bundhelkhand craton and separates it from the Aravalli craton.

(v) The **Chhotanagpur-Singhbhum Mobile Belt** forms the northern boundary of the Singhbhum craton. The Chhotanagpur Granite-Gneiss Complex is located to north of the Chhotanagpur-Singhbhum Mobile Belt.

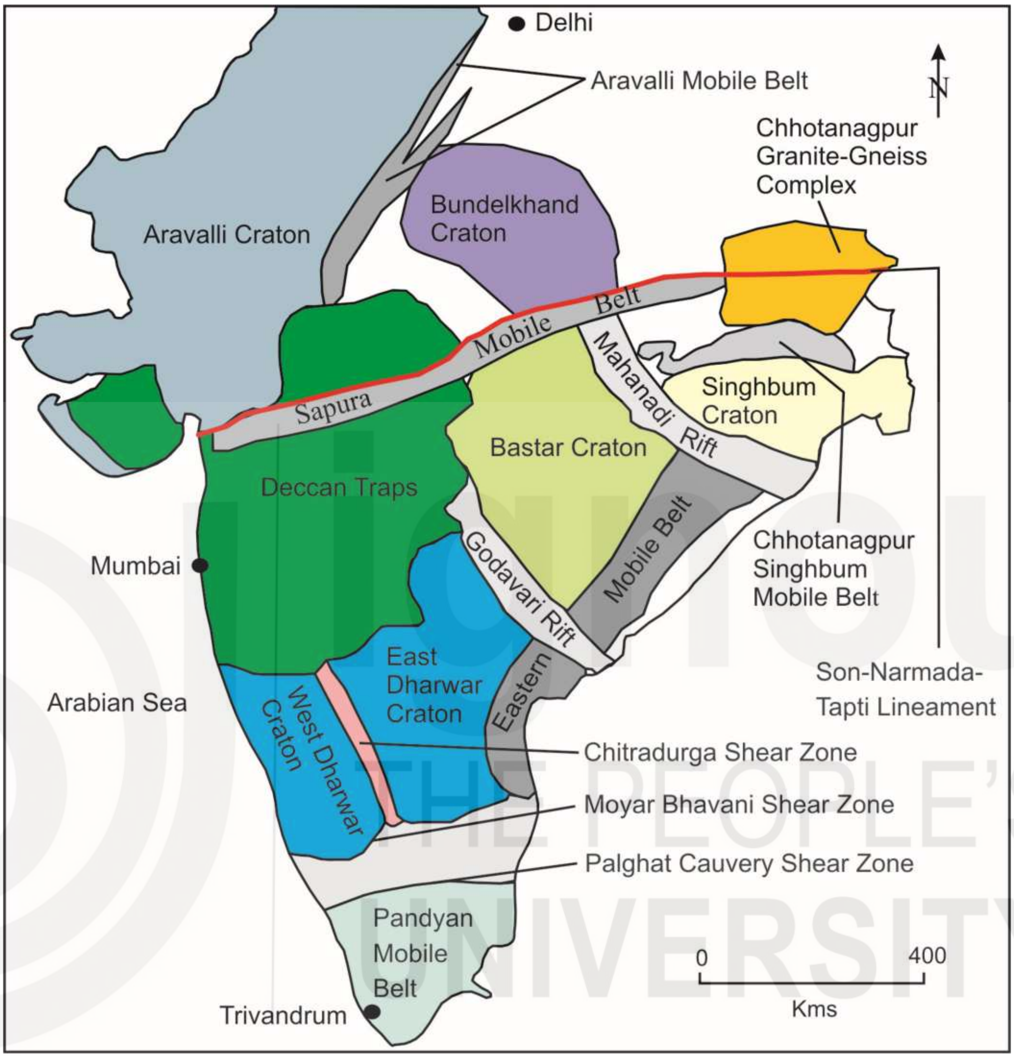

Fig. 3.3: Map of peninsular India showing major cratons and mobile belts. (Source: simplified after Vaidyanadhan and Ramakrishnan, 2008; Sharma, 2009)

3.2.4 Indian Desert

Next to the Indo-Gangetic plains, the Thar Desert occupies a substantial area on the north-western margin of peninsular India. It lies to the west of the Aravalli mountain chain (Fig. 3.1). It is believed that during the Mesozoic era, it was under the sea. But the onset of Pleistocene epoch (2.6 Myr to 11,700 years ago) marked a major climatic change from humid to arid condition. This continued for quite some time with occasional wetter periods. This was one of the reasons for the desertification of this region. The desert sand occupies a substantial area of western Rajasthan. The sand dunes of aeolian (wind) origin constitute the main topography of the region. The desert region also extends into parts of Pakistan. Below the desert sand there are sedimentary rocks of Mesozoic and Cenozoic age.

3.2.5 Coastal Regions

India has a long coastline of over 5700 km. The coastal regions constitute mostly the areas beyond the Western and Eastern Ghats. In addition, they also include Saurashtra coast of Gujarat and Bengal coastline. They can be divided into two coastal regions. They are:

1. **Western Coastal Region**: It lies along the Arabian Sea and extends from the Rann of Kachchh in the north to Kanyakumari in the south (Fig. 3.1). The Rann of Kachchh is a depressed area that gets submerged under sea during the high tide. It becomes an estuary during the monsoon period, but remains exposed in winter months.
2. **Eastern Coastal Region**: It lies along the Bay of Bengal and extends from Ganga delta in the north to Kanyakumari in the south (Fig. 3.1). This coastline is broader than the western coastline. It is a region of low-lying area, where sediments derived from the Ghats are deposited. Accordingly, it bears some depositional landforms of varying thicknesses like deltas of the Mahanadi, Krishna and Cauvery rivers.

The eastern coast is somewhat different from the western coastal region because all the rivers from the Western Ghats flow to the east into the Bay of Bengal. As a result, the eastern coastal region comprises mainly deltas and other depositional landforms. There are also a few lagoons in between the deltaic regions. While sometimes erosional landforms can be seen, they are usually few and mostly restricted to Andhra Pradesh coastline.

It may be noted that the coastal regions of eastern Odisha and Bengal are full of lagoons and lakes in addition to a major deltaic region of the Gangetic river system. There are no erosional landforms. Moreover, the Sunderbans estuary is located in this region that gets submerged like the Rann of Kachchh during the monsoon season.

Learners, you have learnt the physical and structural divisions of India. Before discussing about the stratigraphy of India, spend few minutes to perform an exercise to check your progress.

SAQ 1

a) Name the five linear divisions of the Himalaya.

b) There are two major knee-bends in the Himalayan range, one to the west around Nanga Parbat and the other to the east at Namche Barwa and these are referred to as --

c) The Indus and Ganga river systems are separated by ----------------------------

d) Godavari, Krishna and Cauvery flow from --

e) Name two estuaries of the Indian coastal region.

3.3 STRATIGRAPHY OF INDIA

The stratigraphic record of India is extensive, covering the entire span of the geological time scale, ranging from Precambrian to Recent (Holocene). Among the five physiographic divisions of India, the three, namely, peninsular plateau, extra-peninsular (Himalaya) region and Indo-Gangetic plains cover most of the areas of the country and hence, the stratigraphic successions. It is convenient to divide the stratigraphy of India into four different parts that correspond to the four basic divisions of the geological time scale as given below:

- Precambrian stratigraphy;
- Palaeozoic stratigraphy;
- Mesozoic stratigraphy; and
- Cenozoic stratigraphy.

3.3.1 Precambrian Stratigraphy

Precambrian is a general term (i.e., informal name in a stratigraphic sense) used to denote all rocks older than Cambrian period. It is a long time covering more than 90% of the total life span of the Earth, starting from 4.6 billion years (Gyr) ago and ending at 542 Myr ago. It consists of three eons: **Hadean**, **Archaean** and **Proterozoic**. There is no rock record of Hadean and the rocks of Archaean and Proterozoic are mostly of metamorphic type. As a result, they are either devoid of fossils or yield very little organic matter. Therefore, it is not generally possible to classify Precambrian time on the basis of biostratigraphic principles as in the case of Phanerozoic rocks. The boundaries between eons and period are marked on the basis of radiometric dates which do not indicate the time of deposition but the time of crystallisation which is usually the time of orogenic cycle. Let us discuss the Precambrian rocks of Peninsular India and the Himalayas:

1. **Precambrian Rocks of Peninsular India**

The Precambrian rocks are found mostly in the peninsular part of India, which is also known as the **Indian Shield**. The Indian shield is made up of cratons and mobile belts of Archaean and Proterozoic age, respectively (Fig. 3.3).

- **Archaean Rocks**: The Archaean rocks of peninsular India represent oldest rock deposits and comprise igneous and metamorphic terrains/cratons. These cratons are the Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli. The granite, tonalite, trondhjemite, greenstone and gneisses are main rock types in these cratons. Out of which, the Dharwar craton is discussed in detail in Unit 4 of Block 2 of this course.
- **Proterozoic Sedimentary Basins**: Proterozoic sedimentary basins of peninsular India comprise the intracratonic basins. These basins were formed by rifting or splitting of Archaean cratons due to the development of Proterozoic Mobile Belts among them. These basins are flat, unmetamorphosed and comprise about 20% of the Indian shield. The sediments of Proterozoic rocks were derived from the surrounding older Archaean gneisses and granites. They were mainly deposited in shallow marine conditions, but sometimes in fluvial conditions as well. There are many Proterozoic basins spread all over the peninsular India, but four largest basins are the Vindhyan, Cuddapah, Chhattisgarh and Aravalli known as Vindhyan Supergroup, Cuddapah Supergroup, Chhattisgarh Supergroup and Delhi Supergroup, respectively (Fig. 3.4). The Chhattisgarh Supergroup lies in the Bastar craton. It is bordered by Satpura Mobile Belt to the north. It is

about 2500 m thick and composed mainly of conglomerate, sandstone and limestone. The other three supergroups, the Vindhyan, Cuddapah and Delhi, are discussed in detail in Unit 4 of Block 2 of this course.

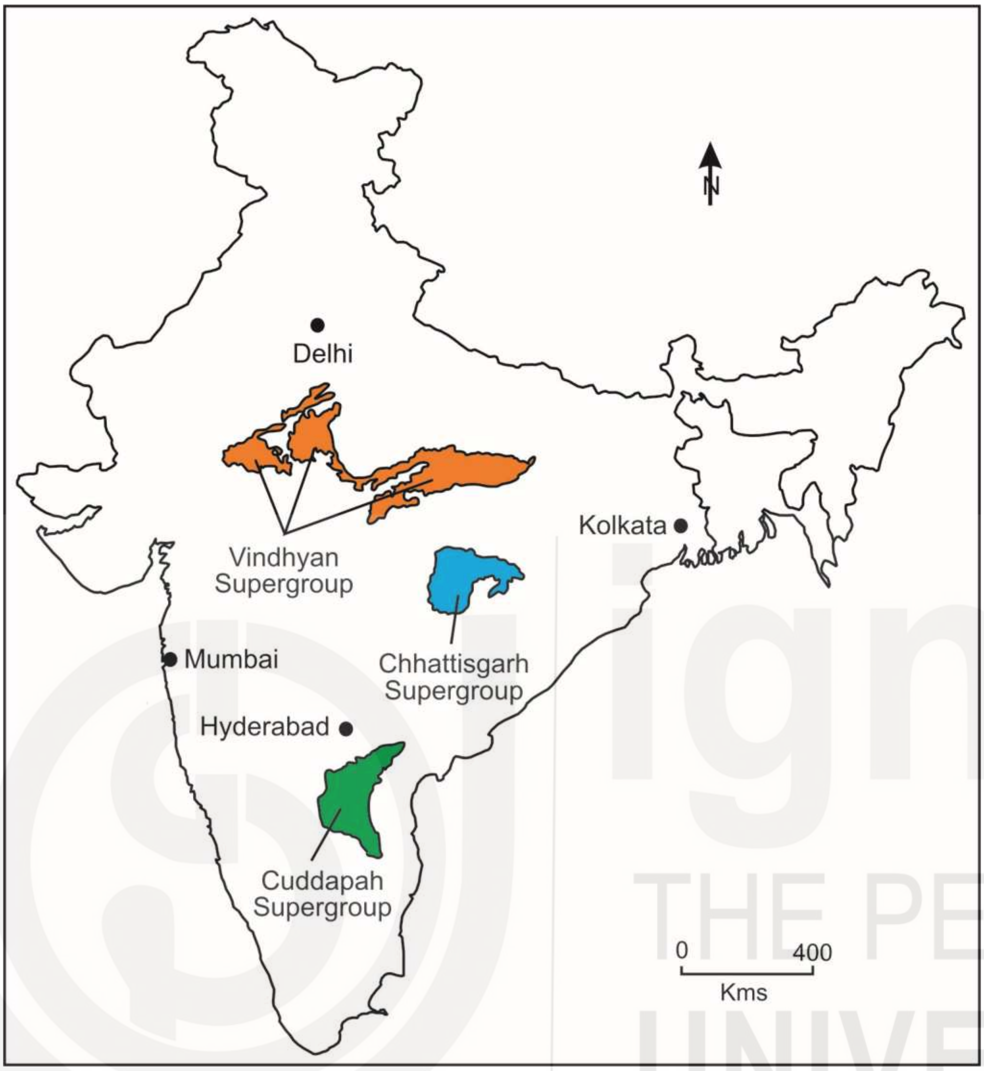

Fig. 3.4: Map showing major Proterozoic basins of peninsular India.

2. **Precambrian Rocks of the Himalaya**

Precambrian rocks of the Himalaya can be divided into two parts representing doubtful Archaean and older Proterozoic rocks that are metamorphosed. They comprise gneisses and granites and other high-grade metamorphic rocks. They are given different names depending on the locality where they are best exposed. For example, the crystalline rocks of Kashmir and adjoining areas are named as **Salkhala Formation** and the same rocks in Himachal Pradesh and Uttarakhand are known as **Vaikrita Formation** (also called **Central Crystallines**).They indicate a possible age of 2000 to 1800 Myr (Palaeo-Proterozoic). They are exposed in the Greater Himalayan region.

The Meso-Proterozoic rocks are exposed inthe Lesser Himalaya and they consist of sedimentary or meta-sedimentary rocks. The stratigraphic resolution of these rocks is beset with problems since superposition is generally disturbed due to structural complications. The important groups in this area are the Jammu Limestone, Shali Limestone, Simla Group and Jaunsar Group. The Neo-Proterozoic rocks in the Lesser Himalaya are known by the Krol and Blaini groups.

3.3.2 Palaeozoic Stratigraphy

Marine Palaeozoic rocks are restricted to the Himalayan region except a few minor marine excursions of Cambrian/Permain age occurring in peninsular India. These marine Palaeozoic outcrops are present in Umaria and Jabalpur areas of Madhya Pradesh and Bikaner-Nagaur area of Rajasthan. The Palaeozoic marine rocks are exposed in Kashmir and Zanskar in Jammu and Kashmir, Spiti in Himachal Pradesh, Uttarakhand and Arunachal Pradesh. In Peninsular India, freshwater sediments of Upper Palaeozoic age constitute the Gondwana Supergroup. Let us discuss the Palaeozoic rocks of Kashmir, Spiti and Gondwana rocks of Peninsular India.

1. **Palaeozoic Rocks of Kashmir**

Palaeozoic succession in Kashmir (Jammu and Kashmir) consists of well-developed marine fossiliferous rocks ranging from Cambrian to Permian. However, there are some breaks in the succession. These breaks constitute disconformities covering Upper Cambrian-Lower Ordovician, Devonian and Upper Carboniferous. In addition, the succession also bears volcanic rocks in Permian known as **Panjal Trap**.

Palaeozoic succession in Kashmir is best exposed in north-western part of Kashmir in the Lolab valley, notably Handwara and Kupwara regions, Liddar valley of Anantnag District and PirPanjal Range north of Banihal. The succession, comprise shales, limestones, sandstones, siltstones and quartzites with rich assemblages of invertebrates notably, trilobites, brachiopods, corals, mollusks, bryozoans, conodonts, etc. The uppermost Palaeozoic rocks also yield the Gondwana plant fossils.

2. **PalaeozoicRocks of Spiti**

The Spiti valley (Himachal Pradesh) contains a complete, best developed, folded, marine fossiliferous succession of Palaeozoic age. It is important to note that Palaeozoic rocks of Spiti are more or less similar to those of Kashmir except for the absence of Permian volcanic rocks. The unconformities are the same as in Kashmir which include Upper Cambrian-Lower Ordovician, Devonian and Upper Carboniferous. A detailed account on the stratigraphy of Palaeozoic succession of Spiti and Kashmir is presented in Unit 5 of Block 2 of this course.

3. **Gondwana Rocks of Peninsular India**

You have read that there are no marine Palaeozoic sediments in peninsular India except the presence of a few sediments of Cambrian/Permianage in Madhya Pradesh and Rajasthan. However, freshwater sediments got deposited from Upper Palaeozoic (Carboniferous-Permian) onwards and these continued into Mesozoic in the Pranhita-Godavari, Mahanadi, Damodar and Narmada-Son-Tapti rift valleys. These rift valleys were developed in response of breaking of Gondwanan landmasses during Upper Palaeozoic. Sediments deposited in these rift valleys are collectively known as **Gondwana Supergroup**. At this time (i.e., Late Palaeozoic), the continents of Africa, South America, Australia, Antarctica and subcontinent India were joined together called **Gondwana Supercontinent**. This supercontinent was surrounding the South Pole in Carboniferous-Permian times covering with glaciers. As it started moving away from the pole, the glaciers started melting. As a result, the succession of the

Gondwana Supergroup, started with glacial deposits and known as **Talchir Formation**.

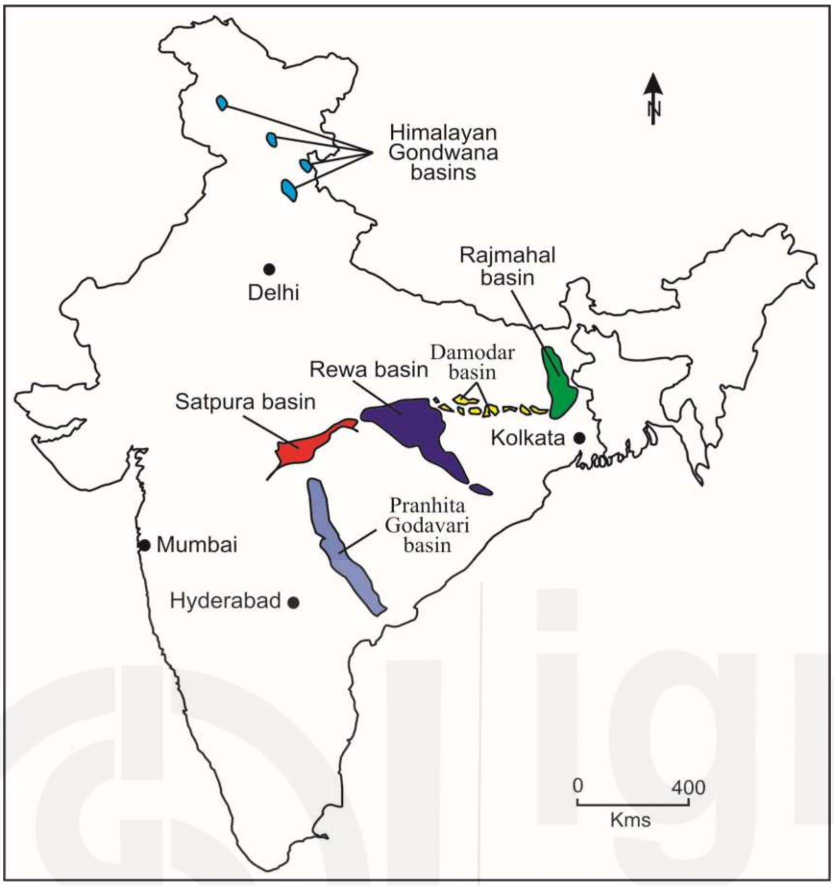

Fig. 3.5: Map showing peninsular and the Himalayan Gondwanan basins of India. (Source: simplified after Naqvi, 2005)

The Gondwana Supergroup is widely distributed in the peninsular as well as extra-peninsular regions of India (Fig.3.5). It is dominantly composed of sandstones and shales with rich coal seams as well as fossil remains of plants and animals. The Gondwana Supergroup is divided into the Lower Gondwana Sequence (Upper Palaeozoic) and the Upper Gondwana Sequence (Mesozoic). The Lower Gondwana Sequence commences with a glacial deposit as you have read above. As the temperature rapidly increased, there was a widespread expansion of plants during the greater part of Permian. As a result, thick deposits of coal were deposited during this time. Of the total production of Indian coal about 95% comes from the Lower Gondwana Sequence. The rocks of this sequence have a domination of shales and are best preserved in Jharkhand, Chhattisgarh, West Bengal and northern parts of Andhra Pradesh. The stratigraphy of the Gondwana Supergroup is discussed in detail in Unit 7 of Block 2 of this course.

Learners, before discussing about the Mesozoic stratigraphy of India, spend few minutes to perform an exercise to check your progress.

SAQ 2

a) Name the important cratons of the Indian peninsula.

b) Name the Neo-Proterozoic groups of rocks of the Lesser Himalaya.

c) What is the name and age of volcanic rocks in Palaeozoic of Kashmir?

3.3.3 Mesozoic Stratigraphy

You already know that freshwater Gondwana rocks extend into Mesozoic and constitute an important element in the peninsular India. Apart from these, the rocks deposited in marine conditions also occur in the peninsular India. They constitute the coastal facies of rocks that were deposited as a result of marine incursions or transgressions along the western and eastern coasts of the peninsula. These marine incursions took place at different intervals of Jurassic and Cretaceous, depositing marine rocks in Kachchh in Gujarat, and Jaisalmer and Barmer in Rajasthan. These rocks were also deposited along the west coast and in the Cauvery basin in Tamil Nadu along the east coast. In addition, one incursion during Cretaceous extended almost to the central part of India along the Narmada region. In the Himalayan region, the marine Permian rocks pass upwards with a minor break into Triassic followed by Jurassic and Cretaceous rocks. Let us discuss the Mesozoic rocks of peninsular India and Himalaya.

1. **Mesozoic Rocks of Peninsular India**

The highly fossiliferous sediments of Jurassic and Cretaceous age are deposited in the pericratonic basins located in the western and eastern coasts as well as central part of the peninsular India. The volcanic rocks of Cretaceous age occur in the central and eastern peninsular India. These basins are:

- **Kachchh Basin**: It consists of Mesozoic succession, which comprises rocks ranging in age from Lower Jurassic to Lower Cretaceous. These rocks are situated between the Great Rann of Kachchh in the north and the Kathiawar (Saurashtra) peninsula in the south Gujarat. In Kachchh, the hillocks projecting out in the Rann are composed of these rocks (Fig. 3.6). The succession is divided into four formations, namely, **Pachcham**, **Chari**, **Katrol**, and **Umia**. The Pachcham, Chari and Karol formations are of Jurassic age and Umiais of Lower Cretaceous. These rocks are highly fossiliferous and contain ammonoids, bivalves, brachiopods, echinoids and some other groups. Similar rocks are also found in Jaisalmer and Barmer regions of Rajasthan.
- **Cauvery Basin**: Along the eastern coast, Cretaceous rocks are exposed in the Cauvery basin in Tamil Nadu and Puducherry (Fig. 3.6). They are divided into four groups, namely, **Uttattur**, **Trichinopoly**, **Ariyalur** and **Niniyur**. Out of these, the Uttattur, Trichinopoly and Ariyalur range from late Lower to Upper Cretaceous in age while the Niniyur is of Palaeocene. All these groups are highly fossiliferous and have yielded ammonoids, bivalves, echinoids, foraminifers, sharks and reptiles. A detailed account on the Mesozoic stratigraphy of the Kachchh, Jaisalmer and Cauvery basins are presented in Unit 6 of Block 2 of this course.
- **Narmada Basin**: The Cretaceous marine rocks are dominantly composed of fossiliferous limestones in the Narmada valley in the central part of India in Madhya Pradesh and Gujarat (Fig. 3.6) referred to as **Bagh Beds**. These beds are richly fossiliferous and have yielded nautiloids, ammonoids, bivalves, gastropods and echinoids. Overlying this is a freshwater formation known as **Lameta Formation**. Sandstones and limestones are the main rock types of the formation. This formation is characterised by the presence of

diverse freshwater to terrestrial fauna consisting of fishes, frogs, dinosaurs and crocodiles.

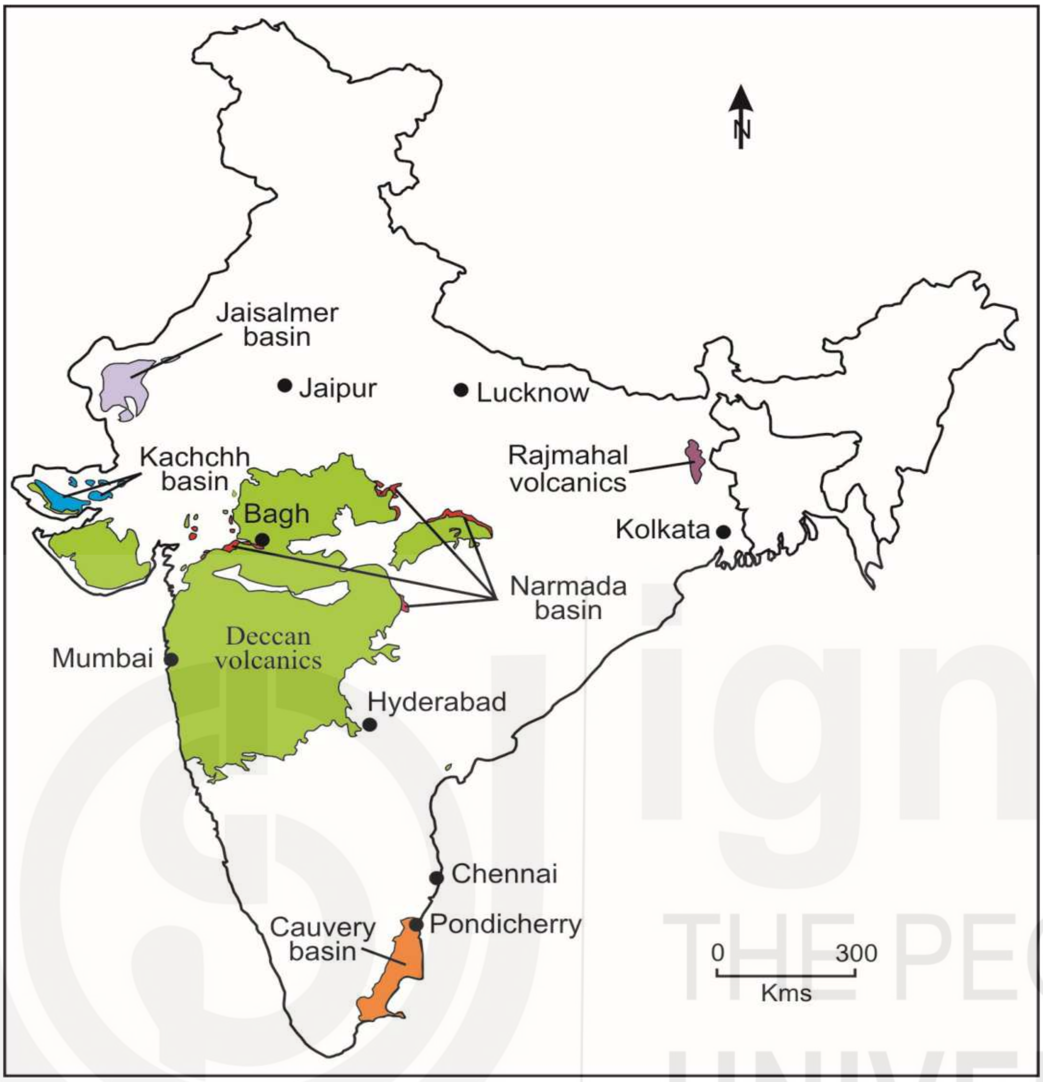

Fig. 3.6: Map showing major Mesozoic basins of India.

- **Upper Gondwana Sequence**: You have already read that the Upper Gondwana Sequence is of Mesozoic age. The rocks of this sequence are widely distributed in Central India notably in Pranhita–Godavari valley and Jabalpur region. They are rich in plant fossils constituting *Ptilophyllum* flora.
- **Rajmahal Volcanics**: They comprise a series of volcanic lava flows and are located in the eastern Jharkhand. They are composed dominantly of basalt and occupy a surface area of about 4100 km^2 attaining a maximum thickness of 600 m. The sedimentary rocks interbedded with the Rajmahal lava flows yield excellently preserved plant fossils, including flowers, seeds, etc. They are of Lower Cretaceous age.
- **Deccan Volcanics**: Towards the end of Cretaceous, peninsular India was engulfed in a major phase of volcanicity and the lava flows covered a vast area including Maharashtra, Karnataka, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Gujarat and Rajasthan (Fig. 3.6). The lavas range up to a maximum thickness of 2500 m and comprise black or dark gray basalt. Beds of volcanic ash associated with the lava flows are a very common feature. There are thin sedimentary beds in between the lava flows which are known

as **intertrappean beds**. A detailed account on the stratigraphy of the Gondwana Supergroup and Deccan Traps is presented in Unit 7 of Block 2 of this course.

2. **Mesozoic Rocks of Himalaya**

Marine Mesozoic rocks are widely distributed in the Tethyan part of the Himalayan region. Triassic rocks are well developed in the Himalayan region and widely distributed stretching from Kashmir (Jammu and Kashmir) in the northwest through Spiti (Himachal Pradesh) to Kumaon (Uttarakhand) in the south east (i.e. along the Himalayan belt). Triassic rocks are best developed in the Spiti region and a detailed account on its stratigraphy is presented in Unit 6 of Block 2 of this course.

The Jurassic rocks of Himalaya are represented by highly fossiliferous black shale named **Spiti Shale** or **Spiti Formation** in the Spiti area of Himachal Pradesh, where it is well developed. This formation contains ammonoids and bivalves in phosphatic nodules. The Cretaceous sediments are represented by the **Giumal** and **Chikkim** formations, which are sparsely fossiliferous.

3.3.4 Cenozoic Stratigraphy

Marine Cenozoic sediments are exposed in continuation to the Mesozoic rocks along coastal areas in peninsular India. Freshwater Upper Cenozoic rocks are also exposed in some parts of the peninsular India. In the Himalayan region, the lower part of Cenozoic received marine sedimentation, while the upper part was replaced gradually by freshwater sedimentation. This is because, in the Early Cenozoic, the Himalayan region was a sea (known as Tethys), but eventually it got uplifted and finally became a mountain range. The Himalayan uplift took place in several phases. Earlier, when it was a sea it was receiving sediment, but when it got uplifted it started providing sediment to the rivers that flowed from it and new freshwater basins were formed in front of it. Let us discuss the Cenozoic marine sediments of peninsular India, freshwater and estuarine sediments of south India and Cenozoic rocks of Himalaya.

1. **Cenozoic Marine Sediments of Peninsular India**

Lower Cenozoic rocks (Palaeogene and Lower Neogene) are widely distributed as marginal deposits almost all around the Indian craton. These rocks are deposited in Kachchh and other western basins including parts of Rajasthan and mainland Gujarat. Cenozoic rocks in Kachchh display a marine sequence from Palaeocene to Pliocene. In that respect, this is one of the few areas in India where such a fossiliferous sequence is exposed.

The outcrops in Rajasthan are confined to three basins from north to south, namely, Bikaner-Nagaur, Jaisalmer and Barmer. Of these maximum exposures are present in the Jaisalmer basin. You have already read that in Tamil Nadu and Puducherry, the Cretaceous marine sequence is unconformably overlain by the **Niniyur Group**. It comprises fossiliferous limestone, shelly limestone and argillaceous nodular limestone and fossils indicating a Palaeocene age.

2. **Cenozoic Freshwater and Estuarine Sediments of South India**

In Tamil Nadu, the Miocene is represented by rocks that may have originally been deposited as a continuous cover over the older formations. But it has since been dissected by streams rendering them as isolated outcrops. Such outcrops are known as **Cuddalore Sandstone**. They are widely distributed from Pudducherry to Thanjavur and Sivaganga and comprising sandstones with bands of conglomerates and clays, indicating deposition in fluviatile, lacustrine and estuarine conditions.

3. **Cenozoic Rocks of the Himalaya**

The Cenozoic rocks in the Himalaya were deposited mainly in the Lesser and Outer Himalayan regions. In addition, some deposits are also known in the Tethys Himalaya in Ladakh. In the Lesser Himalaya, Paleocene and Eocene are represented by marine fossiliferous rocks that extend from Jammu to Himachal Pradesh and Uttarakhand. These rocks are named as the **Subathu Group**. Overlying this is a thick sequence of estuarine and freshwater deposits of Oligocene-Miocene age named **Murree Group**.

In Meghalaya and Assam, a thick sequence of marine rocks followed by freshwater rocks was deposited in Cenozoic times. In Lower Assam, the **Barail Group** is one of the thickest units that have a widespread distribution. This group has an economic importance as it bears coal measures and together with the overlying **Tipam Sandstone** is a repository of hydrocarbons.

The emergence of the Himalayan range following the Early Miocene phase of uplift resulted in the formation of a foreland basin in front of the newly emerged mountain chain. This basin became the site of extensive deposition of fluviatile sediments derived from the uplifted regions of the mountain chain. The suite of sedimentary rocks deposited in this basin has been named as the **Siwalik Group**. The main lithology of the Siwalik Group is sandstone-mudstone alternation while pebbly sandstone and conglomerate predominates towards the upper part of the sequence. The Siwalik rocks bear a rich vertebrate fauna, especially mammals and ranging from Middle Miocene to Pleistocene.

The Upper Pliocene to Lower Holocene fluvial, lacustrine, glacial and aeolian deposits of the Kashmir valley are referred to as **Karewa Group**. The group comprises semi-consolidated sand, gravel, silt and clay which bear occasional lignite seams. A detailed account on the Cenozoic stratigraphy of Himalaya is presented in Unit 8 Block 2 of this course.

Learners, you have learnt the Precambrian, Palaeozoic, Mesozoic and Cenozoic stratigraphy of India. Now, spend few minutes to perform an exercise to check your progress.

SAQ 3

a) Name three groups that are of Cretaceous age in marine coastal sequence of Tamil Nadu.

b) In the Himalayan region the Middle and Upper Jurassic are represented by a highly fossiliferous black shale named --

c) Name the freshwater formation of Miocene age exposed in Tamil Nadu that bears lignite.

d) Which group of rocks of Cenozoic age extends from east to west in the outer Himalaya?

3.4 ACTIVITY

In the given outline map of India (Fig. 3.7), mark and label the following:

1. The physiographic divisions of India: the Himalaya, Indo-Gangetic plains, desert region, peninsular plateau and coastal regions.
2. Mobile belts and Cratons.
3. Vindhyan, Cuddapah and Chhattisgarh Supergroups.

Fig. 3.7: Outline map of India.

3.5 SUMMARY

Let us now summarise what you have learnt in this unit:

- Physiographically, India comprises three well marked divisions from south to north, namely, Peninsular plateau, Indo-Gangetic plain and the Himalayan mountain chain.
- Himalaya can be linearly divided into five parts from north to south. They are Trans Himalaya, Tethyan domain, Greater Himalaya, Lesser Himalaya and Outer Himalaya.
- Peninsular plateau is bounded by Western Ghats, Eastern Ghats and Satpura mountain chain.
- Peninsular shield is composed of cratons such as Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli and mobile belts like Eastern Ghat, Pandyan, Aravalli and Satpura.

- Proterozoic sedimentary basins of Peninsula comprise 20% of the Indian shield.
- Marine Palaeozoic rocks are restricted mainly to the Himalayan region.
- There are three major breaks in Palaeozoic sequence. They are Upper Cambrian-Lower Ordovician, Devonian and Upper Carboniferous.
- Coastal facies of Mesozoic are best exposed in Kachchh, Western Rajasthan and Tamil Nadu
- Towards the end of Mesozoic there was a major volcanic outburst in peninsular India known as the Deccan Traps.
- In the peninsula India, Cenozoic rocks comprise coastal facies while the Himalaya Palaeogene is marine and Neogene is of freshwater origin.

3.6 TERMINAL QUESTIONS

1. Discuss the physiographic divisions of India.
2. Give an account on the Precambrian cratons and mobile belts of the peninsular India.
3. Discuss the Proterozoic sedimentary basins of peninsular India.
4. Write an account of the Palaeozoic rocks of India.
5. Discuss the Mesozoic stratigraphy of India.
6. Describe in brief the Cenozoic stratigraphy of the Himalaya.

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3.8 FURTHER/SUGGESTED READINGS

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3.9 ANSWERS

Self Assessment Questions

1. a) Trans Himalaya, Tethyan domain, Greater Himalaya, Lesser Himalaya and Outer Himalaya.

   b) Syntaxial bends.

   c) Aravalli Range.

   d) Western Ghat, Bay of Bengal.

   e) Rann of Kachchh and Sunderbans estuary.

2. a) Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli.

   b) Krol and Blaini groups.

   c) Panjal Traps of Permian age.

3. a) Uttattur, Trichinopoly and Ariyalur.

   b) Spiti Shale.

   c) Cuddalore Sandstone.

   d) Siwalik Group.

Terminal Questions

1. Refer to Section 3.2.
2. Refer to sub-section 3.3.1
3. Refer to sub-section 3.3.1
4. Refer to sub-section 3.3.2
5. Refer to sub-section 3.3.3
6. Refer to sub-section 3.3.4

Glossary

Aeolian	:	Aeolian deposits are sediments, such as loess, made up of windblown grains of sand and dust, i.e., winds may transport and deposit materials.
Alluvial Deposits	:	Detrital material transported by a river and deposited usually temporarily, at points along the flood plain of a river. They are composed commonly of sands and gravels. Many important minerals occur locally concentrated in alluvial deposits. They are also known as alluvium.
Apparent Dip	:	Apparent dip is the amount of dip in any direction other than that of the true dip. The value goes on reducing as we move away from the direction of the true dip and it becomes zero at right angles to the direction of the true dip.
Arenaceous	:	Refers to sedimentary rocks and deposits of sand size particles.
Argillaceous	:	Refers to rock or sediment in which components are fine grained and mostly are clay minerals.
Attitude	:	By attitude we mean how the beds are displayed in an area. They can be horizontal as they were originally deposited or they can be tilted and dipping in a particular direction. The attitude indicates the amount and direction of the dip, if any.
Batholiths	:	A very large emplacement of igneous intrusive rock that forms from cooled magma at great depth inside the Earth. Batholiths usually contain a complex of acid plutonic rocks and are always related with orogenic belts.
Basin	:	It is a depressed area like sea, lake or river where water flows and brings with it the sediment that gets deposited there.
Beds	:	They are the smallest layers in a sedimentary sequence that can be distinctly seen as separate units. The thickness of a bed varies from one rock unit to another. Thus, we have terms like thick-bedded and thin-bedded denoting the nature of beds in a rock.

Biostratigraphic Unit	:	It is a body or layer of rock sequence characterised by its content of fossils. Range zone, interval zone, assemblage zone and abundance zones are the common biostratigraphic units.
Brunton Compass	:	It is also known as Brunton Pocket Transit, a type of compass made by Brunton, Inc of Riverton, Wyoming. The compass is used by geologists for making various observations in the field including recording attitudes of rocks and location of places.
Cambrian	:	A division of geological time in the Palaeozoic era between 542 and 488 million years.
Catastrophic Event	:	Catastrophic event is a sudden, extensive, or notable disaster that brings about some major changes.
Chisels	:	It is a metal tool with a sharp beveled edge, used to cut or shape rocks, stone, wood or metal.
Concordant Discordant	:	When the beds or rock units are corresponding in direction with the underlying and overlying strata they are referred to as concordant. Conversely, when they cut across the strata.
Conglomerate	:	The cemented and rounded fragments of water worn rock or pebbles which are bound by a siliceous or argillaceous material. The size of fragments can vary from large boulders to gravel so fine that it is almost coarse sand.
Craton	:	The name is derived from a Greek word meaning "strength". It is used to distinguish those portions of continental crust that are stabilised after a series of cycles of orogeny (mountain building) and are composed of crystalline rocks. The term craton is used against **mobile belts,** which are still unstable. The term **shield** is often used to denote a region composed of cratons and associated mobile belts.
Cretaceous	:	A division of geological time in the Mesozoic Era between 145 and 65 million years ago.
Deccan Plateau	:	Deccan plateau is a large plateau in India, located between the mountain ranges of the Western Ghats and the Eastern Ghats.

Deposition : It is the laying down of material through natural processes. The natural agencies may comprise water, wind or glaciers. These agencies bring the material in suspension or solution and deposit them in a basin. When the material is brought in suspension, it is known as **sediment** and the process is called **sedimentation.**

Denudation : It is the sum total of the processes which cause the wearing away of the land surface. It involves the processes of weathering, transportation, and erosion, etc.

Desertification : Refers to the process by which an area becomes a desert, i.e., a type of land degradation in which a dry land region becomes increasingly arid.

Dip : It is defined as the angle that a geological feature (e.g., bed, fault) makes with a horizontal plane. It means that the angle being measured in a direction perpendicular to the strike of the plane.

Disposition : Refers to the process in which something is placed or arranged in relation to other things.

Dolomite : Dolomite is an anhydrous carbonate mineral composed of calcium magnesium carbonate $CaMg(CO_3)$.

Dunes : In areas having loose, unconsolidated, surface deposits, e.g., sandy deserts, a well-established prevailing wind will be able to heap up the sand into regular accumulations called dunes.

Dyke : A columnar body of igneous rock which cuts across the bedding or structural planes of the host rock. Dykes may be composite or multiple and may be found in association with any larger igneous body.

Fault : It is a fracture in a rock along which the adjacent rock surfaces have been differentially displaced

Flora : The naturally occurring native plant life that occurs in a particular region or time. The equivalent term for animal life is fauna.

Genus : Genus is a taxonomic rank used in the biological classification of living and fossil organisms. Its plural version is genera.

Ghats	:	The word Ghat means a step like mountain. The English name of *Sahyadri* is Western Ghats
Gneiss	:	A variety of rocks having a banded or coarsely foliated structure which is formed by regional metamorphism; included under this are a number of rock types which have different origins.
Granites	:	A coarse-grained crystalline plutonic rock having granular texture. It consists essentially of quartz (20-40%), alkali feldspar, and very commonly a mica, biotite and/or muscovite. A number of accessory minerals may be present. Granites occur exclusively as intrusive bodies.
Hiatus	:	Refers to a break, a gap or interruption or discontinuity in the age of strata.
Himalaya	:	The word Himalaya is derived from Sanskrit word *Him-alaya*. *Him* means snow and *alaya* means covered range, which refers to the snow covered mountain range. Most western writers pluralise it as "Himalayas", which is incorrect because the Sanskrit word itself is pluralised.
Jurassic	:	A division of geological time in the Mesozoic Era between 200 and 145 million years ago.
Limestone	:	It is a sedimentary rock composed mainly of calcium carbonate ($CaCO_3$), deposited usually under marine conditions, and composed of chemically derived lime muds or fossilised shells, or both.
Lithology	:	It denotes the physical characteristics of a rock, like rock type, composition, colour, hardness, and other distinguishing features.
Lithostratigraphic Units	:	They comprise bed, member, formation, group and supergroup, and are classified on the basis of lithology.
Magma	:	A naturally occurring molten or semi-molten rock material which is formed within the crust or upper mantle of the Earth and may consolidate to form an igneous rock. It is a complex high temperature fluid substance.
Mappable units	:	They constitute a rock type or a set of rock types that are sufficiently thick and continuous so that they can be recorded in a map to the scale.

Mesozoic : An Era, a division of geological time between 251 and 65 million years ago.

Microfossils : Microfossils are fossils commonly smaller than one millimeter and not larger than four millimeter. The study of microfossils requires the use of light or electron microscopy.

Mishmi Hills : Mishmi hills are in the northeastern part of India in Arunachal Pradesh and occur at the junction of Northeastern Himalaya and Indo-Burma ranges.

Orogeny : Orogeny refers to mountain building processes, i.e., forces and events leading to a large structural deformation of the Earth's crust due to the movement of tectonic plates.

Paleosol : Refers to soils that formed long ago and are preserved by burial underneath either by sediments or volcanic deposits.

Permian : A division of geological time in the Palaeozoic Era between 299 and 251 million years ago.

Physiography : It deals with the physical processes and patterns of the Earth.

Pyroclastic : Pyroclastic rocks are clastic rocks that are composed mainly of volcanic material.

Rann of Kachchh : Rann of Kachchh is a salt marsh located in the Kachchh District of Gujarat, India. It covers a huge area of around 10,000 square miles and the area has desert on one side and the sea on the other side making it an interesting region.

Sandstone : It is a sedimentary rock composed of sand sized grains of minerals, rock or organic material. It also contains a cementing material that binds the grains together.

Sedimentary Sequence : It denotes the beds of different sedimentary rocks lying one upon the other constituting a series. It is customary to use the term for a set of rocks that are available in continuation.

Sedimentary Structures : They are produced during the process of deposition. They are a result of movement in the medium that brings the sediment. The common types of sedimentary structures are ripple marks, cross-bedding, etc.

Shale : It is a fine grained clastic sedimentary rock composed of mud mixed with clay minerals along with silt size particles and other minerals like quartz and calcite.

Silt : Silt is a sedimentary rock composed of tiny particles smaller than sand but larger than clay. Siltstone is consolidated or compacted silt.

Strata : It is the plural of a Latin word *Stratum* meaning a layer of rocks. Strata are used for a series of such layers that are seen in a sequence one above the other.

Stratified Rocks : These are those that are found in layers. The name is derived from strata meaning layers. All rocks produced by sedimentary processes are usually stratified. In addition some volcanic rocks can also be stratified.

Stratigraphic Events : These are major changes that took place in Earth's history. These changes happen suddenly and alter the pattern of sedimentation. They also bring about change in organisms that can be seen from the fossil content.

Strike : The direction in which a horizontal line could be drawn on a plane. A strike line is the line joining points of equal height above or below a datum, on a planar structure.

Time-rock Unit : It is formally known as a chronostratigraphic unit consists of all rock strata in the world that were deposited during a particular interval of time. A time unit, formally known as a geochronologic unit indicates an interval of time during which a time rock unit formed.

Topographical Map : It is a map of an area is one that shows various locations to the scale with contour lines to denote the altitudes at different places giving a total picture of the topography (position of hills and valleys and other elevation details). Topographical maps come in various scales. In India these maps are prepared by the Survey of India and can be obtained from their offices and sale centres.

True Dip : True dip is the angle of the dip with respect to the horizontal in the exact direction in which the beds are dipping. It is always the highest value of the angle of dip.

Ultrabasic Rocks : Igneous rocks which have essentially ferromagnesian minerals to the virtual exclusion of quartz, feldspar and feldspathoids. Originally it was defined as rocks which have less than 45% silica.

Weathering : When rocks are exposed to action of water, air and other natural agencies like frost action, they break-up, decompose or dissolve producing small fragments, soil, etc. This process is known as **weathering**. But when this weathered material gets transported through various agencies like water, wind and glaciers and deposited somewhere else, the process is called **erosion**.

Xenoliths : Refers to an inclusion in an igneous rock in which it is embedded. It differs in origin, composition, structure, etc, from the igneous rock enclosing it.