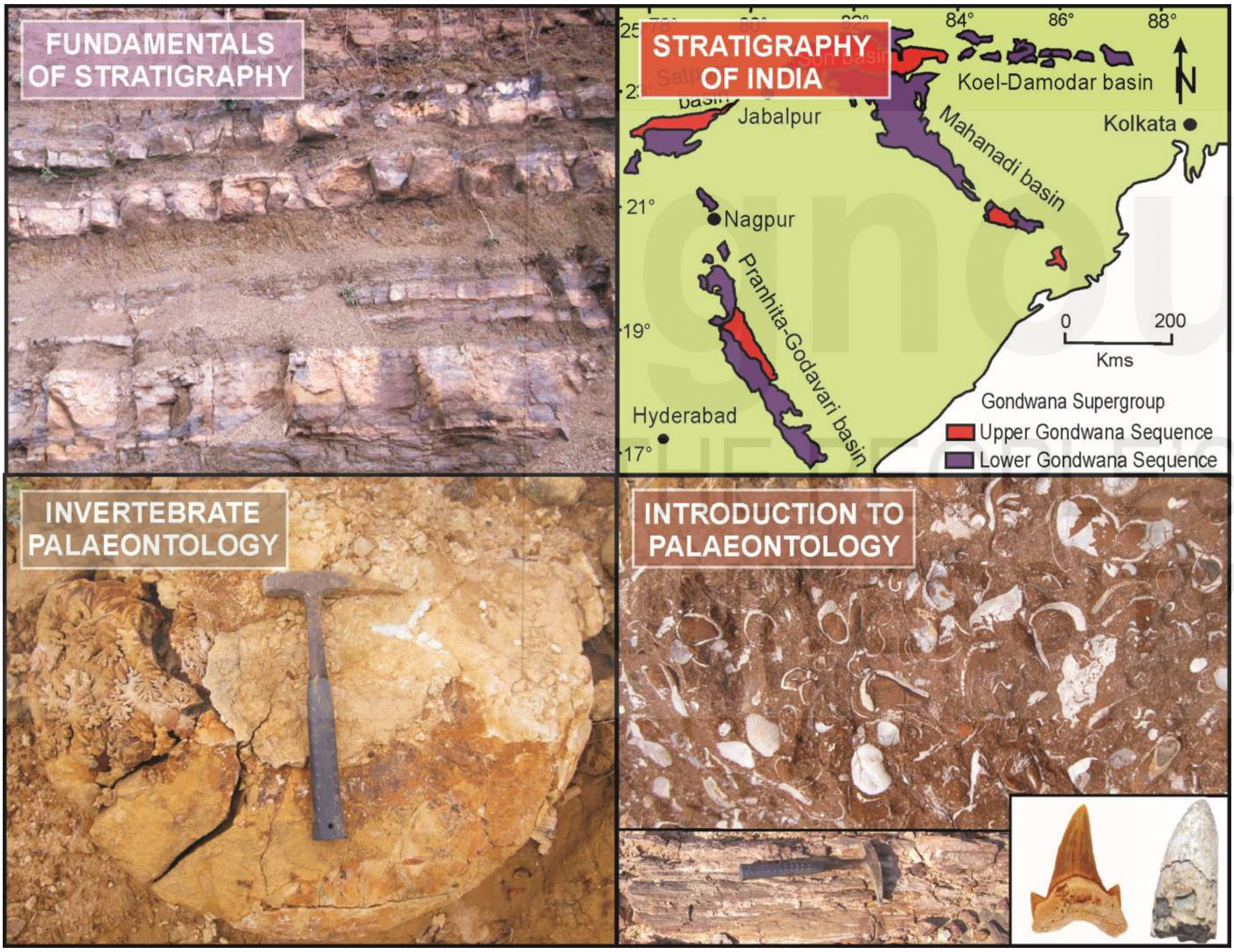
Indira Gandhi National Open University
School of Sciences

BGYCT-137
STRATIGRAPHY AND PALAEONTOLOGY



Palaeontology Volume 2

"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

2

PALAEONTOLOGY

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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=rodINJOA-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

VOLUME 2: PALAEONTOLOGY

The course BGYCT-137: Stratigraphy and Palaeontology consists of four blocks, which have been packaged in two volumes. The Volume 1 deals with stratigraphy and consists of two blocks namely, fundamentals of stratigraphy and stratigraphy of India. The Volume 2 covers palaeontology and comprises two blocks namely introduction to palaeontology and invertebrate palaeontology.

The first block of this volume, Block 3: Introduction to Palaeontology, will introduce you about fossils, fossilisation, microfossils, evolution of horse, plant fossils and uses of fossils in geology.

The second block of this volume, Block 4: Invertebrate Palaeontology, will introduce you about morphology and geological history of various invertebrate fossil groups such as brachiopods, corals, bivalves, gastropods, cephalopods, trilobites and echinoderms.

Expected Learning Outcomes

After studying this volume, you should be able to:

- ❖ define fossil and describe the process of fossilisation;
- ❖ discuss the major evolutionary trends, phylogeny and origin of horse;
- ❖ discuss microfossils and plant fossils; and
- ❖ describe systematic, morphology and geological distribution of invertebrate fossil groups such as corals, brachiopods, molluscs, trilobites and echinoderms.

After studying this volume, you will be equipped with the basic knowledge of palaeontology.

We wish you all success in this endeavour!

Indira Gandhi National Open University
School of Sciences

BGYCT-137
STRATIGRAPHY AND PALAEONTOLOGY

Block

3

INTRODUCTION TO PALAEONTOLOGY

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BLOCK 3: INTRODUCTION TO PALAEONTOLOGY

In Block 1 and 2, you have been introduced to the fundamentals of stratigraphy and stratigraphy of India, respectively. Stratigraphy is the study of layered rocks in time and space. In fact, it is stratigraphy that helps us to reconstruct the history of the Earth and its evolution through geological time. In order to realise the fascination of fossils, you should be familiar with layered (sedimentary) rocks because fossils are always present in the layered rocks. We continue the story in this block where the special focus is on fossils.

The planet Earth is perhaps the only planet that supports life. Fossils, the remains of organisms that lived long ago, present in the rocks tell us that life on the Earth originated about 3.8 billion years ago. The study of fossils, called palaeontology, documents the history of life. Previously, palaeontology was used mainly for the dating of rocks. But, during the last two decades many new dimensions have been added to it. Now, palaeontology is being used to illustrate origin and evolution of life, to explain the impact of climate change on the past life and how it would alter the life of present and future as well. Fossils also provide insights into the mechanism of organic evolution that shaped the present life mainly through various processes like natural selection, mutation and other means involving a genetic change. In addition, the type of organisms varies on land and in sea and their study through fossils is crucial for reconstructing the palaeogeography and biological distribution at different points of time.

The collection and study of fossils hold many surprises and fascinations. It brings you close to the idea of how old life was and how it evolved and diversified with the passage of time. To outline the significance of fossils, you need to recognise and identify them accurately in the field as well as in the laboratory. This may be your first exposure to palaeontology. Therefore, this block is pitched at introductory level and so that it gives you a basic understanding of fossils. In this block, we have included good number of diagrams, illustrations and photographs so that it is easier for you to visualise them and also to stimulate your interest in it.

This block deals with various aspects of study of fossil. In this block, you will be introduced to the basic principles of the study of fossil and their significance, which are covered in four units.

Unit 9 deals with fossils and fossilisation in which you will learn about fossils, their types and process of fossilisation. Besides knowing the significance of fossils, you will also learn about their taxonomic hierarchy, codes of biological nomenclature and geological time scale.

Microfossils are very important in palaeontology because they can be abundantly found in small samples. There are special techniques for their study. In **Unit 10**, you will learn about major groups of microfossils, their collection and techniques of study.

Unit 11 deals with one important group of mammals, namely, horse. It explains the systematic position, major evolutionary trends, phylogeny, probable time and place of origin of horse. It also describes the role of climate in the evolution of horse.

Plant fossils and the Gondwana flora are covered in **Unit 12**. It discusses the classification, modes of preservation and significance of plant fossils. It also describes the Gondwana flora of India and morphological characters of some important plant fossils known from India.

Expected Learning Outcomes

After studying this block, you should be able to:

- ❖ define fossils;
- ❖ describe process of fossilisation;
- ❖ codes of biological nomenclature;
- ❖ outline the methods of studying microfossils
- ❖ discuss the major evolutionary trends, phylogeny and origin of horse;
- ❖ explain the classification, mode of preservation and significance of plant fossils; and
- ❖ describe characteristics of important Gondwana flora 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" at a few places in all units of the block, which invariably end with possible 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 "Possible Answers" beforehand. In any case, the possible answers are not necessarily the best answers. We hope that we have provided you enough space to work on the exercises/questions to check your progress. It should be noted that the check your progresses are not meant to be submitted to your academic counsellor for evaluation, instead, are provided as study tools to help you keep on the right track as you read the units.

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 self-learning materials. This will help you prepare for the term end examination and also in assimilating the content.

Please note that we have provided a questionnaire at the end of the block. After studying the material in the block, complete the questionnaire and mail it to the address given below:

The Course Coordinator BGYCT-137
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School of Sciences
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New Delhi – 110068 (India)

Your feedback pertaining to this block will help us undertake maintenance and timely revision of the block. Do make use of the questionnaire and send it to us.

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

UNIT 9

FOSSILS AND FOSSILISATION

Structure

9.1 INTRODUCTION

Earth is a unique planet of the solar system and the existence of life on it differentiates it from other planets. You might be hearing the news on radio and television or reading in the newspapers or on the internet that scientists are working to find the evidence of life on other planets, especially on the planet Mars. Did you ever think how old our mother Earth is? When and where the first form of life appeared? How big were the dinosaurs? In fact, many of us are always curious to know who were our ancestors–monkeys, chimpanzees or others. It is likely to be true to say that the present day life forms such as plants, animals and micro-organisms may not be sufficient to answer these questions. Now, the fundamental question is how we can find the answers to all the questions related to ancient life.

Let us think about what happens to an organism after its death; whether it is completely destroyed or it leaves some evidence of its existence. Usually, organisms that have hard parts leave some evidence in the form of shells, skeletons, bones and teeth after their death. Once these hard parts get preserved in the sedimentary rocks they are known as fossils. The age of Earth is about 4.6 billion years (Gyr) and the study of fossils shows that life began on Earth around 3.8 Gyr ago. During the course of time, life has faced different phases of evolution, diversification and extinction. Therefore, the history of life can be traced through the study of fossils.

In this unit, you will learn about different types of fossils, processes and conditions of fossilisation and significance of fossils. In addition, we will also discuss the taxonomy hierarchy and biological nomenclature.

Expected Learning Outcomes

After reading this unit, you will be able to:

- ❖ define palaeontology and describe its various branches;
- ❖ discuss fossils and their types;
- ❖ explain the requirements and processes of fossilisation;
- ❖ elaborate biological taxonomic hierarchy;
- ❖ describe code of biological nomenclature; and
- ❖ write about the importance of fossils.

9.2 PALAEONTOLOGY

In simple words, **Palaeontology** is a branch of geology that deals with the study of ancient life or life of past geologic time. In fact, the word palaeontology itself comes from the Greek words “Palaeo” - (ancient) + “onto”- (life) + “logos” - (study) and therefore, it means study of ancient life. Palaeontology is based on the fossil remains of ancient organisms; hence, it may also be defined as the study of fossils. Baron Georges Cuvier (1769-1832) was the first to study and name the fossils (Fig. 9.1). He is considered as the “Father of Palaeontology”. Cuvier was a French scientist and he had vast expertise in anatomy and biology.

Fig. 9.1: Baron Georges Cuvier – Father of Palaeontology. (Source: http://www.macroevolution. net/cuvier.html)

Palaeontology is sometimes spelt as Paleontology, especially in American text books. However, in India we use the British version of the spelling that is

Palaeontology. It is divided into a number of branches (Fig. 9.2) as listed below:

- **Invertebrate Palaeontology**: It deals with the study of fossils of invertebrate animals such as corals, brachiopods, molluscs, trilobites and echinoderms.
- **Vertebrate Palaeontology**: It deals with the study of fossils of vertebrate animals such as fishes, amphibians, reptiles, birds and mammals.
- **Micropalaeontology**: It deals with the study of microscopic fossils, which are not visible to the naked eyes, such as foraminifers, radiolarians and ostracods.
- **Palaeobotany**: It deals with the study of plant fossils, for example - *Glossopteris, Gangamopteris, Thinnfeldia, Sigillaria, Nilssonia, Williamsonia* and *Ptilophyllum*.
- **Palynology**: It deals with the study of fossils of pollen grains and spores.
- **Palaeobiology**: It has recently emerged as a new science for the study of fossils. It involves the study of the biological aspects of the fossils. The main focus of palaeobiology is to study the evolution, adaptation, function, ecology and behaviour of the fossil species rather than studying their geological uses. Palaeobiology provides important data, which helps to reconstruct the way of life in which ancient species lived before fossilisation.

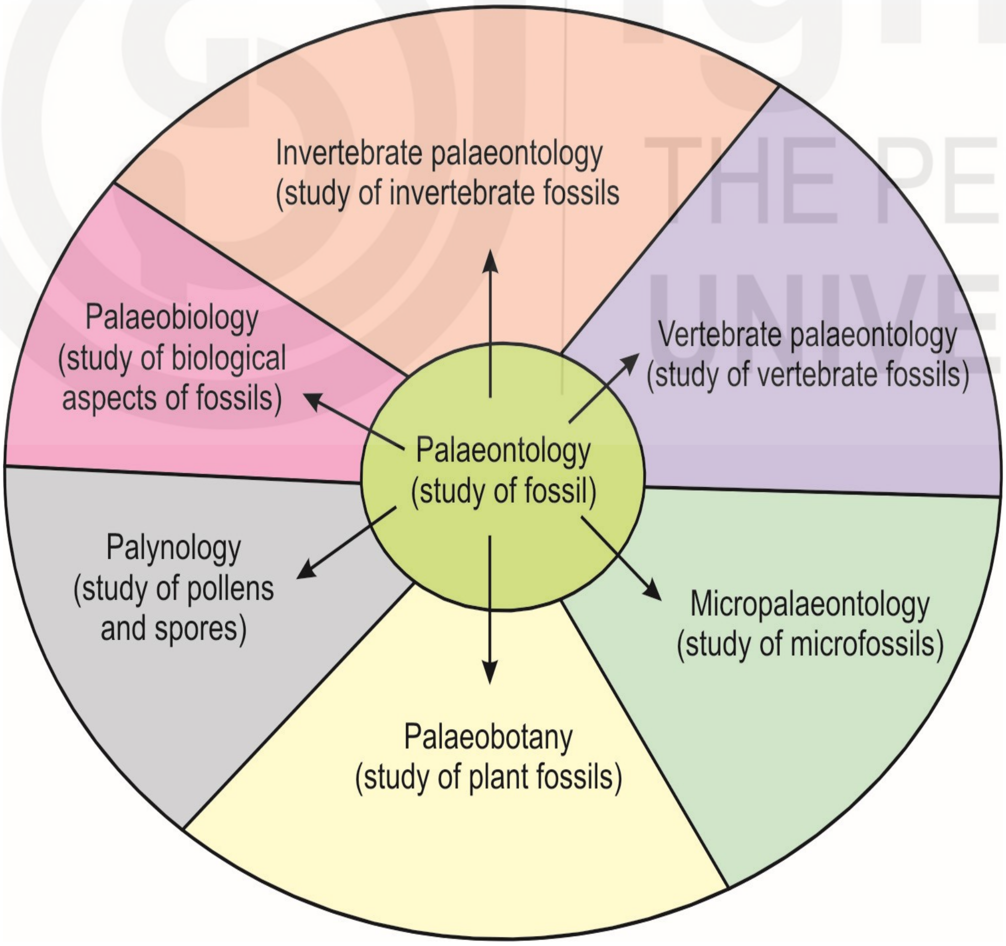


Fig. 9.2: Various divisions of palaeontology.

The information, we get from fossils helps us in understanding the history of life as well as the history of the Earth.

9.3 FOSSILS

In order to study the pre-historic or past life, fossils serve as the only valuable source of information as there is no other consistent source available to study the past life. The word fossil, which comes from the Latin word **fossilium**, was used originally in the sixteenth century to refer to any specimen dug up from the ground, for example mineral, rock and metal as well as organic remains of once-living organisms. It was only during the eighteenth century that the word fossil was strictly used for any evidence of past life preserved in the Earth's crust.

9.3.1 What are Fossils?

The word "fossil" is used to refer to the remains or traces of ancient life which have been preserved by natural processes in the sedimentary rocks (Fig. 9.3). Fossils represent the only direct evidences of ancient life. They may be found as preserved skeletons, bones and shells of the organisms or as preserved impressions of the behavioural activities such as tracks, trails, foot-prints of the organisms. Use of the term fossil is usually restricted to the remains of organisms that died before thousands or millions of years. It is widely accepted that any organic remains found in the rocks older than 10,000 years can be termed as fossil. The organic remains younger than 10,000 years and that are still under the process of fossilisation are known as **subfossils**.

(a) (b) (c)

Fig. 9.3: Fossils: a) Trilobite- an invertebrate fossil; b) Fossil teeth of a vertebrate animal; and c) Plant fossil. (Source: Biostratigraphy Group, Wadia Institute of Himalayan Geology, Dehra Dun)

Fossils vary in size from microscopic bacteria of one micrometer in diameter to gigantic dinosaurs or fossil tree trunks measuring several meters long.

Do you know?

Rocks are of three types: igneous, sedimentary and metamorphic. Of these rocks only sedimentary rocks, are formed by a slow process of deposition of sediments (sand, mud, clay) layer by layer carried by rivers and streams into oceans and other water bodies, have the potential to preserve fossils to any reasonable extent. Whereas igneous and metamorphic rocks hardly have the scope to preserve fossils. This is because igneous rocks are derived from the molten material from below the crust of the Earth and are obviously not suitable for the preservation of organisms at such high temperature. Metamorphic rocks, which are formed by the intensive folding and re-crystallisation of pre-existing rocks and the process of creating new material, tend to destroy the organic remains.

You may have heard about petroleum, coal and natural gas. These are all sources of non-renewable energy and collectively known as **fossil fuels**. Fossil fuels are also formed from the organic remains of ancient organisms. These contain high percentages of carbon and hydrogen and therefore, are usually used as fuel. These are not considered as fossils as they provide little or no information of the past life. Sometimes coal contains well preserved stems, leaves, roots, leaves and cells of ancient plants, which can be identified to a certain level.

9.3.2 Types of Fossils

Many types of fossils are found in the layers of rocks. Among them, some are more common such as body fossils, trace fossils, whereas some others are less common. Based on the mode of preservation, size and uses, fossils are commonly classified into many types as shown in Fig. 9.4.

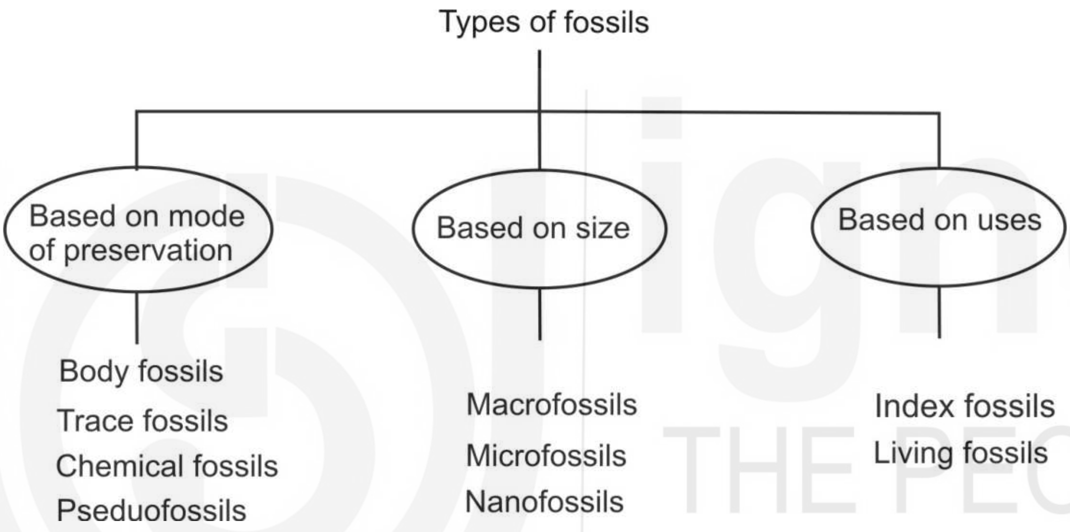


Fig. 9.4: Types of fossils.

i. **Body Fossils**: These are preserved hard parts of the actual organisms. Body fossils may be the whole body of any organism, for example skeleton of dinosaurs, shell of bivalves or body parts of an ancient animal like bones and teeth of fishes, dinosaurs or mammals (Fig. 9.5). These are direct evidence of ancient life and provide information about the shape, size and functions of a once-living organism.

ii. **Trace Fossils**: These are not actual remains of an organism, but are the preserved evidences or impressions of the activities of organisms of the past. Trace fossils may include tracks, trails, burrows, footprints and borings (Fig. 9.6). Trace fossils are also known as **Ichnofossils** and their study is called **Ichnology**.

iii. **Chemical Fossils**: These are organically derived compounds that are preserved in the rocks. Generally, these compounds contain no traces of the actual organisms and are, therefore, considered as an indirect evidence of past life. It has been observed that large organic molecules do not survive long after the death of an organism, but these molecules may break down to smaller stable organic molecules which can survive over long geological time. The ancient DNA preserved in rocks is a common example of chemical fossils.

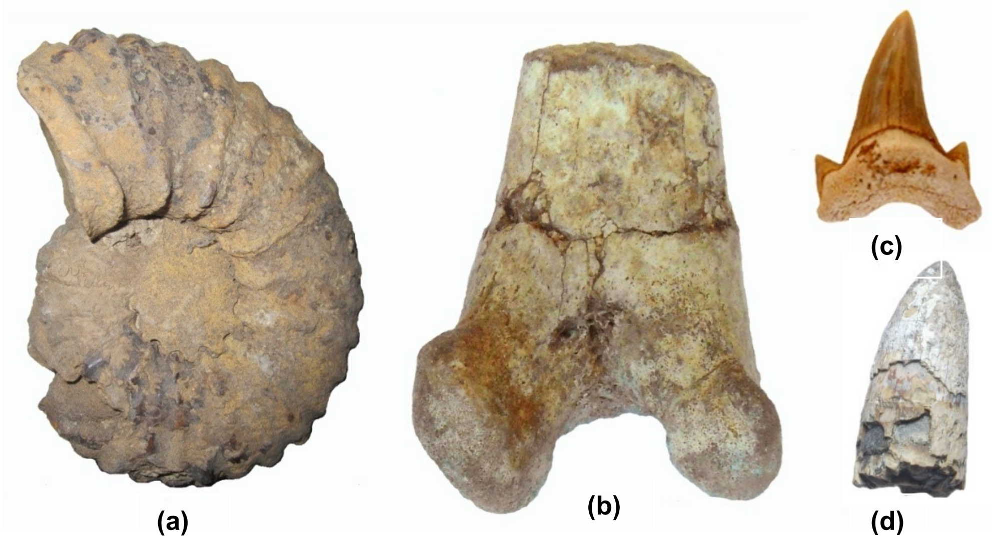


Fig. 9.5: Body fossils: a) Ammonoid; b) Bone of a vertebrate; c) Tooth of a shark; and d) Tooth of a crocodile.

Fig. 9.6: Trace fossils: a) Tracks; and b) Horizontal burrows of the animals
(Source: Dr. Meera Tiwari, Wadia Institute of Himalayan Geology, Dehra Dun)

iv. **Pseudofossils**: These are not fossils though they look like fossils. In nature, there are many inorganic substances, which generally resemble fossils and these are called pseudofossils. Dendrite–an ore of manganese, is a classic example of pseudofossil, which is often mistaken for leaves or ferns because of its tree-like structure (Fig. 9.7).

Fig. 9.7: Dendrite–a pseudofossil. (Source: http://www.pinterest.com/pin/335377503471216391)

v. **Macrofossils**: These are large fossils more than 0.3 mm in size and can be seen with naked eyes (Fig. 9.8a-c). Bones, teeth and shells of animals as well as wood and leaves of plants are the common examples of macrofossils.

(a) (b) (c) (d) (e)

Fig. 9.8: Types of fossils: (a-c) Macrofossils; a) Petrified tusk of an elephant; b) Cross-section of the tusk; c) Bivalve shell and (d-e) Microfossil of ostracods. (Source: Museum, Wadia Institute of Himalayan Geology, Dehra Dun for a and b). Note the scale of the fossils; this will give you the idea on the size of fossils

vi. **Microfossils**: These are very small fossils less than 1 mm in size and require a microscope for their study (Fig. 9.8d-e). Ostracods (animal fossils), pollens and spores (plant fossils) are common examples of microfossils.

vii. **Nanofossils**: These are very small fossils having a size range between 5 to 60 micrometers (μm) and require an electron microscope for study. Nanoplankton is a typical example of nanofossils.

viii. **Index Fossils**: These are characterised by short geological range (age), wide geographic distribution, rapid evolutionary rate and distinct morphological features. For example, trilobites having a geological range from Cambrian to Permian are index fossils for the Palaeozoic rocks. Index fossils are used for the correlation and dating of rocks.

ix. **Living Fossils**: The renowned English naturalist Charles Darwin first used the term living fossil for the East Asian Ginkgo tree. Living fossils include those species which have lived for long spans of geologic time and are still living today with their body showing little or no morphologic changes during the course of evolution (Fig. 9.9).

(a) (b)

Fig. 9.9: Living fossil *Ginkgo*: a) *Ginkgoites* leaf from the Triassic of North Korea (Source: http://www.dges.tohoku.ac.jp/museum/fosgal19.html) **and b) *Ginkgo biloba*- modern living species**. (Source: Dr. Shreekar Pant, BGSB University, Rajouri)

Living fossils have little diversity and the actual reason behind their evolutionary stability is yet to be understood. Living fossils are very important to palaeontologists as they provide the biological data, which is absent in the fossils. *Ginkgo* (Devonian to present) is a living fossil of conifers.

SAQ 1

a) In which rocks would you find fossils and why?

b) What is palaeontology? List various branches of palaeontology.

c) Fossils are remains of ________________________________.

d) Pseudofossils are _______________________ (true fossils/false fossils).

9.4 FOSSILISATION

Fossilisation is the process of transfer of material from biosphere (organic material) to lithosphere (fossil), in which the organic material is being replaced by inorganic mineral matter. The chances of an organism becoming a fossil are very less. It has been observed that for every organism that dies its chances of fossilisation are less than one in a million. You would be surprised to know that most remains do not fossilise after death. Let us examine why this is so. You may be aware that organisms are composed of the following parts:

- soft fleshy parts–made up of unstable organic compounds of carbon, oxygen and hydrogen.
- hard parts, for example shells, skeletons, bones and teeth–made up of stable hard compounds such as calcium carbonate and calcium phosphate, and
- both soft and hard parts.

The story of fossilisation begins with the death of an organism. After the death of an organism, its body gets exposed to natural agencies like biological (bacterial activity), physical (transportation by river or wind) and chemical (reaction with water or gases). When an organism dies, its soft parts begin to decay under bacterial action. When this process is completed no trace of the soft parts of the organism are left behind. Under this process, the soft-bodied organisms get completely destroyed, but organisms with hard parts leave their hard parts undestroyed. The hard parts remaining after the completion of decay are then subjected to transportation by wind, water or even by predators, which result in the breakage and fragmentation of the hard parts before reaching into the sedimentation site. At the sedimentation site, these broken and fragmented hard parts get buried under sediments and then they are physically and chemically altered due to the pressure generated by the overlying sediments and water present within the sediments. Once, they pass through all these processes, they are finally converted into fossils. It may be noted that this entire process takes thousands of years and every stage results in significant loss of information about the organism. During the process of fossilisation, many organisms get destroyed either at the decay, transportation or alteration stage. Therefore, fossilisation or preservation of fossils is considered a chancy business.

Do you know how fossils are formed?

When an organism dies, it falls to the ground and may get buried in the layers of sediments. After thousands or millions of years, its remains get transferred into rocks and become part of the sedimentary layers. Such parts are known as fossils. Finally, after thousands or millions of years, when such sedimentary rocks are exposed on the surface of the Earth by folding, faulting or erosion then fossils can be seen (Fig. 9.10).

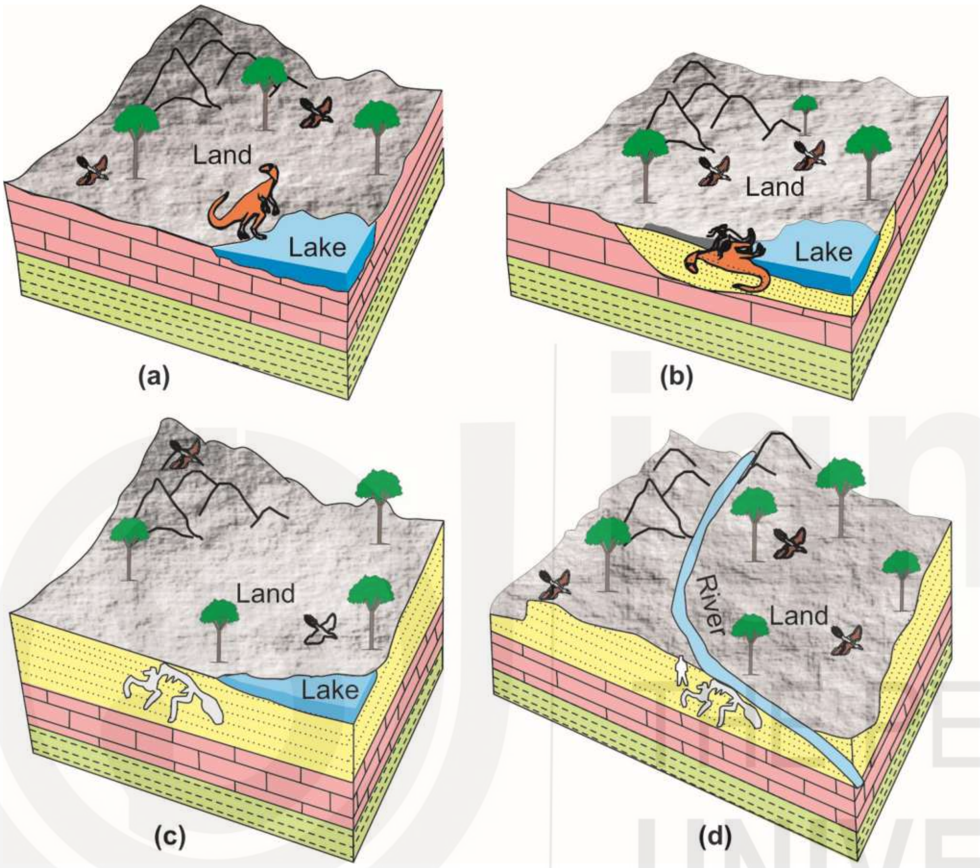


Fig. 9.10: Cartoon showing the process of fossilisation: a) An animal living near the lake; b) Animal dies near the lake and is partially buried under the sediments; c) Animal completely buried under the sediment and converted into fossil after million or thousands of years; and d) After millions of years, the river eroded the layer of sediments and fossil gets exposed.

9.4.1 Conditions for Fossilisation

Like today's organisms which are living in different environments such as in seas, rivers, lakes or on plains or mountains, it is assumed that pre-historic organisms might have lived in similar kinds of environments. It may be noted that all environments are not equally suitable for preservation or fossilisation. Hence, the nature or composition of the organisms and type of environment where they are living play an important role in fossilisation. The favourable conditions for fossilisation are mentioned below:

- **The organisms should have hard parts**: The hard parts of organisms such as shells, bones, teeth and wood take more time to break down and can be preserved as fossils. On the other hand, the soft-bodied organisms, for example, insects, worms and jellyfish decay very quickly after death and are rarely preserved.

- **Rapid burial of organisms after death under a thick cover of sediments**: If the organisms are quickly buried under the sediment, it cuts the supply of oxygen and prevents destruction of the organisms by scavengers and decay.
- **Environment**: The environment plays an important role in the organism's ability to fossilise. It has been observed that marine organisms are more likely to be fossilised than those living on land (Milsom and Rigby, 2010) because marine organisms have greater chance of being covered rapidly by sediments, which increases the chance of fossilisation. Land-based organisms have less chance of being covered by sediments and more risk from scavengers and hence, they have less chances to fossilise.

9.4.2 Processes of Fossilisation

In subsection 9.3.2, we have learnt about various types of fossils. All these types of fossils are formed by a variety of fossilisation processes. Fossilisation may occur in many ways. Sometimes, the entire organism including its soft parts is preserved. In rare cases, only hard parts of the organism are fossilised. In few cases, only imprints and traces of organisms are preserved. Hence, different organism types show different processes of fossilisation.

Fossils occur in many different forms such as unaltered soft parts, unaltered hard parts and altered hard parts. Depending upon the nature of fossils, the processes of fossilisation may be classified into the following types:

i) Unaltered soft parts or exceptional preservation

ii) Unaltered hard parts preservation

iii) Altered hard parts preservation, which is further divided into

(a) Permineralisation or petrifaction

(b) Replacement

(c) Carbonisation

(d) Molds and casts

(e) Tracks and trails

i) **Unaltered Soft Parts or Exceptional Preservation**

In very rare and ideal situations, the whole of the organism including its soft and hard parts may be found to have been preserved. In this type of preservation, the most fragile and delicate soft parts remain unaltered and provide finer details of the soft parts. This type of preservation takes place in several ways such as fossils preserved in amber, tar or ice.

Amber is the fossilised resin of ancient conifer trees. Usually, the sweetness of resin attracts the insects and they come in contact with resin. Due to the stickiness of resin the insects get trapped in it. Later, lumps of resin fall on the ground and get buried in the sediment and finally, turn to solid amber. The Vastan lignite mine in Surat District of Gujarat yields fossiliferous amber with well preserved insects (Fig. 9.11).

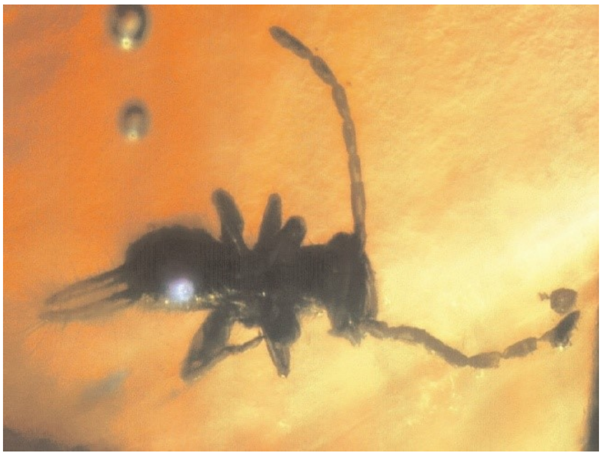


Fig. 9.11: Insect entombed in amber. (Source: Sahni and others, 2006)

Some organisms may fall into crevasses in glaciated areas or become trapped in permanently frozen soil and thus get preserved perfectly. Low temperature and anaerobic (without oxygen) conditions in frozen areas allow the best preservation of the soft body parts of any organism. The woolly Mammoth preserved in the Pleistocene sequence of Siberia is a classical example of preservation in frozen ice.

Sudden burial of the ecosystems by volcanic ash and sand storms also leads to excellent preservation of fossils. The well preserved Cretaceous biota of China and Mongolia are well known examples of biota quickly buried by volcanic ash and sand storms.

ii) **Unaltered Hard Parts Preservation**

Many invertebrates possess hard parts made up of stable compounds such as calcium carbonate, calcium phosphate and silica. It has been found that many shells and skeletons of invertebrates were preserved in the sedimentary rocks with no alteration in their hard parts. However, it does not mean that the organisms are unchanged. In fact, the less stable organic material (soft parts) is removed from their bodies during the process of fossilisation. Fossil record has numerous examples of fossil shells which are millions of years old yet cannot be easily differentiated from the modern shells.

iii) **Altered Hard Parts Preservation**

The story of alteration of the hard parts starts after the burial of the organisms. Most shells and skeletons of animals contain pores, for example, bone marrow in vertebrates. Once an organism gets buried under the thick cover of sediment, the water containing dissolved minerals present within the sediments fills the pores and replaces or alters the hard parts. The pressure generated by sediments facilitates the process of alteration, which may take place in the following ways:

(a) **Permineralisation or Petrifaction**: It is a slow process and involves the removal of organic material by mineralised solution. Most of the shells, bones and wood are porous. In addition, the decay of soft parts increases the porosity of these organic materials. When these porous materials are buried under sediments, the overburden increases the temperature and pressure. As a consequence, the chemical reaction occurs between groundwater and soluble minerals present in the sediments. This reaction leads to the formation of mineralised solution, which fills the pores of organic material thus paving the way for the solution to precipitate in pores. In this way, the organic material is partially or completely replaced by the inorganic matter consisting of silica, calcite or pyrite.

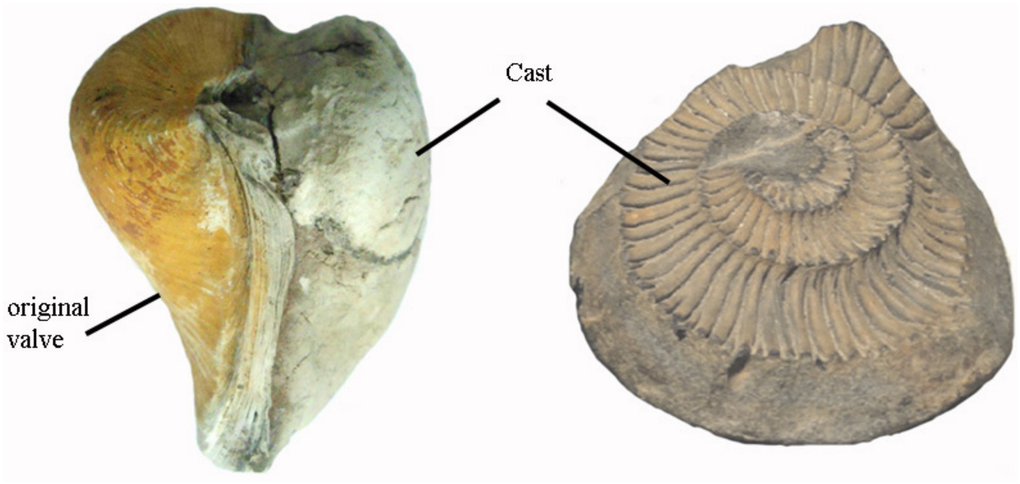
Petrifaction is a very slow process in which replacement occurs molecule by molecule. As a result, very fine details about the organisms get preserved. The petrified wood (Fig. 9.12) of trees and bones of dinosaurs or tusks of elephants are common examples of permineralisation.

Fig. 9.12: Petrified wood.

(b) **Replacement**: It is also a slow process of fossilisation. In this process, the underground water slowly fills the pores of organic material and completely dissolves the hard parts of the organisms trapped in sediments. At the same time the groundwater carries minerals in solution that replace the organic material with such minerals as silica, calcite, hematite and pyrite.

(c) **Carbonisation**: In this process, the soft-bodied animals as well as the stems and leaves of plants buried under the sediments are decomposed or pressed and thus losing hydrogen, nitrogen, oxygen and other volatile constituents. As a result, a thin carbon film is left behind. Such films are enriched in carbon and appear as black shiny fossils. Carbon films create impressions in the rock outlining the shape of the organisms. Plant leaves are commonly preserved in this process. You may find most of the carbonised fossils in the coal mines.

(d) **Molds and Casts**: This process involves the natural duplication of the original organisms. When a shell gets buried in sediment, subsequently, the sediment becomes hard. At the same time the water running through the sediment may dissolve the shell completely, leaving behind an impression or a void of the shell. Such an impression is known as **mold**. If the void is filled with grains of sand or clay, it hardens and produces a replica of the original shell shape, which is known as **cast** (Fig. 9.13).



(a) (b)

Fig. 9.13: Fossils: a) bivalve; and b) Ammonite showing the casts. (Source: Dr. Meera Tiwari, Wadia Institute of Himalayan Geology, Dehra Dun for b)

(e) **Tracks and Trails**: While moving on the soft ground such as mud and sand, the organisms may leave behind impressions of their movements (Fig. 9.6a). For example, the foot prints, burrows and borings are preserved when the soft ground materials harden in rock. These types of fossil impressions are also described as trace fossils.

9.5 TAXONOMIC HIERARCHY

The science of classification of life both extinct and extant forms into meaningful categories or groups, is called **taxonomy**. Based on a certain set of features comprising physical, morphological or molecular characters, the organisms can be grouped or classified. For example, all animals having hair are grouped together in a broad group or category known as mammals. Similarly, animals having feathers are grouped into birds. It may be noted that taxonomy as a science is as old as the human language, but modern work in this science began in the mid seventeenth century by main contributions of Carl Linnaeus (Fig. 9.14), who is known as the father of modern taxonomy. He was the first scientist who proposed an orderly system for classification of various organisms present on the Earth. He proposed that species is the fundamental unit of the biological taxonomy.

At present there are seven main categories of the biological taxonomic hierarchy. In descending order (i.e., higher to lower category), these are **Kingdom, Phylum, Class, Order, Family, Genus,** and **Species** (Table 9.1). This arrangement of taxonomic categories is termed as **taxonomic hierarchy**. The Kingdom is the largest category in the hierarchy system and it can be subdivided into phyla (singular phylum), phyla into classes, classes into orders, orders into families, families into genus (plural genera) and genera include many species. It means each lower category is a subdivision of the higher category. In other words, the species sharing similar features are combined into a genus, closely related genera into families, families into orders, orders into classes, classes into phyla, up to the broadest level of the kingdom. Finally, the whole tree of life can be systematically organised from the most general/highest level at the top (i.e., kingdom) to the most specific/lowest level at the bottom (i.e., species) by using the taxonomic hierarchy.

Fig. 9.14: Carl Linnaeus (1707 – 1778) was a Swedish botanist who is known as the father of modern taxonomy. (Source: http://www.famousscientists.org/carolus-linnaeus)

Table 9.1: Taxonomic hierarchy of humans

Kingdom: Animalia
Phylum: Chordata
Class: Mammalia
Order: Primates
Family: Hominidae
Genus: *Homo*
Species: *Homo sapiens*

It is important to understand taxonomy because it has three folds significance:

- It helps us to identify the species.
- It allows us to assign the taxonomic rank to the species.
- It helps us to reconstruct the evolutionary history of species.

9.6 CODES OF BIOLOGICAL NOMENCLATURE

In 1758, Carl Linnaeus envisioned the need for a uniform method of naming organisms because an organism given a scientific name in Europe might be the same organism in Asia with a different given scientific name. This would create confusion because the same organism or species will have different names in two different geographic areas although their features are the same. In order to avoid such confusions, biologists of the world came into an agreement that there should be a consistent system for scientific naming of organisms, which is known as biological nomenclature. This nomenclature has sets of rules for naming of organisms, which are known as codes of biological nomenclature.

The codes of biological nomenclature are broadly of two types: the **International Code of Zoological Nomenclature** and the **International Code of Botanical Nomenclature**. It is interesting to note that the zoological nomenclature has sets of rules which are used for naming of animals while naming of plants follows the botanical nomenclature. The International Union of Biological Sciences is an international body which governs and ratifies various rules of biological nomenclature from time to time. The international code of biological nomenclature is equally applicable to fossils and living organisms.

Biological nomenclature is a part of taxonomy because biologists used it to assign a name to a new organism and to place it in taxonomic hierarchy as shown in Table 9.1. Now let us discuss the rules of biological nomenclature applicable at species level.

Code of Nomenclature for Species

(i) **Establishment of New Species**: For naming any new species whether it is living or a fossil, the code has following rules:

(a) The name of the species follows the principle of binomial nomenclature. It means that the name of the species has two parts. The first part represents genus while the second part is the trivial name and the two together constitute the specific name or the name of the species. For example, *Homo sapiens* is a species of humans, where *Homo* is the name of the genus or generic name and *sapiens* is the trivial name, both together constituting the specific name.

(b) The first letter of the generic name is written in capital letter and the trivial name with a small letter, for instance, *Homo sapiens.*

(c) The first name and second name of the species should be in italics when printed and underlined when it is hand written.

(d) The name given to a new species has to be suffixed by sp. nov. (i.e., species nova meaning new species). While describing an already named species it has to be suffixed by the name of the author who has described it followed by the year of publication.

(e) The names have to be based on a place, person or character related to the fossil in question.

(f) For every new species, it is necessary to identify a fossil specimen as a type specimen known as **Holotype**. Alternatively, a set of specimens may be identified as type material called **Syntypes**.

(g) Description of the species must be published in a valid medium such as journals, books or magazines in print form and must be circulated among the peer groups so that it gets official recognition and gets communicated worldwide.

(ii) **Law of Priority**: It is a fundamental principle of biological nomenclature. The law states that the first published name given to an organism will be accepted and considered as a valid name for that organism and the subsequently published new name or names for the same organism will be considered as synonyms and therefore invalid.

It is pertinent to know that taxonomic names are generally given in Latin words. The reason behind using Latin words for naming the organisms is very simple. Indeed, basic work on taxonomy was started in Europe and Latin was the common language of European people. Therefore, they used it to name the various organisms.

SAQ 2

a) Name of species should be in …………… when printed and …………………….. when hand written.

b) Name of species always follows a binomial combination (i.e., two names), in which first name represents the ……………… and second is the ……………….. ………… both representing………………

9.7 IMPORTANCE OF FOSSILS

Geology is the science dealing with study of the planet Earth and this study can never be completed without taking fossils into consideration. As you know fossils are naturally occurring clues to the past life and therefore, are important to interpret the history of Earth as well as evolution of life on it. As a result, fossils are often considered as written texts preserved in the rocks in the form of remains of ancient life that provide valuable clues to the following:

9.7.1 Evolution of Life

Organic evolution is a sequence that connects organisms to one another through geological ages from an evolutionary point of view. Further, it establishes ancestor-descendant relationships. The theory of organic evolution states that today's living more advanced and complex life forms had evolved from the more primitive and simpler life forms that lived in the geological past. It should be noted that fossils strongly and clearly support the idea of organic evolution. The fossils of the most primitive life forms like bacteria, blue green algae or Ediacara fauna are found in geologically older rocks, for example, rocks of Precambrian and Lower Palaeozoic. However, fossils of more advanced life forms like vascular plants, mammals or birds occur in geologically younger rocks, for instance, of Phanerozoic times. As the life has changed throughout the geological time and the rocks of the same geological ages contain similar fossils and rocks with different ages have different fossils.

Based on the changes in life, the history of Earth has been divided into five main time divisions, which form the geological time scale. These divisions from oldest to youngest are:

- **Cenozoic**: It is marked by the presence of recent or modern life.
- **Mesozoic**: It is marked by the presence of medieval or middle life.
- **Palaeozoic**: It is marked by the presence of ancient or old life.
- **Proterozoic**: It is marked by the presence of earlier life.
- **Archeozoic**: It is marked by the absence of life or presence of most primitive life.

The above mentioned sequence of life clearly shows that life has gradually changed from simpler forms to more complex forms. It is thus, true to say that the study of evolution of life forms through geological age can only be possible by making a detailed and systematic study of fossils.

9.7.2 Pre-historic Life

When we talk of pre-historic life, it refers to the life of the past that lies between first appearances of life (about 3.8 Gyr ago) to the first human written record or document of history (some 10,000 years ago). Fossils are the only evidence of the past life and many of them represent once-living organisms that are now extinct. As mentioned earlier, life has changed gradually over a long span of geologic time by the process of organic evolution. In addition to organic evolution, other factors such as predation, disease and competition with other organisms may also cause the disappearance or extinction of some organisms. Such organisms are left with no living representatives. The fossils are only a valuable source of information about the extinct organisms as well as biodiversity of the past. The gigantic dinosaurs, ammonites, trilobites and wooly mammoths are examples of some extinct animals that are known today only by their fossil record.

9.7.3 Dating of Rocks

Life is continuously changing through time, resulting in the appearance of new life-forms and disappearance of some of the older ones. The sedimentary rocks contain fossils deposited layer by layer. The principle of order of superposition states that in a sedimentary rock succession, the layers at the bottom are deposited first and hence, are the oldest. The beds overlying them are younger. The fossils contained in this succession will keep changing and it may not be possible to have the same forms throughout the succession. As a result, it is possible to characterise the different layers of the rock succession based on their enclosed fossils. We assign relative geologic age to these fossiliferous layers on the basis of their fossil content. The branch of stratigraphy that deals with relative ages of sedimentary rocks is known as **biostratigraphy**.

There are some ancient organisms, which lived on the Earth for a very short period of time, but they had a wide geographic distribution, rapid evolutionary rate and distinct morphological features. The fossils of such organisms are called **index fossils** and these have served as key fossils to date the rocks. For example, trilobites are used as index for dating rocks of Lower Palaeozoic Erathem and ammonites are used for dating the rocks of Mesozoic Erathem. Fossils are also used for biostratigraphic correlation, in which rock successions of two geographically separated areas can be correlated on the basis of fossils present in them in order to understand their spatial and temporal distribution.

9.7.4 Palaeogeography

You may be surprised to know that the geographic distribution or position of land and sea was very different in the geological past than what we have today. The study of past distribution of land and water is known as **palaeogeography**. The fossils present in the layers of rock successions help us to reconstruct the past distribution of land and water. It is a well known fact that India was once a part of the former Gondwana continents, which separated from it during the Mesozoic Era and collided with Asia in the Early Cenozoic Era. The present day Himalaya was once upon a time a sea and the collision between Indian peninsula and Asia is marked by the formation of the great Himalayan mountain system whereby the sea bottom got uplifted. It is the study of fossils recovered from the Himalayan Mountains that tells us about the existence of the Himalayan Sea that got finally uplifted into a mountain range in the Cenozoic Era. Based on fossil similarities between South America, Africa, Australia, Antarctica, and India, we know that these landmasses were united during the Late Palaeozoic Era and formed a supercontinent known as Gondwana landmass (Fig. 9.15).

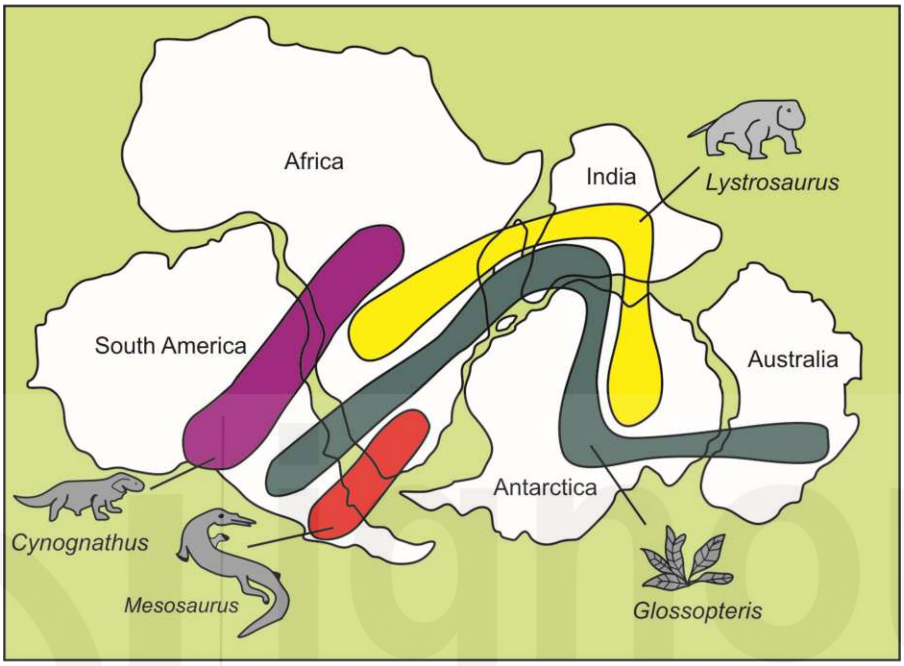


Fig. 9.15: Late Palaeozoic palaeogeographic reconstruction of Gondwanan landmasses based on fossils of land animals and plants- *Cynognathus*, *Mesosaurus*, *Lystrosaurus* and *Glossopteris*. Note that *Cynognathus* and *Lystrosaurus* are land reptiles. Fossils of *Cynognathus* are known from Early Triassic of South America and Africa. Fossils of *Lystrosaurus* are known from Early Triassic of Africa, India and Antarctica. *Mesosaurus* is a small reptile and its fossils are known from Early Permian of South America and Africa. The *Glossopteris* is a plant fossil, which is known from Carboniferous and Permian of all five continents such as South America, Africa, India, Antarctica and Australia. (Source: simplified after Benton and Harper, 2009)

9.7.5 Palaeoclimate

Certain organisms particularly animals and plants are highly dependent on environmental conditions and many of them are narrowly adapted to specific climatic conditions. As a consequence, their fossils provide valuable clues to know the climate of the past or palaeoclimate. Interpretation of palaeoclimate from fossils involves knowledge of the relationship between present day distribution of organisms and their climatic conditions. For example, the fossils of reptiles such as lizards, snakes, etc. are indicators of a warm palaeoclimate because they cannot live in cold climatic conditions as their body is not able to maintain constant warm temperatures. The fossils of the plant cycads indicate tropical and subtropical ancient climate because modern cycads occur in these climatic zones. The margins of plant leaves are excellent indicators of past climate, for example, fossil leaf with smooth margins are good indicators of tropical palaeoclimate whereas leaf with toothed or lobed margins indicates cold climate of the past.

9.7.6 Palaeoenvironment

Like palaeoclimate, fossils are also good indicators of ancient environment (i.e., palaeoenvironment). Based on the fossils, it is easy to recognise marine and non-marine environments. The marine palaeoenvironment is characterised by the presence of cynobacteria, foraminifers, radiolarians, corals, brachiopods, bryozoans, some bivalves, ammonoids and trilobites. However, the presence of fossils of plants, fungi, some gastropods and ostracods, insects, amphibians, birds and most mammals in the sedimentary sequences, generally, indicate non-marine, freshwater and terrestrial palaeoenvironments.

9.7.7 Discovering Oil and Coal Deposits

The oil and coal deposits are the products of ancient animals and plants, hence, fossils play a key role for exploring them. Both these deposits are located deep underground. In petroleum exploration, fossils are used to describe and predict the temporal and spatial distribution of source rock, reservoir rock as well as cap rock. Fossils are also used to determine the precise age of petroliferous basins and the correlation of oil wells and boreholes. During oil exploration and drilling for oil and gas, it is necessary to undertake precise correlation of the oil wells to determine hydrocarbon reserves. This is easily done by the use of microfossils obtained from the core samples and the process is called well logging. For coal exploration, the plant microfossils such as spores are useful to identify and correlate the coal seams. Three microfossil groups, namely, foraminifers, calcareous nannofossils and palynomorphs (i.e., pollens and spores) are commonly used for correlation of oil and coal deposits.

9.8 ACTIVITY

You might have been living near the Himalayan mountains and Indo-Gangetic plain of northern India, coal-yielding Gondwana rocks and the Deccan traps of peninsular India, Rajmahal hills of eastern India, eastern and western Ghats of southern India or small hilly areas of western India. Visit the surrounding hilly areas near you as mentioned above and try to find sedimentary rocks (i.e., sandstone, limestone or shale). Look carefully/focus your eyes on the sedimentary rocks and note whether the rocks yield any fossils. If they do, collect the fossils and wrap in the newspaper. Note the name of location, type of fossil and name of fossil-yielding rock in your field note book. After coming home, try to find whether the fossil belongs to an animal group or to a plant and which process of fossilisation was responsible for its preservation.

9.9 SUMMARY

Let us quickly summarise what you have read in this unit.

- Fossils are clues of past life and their study is known as palaeontology.
- There are two principle types of fossils: body and trace fossils. The other types of fossils are chemical fossils; on the basis of size, fossils can be classified as macrofossils, microfossils and nanofossils; on their usage they can be index fossils and living fossils; objects that look like fossils, but are of inorganic origin are called pseudofossils.

- Fossilisation is the process of transfer of material from biosphere to lithosphere, in which organic material is being replaced by inorganic mineral matter.
- The presence of hard parts and rapid burial after death under a thick cover of sediments are two important conditions for fossilisation.
- Preservation of unaltered soft parts, unaltered hard parts and altered hard parts are main processes of fossilisation.
- Alteration of hard parts occurs mainly due to permineralisation or petrifaction, replacement, carbonisation and formation of moulds and casts.
- Taxonomy is the science of classification of life into categories. It has seven main categories such as Kingdom, Phylum, Class, Order, Family, Genus and Species.
- Codes of biological nomenclature are a uniform, globally accepted scientific method for naming the organisms.
- Fossils are very useful in geology. They are used to know pre-historic life and its evolution, to date the rocks, to determine the ancient geography, climate, and environment and also for discovering and correlating oil and coal deposits.

9.10 TERMINAL QUESTIONS

1. What are fossils? Describe various types of fossils.
2. Explain how fossils are preserved.
3. What is taxonomy? How are the organisms arranged in taxonomic hierarchy?
4. Give a brief account of the codes of biological nomenclature. Discuss the code of nomenclature in naming the species.
5. Write the importance of fossils in Geology? Discuss in detail.

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9.13 ANSWERS

Self Assessment Question

1 a) We find fossils in the sedimentary rocks. Since these rocks are formed by a slow process of layer by layer deposition of sediments carried by rivers and streams into oceans and other water bodies they are suitable for the preservation of fossils.

b) The science of fossils is known as palaeontology. Invertebrate palaeontology, vertebrate palaeontolgy, micropalaeontology, palaeobotany and palynology are the main branches of palaeontology.

c) Body and trace fossils are the main types of fossils. The other types of fossils are chemical fossils, macrofossils, microfossils, nanofossils, index fossils and living fossils. Pseudofossils are a false impression of fossils.

d) Past life.

e) False fossils.

2 a) italics, underlined.

b) genus, trivial name, name of the species.

Terminal Questions

1. Refer to section 9.3.
2. Refer to section 9.4.
3. Refer to section 9.5.
4. Refer to section 9.6.
5. Refer to section 9.7.

UNIT 10

MICROFOSSILS

Structure

10.1 INTRODUCTION

In the previous unit, you have studied about fossils and fossilisation. You now know that palaeontology is the science that deals with the study of fossils. You have also learnt that fossils are of various types, for example, macrofossils and microfossils depending on their size. Fossils provide information related to origin and evolution of life on the Earth and are thus, valuable tools for understanding the history of the Earth. Microfossils are abundant in all sedimentary sequences, ranging from Precambrian to Recent, but macrofossils are usually abundant in the rocks of Phanerozoic ages i.e., from Cambrian onwards.

Microfossils belong to various groups of animals, plants and protists. As you have been already told in Unit 9, the term microfossil is used only because of the microscopic size of the organisms and they do not represent any particular group. The study of microfossils is known as **micropalaeontology**. Microfossils usually occur in large numbers in many sedimentary rocks and are the most abundant and most easily accessible fossils. In fact, a great deal of information in palaeontology is gathered from the study of microfossils. Therefore, in this unit, we will discuss the microfossils in greater detail.

In this unit, we will discuss specifically about microfossils, micropalaeontology, major groups of microfossils and their significance. In addition, we will also discuss methods involved in their collection and study at the end of the unit.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define microfossils and micropaleontology;
- classify the microfossils into mineral- and organic-walled groups;
- outline the importance of microfossils;
- describe the techniques involved in collecting microfossils; and
- explain the methods used for studying them.

10.2 MICROFOSSILS AND MICROPALAEONTOLOGY

Microfossils are the remains of very small single-celled and multi-celled organisms. These are usually less than 2 millimetres (mm) in size. In fact, these are remains of tiny animals and micro-organisms that live in the surface as well as deep waters of the ocean, on the ocean floor and other water bodies such as lakes or ponds and preserve in the sedimentary rocks after death. Therefore, the term microfossil is not strictly restricted to a single kingdom of life as it includes the tiny remains of many groups such as protists, bacteria, fungi, animals and plants. It is worth mentioning here that there is no well-accepted definition of microfossils. However, the term microfossil is commonly applicable to all those organic remains whose study requires the use of light or electron microscope (Armstrong and Brasier, 2005). These are very tiny remains and can be measured in mm. The smallest microfossils may be only 0.001 mm (i.e., 1 micron) in size and the largest are in the range from 1 to 2 mm in size. Fossils larger than 2 mm are generally referred to as **macrofossils**.

The broken and fragmentary microscopic parts such as shell pieces, bones, jaws and teeth of macro-organisms are also considered as microfossils. However, it needs to be remembered that these microscopic remains (i.e., fragmentary skeletal elements of macro-organisms) are usually ignored by many micropalaeontologists, because many of these represent broken and imperfect remains and thus, provide incomplete or little information. On the other hand, the remains of some micro-organisms particularly foraminifers, radiolarians, ostracods, diatoms, dinoflagellates, spores and pollen are usually preserved as the complete fossils and are of great interest to micropalaeontologists.

While the small size is the main criterion for classifying microfossils, it is important to note that some remains of foraminifers may be more than 2 mm or about 15 cm in diameter, but they are still referred to be microfossils. Thus grouping of microfossils in such cases is based on the method of study where the use of microscope constitutes the determining criterion.

As you already know that microfossils are very abundant in all environments including marine, brackish water and freshwater. And, the micropalaeontology is a branch of palaeontology dealing with the study of microfossils and nanofossils the latter being in the range between 5 and 60 μm (micrometer) in size. The history of micropalaeontology is quite old, about more than two centuries, but it appeared as a major discipline during the early twentieth century. Prior to 1925, micropalaeontology mainly dealt with fossil foraminifers because a large number of micropalaeontogists were involved in their study. The study of other microfossil groups such as radiolarians, ostracods, diatoms, dinoflagellates, pollen and spores started extensively after 1925. It may be noted that after 1945, the micropalaeontology found its extensive and undisputed uses in petroleum exploration as a result of which the study of microfossils received a boost and it became the most important branch of palaeontology.

10.3 MICROFOSSIL GROUPS

As stated earlier, the microfossils are remains of hard parts of tiny micro-organisms. Most of these organisms do not possess hard shells or tests as a result of which they do not get preserved as fossils. However, there are some micro-organisms, whose shells or tests are made of mineral matter and tough organic material and as a consequence, they often get preserved as fossils. On the basis of the composition and structure of shell/test, microfossils are divided into following two groups:

Main microfossil groups

Mineral-walled microfossils
- Foraminifers
- Radiolarians
- Diatoms

Non-mineral (organic)-walled microfossils
- Acritarchs
- Dinoflagellates
- Pollen and spores

10.3.1 Mineral-walled Microfossils

This group of microfossils includes the remains of those micro-organisms that have mineralised shells or tests such as foraminifers, radiolarians, diatoms, ostracods and conodonts. The shells of mineral-walled microfossils are commonly made up of mineral matter such as calcium, silica or phosphate, which makes shells hard and resistant for external physical and chemical agencies and thus, possess higher preservation potential as fossils. Let us discuss important fossils belonging to mineral-walled microfossils.

(i) **Foraminifers**

Foraminifers, nicknamed “forams,” are single-celled heterotrophic protozoans with hard and preservable test or shell. They differ from other protozoans in possessing a hard test and a complex network of branched fibre-like **pseudopodia**, which form a net around the test and are used to capture the food particles from the water (Fig. 10.1). Forams live in marine waters at all depths. Broadly, they adopted two main modes of life namely benthic and planktic. Majority of forams are benthic where they live on or in the seabed whereas planktic forams commonly drift by the ocean currents and predominately live in equatorial and tropical regions.

Foraminifers belong to Kingdom Protista, Phylum Sarcodina, Class Rhizopoda and Order Foraminferida. Skeleton of foraminifers is popularly known as test or shell.

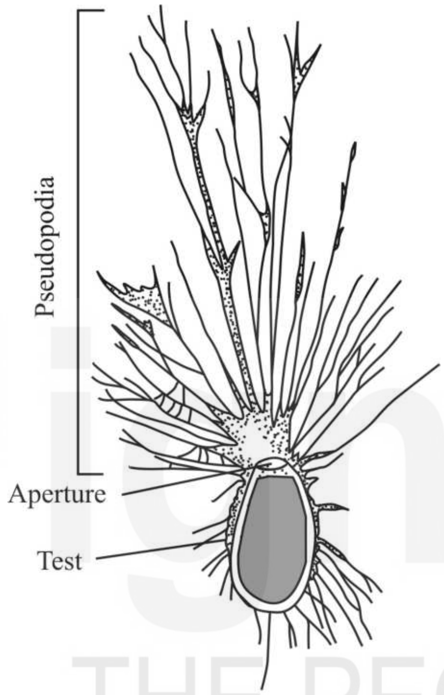
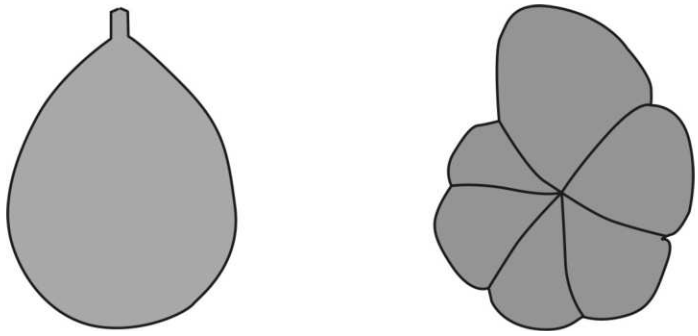


Fig. 10.1: Schematic view of a living foraminifer showing the relationship between pseudopodia and test. (Source: redrawn and simplified after Stearn and Carroll, 1989)

Morphology: The test of forams is usually made of at least three types of hard material such as calcium carbonate, tectin and agglutinated matter. Calcium carbonate is an inorganic matter secreted by the forams and tectin tests are made of an organic material composed of complex carbohydrate and protein. The agglutinated (i.e., glued) test may be composed of very small sand grains and other particles that are cemented together. Test of forams is often less than 1 mm in diameter and may be composed of single or multiple chambers (Fig. 10.2). The single-chambered test is termed as **unilocular** and a test having more than one chamber is described as **multilocular** (Fig. 10.2).



(a) (b)

Fig. 10.2: Tests of foraminifer: a) Unilocular; and b) Multilocular.

The tests of forams have a number of forms, which are governed by arrangements of the chambers. Linear and coiled are two main forms of the test. The linear tests display uniserial, biserial and triserial pattern depending on the number of rows in which the chambers are arranged whereas coiled tests show planispiral and helical forms depending on the fact if they are coiled in a single plane or drawn out around an axis (Fig. 10.3).

(a) (b) (c) (d)

Fig. 10.3: Photographs of foraminifers showing different forms: a) Uniserial; b) Biserial; c) Planispiral; and d) Helical. (Source: Dr. B.C.S. Raja Reddy, SV University, Tirupati)

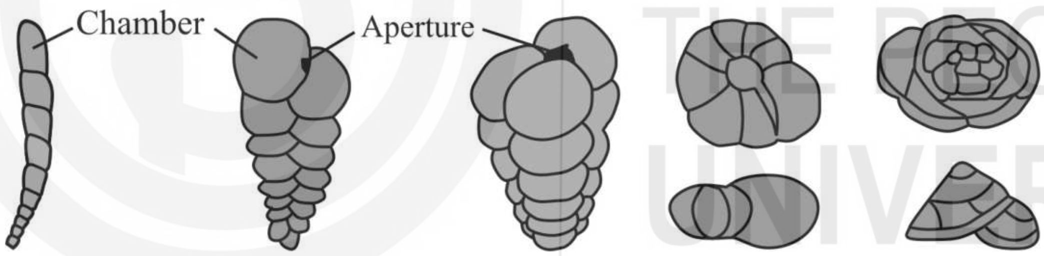
Uniserial form: It has a single row of chambers (Fig. 10.4a)

Biserial form: It has two rows of chambers (Fig. 10.4b)

Triserial form: It has three rows of chambers (Fig. 10.4c).

Planispiral form: Chambered are arranged in a single plane (Fig. 10.4d)

Helical form: Chambers are arranged along a vertical axis (Fig.10.4e).



(a) (b) (c) (d) (e)

Fig. 10.4: Line drawing of foraminifer tests showing different forms: a) Uniserial; b) Biserial; c) Triserial; d) Planispiral; and e) Helical. (Source: simplified after Milsom and Rigby, 2010)

The chambers of forams vary in shapes. The single-chambered tests are usually in flask or tabular shape whereas, multi-chambered tests display spherical and club shapes. Each test of forams has an opening, known as **aperture** (Fig. 10.1 and 10.4b-c). Besides aperture, forams have a number of small internal openings known as **foramina** (singular foramen) as shown in Fig. 10.5. Hence, this group is named after the presence of foramina on their tests. The external surface of the test is variably ornamented from completely to partially smooth, pitted, ribbed or may bear spines and ribs.

Geological Range: Forams are one of the most diverse and extensively studied groups of microfossils. They range in age from Cambrian to Present and diversified during the Cretaceous period.

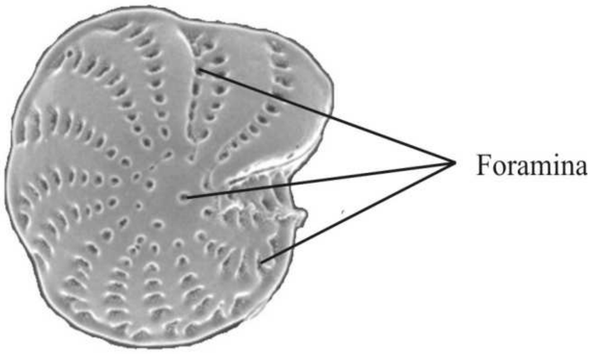


Fig. 10.5: Photograph of a foraminifer showing foramina. (Source: Dr. B.C.S. Raja Reddy, SV University, Tirupati)

(ii) **Radiolarians**

The radiolarians are single-celled planktic protozoans that have delicate internal skeletons. Like foraminfers, radiolarians capture food particles with thread-like extensions known as **pseudopodia** that radiate outwards from the centre of the skeleton (Fig. 10.6). They are characterised by having a skeleton in the form of a perforated membranous central capsule (Fig. 10.6). Most forms of radiolaria display radial symmetry, which is commonly marked by radial skeleton spines and is a characteristic feature of radiolarians. The name of radiolarians is derived from the radial symmetry of their skeletons. However, it is worth mentioning here that some radiolarians lack radial symmetry.

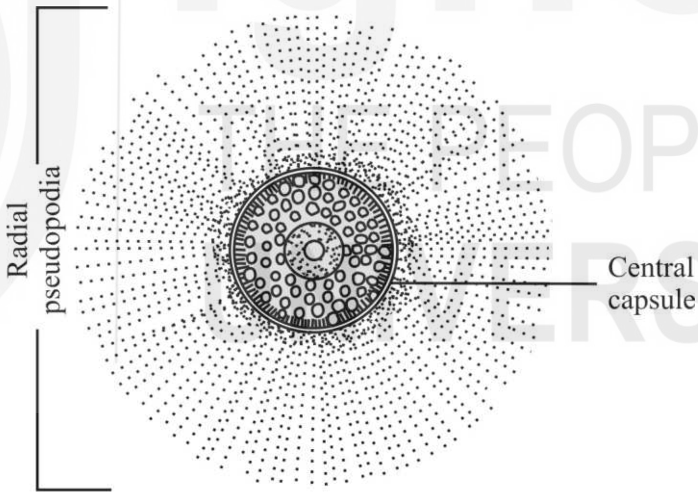


Fig. 10.6: Schematic view of a radiolarian. (Source: simplified after Shrock and Twenhofel, 2005)

Radiolarians are exclusively marine organisms, living mostly as solitary forms but a few are colonial forms. The average diameter of an individual radiolarian is between 50 and 200 µm, buy some colonies reach upto 5 mm in length. After death, they get deposited on the ocean floor where they form radiolarian ooze after mixing with deep sea sediments.

Radiolarians belong to Kingdom Protoza, Phylum Radiozoa and Subphylum Radiolaria.

Morphology: The beautiful skeleton of radiolaria is made up mostly of silica secreted by the organism. However, some skeletons are made from strontium sulphate and a few others by a combination of silica and organic material. In living condition, the skeleton is completely composed of cytoplasm that protects it from dissolution in the seawater. The skeletons are mostly spherical or helmet to space-ship shaped and are formed by spines, bars and perforated plates. **Spines** are elongated external features of the skeleton that are attached only at one end whereas **bars** are elongated internal features that attach at both ends (Fig. 10.7). A perforated plate has more or less evenly spaced pores without a specific plate boundary. Based on the symmetry, radiolarians are divided into two types: spumellar and nassellar. The **spumellar** radiolarians are recognised by their radial symmetry whereas **nassellar** by bilateral symmetry and conical to bell-shaped skeletons (Fig. 10.7).

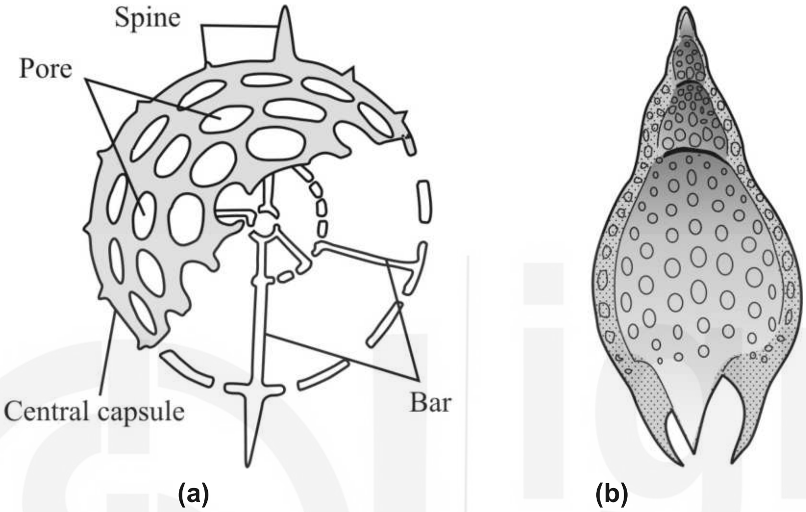


Fig. 10.7: Line drawing of radiolarians showing characteristic morphological features: a) Spumellar radiolarian; and b) Nassellar radiolarian. (Source: simplified after Benton and Harper, 2009)

Geological Range: Like foraminifers, radiolarians also have a long geological history. They first appeared in the Cambrian and are still surviving in the present day ocean waters. At the sea bottom, their skeletons form silica-rich sedimentary rock known as **siliceous** or **radiolarian chert**.

(iii) **Diatoms**

Diatoms are unicellular photosynthesising algae with golden brown photosynthetic pigment. They secrete a minute siliceous (made of silica) skeleton. They commonly range between 20 and 200 microns in diameter or length, but some forms can be up to 2 mm long. These are mostly non-motile algae and may exist either in solitary or colonial form. Being photosynthetic micro-organisms they usually occupy the photic zone (i.e., up to 200 m depth) of the water bodies, where enough light penetrates for photosynthesis. Diatoms live in almost all kinds of environments from marine to freshwater.

Diatoms belong to the Kingdom Plantae, Sub-kingdom Chromista, Infra-kingdom Diatomea and Class Bacillariophyceae (Diatoms)

Morphology: The skeleton of a diatom is made up of silica and is called a **frustule**. It consists of two unequal valves, in which larger a valve fits onto a smaller valve like the lid of a box (Fig. 10.8a). Based on the morphology of frustule or skeleton, diatoms are classified into pennales and centrales. The frustules of pennale diatoms are linear to elliptical or rectangular and centrales diatoms are characterised by having frustules which are circular, triangular or quadrate and show radial symmetry as shown in Fig. 10.8b-c. It has been observed that pennale diatoms live in freshwater conditions and centrales live in marine conditions. The frustules of diatoms are frequently dotted with minute holes described as **punctae**. The outer openings of punctae are sealed by porous plates of the frustules.

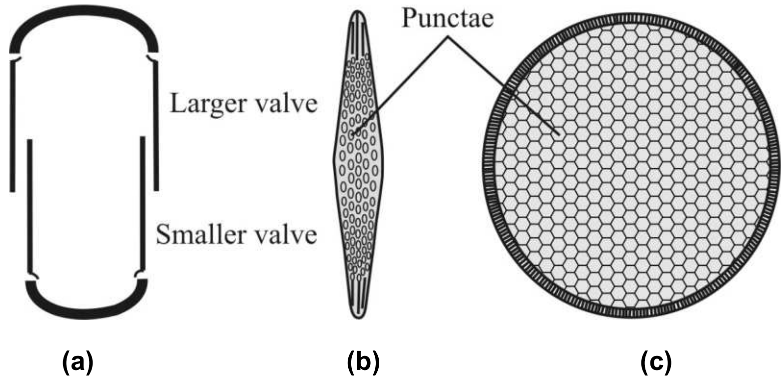


Fig. 10.8: Schematic views of diatom frustules: a) Two valves of a frustules; b) Pennate diatom; and c) Centrale diatom.

Geological Range: Diatoms first appeared in the Mesozoic era probably during the Jurassic and are still living. The frustules of diatoms are dominantly preserved in the deep sea sediments, where they form a diatom-rich rock known as **diatomite**.

SAQ 1

a) How can you differentiate organic-walled microfossils from mineral-walled microfossils?

b) Fill in the blanks.

1. Those organic remains whose study requires a microscope are described as ………………. (Macrofossil/Microfossil).
2. Geological range of foraminifers …………………………………. (Palaeozoic to Present/ Precambrian to Present/ Mesozoic to Cenozoic).

c) Which fossil group makes siliceous or radiolarian chert?

(i) Diatoms (ii) Radiolarians (iii) Ostracods (iv) Foraminifers.

d) List the key morphological features of radiolarians.

10.3.2 Non-mineral (Organic) Walled Microfossils

This group of microfossils includes the remains of those micro-organisms whose shell wall is made up of hard and tough organic or non-mineralised proteinaceous material. The shells of such micro-organisms are much resistant to microbial and chemical attacks as well as to the adverse effects of temperature and pressure after their burial in sediments. As a consequence, they get easily fossilised and are very common in sedimentary rocks. There are three main types of organic-walled microfossils as mentioned below:

- Dinoflagellates
- Acritarchs
- Spores and pollen

Other less abundant forms of organic walled microfossils include Chitinozoa and some fungal remains. Broadly, organic-walled microfossils are termed as **palynomorphs**. The study of palynomorphs forms a separate branch of palaeontology, called **palynology**. Palynomorphs may include the microscopic remains of plants and animals varying in size from about 5 to 500 µm. These are composed of organic compounds such as chitin, which are highly resistant to biological, chemical and other forms of destruction.

(i) **Dinoflagellates**

Dinoflagellates are minute, aquatic, single-celled eukaryotic micro-organisms commonly regarded as some form of algae (Fig. 10.9). They have two whip-like tails called **flagella** for locomotion. They drift frequently from one place to another mainly by movements of water and live mostly as solitary organisms, but colonial forms also exist. It is interesting to note that dinoflagellates possess both plant-like and animal-like characters. Some dinoflagellates are autotrophic, but few others are heterotrophic. Most dinoflagellates live in the photic zone of oceans and other water bodies.

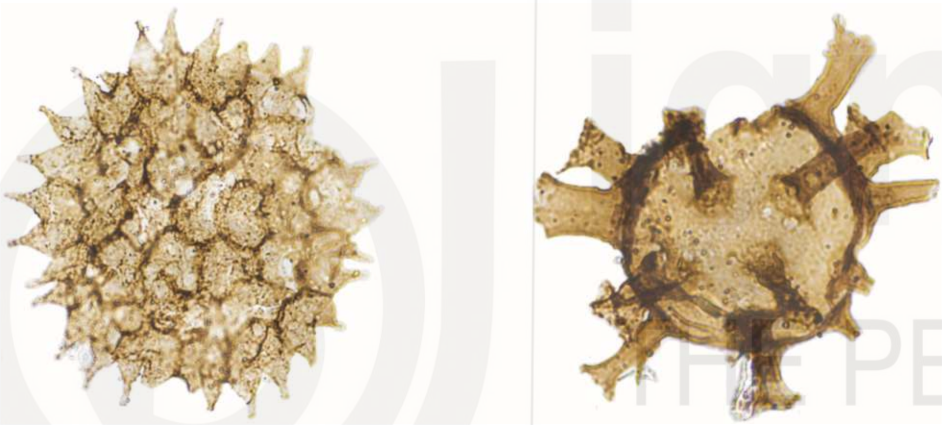


Fig. 10.9: Photographs of dinoflagellate microfossils. (Source: Dr. Y. Raghumani Singh, Manipur University, Imphal)

The dinoflagellate life cycle rotates between two stages viz., motile (swimming) and a cyst (benthic). The motile stage dinoflagellates are rarely preserved. On the other hand, dinoflagellates of cyst stage are formed from resistant organic material that freely fossilise and are commonly found in the fossil record. Cyst ranges in size from 40 to 150 µm. Dinoflagellates live in aquatic environments from marine to freshwater.

Dinoflagellates belong to Kingdom Protozoa, Phylum Dinozoa and Subphylum Dinoflagellata.The name dinoflagellates is derived from two Greek words dinos meaning whirling and flagella meaning whip, hence referred to the movements by flagella.

Morphology: About 10% of dinoflagellates develop tough and resistant organic structures called **cyst**. It is the resistance of cysts that freely fossilise them and leaves a fossil record. The two flagella of dinoflagellates are described as a **transverse flagellum** that encircles the body in the cingulum and a **longitudinal flagellum** that lies in the central area and forms a sulcus towards the top or apex. **Cingulum** is the central equatorial position in the form of a transverse furrow whereas **sulcus** is the position in a longitudinal furrow. The half of dinoflagellate from centre to top (apex) is termed as **epitheca** and from centre to antapex is **hypotheca** (Fig. 10.10). Top of cyst is known as apex and its bottom is termed as antapex.

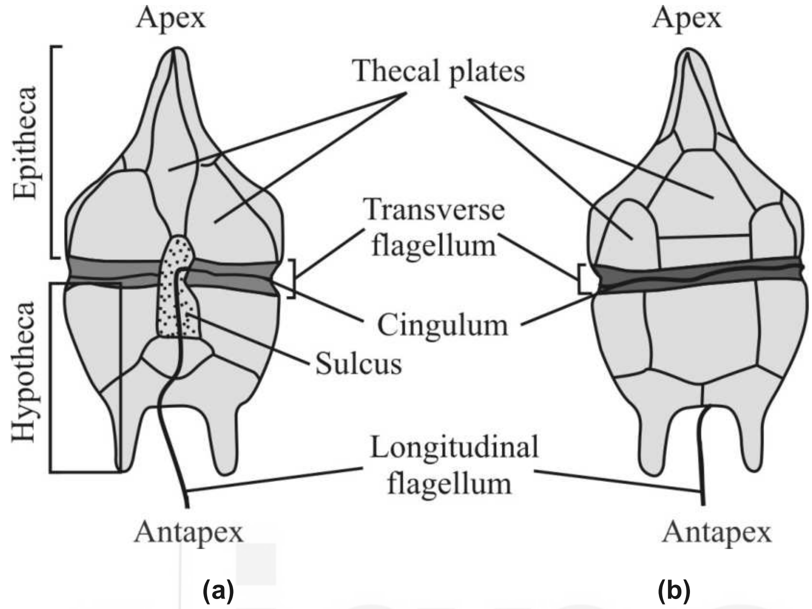


Fig. 10.10: Line drawing of dinoflagellate showing morphological features: (a) Ventral view and b) Dorsal view.

Cyst may be composed of many small plates known as **theca** or **thecal plates**. There are three basic types of cyst: proximate, chorate and cavate (Fig. 10.11).

- **Proximate cysts**: In these cysts, the theca is almost the same in size and shape and has close contact with the thecal wall.
- **Chorate cysts**: They show no traces of a reflected sulcus or cingulum
- **Cavate cysts**: These cysts have two walls- an inner wall and an outer wall.

Cysts may be smooth or bear granules, ridges, indentations, crests or short spines as well as horns.

Geological Range: Dinoflagellates seem to have appeared in the Palaeozoic era possibly during the Silurian and are still living.

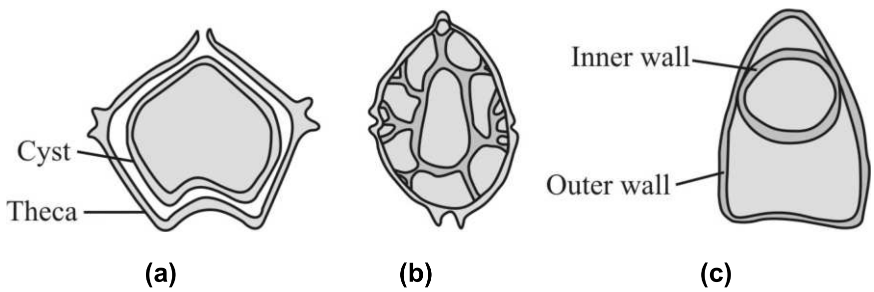


Fig. 10.11: Types of dinoflagellate cyst: a) Proximate; b) Chorate; and c) Cavate.

(ii) Acritarchs

Acritarchs are microscopic organic-walled vesicular microfossils with unknown biological affinities. They form probably a polyphyletic group (i.e., a group originated from more than one ancestor) and may include many different kinds of organisms from bacteria to single-celled protists or multi-celled eukaryotes (e.g., fungi, algae or animal eggs). It is believed that they probably represent the cyst stages or benthic phases in the life cycles of planktic algae similar to dinoflagellates cyst stage. Acritarchs range in size from less than 10 microns to more than 1 mm, but the majority of acritachs fall in the range between 15 and 80 microns. They are exclusively marine micro-organisms.

Morphology: The test of an acritarch consists of spherical to ovoidal or triangular central cavity termed as **vesicle** (Fig. 10.12). Most vesicles range in size between 50 to 100 µm. The wall of the vesicle may consist of one to three layers, which are made of tough and hard organic material known as **sporopollenin**. The central cavity can be closed or open externally through a pore called **pylome**. The external or outer surface of the vesicle may be smooth or ornamented by spines, ridges, processes, indentations or pores. All these features represent outgrowths of the vesicle wall. The shape of the vesicle and absence or presence of ornamentations as well as processes are used to classify the acritarchs.

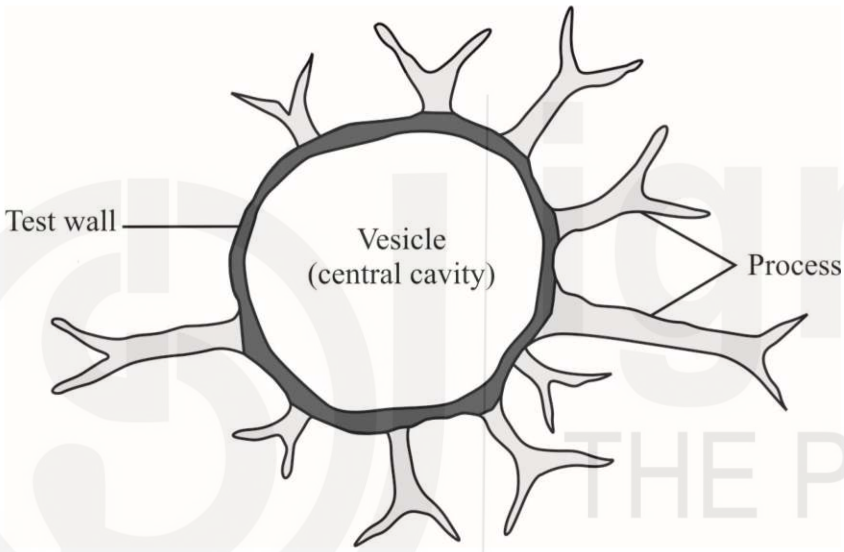


Fig. 10.12: Line drawing showing morphology of an acritarch. (Source: simplified after Benton and Harper, 2009)

Geological Range: The acritarchs are one of the oldest documented fossils. They first appeared in the fossil record in the Precambrian about 1.8 billion years ago, and are still present in modern seas. They are considered the most complex Precambrian fossils.

(iii) **Spores and Pollen**

Spores and pollen are reproductive parts that are produced during the life cycles of plants (Fig. 10.13). Spores are reproductive parts produced in the life cycles of lower plants such as bryophytes and ferns whereas pollen grains are the sperm-carrying reproductive parts produced by the higher plants both gymnosperms and angiosperms. Both spores and pollen of land plants have very resistant walls made of organic material known as **sporopollenin** and fossilise freely. They are very tiny grains, typically range in size between 10 and 200 µm. These grains are produced in large numbers by plants and can travel widely, rapidly and freely in air and water and they settle down at the bottom of lakes, ponds, rivers and oceans as a part of sediments. The word pollen may be used as singular as well as plural form.

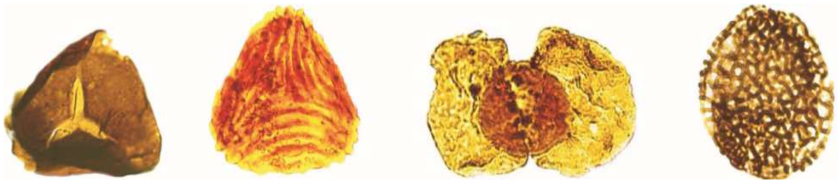


Fig.10.13: Photographs of spores and pollen: a) to b) Fossil spores; and c) to d) Fossil pollen. (Source: Dr. Y. Raghumani Singh, Manipur University, Imphal)

Morphology: The morphology of spores is largely controlled by divisions of the spore mother cell (i.e., the cell from which the spore develops). It splits into a tetrad comprising four small spores. Tetrad has two types of arrangement of spores such as tetrahedral and tetragonal. In tetrahedral arrangement, the cell is divided into four spores at once and all these four spores are in contact with each other at three contact areas/faces forming a Y-mark in the contact area. The spores having Y-mark show radial symmetry and are termed as **trilete spores** (Fig. 10.14).

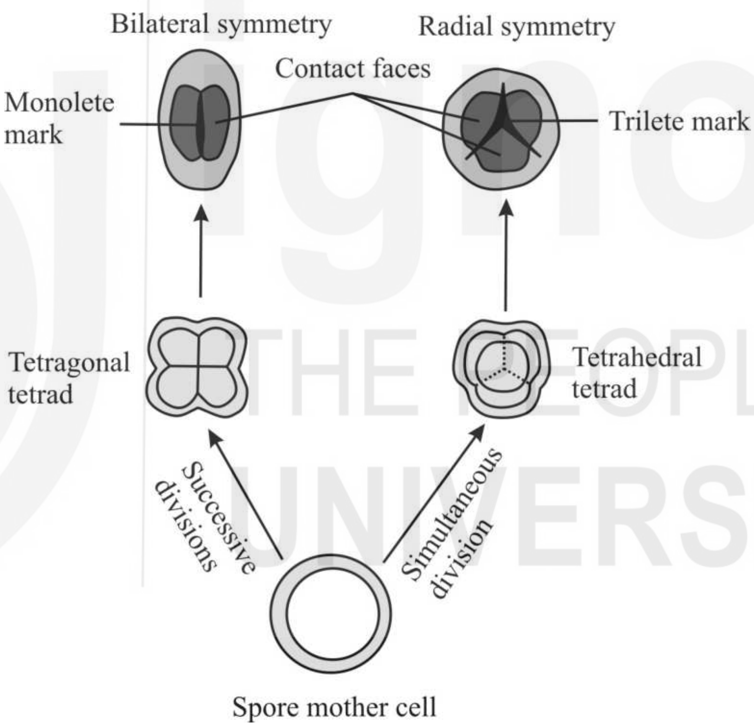
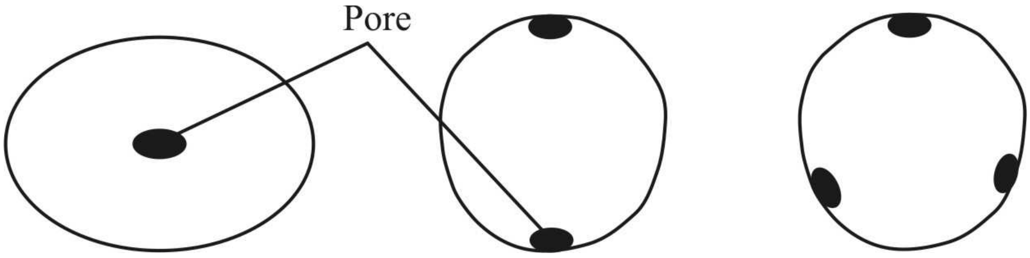


Fig. 10.14: Morphology of spores and their formation from a spore mother cell.

On the other hand, the tetragonal tetrad shows successive divisions of the cell into spores, where the cell first divides into two spores which subsequently subdivide further. The spores of tetragonal arrangement have two contact areas marked by a single scar. The spores with a single scar (i.e., contact mark) display bilateral symmetry and are named as **monolete spores** (Fig. 10.14).

Pollen grains range in size from 20 to 150 μm. They are typically oblate, spheroidal and prolate in shape. Many individual pollen have no pore and such pollen are termed as **inaperturate** whereas others have one or more pores. Pollen having one pore are known as **monoporate**, those with two pores are called **diporate**, and having three pores are **triporate** (Fig. 10.15). Most spores and pollen have a double-layered wall structure with inner and outer wall layers. The outer layer is highly resistant and fossilises freely. It is ornamented variably having granulations, pits and rod-like extensions. The shape and arrangement of pores are important features in the classification of spores and pollen.



(a) (b) (c)

Fig. 10.15: Forms of the pollen: a) Monoporate; b) Diporate; and (c) Triporate.

Geological Range: The earliest reported occurrences of spores are from the Silurian rocks whereas oldest pollen are known from the rocks of Devonian, and both spores and pollen are continuously living up to the present day. The evolutionary history of spores and pollen is closely associated with the evolution of land plants.

10.3.3 Significance of Microfossils

The microfossils are minute microscopic organic remains that are usually found almost in all types of sedimentary rocks and rarely in low grade metamorphic rocks. Some characteristics of microfossils such as global distribution, distinctive morphology, climate sensitive nature and rapid evolutionary rate make them ideal for stratigraphic studies. As a whole, microfossils are broadly used for stratigraphic correlation, dating of rocks, reconstruction of environment, climate and oceanic circulation patterns of the geological past. They find extensive industrial use in logging of oil wells and location of source rocks for oil and gas.

10.4 COLLECTING MICROFOSSILS

It is a well accepted fact that microfossils are more abundant and widely distributed in most of the sedimentary rocks as compared to larger or macrofossils. In addition to this, microfossil-bearing rocks can provide a large amount of information on various aspects of the geological past such as origin and evolution of life, palaeoecology, palaeoclimate, palaeoenvironment, etc. and their study is very significant in geology. It is important to note that macrofossils, which are larger in size, are commonly visible to naked eye in the field. On the other hand, the size of microfossils is so small that we cannot see them with naked eye in the field. As a consequence, the study of microfossils involves specialised methods and techniques for their collection in the field and preparation in laboratory.

The main methods and techniques used to collect the microfossils are given below:

- Geological fieldwork
- Sampling
- Processing
- Separation

10.4.1 Geological Fieldwork

Fieldwork is an important component of any palaeontological as well as geological study. It depends on the specific aim and goal of the study. During the fieldwork, we visit the geological site where we wish to collect the samples systematically according to the objectives of the study. We also record the attitude of beds of a geological section/site and its lithology as well as draw the sketches in the field diary. In addition, we also record the geographic coordinates of the area with the help of Global Positioning System (GPS) or topographic map and also take its photographs.

A field kit is an essential requirement for field work and it may contain the following equipment (Fig. 10.16):

- Hammer
- Chisels and shovels
- Compass clinometers/Brunton compass
- Measuring tape and hand lens
- Topographic and geologic maps
- Field notebook/diary
- Plastic and cloth sample bags
- Plastic acid bottle (for identification of limestone)
- Knife, field camera and GPS
- First aid box

(a) (b) (c) (d) (e)

Fig. 10.16: Field equipments: a) Geological hammer; b) Chisel; c) Brunton compass; d) Measuring tape; and e) Hand lens.

10.4.2 Sampling

You have read that microfossils are usually not visible in the field because they are too small. However, some forms of foraminifers and ostracods are large enough to be seen with naked eyes. In this case, you can identify the particular bed/layer where samples can be collected for mircopalaeontological studies. In other cases, the samples are usually collected at random and you will not know whether or not samples will yield microfossils until they are processed in the laboratory. Depending on the nature of study, samples can be collected vertically (i.e., from the bottom to the top) at regular or irregular intervals of a geological section. For micropalaeontogical studies, we usually collect samples from within the rock and not from the weathered surface since there is a chance of contamination in weathered surface samples.

The samples can be taken from any geological site, where rock succession is well exposed both horizontally as well as vertically. The subsurface samples can be collected from the core samples obtained during the drilling process undertaken by the oil companies or from the open mines.

While collecting samples, the following precautions must be taken into consideration:

(i) Do not collect samples from a weathered rock exposure.

(ii) Clean the top or weathered surface of exposure before taking samples.

(iii) Always collect samples from fresh rock surfaces.

(iv) Clean equipment such as hammers, chisels and shovels before a sample is taken in order to avoid contamination.

(v) Put each sample into a new sample bag and label it carefully with the locality and bed information and enter the same details in your field notebook.

(vi) For micropalaeontolgical studies, the size of sample should be 200 gram to 1 kg.

(vii) Microfossils are more common in fine grained sediments such as clay, mudstone or silt than in coarse grained rocks like sandstone.

(viii) Try to collect samples from soft fine grained rocks such as mudstone, siltstone or clay.

(ix) Samples may be collected from lower (i.e. base of the section) to the higher (i.e. top) elevation level.

(x) Care should be taken to avoid contamination at every step while doing sampling and to avoid accidents while doing the fieldwork.

10.4.3 Processing

After collecting samples in the field, they are taken into the laboratory for processing or preparation in order to separate or recover microfossils from them. It may be noted that all collected samples may not be equally soft or hard. Therefore, based on the nature of lithology, different processing treatments may be given to the collected samples. The processing treatment for samples containing softer sediments such as shales, clay or mudstones begins with breaking them into smaller pieces usually less than 3 cm in size and drying them. Once the sample is dried, then we place them in a container (e.g., a plastic tub) covered with water for 10-12 hours. This allows the sample to disintegrate and form mud slurry if the rock is very soft. This slurry can then be screen washed with water by using sieves of different mesh size, for example, 80, 100, 200 or 280 depending on the type of microfossil which we are looking for (Fig. 10.17). The washing of sample removes the unwanted fine particles of clay or sand from the samples. The screen washing is the simplest and most efficient technique for processing of soft sediments or samples.

Fig. 10.17: Test sieve.

For the disintegration of hard samples containing limestone and sandstone or hard mudstone, a number of chemicals such as sodium bicarbonate, sodium hydroxide and sodium sulphate may be used. Alternating freezing and thawing method is also employed for disintegration of samples.

The samples of very hard rocks such as chert can be studied by preparing their thin sections. It is important to keep in mind that while processing the samples, half of the sample should be preserved in the laboratory for reference or for use in case the process of separation fails in the first instance or there are some interesting results that need to be re-investigated.

Once the samples are disintegrated after employing the above mentioned methods, the obtained residue must be dried completely. The residue obtained is then put in the plastic sample bags and numbered with respect to their location and stratigraphic position.

10.4.4 Separation

Separation of microfossils from the dried residue requires a high-resolution binocular light microscope. Here, we first put the dried residue containing microfossils and matrix of a particular sample bag in the picking tray (Fig. 10.18a) and examine it under the microscope (Fig. 10.18b). We pick up the microfossils with the help of fine-hair brush and store them in the micropalaeontological assemblage slide (Fig. 10.18c). On the other hand, the thin sections of samples can be directly viewed under the microscope. The use of digital camera and computer attachment with microscope is preferable during the study of a thin section. While viewing thin sections, if we get any microfossils, the same can be viewed under the microscope or seen on the screen of the computer if we are using the attachment, where we can take their photographs for further studies.

(c) **(b)**

Fig. 10.18: Tools and instruments used for separating microfossils: a) Picking tray; b) Microscope; and c) Micropalaeontological assemblage slide.

SAQ 2

a) List the important groups of fossils belonging to organic-walled microfossils.

b) What is the composition of shells of organic-walled microfossils?

c) Fossil spores and pollen are the remains of reproductive parts of ------------ .

d) List equipment of the geological field kit.

10.5 STUDYING MICROFOSSILS

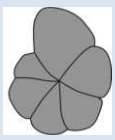
The study of microfossils involves their description and identification. It is a challenging job and requires knowledge of taxonomy and biological classification and involves consultation of reference books, e.g., fossil identification guides and textbooks of palaeontology.

For description and identification of microfossils, we need a high-resolution binocular microscope and sometimes a Scanning Electron Microscope (SEM). After separating or isolating microfossils from the matrix, these are examined under the microscope. During their examination, all morphological details are to be noted and their photographs taken. In addition, line drawings help in illustrating the important morphological features seen through microscope. The microfossils under study are compared with the previously described fossils in order to know whether material under study is new or a previously known species. If it represents a new form, a new name may be given to it according to the code of biological nomenclature.

10.6 ACTIVITY

List of important microfossils is given in the Table 10.1. The important facts of foraminifers are also given. You are required to study the similar facts for other microfossil groups and accordingly, fill in the table as done in case of foraminifers.

Table 10.1: Microfossil groups

Name of Microfossil	Mineral /organic-walled micro-fossils	Composition of the shell/ test	Key morphologic features	Line drawing	Geologic range
Foraminiferans	Mineral-walled microfossil	Calcium carbonate, tectin and agglutinated	Aperture, foramina, unilocular, multilocular, uniseral, biserial, triserial, planiserial and helical		Cambrian to present
Radiolarians					

Diatoms					
Dinoflagellates					
Pollen and spores					

You can also collect some photographs of microfossils from internet and paste them in their respective group given in Table 10.1.

10.7 SUMMARY

In this unit, you have learnt about the following:

- Microfossils are the remains of very small single-celled and multi-celled organisms. These are usually less than 2 mm in size.
- The term microfossil is applicable to all those organic remains whose study requires the use of a light or electron microscope.
- The study of microfossils is known as micropalaeontology. The history of micropalaeontology is more than two centuries old.
- Foraminifers, radiolarians and diatoms are the main groups of mineral-walled microfossils, whereas acritarchs, dinoflagellates, spores and pollen are the main groups of organic-walled microfossils.
- Foraminifers are single-celled protozoans and may be planktic or benthic in mode of life. The majority of foraminiferal tests are multi-chambered bearing many small internal openings known as foramina. They range in age from Cambrian to present.
- Radiolarians are single-celled planktic protozoans characterised by radial symmetry. They are exclusively marine and range in age from Cambrian to present.
- Diatoms are unicellular photosynthesising non-motile algae that live in almost all kinds of environments from marine to freshwater. Their skeleton, called frustule, is made up of silica and consists of two unequal valves. They range in age from Mesozoic to present.
- Dinoflagellates are small, aquatic, single-celled eukaryotic micro-organisms commonly regarded as algae. They possess both plant-like and animal-like characters. About 10% of dinoflagellates develop tough and resistant organic structures called cyst, which fossilise freely. They range in age from Palaeozoic to present.
- Acritarchs are microscopic organic-walled vesicular microfossils with unknown biological affinities. They are exclusively marine and are the oldest known group of microfossils. They range in age from Precambrian to present.

- Spores and pollen both are part of the plant reproductive system. Spores are the reproductive bodies of lower vascular plants and their earliest occurrences are known from Silurian rocks. Pollen are the sperm-carrying reproductive bodies of seed plants. They occur first in Devonian rocks. The occurrences of spores and pollen reflect the evolutionary history of land plants.
- Microfossils are broadly used for stratigraphic correlation, dating the rocks, reconstruction of environment, climate and oceanic circulation patterns of the geological past and are also useful in oil industry.
- The collection of samples from the field and extraction of microfossils from them in laboratory involves fieldwork, sampling, processing or preparation of samples and sorting of microfossils under microscope.
- The study of microfossils involves their description and identification. For this purpose, a high-resolution biological microscope and sometimes Scanning Electron Microscope are used.

10.8 TERMINAL QUESTIONS

1. What are microfossils? Discuss various types of microfossils.
2. Write about mineralised microfossil groups.
3. Discuss the importance of microfossils.
4. List out the methods that are followed while collecting microfossil samples in field.
5. Write notes on the morphology and geological age range of the following:
   i. Radiolaria
   ii. Foraminifera
   iii. Dinoflagellates
   iv. Spores and pollen

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10.10 FURTHER/SUGGESTED READINGS

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10.11 ANSWERS

Self Assessment Questions

1. a)

Organic-walled microfossils	Mineral-walled microfossils
The shells of organic-walled microfossils are commonly made up of hard and tough organic or non-mineralised proteinaceous material, which makes shells resistant to microbial and chemical attacks as well as to the adverse effects of temperature and pressure after their burial in sediments and hence, commonly found as fossils. Dinoflagellates, acritarchs, spores and pollen are main types.	The shells of mineral-walled microfossils are commonly made up of mineral matter such as calcium, silica or phosphate, which makes shells hard and resistant for external physical and chemical agencies and thus, possess higher preservation potential as fossils. Foraminifers, radiolarians, diatoms, ostracods and conodonts are common groups.

b) (1) Microfossils (2) Palaeozoic to present.

c) (i) Diatoms

d) The skeletons of radiolarians are made up of silica secreted by the organism. The skeletons are mostly spherical or helmet to space-ship shaped and are formed by spines, bars and perforated plates. Spines are elongated external features of the skeleton that are attached only at one end where as bars are elongated internal features attached at both ends. A perforated plate has more or less evenly spaced pores without specific plate boundary. Based on symmetry, radiolarians are divided into two types: spumellar and nassellar.

2. a) Dinoflagellates, acritarchs, spores and pollen are main types of organic-walled microfossils.

a) The shells of organic-walled microfossils are made up of hard, tough and resistant organic material known as sporopollenin.

b) Plants.

c) The main equipment of a geological field kit includes hammer, chisels and shovels, compass and clinometers, measuring tape and hand lens, topographical and geological maps, field notebook/diary, plastic and cloth sample bags, plastic acid bottle, knife, field camera and GPS and first aid box.

Terminal Questions

1. Refer to section 10.2 and 10.3.
2. Refer to subsection 10.3.1.
3. Refer to subsection 10.3.3.
4. Refer to section 10.4.
5. Refer to subsection 10.3.1 and 10.3.2.

UNIT 11

EVOLUTION OF HORSE

Structure

11.1 INTRODUCTION

Vertebrates are a diverse group of organisms ranging from lampreys to human beings. The group includes animals with backbone, such as fishes, amphibians, reptiles, birds and mammals. The dinosaurs that have caught public attention by making their appearance in several films and books too are vertebrates. Vertebrates have a long geological history on the planet Earth beginning more than 500 million years (Myr) ago, starting from the Cambrian to the present.

They first appeared in the fossil record during the Cambrian period of the Palaeozoic era. Fishes, amphibians and reptiles were the most dominant groups of vertebrates in the Palaeozoic and Mesozoic eras. In the Mesozoic era, dinosaurs- a group of reptiles, and mammals made their appearance. Dinosaurs had a wide geographic distribution, being reported from all continents and were the largest animals to roam the Earth during the Mesozoic era. The mammals began to diversify only after the demise of dinosaurs at the close of the Mesozoic era at around 66 Myr ago. In the Cenozoic era, mammals rapidly occupied every niche and corner of the globe and therefore, the Cenozoic era is also known as the "**Age of Mammals**".

Mammals of the Cenozoic era belong to three groups: placentals (that give birth to young ones), marsupials (in which an offspring after birth continues to develop within the pouch of the mother) and monotremes (egg laying mammals). Among these three groups, the placentals like the horses, elephants and humans have a well-documented fossil record.

Now we will deal with one of the most important groups of placental mammals namely, horse. In this unit, we will discuss the systematics, evolution and phylogeny of horse. In addition, we will also learn how climate has played a role in the evolution of horse.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ outline the systematic positions of horse;
- ❖ describe the probable time and place of its origin;
- ❖ discuss the major evolutionary trends in horse;
- ❖ enumerate their phylogeny; and
- ❖ discuss the role played by the climate in the evolution of horse

11.2 EVOLUTION OF HORSE

Among all the vertebrates there is no other group whose fossil record is better known than that of the horses, the odd-toed ungulate mammals. The word ungulate refers to the mammals that bear hooves on their fingers and toes rather than claws. Horses are odd-toed ungulates like the rhinoceros and tapirs that have either 1, 3, or 5 counts of toes on their hand or foot and thus, belong to the Order Perissodactyla. In contrast, cows and camels are even-toed ungulates (2 or 4 toes) that are included in the order Artiodactyla. **Equidae** is the family of horses. It comprises a single extant genus *Equus*, in which horses are placed along with the donkeys and zebras

11.2.1 Systematic Palaeontology

Kingdom	Animalia
Phylum	Chordata
Subphylum	Vertebrata
Class	Mammalia
Order	Perissodactyla
Family	Equidae
Genus	*Equus*

11.2.2 Place and Time of Origin

The story of evolution of horse started at the beginning of the Eocene epoch of the Cenozoic era and North America is considered as the original home of the horses. As stated earlier horses, rhinoceros and tapirs belong to the mammalian group perissodactyls. It is believed that perissodactyls originated in a forest environment by Early Eocene times. Whereas the tapirs and, to some extent, rhinoceroses, retained their forest specialisations, modern horses adapted to life on grasslands. Because of their habit to live in large herds, horses have been buried and fossilised in large numbers since the earliest stage of their evolution. In North America, an almost complete sedimentary sequence from the Eocene to the Recent is present that has yielded well-preserved fossil horses since the early 19^{th} century, because of which the evolutionary history of horses is well-documented among all mammals.

Horse remains have also been found from different stratigraphic horizons in Europe and Asia as we ascend the geological column, but the fossil record is not as complete as in North America. The recent findings of the earliest horse *Hyracotherium* from Europe and a speculated ancestor of horse *Radinskya* from China questions the birth place of horses, although many palaeontologists believe North America as the birth place of horses because the entire evolutionary sequence of the horses is known from here. In addition, recent studies have also shown that *Hyracotherium* was not a true horse.

Though the question of biogeographic origin of the equidae is currently unresolved, it is well established that during the Early Eocene, the Equidae could move between North America and Eurasia through a land bridge in the North Atlantic ocean called as the **DeGeer dispersal route** (Fig. 11.1), which by early Middle Eocene was severed thus restricting the movement of animals either way. Thereafter, the Equidae became extinct in Europe, but continued to evolve in isolation in North America until the Oligocene. The land connections between North America and Europe were re-established in the Miocene, about 24 Myr ago and the equids again dispersed to Europe and from there to the Old World. Though the DeGeer dispersal corridor was no longer available, these migrations could take place during the times of lowered sea levels that exposed the shallow Barrents shelf between Siberia and the Aleutian Islands, forming the **Bering land bridge** (Fig. 11.1). Throughout the remainder of the Cenozoic era whenever the sea level dropped the Bering land bridge was exposed and the equids migrated from North America to Europe and the old world, such as in the Middle Miocene, Pliocene and Pleistocene times. The horses also dispersed to South America during the great faunal interchange that occurred about 4 to 3 Myr ago when the land connection was established between the Americas by way of the **Isthmus of Panama** (Fig. 11.1). By the end of the Pleistocene, the horses became extinct in North America, but survived in other parts of the world to continue till today. Horses were re-introduced in the New World by early human migrants.

Do you know?

The “Old World” consists of Africa, Europe and Asia. The term originated in the early 16th century after the discovery of North and South America called as the “New World” by the Europeans who till then thought of the world as consisting of Africa, Asia and Europe only.

The evolutionary history of the horse was one of the first to be developed and cited as evidence for the evolutionary process soon after the theory of evolution was proposed by Darwin in his book ‘Origin of Species’ in 1859. The story of the horse soon became a classic example of evolution, appearing in every text book on the subject.

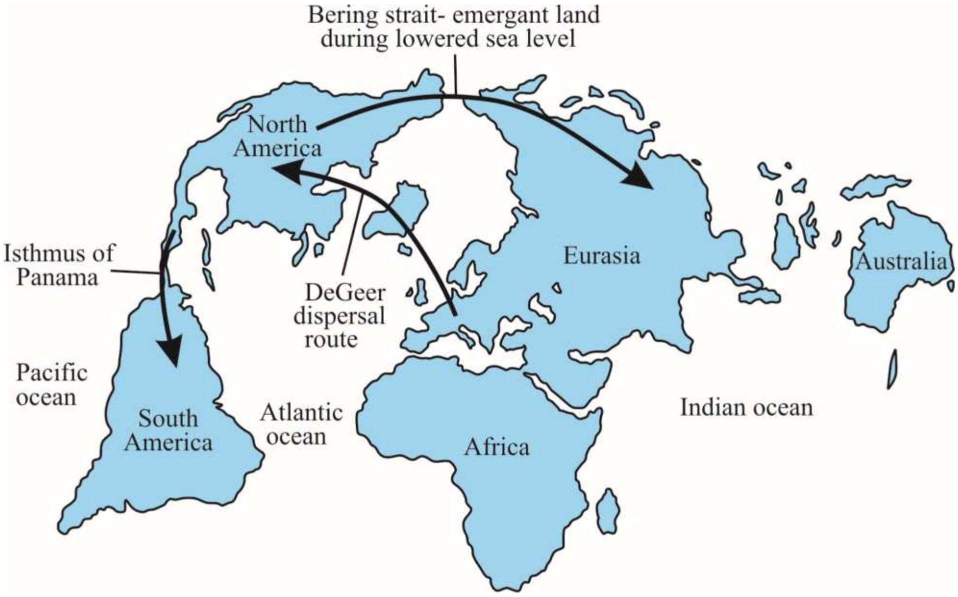


Fig. 11.1: Map showing the dispersal routes for the migration of horses during different points of time in the Cenozoic era. (Source: simplified and redrawn after MacFadden, 1992)

11.2.3 Major Evolutionary Transitions

The horse originated in the Eocene and through time it underwent a number of changes from a dog-like ancestor to what it is today. The main changes which are exhibited in the phylogeny of horse are listed below (after Colbert, 1980):

1. Increase in body size
2. Lengthening of legs and feet
3. Reduction of lateral toes with emphasis on the middle toe
4. Straightening and stiffening of the back
5. Widening of the incisor teeth
6. Molarisation of the premolars (i.e., in order to grind food premolars became like molars)
7. Increase in height of the crown of the cheek teeth
8. Development of crests on molars
9. Deepening of the front portion of the skull and of the lower jaw to accommodate the high crowned teeth
10. Lengthening of the face in front of eyes also to accommodate the high crowned teeth
11. Increase in brain size

11.2.4 Phylogeny of Horse

The phylogeny of horses has been and still is one of the acceptable and most frequently quoted examples of evolution. You can see summary of the phylogenetic history of horse in Figs.11.2 and 11.3, which show the major changes that took place in the skeleton of horses during the course of their evolution.

Let us discuss the different evolutionary stages of horse during the Cenozoic era.

(i) **Horses in Eocene**

Eohippus: *Eohippus,* commonly known as the dawn horse, was a small animal about 10-20 inches (25-50 cm) high at the shoulder, had an arched back, short neck, short snout, short legs and a long tail (Fig. 11.3). Its legs were flexible and rotatable with all major bones present and un-fused. It had 4 toes on each of the front foot and 3 toes on hind feet. Vestiges of other toes were however still present. *Eohippus* walked on dog-like padded feet and had only small hooves on each toe. It was a forest dweller that looked more like a dog than a horse. It browsed on soft foliage. Its teeth were low-crowned. Each side of the jaw had 3 incisors, 1 canine, 4 premolars and 3 molars (i.e., its dental formula was 3143/3143). The cusps of the molars were slightly connected by low crests. It became extinct in the Early Eocene, around 49 Myr ago, but prior to its extinction, it evolved into *Orohippus* (Fig. 11.2).

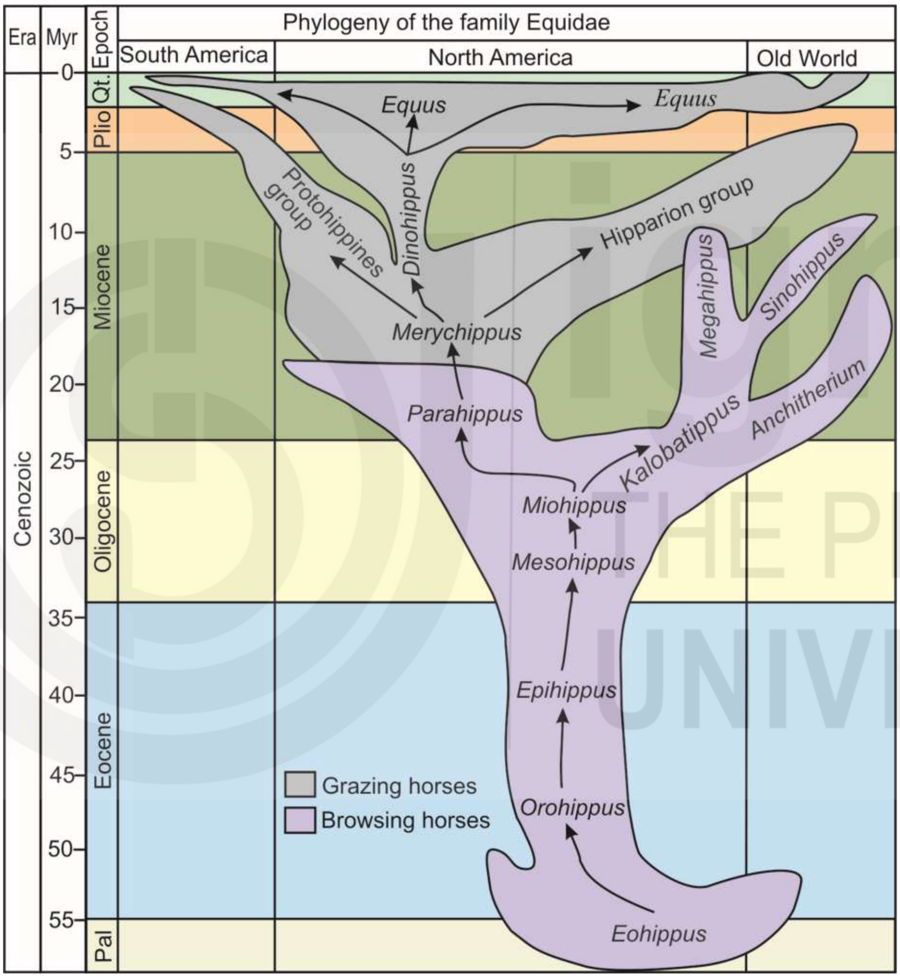


Fig. 11.2: Phylogeny of horse (Source: simplified and redrawn after MacFadden, 1992)**, Pal stands for Palaeocene, Plio for Pliocene and Qt for Quaternary.**

Do you know?
A dental formula is a summary of a mammal's teeth. The number of teeth of each type is written for one side of the mouth with the upper and lower teeth shown on separate rows.

Orohippus: *Orohippus* means "mountain horse", although it never lived in the mountainous region. It looked largely like *Eohippus*. The major changes that took place in *Orohippus* were the loss of the toe vestiges and change in dental morphology. It was about 10-20 inches (25-50 cm) high at the shoulder with a dog-like look and padded feet. It had a small brain, arched back, and short legs, neck and snout (Fig. 11.3). Its diet comprised tougher plant material than that of *Eohippus* and this brought in molarisation of the 4th premolar and more pronounced development of the crests on the teeth. *Orohippus* survived until 46 Myr ago.

Epihippus: It arose from *Orohippus* in the Middle Eocene times (Fig. 11.2) about 47 Myr ago. Like *Orohippus* and *Eohippus*, *Epihippus* was a small, dog-like, pad-footed and small-brained horse. It had 4 toes in front and 3 behind. Meanwhile, the evolution of teeth continued. In *Epihippus*, the last two premolars became molarised, making five cheek teeth grinding type. The teeth however, remained low-crowned, but with well-developed crests. It has been seen that *Epihippus* was slightly larger than *Orohippus* and became extinct by the end of Eocene.

Mesohippus: By the Late Eocene time, approximately 40 Myr ago the horse genus *Mesohippus* descended from *Epihippus* (Fig. 11.2). *Mesohippus* also known as an intermediate horse was slightly larger than *Epihippus*. Standing 24 inches (71 cm) high at the shoulder, it was of the size of a sheep. Its back was less arched, and the legs, neck, snout and face a little longer (Fig. 11.3). However, *Mesohippus* retained three toes on its hind feet whereas on its front feet the 4th toe was reduced. *Mesohippus* like its ancestors was still pad-footed. The third last premolar however continued the evolutionary trend of molarisation, thereby resulting in six grinding cheek teeth in *Mesohippus* as well as all the later horses. *Mesohippus* continued to survive until 29 Myr in the Late Oligocene.

(ii) **Horses in Oligocene**

Miohippus: It arose from *Mesohippus* in the Late Oligocene time (Fig. 11.2) about 37 Myr ago. It was a larger horse with a slightly longer skull than *Mesohippus*. A characteristic feature of *Miohippus* was the development of a variable extra crest on its upper cheek teeth, a trait that was retained by all the later horses. The ankle joint of *Miohippus* also changed a little. *Miohippus* continued for a while as it was, and then by the Early Miocene, it had split into two branches. One of the branches continued as three-toed browsing horses such as *Kalobatippus, Anchitherium, Megahippus* and the Asian *Sinohippus*. The other branch that arose from *Miohippus* was that of *Parahippus*.

(iii) **Horses in Miocene**

Parahippus: As stated above, *Parahippus* evolved from *Miohippus* (Fig. 11.2). It was both a browser and a grazer (a mixed feeder). Appearing in Early Miocene around 25 Myr ago, *Parahippus* was a little larger than *Miohippus*, with about the same brain size and body form (Fig. 11.3). However, as this horse started eating grass its teeth became slightly high-crowned (hypsodont). *Parahippus* adapted to a running mode, which in turn developed springy foot ligaments, although the foot still remained three-toed. *Parahippus* went extinct by 15 Myr ago.

Do you know?

Hypsodont dentition comprises high-crowned and short-rooted teeth. This dentition is characteristic of those animals that feed on gritty and fibrous food material such as grasses.

Merychippus: *Parahippus* by about 18.5 Myr ago evolved into a spring-footed, hypsodont horse, named *Merychippus* (Fig. 11.2). *Merychippus* was about 40 inches (1 m) high at the shoulder. It was still three-toed, but a fully spring footed horse that stood permanently on the tiptoe (Fig. 11.3). The side toes though present were of variable size whereas the central toe was a little larger with a well developed large hoof. Also the leg bones were fused and reduced in size to eliminate leg rotation. These transitions occurred as *Merychippus* adapted to rapid running over hard ground. Another major transformation that took place in *Merychippus* was the increase in the height of its teeth as it fed dominantly on grass. It was the first member of the line of descent of the grazing horses that marked the transition of horses from primitive browsers to the modern grazers. It is, therefore, also known as a ruminant horse. However, to accommodate the large teeth, the jaw became deeper, and the muzzle (the projecting part of the face, including the nose and mouth) became elongated. This gave *Merychippus* a new look and so it was aptly named as *Merychippus*, "the horse with a new look".

Merychippus underwent rapid speciation called "**merychippine radiation**" giving rise to new horse species that fall in three major groups. These groups are hipparions, protohippines and true equines.

Hipparions were small to large pony like, three-toed grazing horses that emerged around 16 Myr ago. They include forms like *Comohipparion*, *Pseudhipparion*, *Neohipparion*, *Hipparion* and *Nannippus*. These horses spread from North America to the Old World, reaching the Indian subcontinent about 14-13 Myr ago.

Protohippines evolved by 16 Myr ago. *Protohippus* and *Calippus* were the older, smaller forms that retained three toes in their feet. By the Middle Miocene the protohippines line of descent was represented by *Pliohippus*. Initially, a three-toed horse, *Pliohippus*, through three successive stages in the Early Pliocene, lost side toes, ultimately culminating into a single-toed *Pliohippus* (Fig. 11.3). *Pliohippus* gave rise to the "hippidions" which were stocky, short-legged, single-toed horses with odd boxy skulls. These horses travelled from North America to South America and thrived there at least up to 2-1 Myr ago.

True equines include the present day horse and its ancestors. They comprise both three-toed as well as single-toed horses. The three-toed horses were *Merychippus* in which the side toes were smaller than the central toe, whereas, the single-toed horses are *Dinohippus* and *Equus*. By 12 Myr ago, *Dinohippus* descended from *Merychippus* (Fig. 11.2). *Dinohippus* the one-toed horse had slightly straighter teeth than those of *Merychippus*. It looked very similar in foot, tooth, and skull morphology to the modern horse (Fig. 11.3).

(iv) Horses in Pliocene

Descendents of "hipparions" and "protohippines" stock continued into the Pliocene and spread to the old world and South America. *Dinohippus* the true equine was the most common horse in North America in the late Pliocene. It gave rise to the modern day horse, *Equus*.

(v) Modern Horse

Equus: It is the genus of all the modern equines that first arose around 5 Myr ago from *Dinohippus*. The first *Equus* was 52 inches (1.3 m) tall (the size of a pony), with a rigid spine, long neck and legs, fused leg bones with no rotation, long nose, flexible muzzle and a deep jaw. The brain was a bit larger than that of *Dinohippus*. *Equus* soon diversified into several species that co-existed with other horses. *Equus* like *Dinohippus* is single-toed (Fig. 11.3). However, its teeth are straight and higher-crowned than of *Dinohippus* (Colbert and others, 2001).

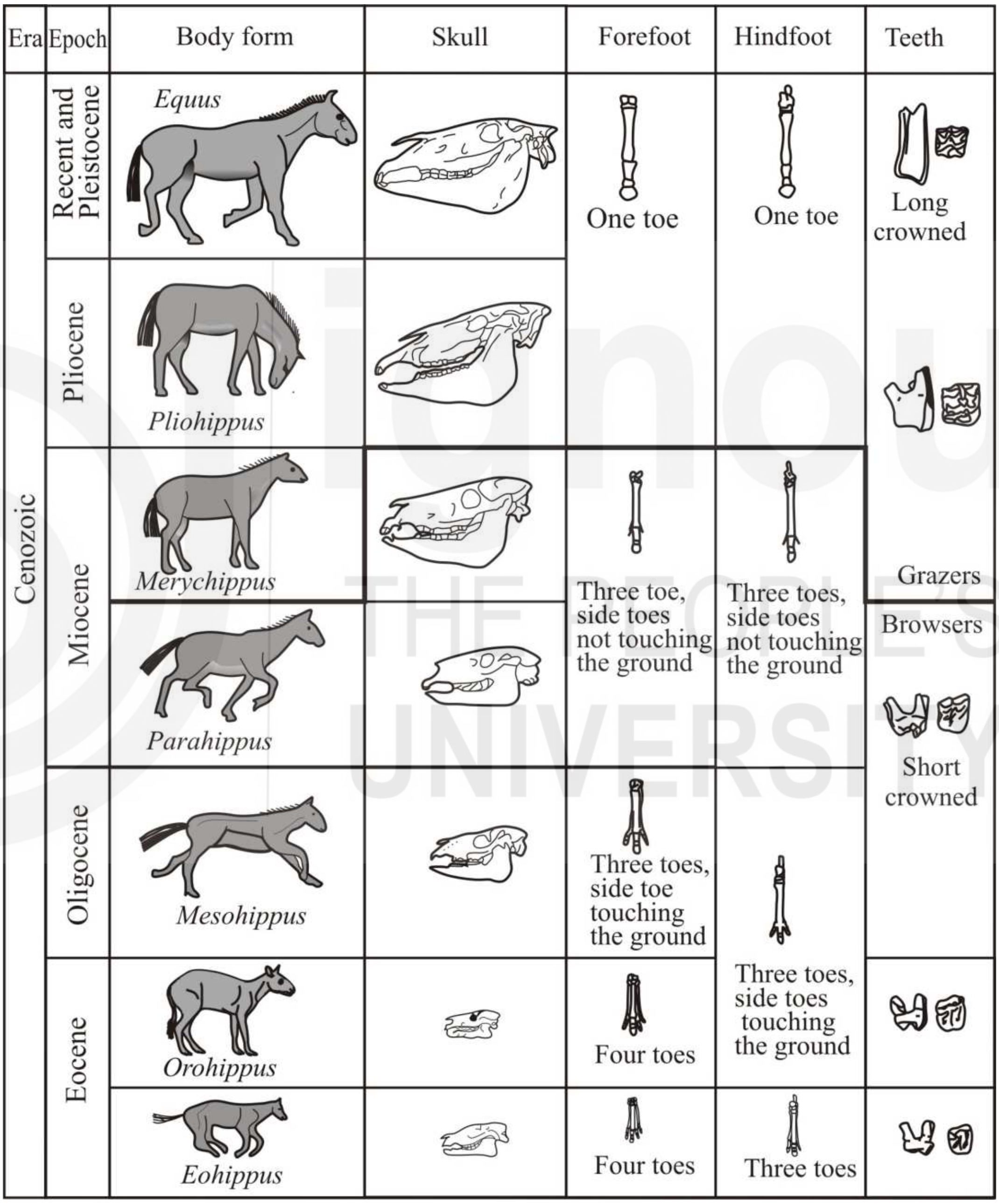


Fig. 11.3: Morphological changes that took place in horses during the course of evolution. (Source: modified after Benton, 2005)

During the first major glaciation of the Late Pliocene, about 2.5 Myr ago, certain *Equus* species crossed to the Old World. Some entered Africa and diversified into the modern zebras. Others spread across Asia, the Middle East and Africa where they adapted to desert life such as Kiangs, Onagers and wild asses including donkeys. Still others spread across Asia, Africa, South America, and Europe as the true horse, *Equus caballus*.

It is worth mentioning here that *Equus* arose in North America and at the end of Pleistocene epoch (11000 years ago), it became extinct in North America probably as a result of climate change and overhunting by humans. Later in the 16th century the horse was reintroduced in North America by humans.

Do you know?

The Miocene to Pliocene fossil record of the Siwalik Hills of the Indian Subcontinent yields abundant material of hipparionine equids. The oldest fossil comes from the Chinji Formation and its equivalent beds dated around 14-13 Myr old. The fossil horse recovered is *Hipparion* which was an immigrant from North America. Though, *Hipparion* was not the dominant component of mammalian taxa initially, its number and diversity increased by the upper part of the Middle Siwaliks. However, by the Upper Siwalik times it became extinct and was replaced by *Equus*. Species of fossil *Equus* are also known from the Karewa deposits of the Kashmir valley and from Pleistocene alluvial deposits of the Narmada valley.

11.3 ROLE OF CLIMATE IN THE EVOLUTION OF HORSE

You now know that the beginning of the evolution of horse took place in the Cenozoic era, close to the Palaeocene-Eocene boundary. You may find it interesting to note that the Palaeocene–Eocene boundary witnessed an abrupt global warming, which is commonly referred to as the Palaeocene–Eocene Thermal Maximum (PETM). At this boundary many modern mammalian taxa appeared and so did the first horse *Eohippus*. The major changes that took place among horses during the course of evolution were the reduction in the number of toes and deepening of the cheek teeth (i.e., premolars and molars). These changes are linked to changes in environmental conditions which brought retreat in forest cover and spread of grasslands. The Eocene warming trend continued at least up to its earliest part which brought in only minor evolutionary changes in *Eohippus* and its near descendants. The body and feet stayed mostly the same, with slight changes in the toes. The major change was in the teeth of Eocene equids as they started to eat more plant browse and less fruit. They also developed more grinding teeth to eat the slightly tougher food.

With the onset of the Late Eocene, the cooling of the Earth began and small ephemeral ice sheets developed and the climate became drier. This affected the vegetation patterns with vast forests shrinking and grass evolving during the Late Oligocene–Early Miocene times. So as we move toward the Oligocene, horses become as mixed feeders and by Miocene horses changed their dietary mode from browsing to grazing. Since grass is difficult to chew and wears down teeth rapidly due to its high silica content, horse teeth increased the height of the tooth crowns so that the teeth remain out of the gum as their tops were continuously worn down. There was an increase in body size and length of the face as well.

The grazing horses also adapted to rapid running on open grasslands. They started to become leggier for better speed out in the open eventually becoming specialised runners. The bones of the legs began to fuse together, and the leg bones became specialised for efficient forward-and-back strides, with flexible leg rotation being eliminated. Most significantly, the horses began to stand permanently on tiptoe i.e., they changed from three-toed to single-toed horse, another adaptation for speed, instead of walking on dog-like pads.

In Pleistocene times, the climate again changed as Earth went into a glacial mode. The Pleistocene climate change accompanied by the overhunting by man led to the extinction of numerous mammals in North America including the modern horse, *Equus*. The warming and cooling episodes of the Cenozoic had also brought in global sea level changes that formed land bridges during the fall of sea level which facilitated the dispersal of horse from North America to the rest of the world. The horses, though became extinct in North America where its entire lineage proliferated, survived in other parts of the world.

The fossil history of equids reveals that the progression between different equid species was not as smooth and consistent as was once believed. Though some transitions like molarisation of premolars were gradual, others like reduction in toes and increase in body size were abrupt. Since these changes were the adaptations required by the horse to survive the changing climate, it can be said that the evolution of horse was driven by climate change.

SAQ 1

a) Fill in the blanks.

1. ______________________ is the family of horses.
2. ______________________was the first horse genus.
3. ______________________ is the possible place of origin of horse.

b) Match the following:

(i) Dog-like padded feet	(a) *Merychippus*
(ii) Mountain horse	(b) *Parahippus*
(ii) A mixed feeder	(c) *Orohippus*
(iv) The horse with a new looks	(d) *Eohippus*

c) What is *Equus*?

11.4 ACTIVITY

You will find the generalised evolutionary sequence of horse from *Hyracotherium* to *Equus* through the Cenozoic era in the Fig. 11.6. In this figure, some evolutionary stages of horse are missing. Here you have to do following three things:

Here you have to do three things:

i) identify the missing stages,

ii) write them at an appropriate level in the sequence and

iii) mark the boundary between browsing and grazing horses.

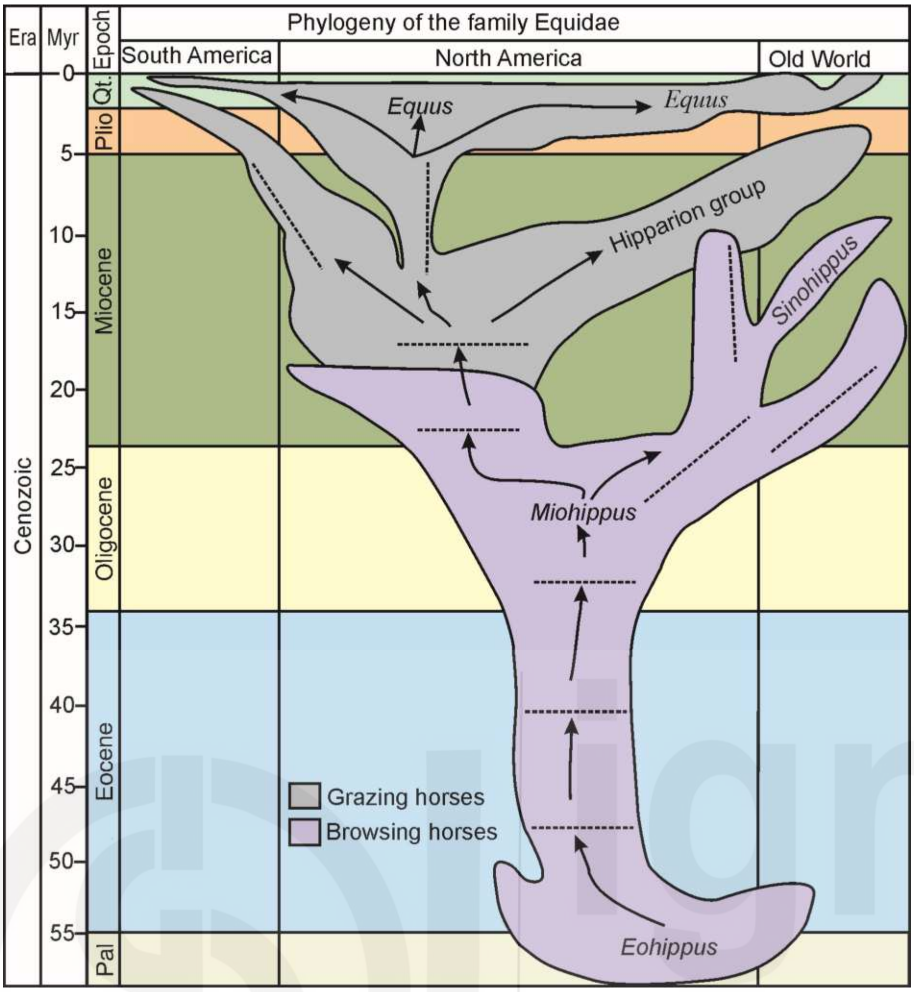


Fig. 11.6: Evolutionary sequence of horse. Pal stands for Palaeocene, Plio for Pliocene and Qt for Quaternary.

11.5 SUMMARY

Let us quickly summarise what you have learnt in this unit.

- Horses are odd toed ungulates like the rhinoceros and tapirs that have 1, 3 or 5 numbers of toes on their hand and feet and thus, belong to the order Perissodactyla.
- Equidae is the family of horses. It comprises a single extant genus *Equus*.
- Ancestor of the horses first appeared in North America during the Eocene epoch.
- The evolutionary sequence of Equidae from the oldest to the modern horse comprises *Eohippus – Orohippus – Epihippus – Mesohippus – Miohippus – Parahippus –Merychippus – Dinohippus – Equus*.
- The evolution of horse involves increase in body size, lengthening of legs and feet, reduction of toes, modification of dentition, deepening of the front portion of the skull and of the lower jaw, lengthening of the face and increase in brain size.
- The major evolutionary changes among the horse were brought by change in environmental conditions such as retreat in forest cover and spread of grasslands.

11.6 TERMINAL QUESTIONS

1. Write in brief on the major trends of evolution of horse.
2. Describe the phylogeny of horse.
3. Discuss the role of climate in the evolution of horse.

11.7 REFERENCES

- Benton, M.J. (2005) Vertebrate Palaeontology, 3rd edition, Blackwell Science Ltd., USA.
- Colbert, E.H. (1980) Evolution of the Vertebrates – A history of the backboned animals through time. John Wiley & Sons, USA, Pp. 379-384 and 425-437.
- Colbert, E.H. and others (2012) Colbert's Evolution of the Vertebrates – A history of the backboned animals through time, Wiley India (Pvt.) Ltd., New Delhi (reprinted).
- MacFadden, B.J. (1992) Fossil Horses: Systematics, Paleobiology, and Evolution of the Family Equidae, Cambridge University Press, Cambridge.

11.8 FURTHER/SUGGESTED READINGS

- Colbert, E.H. and others (2012) Colbert's Evolution of the Vertebrates – A history of the backboned animals through time, Wiley India (Pvt.) Ltd., New Delhi (reprinted).
- Jain, P.C. and Anantharaman, M.S. (1996) Palaeontology – Evolution and Animal Distribution, Fourth Edition, Vishal Publications, Jalandhar.

11.9 ANSWERS

Self Assessment Questions

1. (a) Equidae.

   (b) *Eohippus.*

   (c) North America.
2. (i) - (d), (ii) - (c), (iii) - (b), (iv) - (a)
3. *Equus* is a genus of all modern equines. It first arose around 5 Myr ago from *Dinohippus*. The first *Equus* was 52 inches (1.3 m) tall (a size of pony), with a rigid spine, long neck and legs, fused leg bones with no rotation, long nose, flexible muzzle and a deep jaw. The brain was a bit larger than that of *Dinohippus*. *Equus* soon diversified into several species that co-existed with other horses. *Equus* like *Dinohippus* is single-toed. However, its teeth are straight and higher-crowned than *Dinohippus*.

Terminal Questions

1. Refer to subsection 11.2.3.
2. Refer to subsection 11.2.4.
3. Refer to section 11.3.

UNIT 12

PLANT FOSSILS AND GONDWANA FLORA

Structure

12.1 INTRODUCTION

The animals, plants and micro-organisms are the three main life forms surviving today. Even their fossilised remains are found in rocks that tell us about their past history. The animals comprise invertebrates and vertebrates. In Block 4, you will read about the invertebrates and their geological history that began in the latest Precambrian time. You also read about the microfossils in Unit 10 that too have a long geological record beginning from Precambrian onwards. In Unit 11, you read the evolutionary history of one of the vertebrate groups i.e., horse. In this unit, you will read the plant fossils and the Gondwana flora of India.

Like the kingdom Animalia, plants also form a separate kingdom known as the **Plantae**. It is thought that plants appeared first in the Precambrian, but their fossil record is poor. It is also proposed that earliest plants were aquatic and during the Ordovician period a transition from water to land took place that gave rise to non-vascular land plants. However, it was during the Silurian period, that the vascular plants appeared first on the land. The flowering plants emerged rather recently, during the Cretaceous period. It is interesting to note that plants, whether living or dead, are beneficial to humans, as living plants provide the continuous supply of oxygen and food and dead remains form the huge coal deposits that meet our energy demand.

The fossil record of plants as a whole is sporadic because they have a low preservation potential and as such fossilised remains of plant fossils largely comprise materials such as leaves, cones, barks, flowers and petrified wood. In this unit, we will discuss about the plant fossils and classification of plants, their modes of preservation and applications. We will also discuss about the Gondwana flora of India and the morphological characters of some of the important Gondwana plant fossils.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define plant fossils and classify the plants;
- ❖ discuss the modes of preservation of plant fossils;
- ❖ elaborate the significance of plant fossils
- ❖ discuss Gondwana flora; and
- ❖ describe some common forms of plant fossils.

12.2 PLANT FOSSILS

Before discussing the plant fossils, it is important to introduce know you to what plants are. We have read in our school text that plants are multi-cellular organisms which by way of photosynthesis manufacture food. In nature, there exist many other organisms that can manufacture their food, but all of them are single-celled organisms whereas only the true plants, also called as **metaphytes** are multi-cellular organisms that can manufacture food.

Another important feature in plants is the alternation of generations of two morphologically distinct vegetative phases, the gametophyte and the sporophyte (Fig. 12.1). In the gametophyte generation, plant is composed of haploid cells that produce the sex cells- the gametes. The gametes fuse to form diploid zygotes which then initiate the development of the sporophyte generation- the spore-producing stage of the plants. The germination of spores produces the next gametophyte generation. In the plants that made their appearance earlier in the geological time the gametophyte generation dominated and continues as such in the primitive surviving forms such as mosses. On the other hand, the plants that appeared later in the geological time, the sporophyte stage dominates such as in ferns, gymnosperms and angiosperms.

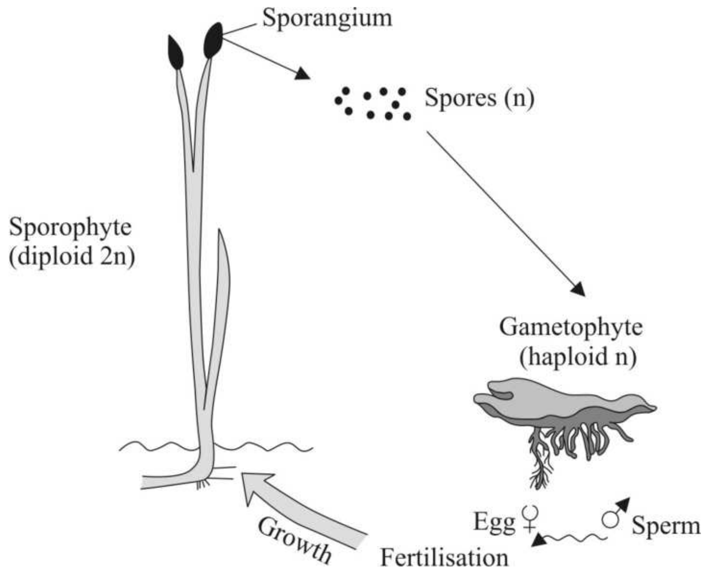


Fig. 12.1: Plant life cycle showing alternation of generations.

12.2.1 Definition

Plant fossils are the remains of the past plant life that have been preserved in sediments of the Earth's crust. The study of fossil plants falls into two disciplines, palaeobotany and palynology. **Palaeobotany** deals with the study of macroscopic (visible with the naked eye) plant remains such as leaves, petrified wood, flowers or seeds. **Palynology** involves the study of microscopic (visible with the microscope) plant remains such as pollen and spores. Palynology is usually treated as a branch of micropalaeontology.

12.2.2 Classification

The present scientific understanding suggests that plants have originated from algae to which they are closely related. The algal groups and plants together form a clade termed as the **Chlorobionta** that are all characterised by the possession of chlorophyll and similarities of their chloroplasts. Plants within this larger clade are sub-grouped as a major group **Embryophyta** that is characterised by alternation of generations. All plants make food and in order to do so they require sunlight, carbon dioxide and water. The water from roots to the leaves and the manufactured food from the leaves to the different parts of the modern plants distributes by way of vessels. However, this was not the same in the plants that made their appearance during the early stages of the plant evolution.

There are many classifications of plants, but they are classified broadly into four following groups:

- Thallophyta
- Bryophyta
- Pteridophyta
- Spermatophyta

Thallophytes, bryophytes and pteridophytes are seedless and flowerless plants and together they are all called as the **Cryptogams** whereas spermatophytes including gymnosperms and angiosperms are seed and flower-bearing plants, respectively, and termed as **Phanerogams**. The embryophytes include bryophytes, pteridophytes and phanerogams.

(i) **Thallophyta**

Plants belonging to the phylum Thallophyta are single as well as multi-celled and most of them are of primitive type. They vary in size and range usually from single-celled micro-organisms to large sea-weeds. The body of thallophytes is normally not differentiated into root, stem or leaves; rather it is made of a uniform mass of vegetative tissues known as thallus. They occur in water (both marine and freshwater) as well as on land. Algae is one of the dominant groups of thallophytes, other groups include fungi, bacteria, diatoms and lichens. They range in age from Precambrian to present.

(ii) **Bryophyta – Non-vascular plants**

The term Bryophyte is derived from Greek "Bryon" meaning "moss" and "Phyte" meaning plant and hence, it refers to a group of plants that contain moss. Bryophytes are considered as the first land plants. They are rather simple, small, non-vascular plants (Fig. 12.2a) that are more advanced than thallophytes and are found in a wide variety of habitats, but commonly thrive in marshy and swampy areas. Bryophytes are highly diverse and at present this group has more than 25,000 living species. They comprise mainly three distinctive groups such as mosses, liverworts and hornworts. It may be noted that bryophytes exhibit some peculiar adaptations to life on land. For example, they possess a waterproof cuticle on their stems and leaves to prevent the loss of moisture due to evaporation under dry conditions whereas some forms developed root-like structures known as rhizoids that attach them in the substrate in order to get food from soil. Bryophytes have a poor fossil record possibly due to their low preservation potential. They probably appeared first during the Ordovician period and are still living today.

(iii) **Pteridophyta – Vascular plants with no true seed and flower**

The term Pteridophyte is derived from two Greek words "Pteryz" meaning "winged" and "Phyto" meaning "plant". Hence, it refers to a group of plants that has a wing-like appearance of leaves. Pteridophytes (pronounced as teridophytes and initial "p" is silent) are vascular plants with no true seed and flower and are more advanced as compared to the bryophytes. The vascular system of pteriodophytes is made up of a series of vessels that include xylem and phloem in which nutrients are translocated. The pteridophytes possess leaves, roots and true stems (Fig. 12.2b). Moreover, their roots are well-developed that can penetrate deep into the soil or substrate in search of nutrients. In addition to the vascular system, pteridophytes possess epidermis (skin), an outermost cellular layer that covers the whole body of plants and also provides protection to them during their growth. All these innovations make pteridophytes more suitable to live on the land. Ferns or filicales, horsetails or equisetales, club-mosses or lycopodiales and sphenophyllales are the main groups of pteridophytes. The pteridophytes have a long geological history. They appeared first during the Silurian period and are still surviving today. Pteriodophytes were dominant on the land during the Late Palaeozoic era, which is also known as the "**Age of Pteridophytes**" in the history of plants.

Fig. 12.2: Living members of plants: a) bryophyte; b) pteridophyte; c) gymnosperm; and d) angiosperm. (Courtesy: Dr. S. Pant, BGSB University, Rajouri)

(iv) **Spermatophyta- The vascular plants with seed and flower**

Spermatophytes are the vascular plants that produce seed and are also known as seed plants. The distinctive features of spermatophytes include the development of a pollen tube and the production of seeds. They appeared first during the Devonian period. Spermatophytes are classified into two groups: gymnosperms and angiosperms.

(a) **Gymnosperms**: The term gymnosperms is derived from the Greek words “Gymnos” means “naked’ and “Sperma” means “seed” and hence refers to a group of naked-seeded plants. These are seed-bearing plants. The seeds of gymnosperms are naked and are not enclosed in the ovaries as in case of angiosperms. Conifers, cycads, gnetophytes and *Ginkgo* are the main groups of gymnosperms. However, pine (conifers) is one of the dominant forms of the gymnosperms (Fig. 12.2c). It is thought that gymnosperms evolved from seedless plants. They range in age from Devonian to present and were a dominant component of the ecosystem during the Carboniferous.

(b) **Angiosperms**: The term Angiosperm is derived from the Greek words “Angeion” means “vessel” and “Sperma” means “seed” and hence refers to a group of plants whose seeds are enclosed in protecting vessels or within a fruit. These are true flowering plants (Fig. 12.2d) and commonly differ from gymnosperms by the fact that the seeds of angiosperms are enclosed in protecting vessels or ovaries. Monocots and dicots are the two main groups of angiosperms. **Monocots** are characterised by having a seed with one cotyledon or seed leaf, leaves with parallel veins and well-developed flowers. Grasses and palm trees are typical examples of monocots. **Dicots** are characterised by having a seed with two cotyledons or seed leaves, leaves have veins with a net-like network and their stems are thicker at the bottom. Oak and poplar trees are some examples of dicots. Angiosperms appeared first during the Early Cretaceous and are still surviving as a dominant plant group on the Earth.

Did you know: The first land plants to appear were the bryophytes, well preserved specimens of which are known from Middle to Late Silurian times. However, indirect evidence for the presence of plants prior to Silurian such as soils with root-like structures is known since long from the Ordovician. Recent discovery of plant spores as old as 470 million years (Middle Ordovician) from Oman (Wellman et al. 2003) having affinities with liverworts provides definite evidence that land plants made their appearance by the Middle Ordovician.

12.2.3 Modes of Preservation

The fate of most organic material produced by living systems is to be decomposed to carbon dioxide and water, and recycled into the biosphere. The fact that organic matter is present in many sedimentary rocks indicates that the decomposition is not 100% and plants and other organic remains get preserved as fossils. Plants become fossilised in a variety of ways. Each type of preservation carries different information about the once living organism. Also not all organic compounds are equally resistant to degradation and decay. Plant cell walls are composed primarily of the polysaccharide polymer cellulose and are far more likely to escape decomposition than internal membranes and organelles, which are rich in protein, lipids and sugars. Secondary compounds, such as those impregnating or covering cell walls are also resistant to decomposition such as lignin, wax, cutin and sporopollenin, which forms the external shell of spores and pollen (Benton and Harper, 2009; Milson and Rigby, 2010).

For the preservation of plant fossils, three conditions are required:

- Rapid burial in sediments,
- Reducing burial environment, i.e., absence of oxygen and
- Fixing of the organic material to retard anaerobic decay.

Consequently, plant fossils are well preserved in environments that are very low in oxygen because most decomposers require oxygen for metabolism. Such sediments are commonly gray, green or black in colour. Plant fossils are usually found in fine-grained sediments such as sand, silt or clay and also in association with organic deposits such as peat (coal). Six modes of preservation of plant fossils are commonly recognised, and are listed below:

- Compressions
- Impressions
- Casts and Molds
- Permineralisation
- Compactions
- Molecular Fossils

(i) **Compressions**

Compressions are plant remains that have suffered physical deformation such that the three dimensional plant parts are compressed into two dimensions. Compressions preserve organic matter such as leaves that often retain cuticles. Peat too is a compression, a thick accumulation of plant debris relatively free of mineral sediment. Compressions are excellent records of external form, especially for planar structures like leaves.

(ii) **Impressions**

Impressions, like compressions, are two dimensional imprints of plants found most commonly in fine-grained sediment such as silt or clay (Fig. 12.3). However, unlike compressions they are completely devoid of any organic matter. In fact, impressions are compressions without organic material. The impressions of plants preserved in the fine-grained sediments contain remarkable details of original external form of plants. Impressions, like compressions, record information about external shape and morphology of plant organs. Leaves are among the most common organs preserved as impressions.

Fig. 12.3: Photograph showing impressions of fossil leaves.

Let's try to think what is the type of mode of preservation in a rock which when split apart was found to have plant imprints on its two slabs. The organic matter, however, was adhered to only one side of the rock. In this case, the side with the organic material is the **compression**, while the corresponding side without the organic material is **impression.**

(iii) **Casts and Molds**

When sediment is deposited into cavities left by the decay of plant parts, a cast is resulted. A mold is essentially a cavity left in the sediment by the decayed plant tissue. Casts and molds usually lack organic matter. Casts and molds may be found together with the cast filling the mold. Molds are formed when soft sediment surrounding the structure lithifies or hardens before the structure decays. When the mold gets filled with sediment that subsequently hardens, a cast is formed. Casts and molds record external or sometimes internal organ features. Unlike compressions and impressions, molds and casts often are true records of the original three dimensional shape of the plant structure.

(iv) **Permineralisation**

It occurs when the plant tissues are infiltrated with mineral rich fluid. Minerals like silica, calcium carbonate, phosphate or pyrite precipitate in cell and intercellular spaces, thus preserving internal structures of plant parts in three dimensions. This type of preservation is also known as the "structural preservation" of organic material and thus, permineralisations yield detailed information about the internal structure of the once living plant. The mineral matter many times replaces the cell-wall and other internal structures wherein, the organic material is lost (Fig. 12.4). Such kind of preservation is called petrifaction. The permineralised wood thus preserves the cellular detail of wood anatomy and the lignin of cell walls (i.e., organic matter) by mineral in filling whereas petrified wood on the other hand lacks cellular preservation and organic matter.

Fig. 12.4: Petrified fossil wood.

Do you know?

Silica permineralisation (silification) occurs in areas where silica-rich volcaniclastic sediments are weathering such as the famous upright trees of Yellowstone National Park, USA, whereas, permineralisation with calcium carbonate (calcite or dolomite) is particularly common in coal seams, where peat gets permineralised as “coal balls” such as in Carboniferous coal seams. Coal balls are rounded to ellipsoidal fossils that preserve plant remains.

(v) **Compactions**

In compaction, plants retain their external form with only slight volume reduction i.e., it is three dimensional. Compactions possess organic material and are not mineralised. Compactions are common in peat, brown coals (lignite) and soft sediments and more so if the fossils are younger. Pollen and spores are often preserved as compactions. Internal structure, especially of thick walled hard fruits, is sometimes well-preserved as compactions.

(vi) **Molecular Fossils**

Break down products of chlorophyll, carbohydrate and lignins preserved in fossil leaves and lipids and their derivatives in sediments are the examples of molecular fossils. Molecules of oleananes, formed by flowering plants, some ferns and lichens are more usually found preserved in sediments. Rarely, but genetic material DNA and RNA too gets preserved. The preservation of these chemical products of plants is highly variable. Further, it depends on oxygen levels during deposition and temperatures experienced by the rocks since preservation.

SAQ 1

a) Match the following

(i) Compression	(a) Plant remains infiltrated by mineralising solutions.
(ii) Impression	(b) Plant imprints having organic matter.
(iii) Compaction	(c) Plant imprints lacking organic matter.
(iv) Perminerlisation	(d) Plant remains with little reduction in volume.

b) Flower-bearing plants are known as ---------------- .

c) List the four groups of plants.

12.2.4 Significance

Plant fossils are significant in many areas of geology. They have played a key role in correlating sedimentary sequences, reconstructing past geography, climate and ecology, in addition to understanding plant evolution on the Earth. Let us discuss some of the important utilities of plant fossils.

1. Correlation of rock units which are widely separated geographically based on similar fossil leaves, seeds, etc.
2. Fossil plants have been used in palaeogeographic reconstruction i.e., reconstructions of the palaeoposition of continents with respect to each other. Recall, the presence of the *Glossopteris* flora during the Carboniferous - Permian times in South America, Africa, India, Antarctica and Australia as discussed in Unit 9. This plant has been cited as evidence for the formation of these landmasses into a supercontinent known as Gondwanaland.
3. Palaeoecology, the study of the past ecology, can also be deduced from the fossils. The principle means of inferring palaeohabitat is through the assumption that the habitat preferred by modern analogues is that of fossil relative. Using this uniformitarianism principle (i.e., present is the key to the past), the area from where fossils plants are recovered, its palaeoecology can be reconstructed.
4. An important application of plant fossils is determining the palaeoclimate, i.e., the climate of the past. In this regard, several approaches have been made over the years, a brief account of which is given here.
   (i) The Nearest Living Relative (NLR) method is based on the premise that climatic preferences of the fossils are similar to those of their NLR. Thus, in order to infer past climates comparison of as many fossils as possible within a flora to their most closely related living taxa is made. The more species in a fossil flora that have NLRs, the more precise is the palaeoclimatic interpretation. Also, more closely a fossil taxon is related to an extant one, more precise is the result. The method is particularly useful when dealing with Cenozoic floras, as these are more likely to have close living relatives. Further back in time, the method is less effective as older fossil taxa do not have close living relatives.

   (ii) Upchurch and Wolfe (1987) established ways of assessing palaeotemperatures and rainfall measures based upon the plant morphology drawing analogy with the modern ones as:

   (a) largest leaves are found in tropical rain forest, and size diminishes as temperature and moisture decline

   (b) in tropical areas leaves have entire (unbroken) margins (Fig. 12.5a), whereas in temperate areas there are many more leaves with toothed margins (Fig. 12.5b)

   (c) leaves from tropical rain forest species have elongated tips to allow water to clear the leaf during excessive downpours (Fig. 12.5c)

   (d) the proportion of deciduous trees (those that shed all their leaves simultaneously in winter or during the dry season) to evergreens is highest in temperate zones

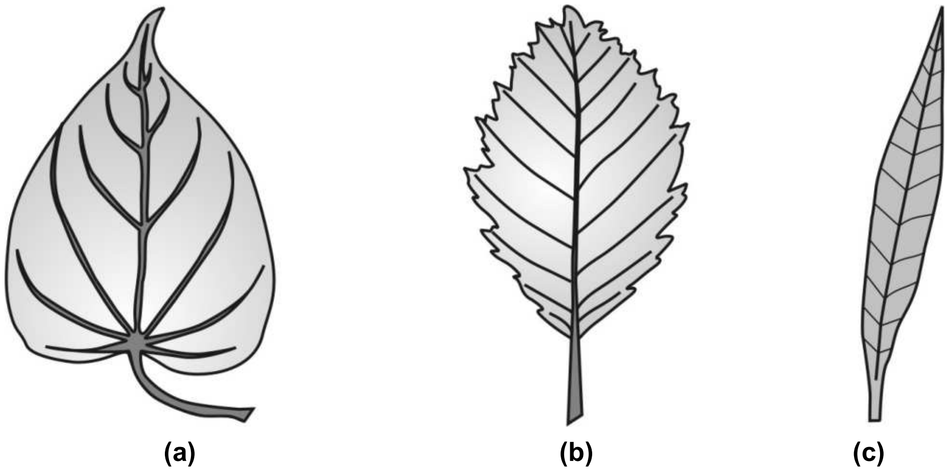


Fig. 12.5: Morphology of leaves: a) smooth margin; b) toothed margin; and c) elongated tip leaves.

5. Dendrochronology or tree ring dating is a method of dating based on the analysis of patterns of tree growth rings. It is used to determine the age of archeological sites by studying the growth rings present in the wood that has been used for construction, paintings, furniture, etc.
6. In addition, the fossilised plant organic material serves as a sample for carbon dating, as well as for stable isotope studies for determination of past levels of salinity, temperature and carbon dioxide content.

12.3 GONDWANA FLORA OF INDIA

Prior to discussing the Gondwana flora of India, it is pertinent to learn about the Gondwana and Gondwana Supergroup. Gondwana is the name given to the southern part of the supercontinent Pangaea. It has been proposed that Pangaea existed from approximately 510 to 180 million years (Myr) ago. About 200-180 Myr ago, Pangaea broke into two landmasses. The southern landmass is termed as Gondwana and northern one as Laurasia. Gondwana included the modern landmasses of South America, Africa, Antarctica, Australia, Madagascar and the Indian subcontinent which today are separated from one another, whereas the Laurasia includes North America, Europe and Asia excluding India.

In India, the Upper Carboniferous/Lower Permian to Lower Cretaceous sedimentary basins of peninsular India are grouped into the Gondwana Supergroup. It is named after the Gond Kingdom of Central India (Madhya Pradesh), where these rocks were first discovered. It may be noted that the name Gondwana is used for the southern landmasses such as South America, Africa, Antarctica, Australia, Madagascar and India, and, Gondwana Supergroup is used for Gondwana sedimentary basins of India. The Gondwana basins of India occupy 50,000 sq. km area and are present along six linear belts such as Damodar basin, Rewa basin, Wardha valley, Pranhita-Godavari basins, Mahanadi basin and Rajmahal basin. Based on plant fossils the Gondwana Supergroup is classified into two groups: the Lower and the Upper Gondwana (Table 12.1). The Lower Gondwana Group is characterised by the presence of *Glossopteris* flora while Upper Gondwana is characterised by *Dicroidium-Ptilophyllum* flora.

Table 12.1: Classification of Gondwana Supergroup

Supergroup	Group	Floral Phase	Age
Gondwana	Upper Gondwana	*Ptilophyllum*	Jurassic to Lower Cretaceous
	Lower Gondwana	*Glossopteris*	Upper Carboniferous / Lower Permian to Triassic

(i) ***Glossopteris* Floral Phase of the Lower Gondwana Group**

In the Late Carboniferous-Permian times the Gondwanan landmasses were covered by ice because of which the flora was scanty. The flora during this time comprised forms such as *Gangamopteris*, *Noeggerathiopsis*, *Plicatipollenites* and *Potoniciporites*. The leaves of these plants were small in size, with fine venation and absence of a mid-rib such as in *Gangamopteris*.

As the glaciers started retreating by Permian times both land and higher temperatures were available for the growth of plants such that leaves of *Gangamopteris* as large as 8 cm in length have been recorded. Also conifer like *Paranacladus* made its appearance. Later in the Permian itself, leaves of *Gangamopteris* as long as 35 cm and 8 cm wide grew. Plants started to diversify. About 14 species of *Gangamopteris* and 11 of *Noeggerahiopsis* are reported from the Lower Permian deposits. Gymnosperms like *Buriadia* too made its appearance as did the ferns. The *Gangamopteris*, however, declined and finally became extinct giving way to *Glossopteris*.

Glossopteris, another important Lower Gondwana plant appeared during this time and soon became the most diversified taxon at species level that lasted on the Gondwanaland until the Triassic time. The plant leaves in the Late Permian with the onset of warm and moist conditions grew in size. Leaves of *Glossopteris* were about 60 cm in length, 15 cm wide with a 1.5 cm thick petiole. The leaves possessed a mid-rib and reticulate venation. About 70 species of *Glossopteris* are known to have existed on the former Gondwanan landmasses. This time of the Gondwana history, because of the dominance of the *Glossopteris*, has been called as *Glossopteris* floral phase and the rocks yielding the plant assemblage as discussed above represent the Lower Gondwana flora.

During the Triassic *Glossopteris* was present, but its numbers had fallen sharply as the climate changed from warm temperate to semi arid. *Glossopteris* flora finally became extinct by the Middle Triassic. This was replaced by *Thinfeldia* (also referred to as *Dicroidium*) as the dominant flora of the Triassic Gondwanaland. In the lower part of the Triassic, along with *Thinfeldia* plants like *Lepidopteris*, *Cycadopteris*, and *Neocalamites* lived on the Gondwanaland. The leaves of the plants were forked, having a thick rachis and cuticle all indicating semi-aridity. However, towards the upper part of the Triassic with the return of warm and humid conditions plants like *Pterophyllum*, *Taeniopteris* and *Pseudopteris* made their appearance in addition to the continuation of *Thinfeldia*. Conifers like *Podozamites* and *Araucarites*, ferns like *Cladophlebis* and *Parsoraphyllum* as well as *Ginkgo* and *Baiera* were present, but rare. The dominance of *Thinfeldia* throughout the Triassic has led some of the geologist to call this time period as the ***Thinfeldia* floral phase** and divide this part of the Gondwanas as Middle Gondwana whereas the continuation of *Glossopteris* during this time though in less numbers has been suggested by others to be clubbed as part of the *Glossopteris* floral phase and, therefore, as part of the Lower Gondwana thereby dividing the Gondwana Supergroup into the Lower and the Upper Gondwana rather than into the lower, middle and upper.

(ii) ***Ptilophyllum* Floral Phase of the Upper Gondwana**

By the Jurassic times initial rupturing of the Gondwana landmasses began. The climate from warm humid in the beginning of the Jurassic changed to temperate and seasonal towards the end. This time period is marked by the dominance of *Ptilophyllum* flora characterised by the presence of *Ptilophyllum*, Equisetales, filicales, pteridosperms, cycadophytes, coniferales and ginkgoales throughout the Gondwana. During the Early to Middle Jurassic, the cycadales and ferns such as *Marattiaceae* and *Osmundaceae* that lived in warm and moist conditions whereas during the Late Jurassic to Early Cretaceous conifers and ginkophytes like *Ginkgoites* and *Brachyphyllum* became abundant as the annual climate became seasonal with hot and wet summers and cold and dry winters. Ferns like *Polydiaceae* and *Onychiopsis* though present were rare. This time period, because of the dominance of *Ptilophyllum*, is called as the *Ptilophyllum* floral phase and forms the upper part of the Gondwana.

Now, we will provide a brief description of some of the important plant fossils known from the Gondwana Supergroup.

12.4 DESCRIPTIONS OF SOME PLANT FOSSILS

In this section, we will discuss some important genera of plant fossils, which commonly occur in the Gondwana Supergroup of peninsular India. Gondwana Supergroup comprises a sedimentary succession that was deposited during the Upper Carboniferous/Lower Permian to Lower Cretaceous times. It contains huge coal deposits and yields well-preserved floral remains.

12.4.1 *Glossopteris*

Glossopteris is an extinct genus of Glossopteridales flora that once dominated the supercontinent Gondwana during the Permian. It is a leaf morphogenus. The leaf of *Glossopteris* is simple, spatulate (broad rounded apex and tapering base), petiolate, lanceolate (longer than wide and tapering to a point) to tongue-shaped with an entire margin. It is characterised by the presence of a mid-rib (Fig. 12.6a) made up of several parallel vascular strands that extend to near the leaf tip. The outer bundles of the mid-rib give off laterals that repeatedly dichotomise (divide into two parts) and anastomose (fuse together) to form a uniform reticulate (net like) pattern of veins. The upper surface of the leaf is devoid of stomata (an opening through which gas exchange takes place). The stomata on the lower surface are present.

Stratigraphic Range: Permian to Middle Triassic.

Distribution: *Glossopteris* is known from Australia, Antarctica, Africa, South America and India.

12.4.2 *Gangamopteris*

Gangamopteris is also an extinct genus of Glossopteridales flora. Like *Glossopteris*, it is also based on fossil leaves (Fig. 12.6b). It is a common element of the Permian Gondwana floras and its general morphology is like that of *Glossopteris*. *Gangamopteris* is generally found in the Lower Permian rocks, whereas *Glossopteris* is believed to have its greatest distribution in the Upper Permian rocks. The *Gangamopteris* leaf is simple and spatulate with a sessile base (without a stalk borne directly on an axis) and an entire margin. *Gangamopteris* is distinguished by the absence of a well-defined mid-rib and more uniform parallel to sub-parallel venation. The whole leaf of *Gangamopteris* has similar stomatiferous areas bounded by non-stomatiferous areas, another feature used for assignment of a fossil leaf to *Gangamopteris*.

Stratigraphic Range: Upper Carboniferous to Permian.

Distribution: *Gangamopteris* is widely known from India, Australia, South Africa and South America.

12.4.3 *Vertebraria*

The roots of *Glossopteris* and *Gangamopteris* plants are called *Vertebraria*. This genus is well preserved in form of compressions, impressions and petrified fossils. The form has a median ridge or depression with rectangular lateral segments present on its either side that give it the appearance similar to the vertebral column of vertebrates (Fig. 12.6c). The lateral segments alternate slightly.

Stratigraphic Range: Upper Carboniferous to Middle Triassic.

Distribution: *Vertebraria* is known from Australia, Antarctica, Africa, South America and India.

12.4.4 *Thinnfeldia*

The genus *Thinnfeldia* was historically used for *Dicroidium* like foliage (cluster of leaves) from the Northern Hemisphere. The fronds (a large divided leaf) of *Thinnfeldia* are bi- or multi-pinnate. The rachis (main axis of the frond) is broad and branched (Fig. 12.6d). The pinnules are linear with an entire or lobate margin. Mid-rib is prominent with numerous veins spreading from it. It is commonly found in the Upper Gondwanan formations of India.

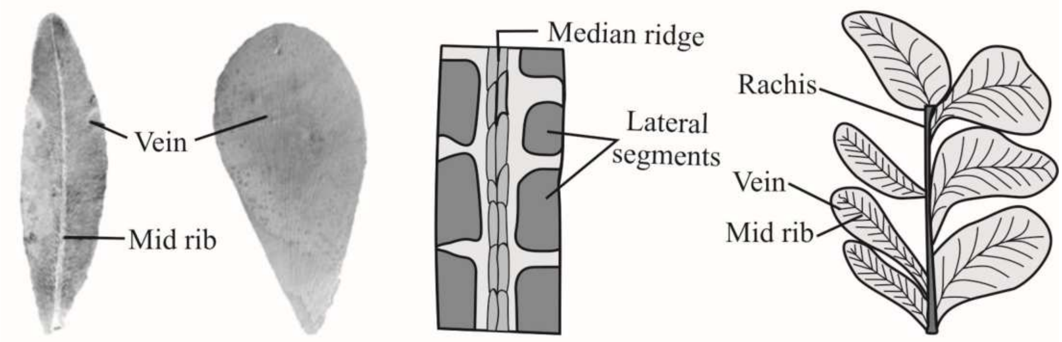
Stratigraphic Range: Upper Triassic to Jurassic.

12.4.5 *Sigillaria*

Sigillaria was a Carboniferous–Permian arborescent (tree-like) stem genus of a lycopod that was about 20 meter tall. The stem was straight and lacked extensive branching. The leaf bases left leaf scars on the stem that gave it a ribbed appearance (Fig. 12.7a). They were hexagonal to elliptical in outline. Though helically arranged leaves appear to be aligned in vertical rows. Sporangia were borne on the stem surface amongst the leaves.

Stratigraphic Range: Carboniferous to Permian.

Distribution: It is known from Europe, Asia and North America.



(a) (b) (c) (d)

Fig. 12.6: Plant fossils: a) *Glossopteris*; b) *Gangamopteris*; c) *Vertebraria*; and d) *Thinnfeldia*.

12.4.6 *Nilssonia*

Nilssonia is a leaf genus. The leaf is compound with a broad rachis and rectangular leaflets that are attached by the whole base to the rachis (Fig. 12.7b). The rachis is ridged and the venation is parallel running from the base to the apex of the leaflet. Leaflets have an entire margin with the lamina (flattened blade portion) attached to the upper surface of the rachis. *Nilssonia* foliage was produced by members of Cycadales. The leaves were arranged in dense clusters on the distal portion of the shoots.

Stratigraphic Range: Upper Triassic to Cretaceous

Distribution: *Nilssonia* is known from Europe, North America and India.

12.4.7 *Williamsonia*

Williamsonia was a small tree about 2.0 m tall with a crown of pinnate leaves at the apex. The trunk had scars that marked the former position of scaly, helically arranged leaves (Fig. 12.7c). Sporangia, the reproductive organs were borne among the leaf bases on the trunks. It had slender branching stems with leaves widely separated along the stems. Permineralised remains of *Williamsonia* have been reported from the Jurassic of India.

Stratigraphic Range: Jurassic to Cretaceous.

Distribution: *Williamsonia* is known from Europe, North America, South America and India.

12.4.8 *Ptilophyllum*

Ptilophyllum is a leaf genus. The leaf is compound with a wide rachis and numerous lanceolate pinnules with an entire margin (Fig. 12.7d). The pinnules attach to the upper surface of the rachis obliquely. The pinnules are asymmetrically aligned on either side of the rachis having a broad base proximally (nearest to the axis or point of attachment) that tapers distally (farthest from the axis or point of attachment) into an acute apex. Forking between the pinnules occurs distally. Pinnules had a prominent mid-rib with veins arising from the entire region of attachment and running parallel to the margin.

Stratigraphic Range: Jurassic to Cretaceous

Distribution: It is known from South America, India, Antarctica, Australia, Europe, Russia and North America.

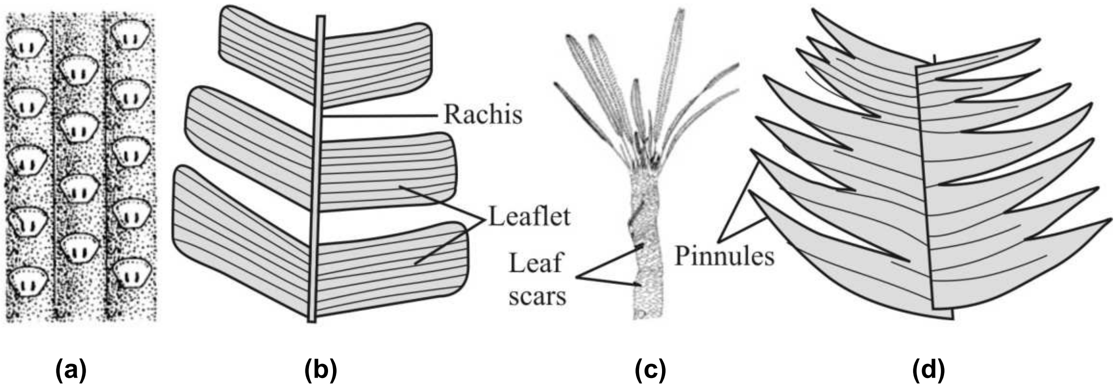


Fig. 12.7: Plant fossils: a) *Sigillaria*; b) *Nilssonia*; c) *Williamsonia*; and d) *Ptilophyllum*.

SAQ 2

a) Match the following.

(i) Glossopteris	(a) Upper Gondwana flora.
(ii) Ptilophyllum	(b) Lower Gondwana flora.
(iii) Dendrochronology	(c) Absence of well-defined mid-rib.
(iv) Gangamopteris	(d) Tree ring dating.

b) List the important plant fossils of the Lower Gondwana group.

12.5 ACTIVITY

Given below are line drawings of three plant fossils (Fig. 12.8). Label their various parts and identify them based on the morphological description.

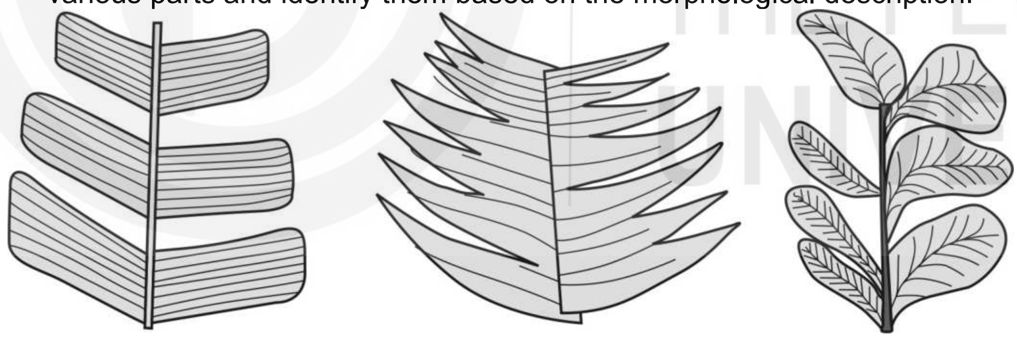


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Fig. 12.8: Line drawing of plant fossils.

12.6 SUMMARY

- Plant fossils are remains of the past plant life. The study of fossil plants falls into two disciplines, palaeobotany and palynology. Palaeobotany deals with the study of macroscopic plant remains, whereas palynology involves the study of microscopic plant remains.
- Plants are classified broadly into four following groups: thallophytes, bryophytes, pteridophytes and spermatophytes.
- Thallophytes have no well differentiated body parts such as root, stem or leaves. They range in age from Precambrian to Present. Bryophytes are

simple, small, non-vascular, first land plants and are more advanced than thallophytes. Pteridophytes are vascular plants with no true seed and flower. They range in age from Silurian to present.

- Spermatophytes are vascular plants that produce seed and also known as seed plants. These are classified into two groups: gymnosperms and angiosperms. Gymnosperms are seed-bearing plants and range in age from Devonian to Present. Angiosperms are flowering plants ranging from Early Cretaceous to Present.
- Rapid burial of plant remains in sediments, reducing burial environment and fixing of the organic material to retard anaerobic decay are the main conditions for the preservation of plant fossils.
- Compressions, impressions, casts and molds, permineralisation, and compactions are the main modes of plant fossil preservation.
- Plant fossils are significant for correlating sedimentary sequences, reconstructing geography, climate and ecology of the past and for documenting the plant history.
- *Glossopteris, Gangamopteris, Vertebraria, Thinnfeldia, Sigillaria, Nilssonia, Williamsonia* and *Ptilophyllum* are the important forms of the plant fossils, which are commonly found in the sediments of the Gondwanan Supergroup.
- On the basis of plant fossils, the Gondwana Supergroup is classified into the Lower and the Upper Gondwana groups. The Lower Gondwana Group is characterised by the presence of *Glossopteris* flora while the Upper Gondwana is characterised by *Dicroidium-Ptilophyllum* flora.

12.7 TERMINAL QUESTIONS

1. What are plant fossils? Discuss the main modes of their preservation.
2. Describe the various divisions of plants.
3. Plant fossils are very useful in Geology. Explain.
4. Discuss Gondwana flora of India.
5. Write short notes on the following:

   (i) *Glossopteris* (ii) *Vertebraria* (iii) *Williamsonia* (iv) *Ptilophyllum*

12.8 REFERENCES

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12.9 FURTHER/SUGGESTED READINGS

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12.10 ANSWERS

Self Assessment Questions

1. a) (i) – (b), (ii) – (c), (iii) – (d) and (iv) – (a).

   b) Angiosperms.

   c) The four major groups of plants are thallophytes, bryophytes, pteridophytes and spermatophytes.

2. a) (i) – (b), (ii) – (a), (iii) – (d) and (iv) – (c).

   b) The important plant fossils of the Lower Gondwana Group are *Glossopteris*, *Gangamopteris, Vertebraria, Schizoneura, Phyllotheca* and *Sphenophyllum*.

Terminal Questions

1. Refer to subsections 12.2.1 and 12.2.3.
2. Refer to subsection 12.2.2.
3. Refer to subsection 12.2.4.
4. Refer to section 12.3.
5. Refer to subsections 12.4.1, 12.4.3, 12.4.7 and 12.4.8.

Glossary

Acritarchs	:	A group of organic-walled microfossils that appeared first in the fossil record during the Precambrian times. They are widely used for Precambrian and Palaeozoic biostratigraphic studies. The name acritarch is derived from two Greek words acritos meaning unknown and arche meaning origin and hence, it refers to organisms of uncertain origin.
Benthic organisms	:	Those who live at the ocean bottom.
Calcite	:	A mineral with a composition of calcium carbonate. Most limestones are made of this mineral. Many organisms use it to build their skeleton and shell.
Carbonisation	:	A process of fossilisation, in which the organic substance after its burial is transformed into a thin carbon film.
Chert	:	A fine-grained siliceous microcrystalline sedimentary rock that may contain microfossils.
Chitin	:	A hard organic material usually made of protein and found in the skeleton of arthropods and sponges.
Coal	:	A carbon-rich sedimentary rock formed from the remains of fossil plants.
Cocoliths	:	Minute, individual calcareous plates or discs that occur as part of the protective covering of a group of the single-celled algae called coccolithophorids.
Crevasse	:	A deep crack in an ice sheet or glacier.
Cuticle:	:	A very thin waxy film covering the surface of plants, derived from the outer surfaces of the epidermal cells.
Diatoms	:	Small microscopic algae that appeared first in the Jurassic period.
Dinosaurs	:	A diverse extinct group of Mesozoic terrestrial reptiles.
Dinoflagellates	:	A group of organic-walled microfossils. They have both animal and plant-like characters. They appeared first in the Silurian period.

Evolution	:	The change of organisms over time.
Extinction	:	The complete disappearance of a species, genus or family.
Foraminifers	:	Mineral-walled microfossils that appeared first in the Early Cambrian period.
Fossils	:	Clues to the past life preserved in the rocks.
Fossil record	:	The totality of fossils preserved in all rocks of the world
Fossilisation	:	The process of fossil formation by which organic material is replaced by inorganic mineral matter.
Hadean Eon	:	An informal lifeless Eon for Precambrian times, which ranged from 4567 to 4000 million year ago.
Invertebrates	:	are animals without backbone that appeared first in the Late Precambrian times. Brachiopods, corals, molluscs, echinoderms and trilobites are common examples.
Microfossils	:	Remains of microorganisms that are usually less than 1 mm in size. They are so small that high-resolution microscope is used for their study. A very simple and well-known definition of microfossils is that these include all remains whose study requires a microscope.
Nanoplanktons	:	Small planktonic organisms ranging in size from 2 to 20 μm in size.
Palaeoclimate	:	The climate of some former period of geological time.
Palaeoenvironment	:	An environment of the geological past.
Palaeogeography	:	The distribution of land and sea over geological history.
Palaeontology	:	The study of life of the geological past. In American texts it is spelt as Paleontology
Petrifaction	:	A process of fossilisation by which organic material is replaced by inorganic matter.
Phanerozoic Eon	:	A broad division of geological time scale from 542 million years to present. It comprises Palaeozoic, Mesozoic and Cenozoic eras.

Phylogeny : The history or course of development of the evolution of a species or group.

Planktic organisms : Ogranisms live either on the surface of water or within the water column

Predation : An act of preying by a predator that kills and eats the prey.

Predator : An animal that preys on others.

Rachis : The main axis or a stem of a plant, especially a grass that bears flower stalks at short intervals.

Pyrite : An iron sulphide mineral.

Radiolarians : Mineral-walled single-celled microfossils that appeared first in the fossil record during the Cambrian period.

Sedimentary rocks : Layered or stratified rocks such as sandstone, limestone and shale, which are formed by the deposition of the sediments.

Sedimentation : The process of deposition of sediments layer by layer in a depositional basin.

Species : A group of closely related individuals that can interbreed.

Sporangium : A cell or structure in which spores are produced. It can be composed of a single cell or can be multi-cellular. Ferns, mosses, algae and fungi release spores from sporangia.

Taxonomy : A science of systematic classification of life into various ordered categories such as species, genus, family or kingdom.

Vertebrates : Animals having backbone such as fishes, amphibians, reptiles, birds and mammals.