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.

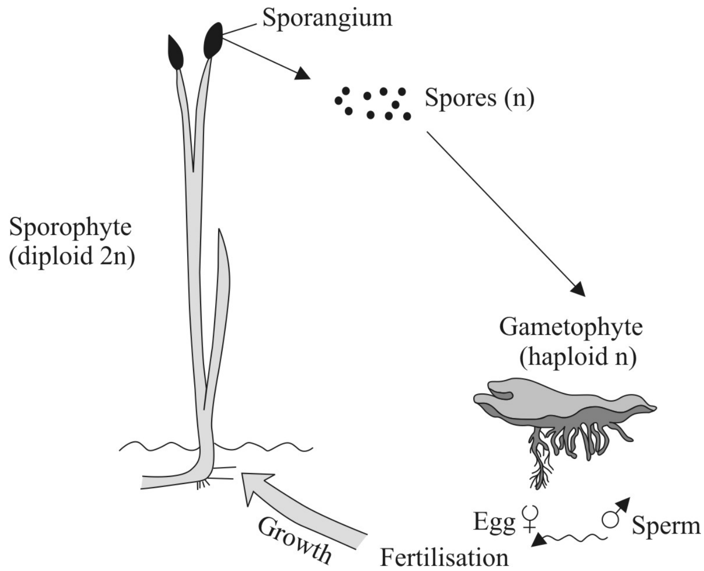


Fig. 12.1: Plant life cycle showing alternation of generations.

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.

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

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

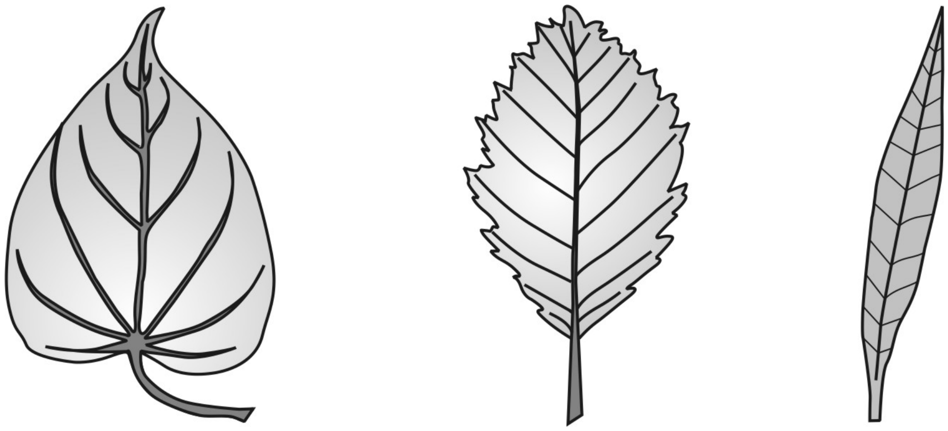


Fig. 12.5: Morphology of leaves: a) smooth margin; b) toothed margin; and c) elongated tip leaves.

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.

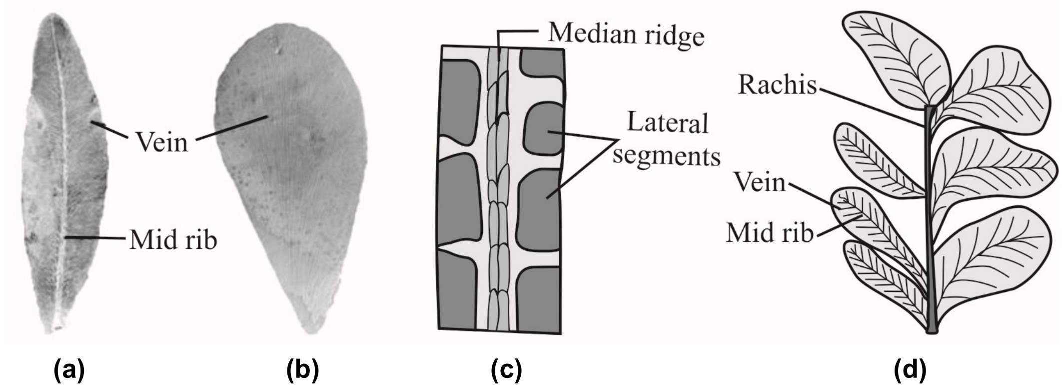


Fig. 12.6: Plant fossils: a) *Glossopteris*; b) *Gangamopteris*; c) *Vertebraria*; and d) *Thinnfeldia*.

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.

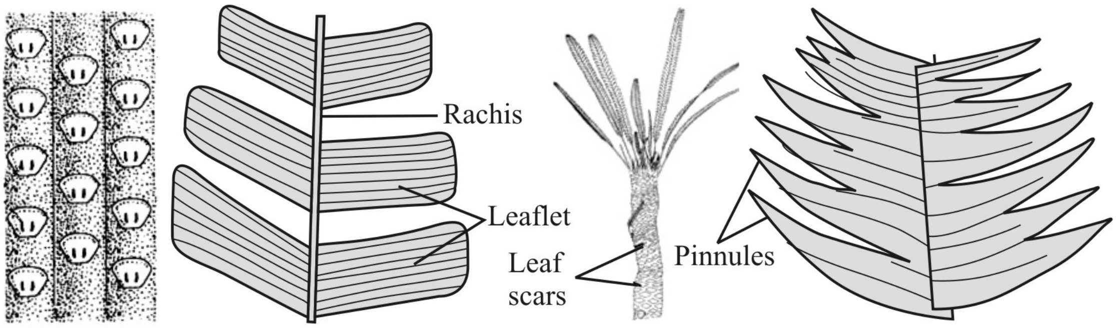
Distribution: *Williamsonia* is known from Europe, North America, South America and India.

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.



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

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.

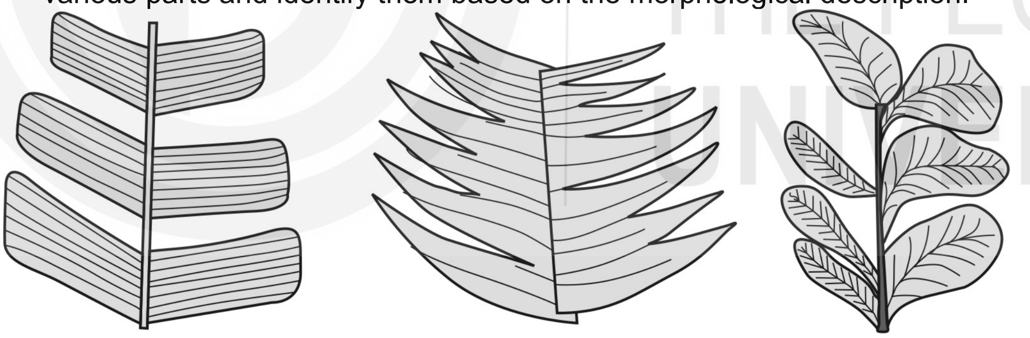


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Fig. 12.8: Line drawing of plant fossils.

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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- Wellman, C.H., Osterloff, P.L. and Mohiuddin, U. (2003) Fragments of the earliest land plants, Nature vol. 425, 282–285.

12.9 FURTHER/SUGGESTED READINGS

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- Shukla, A.C. and Mishra, S.P. (1975) Essentials of Palaeobotany, Vikas Publishing House Pvt. Ltd., Noida.

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.