BSCBO- 103

B.Sc. I YEAR

Pteridology, Gymnosperms and Palaeobotany

DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY

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BLOCK I: PTERIDOPHYTES

UNIT 1: GENERAL FEATURES (CLASSIFICATION, TELOME THEORY, STELAR SYSTEM, HETEROSPORY AND LIFE-CYCLE)

1.1 OBJECTIVES

This unit describes general features, classification, telome theory, stelar system, heterospory and life- cycle in pteridophytes. After reading this unit you will be able to:

- Describe habit and habitat of pteridophytes, their characteristics and classification.
- Relate telome theory with the origin of higher pteridophytes from the lower pteridophytes.
- Describe stelar variation and evolution of stele in pterdophytes.
- Understand the phenomenon of heterospory in pteridophytes and its significance.
- Explain life-cycle in pteridophytes.

1.2 INTRODUCTION

The term Pteridophyta is derived from Greek word **Pteron** meaning a feather and **Phyton** meaning a plant therefore, pteridophyta is a group of plants with feather like appearance. This group includes higher cryptogams which are also known as **Vascular Cryptogams**. The term **c**ryptogams (kruptos= hidden, gamos= wedded) was suggested by Linnaeus in 1754 for all non-flowering plants that reproduce by means of spores and do not produce seeds. The term **vascular** indicates the presence of vascular tissues (xylem and phloem) for the conduction of water and food. Thus, the vascular cryptogams or pteridophytes can be defined as an assemblage of seedless vascular plants that have successfully invaded the land and reproduce by means of spores.The main features of pteridophtes are:

1. These plants have an independent gametophyte and an independent sporophyte. This is contrast to the bryophytes where the sporophyte is a parasite on gametophyte and the gymnosperms and angiosperms where the gametophyte is a parasite on sporophyte.
2. The dominant phase of life-cycle is the sporophyte.
3. This was the first group of vascular plants to invade the land.
4. This was the first group to have a vascular system (xylem and phloem).
5. They do not produce seeds but produce spores.

They include most primitive living and fossil vascular plants. They are represented by about 400 living and fossil genera and some 10500 species. The fossil records indicated that these plants originated about 380 million years ago, in the Silurian period of the Palaeozoic era and formed dominant vegetation on earth during the Devonian period. The tree ferns, giant horse tails and arborescent lycopods dominated during this period.

1.3 GENERAL FEATURES OF PTERIDOPHYTES

Habit and Habitat: The plant body is sporophytic, differentiated into root, stem and leaves (except in the most ancient fossil pteridophytes and the most primitive living members of the group). They show much variation in their form, size and habit. They range from small annuals (e.g. *Azolla*, *Salvinia*) to large tree like perennials (*Angiopteris, Osmunda*). The

branching of the stem shows a range of variation. It may be monopodial and dichotomous. The adventitious roots arise on the stem or in many ferns on the petiole.

Most of the living pteridophytes are terrestrial, growing in moist and shady places. Some members (*Azolla, Marsilea, Savinia* etc) are aquatic and few forms grow (*Equisetum arvense*) in xerophytic habitats (Fig. 1.1).

A B

Fig. 1.1.Range of habitat A- Aquatic (*Salvinia*); B- Xerophytic (*Equisetum*)

The leaves are scaly (*Equisetum*), small and sessile (*Lycopodium*), or large, petiolate and compound (e.g. ferns) (Fig. 1.2). Based on size and venation pattern the pteridophytes are:

a. Microphyllous: Includes plants with small leaves. The microphyll is distinguished from the megaphyll by its simple venation (e.g. *Equisetum*, *Lycopodium*).

b. Megaphyllous: Includes plants with large leaves. Megaphyll is distinguished from microphyll by its complex venation (e.g. ferns).

A B C

Fig.1.2. Leaves in pteridophytes; A- scale leaves (*Equisetum*); B-microphyll (*Lycopodium*) ; C-megaphyll (*Dryopteris*).

Anatomical structure

The root and stem have well developed vascular system composed of xylem and phloem. Only the sporophyte shows any appreciable development of conducting tissues. The recorded instances of such tissue in gametophytes are rare and amount of xylem and phloem are scanty.

The stellar organizations are haplostelic protostele (*Selaginella*), plectostele (*Lycopodium*), siphonostele (*Equisetum*), dictyostele (*Pteris* and *Pteridium*) and polycyclic (*Marattia*) (Fig.1.3). The xylem is made up of tracheids and phloem has sieve tubes only. Except for lower group the photosynthetic tissue is restricted only to leaves. The megaphyll show differentiation of the mesophyll into palisade and spongy tissues. The root shows a diarch structure which is almost constant throughout the pteridophytes and has been regarded as a conservative organ.

Sporangia: They reproduce by spores produced in sporangia. The sporangia are borne either on the leaves called sporophylls or in axils between the leaves and the stem (Fig.1.4). Sporophylls are either uniformly distributed (*Pteris*) or are aggregated into compact ones (**strobilii**) at the apex of the stem (*Equisetum*). In aquatic forms like *Azolla* and *Marsilea* the sporangia are present within specialized structure called sporocarps. In some pteridophytes e.g. Filicales; the sporangia are aggregated in clusters known as **sorus/sori** Most of the pteridophytes produce only one type of spores and known as **homosporous** (*Lycopodium*) while some produce two different kinds of spore and known as **heterosporous** (*Selaginella*) (Fig.1.5).

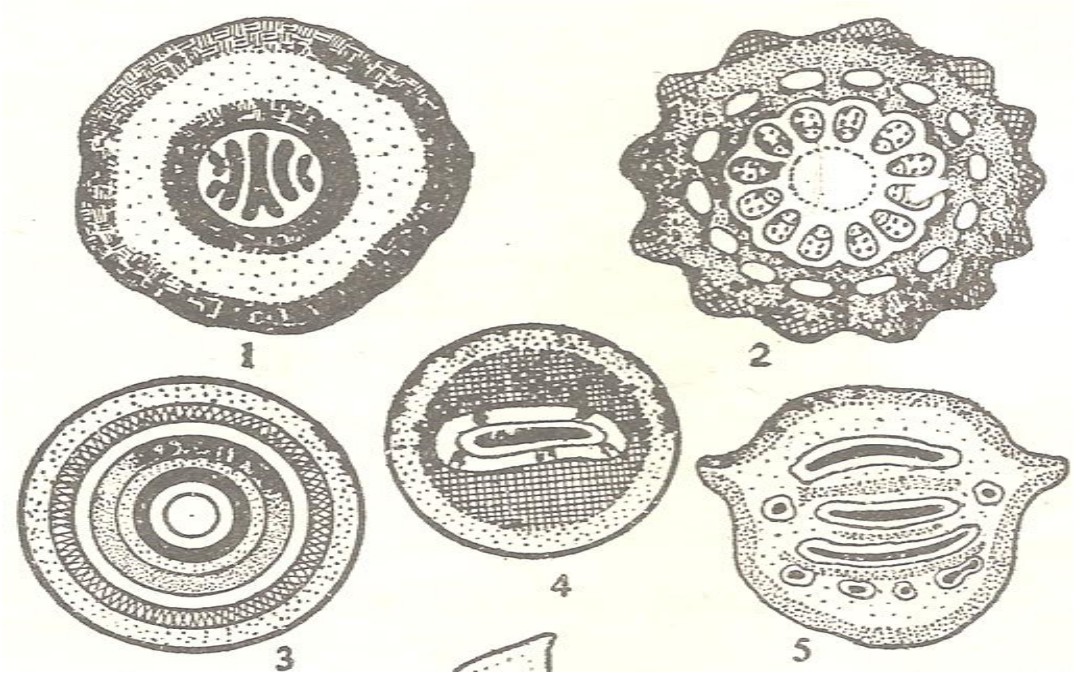
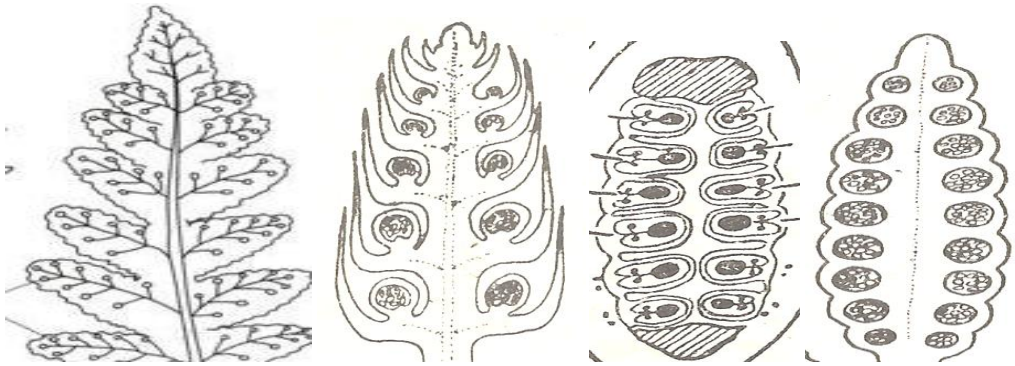
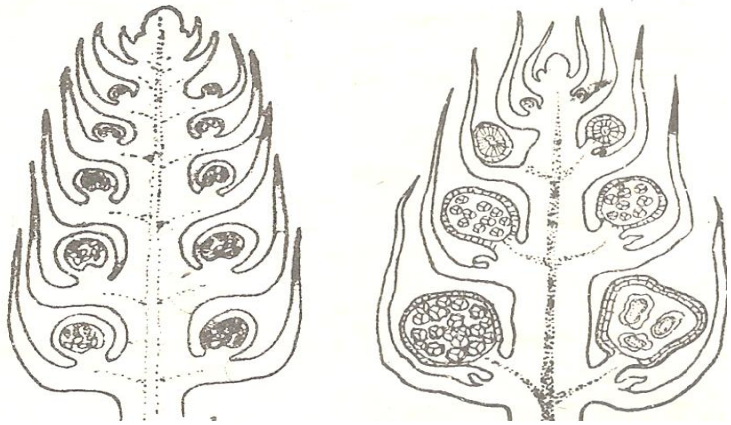


Fig.1.3. Variation in stele in pteridophytes.1-Plectostele (*Lycopodium*); 2-Siphonostele (*Equisetum*); 3-Polycyclic stele (*Marsilea*) 4- Haplostele (*Selaginella*): 5- Dictyostele (*Ptridium*).



A B C D

Fig.1.4. Range of sporangial structure in pteridophytes A- Sporophyll (*Dryopteris*); B- Cone (*Lycopodium*); C- Sporocarp (*Marsilea*); D-Sori (*Ophioglossum*).



A B

Fig.1.5.Types of sporangium A-Homosporous (*Lycopodium*); B- Heterosporous (*Selaginella*)

The development of sporangia may be

a. Eusporangiate- The large sporangium initiated from a group of superficial cells which by periclinal division gives rise to outer layer of primary wall cell and inner layer of sporogenous tissue. e.g. *Psilotum*, *Lycopodium* (Fig. 1.6).

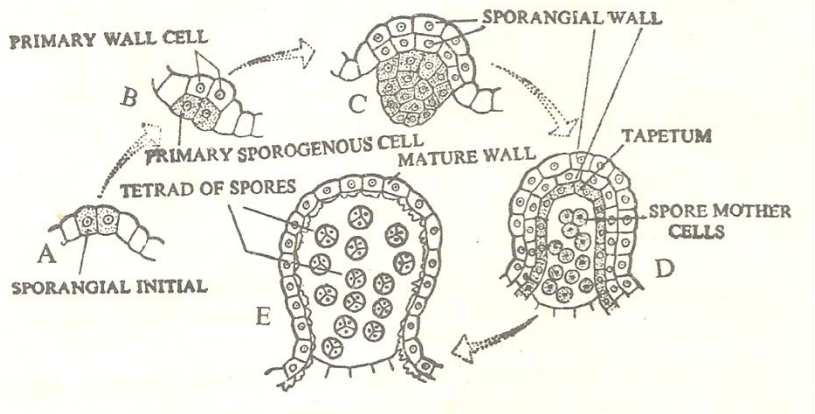


Fig. 1.6.Eusporangiate type of sporangial development

b. Leptosporangiate- The relatively small sporangium develops from a single initial cell which by periclinal division forms an outer and inner cell, the former forms the entire sporangium, its contents and stalk and the later do not take part in this process e.g. *Salvinia* and *Marsilea* (Fig. 1.7).

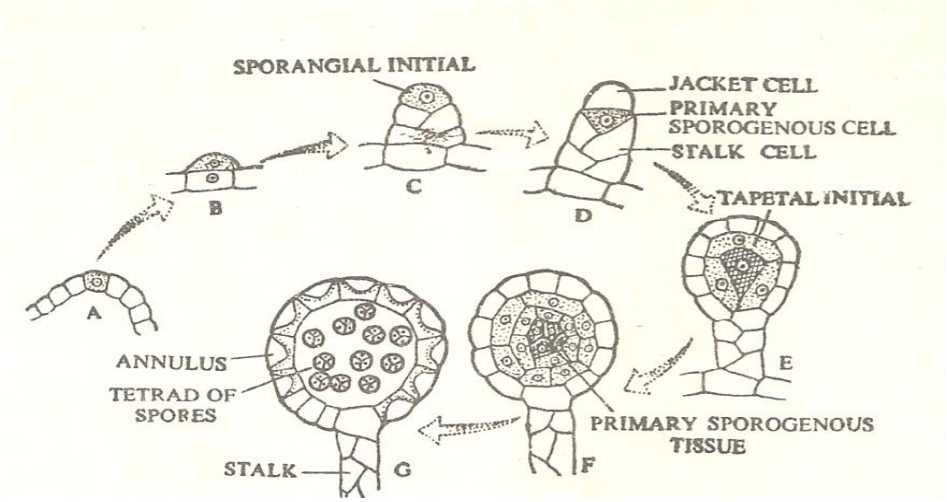


Fig.1.7. Leptosporangiate type of sporangial development

Gametophyte: The haploid spores on germination give rise to the haploid gametophyte or prothalii. One of the most characteristic feature of pteridophytes is that the sporophyte has become the dominant part of life-cycle while the gametophyte has much been reduced. The gametophytes are of two types i.e. homosporous and heterosporous. In homosporous forms the gametophyte grows upon the soil and form independent plant. Such gametophytes are known as is exosporic gametophytes (*Psilotum*, *Lycopodium* and *Ophioglossum*). In heterosporous species gametophyte for most of its part is retained within sporangium and are called endosporic gametophytes (*Selaginella*, *Marsilea*, *Isoetes*). There is much variation in the shape and the size of the gametophytes (Fig. 1.8). In most of the vascular cryptogams, the exosporic gametophyte grow exposed to light and remain attached to the ground by many rhizoids (Fig. 1.8) In such cases they produce their food and live an independent life e.g. ferns. In some pteridophytes, exosporic gametophytes are devoid of chlorophyll and obtain their food by the symbiosis through mycorrhiza e.g. *Psilotum.* Such gametophytes are saprophytic in nature. The endosporic gametophytes are greatly reduced structures. They develop largely or entirely within spore wall and live on food deposits in the spore.

Sex organs: The gametophyte or prothallus bears the sex organs, the antheridia and archegonia. Gametophyte of homosporous species is monoceous that is both antheridia and archegonia are born in large number on the same gametophyte. In heterosporous species, gametophyte is dioecious that is antheridia and archegonia develop on different gametophytes. Antheridia may be embedded in the tissue or gametophyte or they may project from it. Former are embedded antheridia (*Lycopodium, Selaginella*) while the later are called projecting antheridia (leptosporangiate ferns). At maturity, antheridia are a globular structure with large number of androcytes. Each androcyte gives rise to a single motile antherozoid. The archegonium is a flask shaped structure consisting of a basal swollen embedded structure, the venter and a short neck. The venter encloses venter canal cell and neck canal

cell are present inside neck. At maturity, the apical cell separate, the neck canal cell disintegrates forming a passage for antherozoid to reach egg.

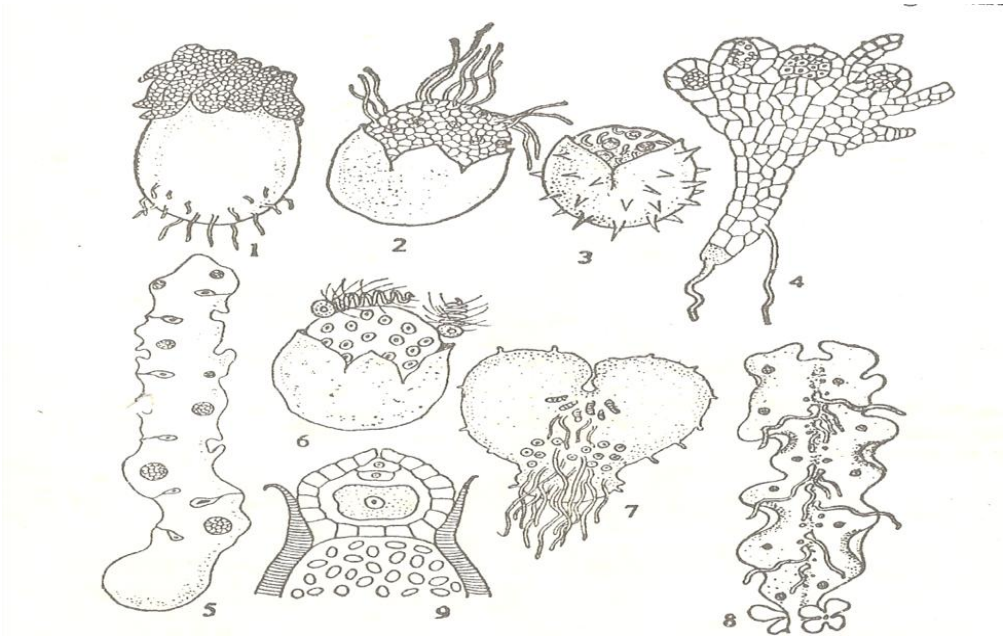


Fig.1.8. Variations in the gametophyte of pteridophytes. 1-*Lycopodium*; 2-*Selaginella* (female);3-*Selaginella* (male); 4-*Equisetum*; 5-*Ophioglossum*; 6- *Marsilea* (male) 7-*Pteridium*; 8-*Osmunda*; 9- *Marsilea* (female).

Fertilization: In all the cases fertilization takes place by the agency of water. The fusion of male gamete and egg give rise to a diploid zygote.

Embryo: The zygote divides to form an embryo which undergoes repeated divisions to form a new sporophyte

The pteridophytes occupy an intermediate position between bryophytes and spermatophytes, therefore, they show certain similarities with bryophytes on one hand and the spermatophytes on the other.

Resemblances with Bryophytes

The pteridophytes (vascular cryptograms) resemble the bryophytes in the following features:

1) Terrestrial habit.
2) Like the bryophytes, they reproduce asexually by means of spores. The spores are formed in the same manner in both the groups.
3) The sex-organs, the antheridia and archegonia are essentially identical as regards to their structure and ontogeny.
4) In both the groups, the sex-organs have sterile jackets around them.
5) The male gametes, *i.e.* the sperms are ciliated.
6) Fertilization takes place in presence of water.
7) Encapsulation of the embryo in the archegonium.
8) Dependence of early embryo (sporophyte) upon the gametophyte.
9) They exhibit regular interval of generations.

Differences between Pteridophytes and Bryophytes

The pteridophytes differ from bryophytes in the following features:

1) In the bryophytes, the gametophytes is the dominant and conspicuous generation, the diploid sporophyte being nothing more than a spore bearing structure and is dependent on the gametophyte for the nourishment. In the pteridophytes, it is sporophyte rather than the gametophyte which constitutes a large, conspicuous and dominant phase in the life cycle, while the gametophyte is always small and inconspicuous.
2) Plant body in pteridophytes shows differentiation into true roots, stem and leaves. In bryophytes, there may stem with leaves but there are no roots.
3) All the vegetative organs of sporophyte of pteridophytes possess vascular supply whereas bryophytes do not possess vascular tissue.
4) All bryophytes are homosporous, while pteridophytes may be homosporous or heterosporous.

Resemblances with Spermatophytes

The pteridophytes resemble the seed-bearing plants (spermatophytes) in the following features:

1) In both the groups, the sporophyte is the large, conspicuous, freely existing, independent and dominant phase in the life cycle. The sporophytic plant body is differentiated into true roots, stem and leaves.
2) All the vegetative parts of the sporophyte have typical xylem and phloem cells. The xylem consists of tracheids and xylem parenchyma, vessels being absent in majority of the pteridophytes (except *Selaginella* and *Marsilea*) and gymnosperms (except Gnetales). Phloem consists of sieve-tubes and phloem parenchyma. The companion cells being absent.

Differences between Pteridophytes and Spermatophytes

1) Pteridophytes differ from the spermatophytes in that they do not produce flower, fruits and seeds.
2) In pteridophytes, excepting few cases, the spores or gametophytes developed from them are invariably liberated from sporangia, instead of being permanently retained within them.
3) In spermatophytes, water is not necessary for fertilization.
4) Steles are more advanced in spermatophytes than those of pteridophytes.

1.4 CLASSIFICATION

The present system of classification of plants began with the publication of “Species Plantarum” in 1753 and “Systema Naturae” in 1761 by Linnaeus; the author of the binomial system of nomenclature, wherein it was stated that every organism has a generic name and a species name. Linnaeus recognized 24 major categories of plants. Twenty three of these often called Phanerogams and include vascular plants with visible flowers and the last Cryptogamia with plants having hidden flowers not visible to nacked eye. The cryptogamia of Linneaus included ferns and fern like plants, mosses, liverworts, algae and fungi. This group has now

been divided into a number of separate categories. Now-a-days plants that do not produce seeds are known as Cryptogams while seed bearing plants vascular plants are phanerogams. In 1880, the cryptogams of the plant kingdom were divided into three large divisions: Thallophyta, Bryophyta and Pteridophyta (Fig 1.9). The name-Thallophyta was first introduced by Endlicher in 1836, who called this division, a kingdom. Later on in 1866 Haeckel introduced the names Bryophyta and Pteridophyta.

Long ago botanist divided vascular plants into two groups: **Pteridophyta** that include plants that do not produce seeds and **Spermatophyta** that include plants that do produce seeds. This system of classification was based on possession of seeds. In some system of classification all vascular plants are included in a single division **Tracheophyta** including plants with vascular tissue and taking their name from tracheids of xylem.

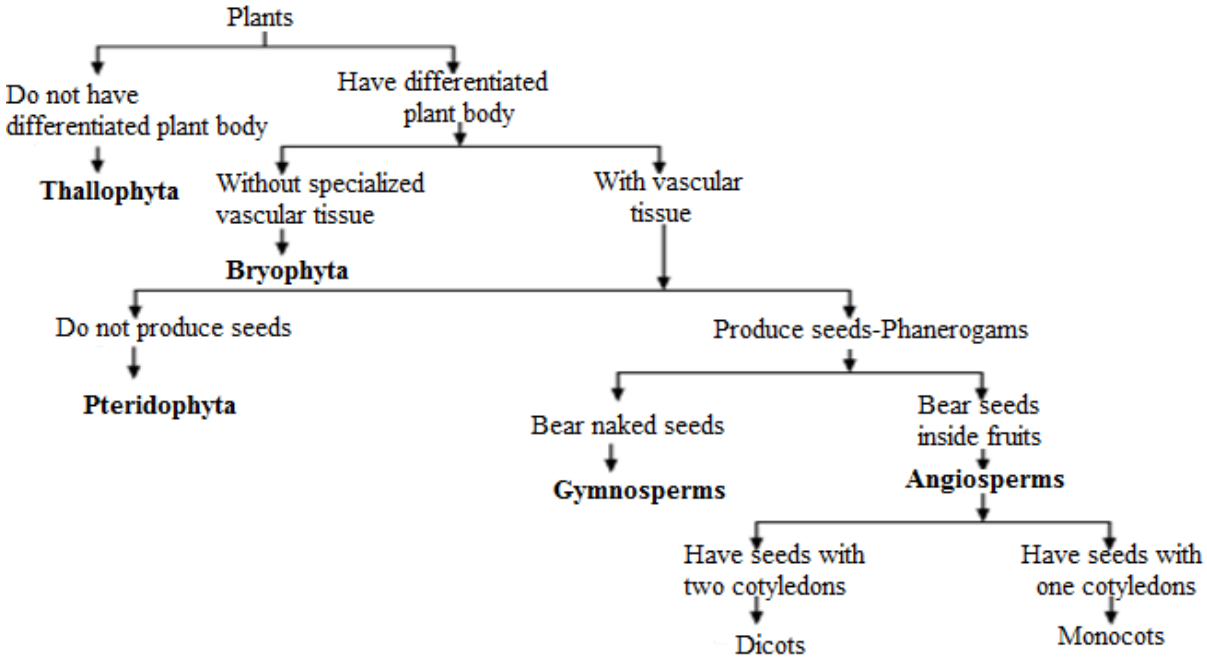


Fig.1.9. Early system of classification showing position of Pteridophyta in plant kingdom

In 1936 Eames divided Tracheophyta into four groups:

Division: Tracheophyta

Group 1. Psilopsida (Psilophytales and Psilotales)

Group 2. Lycopsida (Lycopodiales, Selaginellales, Lepidodendrals, Pleuromeiales and Isoetales)

Group 3. Sphenopsida (Hyeniales, Sphenophyllales and Equisetales)

Group 4. Pteropsida (Filicineae, Gymnospermae and Angiospermae)

In 1950, the International Code of Botanical Nomenclature amended and recommended that all names of divisions end in the suffix-phyta class in the suffix opsida, order in the suffix ales and family with suffix aceae. The most accepted system of Classification of vascular

cryptogams that is based on Smith (1955), Bold (1957), Benson(1957) and Takhtajan(1964) may be referred to as follows:-

DIVISION- PSILOPHYTA

Class -Psilophytopsida

Order –Psilophytales*

Class -Psilotopsida

Order –Psilotales

DIVISION LYCOPHYTA

Class -Eligulopsida

Order –Lycopodiales

Class -Ligulopsida

Order –Selaginellales

Order-Lepidodendrales*

Order- Isoetales

Order-Pleuromeiales*

DIVISION- SPHENOPHYTA

Class- Sphenophyllopsida

Order-Sphenophyllales

Class- Calamopsida

Order-Calamitales*

Order-Hyeniales*

Order-Equisetales

DIVISION- FILICOPHYTA

Class- Primofilicopsida

Order-Cladoxylales*

Order-Coenopteridales*

Class-Eusporangiopsida

Order -Ophioglossales

Order-Marattiales

Class-Protoleptosporangiopsida

Order -Osmundales

Class- Leptosporangiopsida

Order- Filicales

Order-Marsileales

Order-Salviniales

(* Known as fossil without any living representative)

The characteristic features of these divisions are as follows:

Division Psilophyta:

1. The sporophyte is differentiated into a rhizoid bearing subterranean rhizome and dichotomously branched aerial shoots.
2. The true roots are absent although rhizoids are present on the rhizome. The leaves are usually absent or if present they are small, simple and spirally arranged.
3. The vascular system is of protostelic type which consists of a central cylinder of xylem composed of tracheids and surrounded by ill defined phloem (*Rhynia*). In some species actinostele is present with radiating xylem strand (*Psilotum*). Leaf gaps are absent from vascular cylinder.
4. The terminal sporangia are borne singly at the tips of short or long branches and are thick walled. The sporangia are homosporous i.e. produce only one type of spores.
5. The gametophyte is subterranean colourless and associated with mycorrhizal fungi.
6. Antherozoids are multiciliate.

Division Lycophyta:

1. The sporophyte is differentiated into stem, roots, and leaves, representing an advance over Psilophyta.
2. The leaves are microphyllous, though a few of the fossil genera (*Lepidodendron, Pleuromia*) had leaves several feet long. The leaf is generally with a single unbranched vascular bundle (vein) but the leaf trace leave no gap in the stele.
3. The vascular strands or steles may be protostelic, siphonostelic, or polystelic.Vascular tissue consists of xylem tracheids and phloem.
4. Sporophylls produce a single sporangium on the adaxial side near its base. The sporophylls are borne in strobili. They are homosporous (*Lycopodium*) or heterosporous (*Selaginella*).
5. The antherozoids are biflagellate or multiciliate.
6. Secondary growth does not take place except *Isoetes.*

Division Sphenophyta:

1. The sporophyte is differentiated into stem, roots and leaves.
2. The stem possesses distinct ridges and furrows and is jointed with distinct node and internode. The branches arise in whorls from the node.

3. The foliage leaves are borne in transverse whorls upon stems and their branches. The leaves are short lived and form a sheath around each node.
4. The vascular cylinder is protostelic or siphonostelic. The leaf-gaps are absent.
5. The sporangia are produced upon a specialized structure, the sporangiophores present at the apex of the stem. They are homosporous though some extinct forms were heterosporous.
6. The antherozoids are multiciliate.
7. The embryo lacks a suspensor and embrogeny is exosporic.

Division Filicophyta:

1. The sporophyte is differentiated into stem, leaves and roots. In some genera roots are absent.
2. The leaves are large in relation to the size of the stem and generally known as fronds.
3. The stems are protostelic, siphonostelic, dictyostelic and sometimes polystelic. Except protostelic form they possess leaf-gaps in their vascular cylinders.
4. The leaf bears many sporangia on either the margin or upon the abaxial face of the leaves. Mostly they are homosporous, but a few are heterosporous.
5. The sex organs are found on the ventral surface of the heart-shaped prothallus (gametophyte).
6. The antherozoids are multiflagellated.

1.5 THE TELOME THEORY

The discovery of a group of earliest known land plants with simple organization of the sporophyte (rootless, dichotomously branched, single sporangium terminating a branch tip, protostele vascular cylinder) from the upper Silurian and lower and middle Devonian deposits has been of the greatest important to the understanding of the structure and phylogeny of vascular plants.

A theory which is based primarily upon the studies of the lower vascular plants, living as well as fossil and at the same time is capable of general application to all vascular plants has been suggested by Zimmermann, under the title of **Telome theory** (1930 and later elaborated on 1952).

The term telome has been given to the simple ultimate terminal portions of a dichotomously branched axis. These axes are undifferentiated and single nerved.

Zimmermann defines the telome as the single-nerved extreme portion (at base or apex) of the plant body from the tip to the next point of branching. The following two types of telomes have been recognized on the basis of their function:

(a) Vegetative or sterile telomes: These telomes are without sporangia and they are called phylloids.

(b) Fertile telomes: Those telomes which bore terminal sporangia are called fertile telomes.

Following evolutionary development telomes may be grouped together in various ways to form more complex bodies or Syntelome. Syntelome composed of either sterile (phylloid trusses) or of fertile (fertile telome trusses) or mixture of the two (mixed telome).The telome grow and divides dichotomously, the new segments becomes new telomes and older segment below are mesomes.

The Origin of Telomes and the Ancestors of Primitive Land Plants

According to the Telome theory the early land plants originated from the green algae which lived in tidal zone of the Cambrian and Silurian sea coasts. The plant body of those algal ancestors was undifferentiated branched thallus (primitive telome). According to Zimmermann these primitive telomes were formed from the unicellular stage by the following five elementary processes:

(i) Interconnection of cells

(ii) Differentiation of meristem

(iii) Rotation of cell axis

(iv) Shifting of chief phases in alternation of generation

(v) Differentiation of different permanent tissues

The dichotomously branched thallus had a central strand of mechanical tissue. These algal ancestors showed alteration of generation.

The Primitive Land Plant

The telome theory visualizes the Psilophytales of the upper Silurian and lower and middle Devonian deposits (*Zosterophyllum*, *Rhynia*, *Horneophyton*, *Psilophyton* etc) as representing the sporophyte of the ancient vascular plants. The sporophyte was relatively undifferentiated (no distinction between leaf and stem) and consisted of single-veined (protostele) telomes which may be sterile and fertile. The aerial portion developed stomata and the basal portion, hairs or rhizoids. The fertile telome produced terminal sporangia (Fig. 1.10).

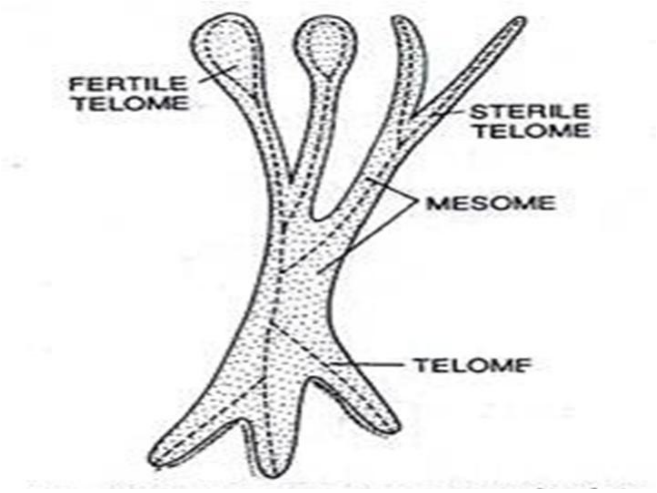
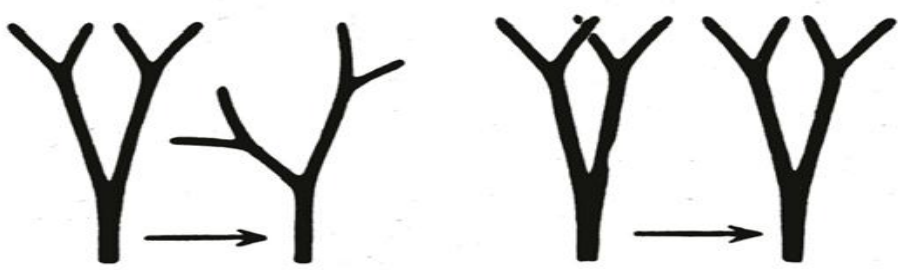


Fig.1.10. Hypothetical diagramme of a primitive land plant

Evolution of the Higher Land Plants

From the primitive syntelome of the early land plants the sporophytes of higher land plant evolved by certain organogenetic processes called "**elementary processes**" each following its own trends.Zimmerman suggested that the following elementary processes were responsible for the development of higher vascular plants from the early vascular cryptogams.

1. **Overtopping:** Of the two usually equal dichotomies from the telome one become stronger and erect becoming the axis which grew further while the other remained overtopped as a short lateral branch (Fig. 1.11 A). Thus from an equal dichotomy to a sympodial and finally to a monopodial system the contrast in shoots between axis and its lateral members became evident and finally it led to the formation of an axis with lateral appendages, the leaves, e.g. open-veined pinnately compound type of fern leaf and between rachis and leaflet. Overtopping mesomes formed the rachis and the overtopped mesomes constituted the leaflets.
2. **Planation**: Branching in more than one plane (cruciate dichotomy) is replaced by a dichotomy in a single plane (fan shaped dichotomy). Thus plantation caused telomes and mesomes to arrange them in a plane (Fig. 1.11 B). By this process an organ of radial symmetry gives rise to one of bilateral symmetry. Plantation concerns mainly the evolution of the leaf.



Overtopping Planation

A B

Fig. 1.11.Digammatic representation of Overtopping and Planation

3. Syngenesis (**fusion or webbing**): Fusion of the telome of telome trusses by the development of connecting tissue (as in the foot of swan) is called syngenesis or webbing. Telomes and mesomes connect by the formation of parenchymatous tissue between them (parenchymatous webbing) or by parenchymtous webbing accompanied by the fusion of their stele (Fig.1.12).

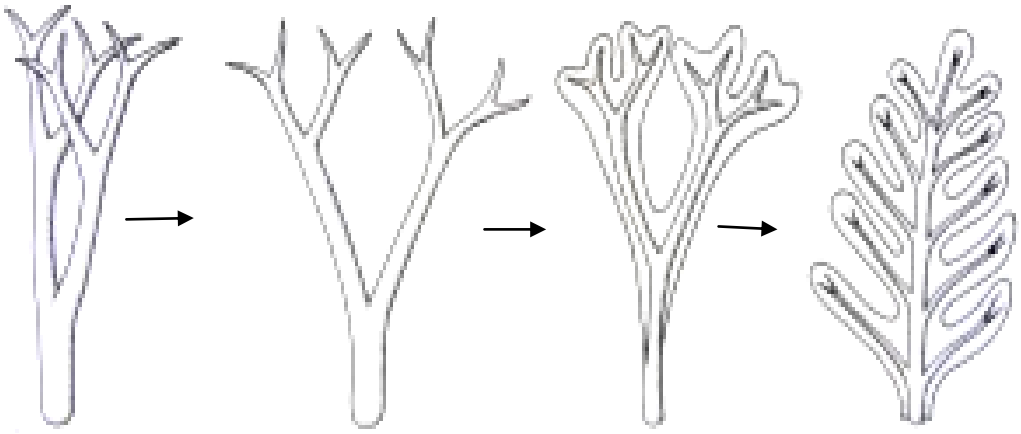


Fig.1.12. Diagramme showing Webbing or syngenesis

Syngenesis is a very important elementary process because it explains the origin and evolution of both the leaf and stele of the stem. It leads to the formation of:

(i) Foliar appendages with open dichotomous venation. In this case the sterile telomes (Phylloids) become united only by the development of (parenchymatous webbing)

(ii) Pinnately veined leaf: Parenchymatous webbing was accompanied by over-topping.

(iii) Leaf with reticulate venation: if fusion of steles or vascular bundles also occurred.

(iv) Parenchymatous webbing led to the polystelic condition (in an open form) as in many species of *Selaginella*.

(4) Reduction: It implies a simplification of the telome trusses. It involved transformation of a syntelome into a single needle-like leaf. According to Zimmermann the microphyllous leaves of Lycopods were evolved by the reduction of telome trusses (Fig. 1.12).

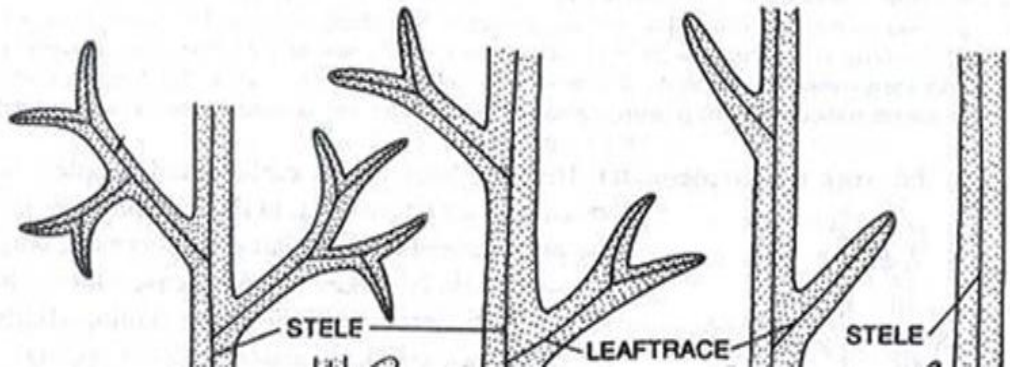


Fig 1.12. Steps in the Reduction process

(5) Curvation- This process resulted in unequal growth of the tissue on two opposite flanks of the organ. Wilson (1953) recognized two separate sub-processes

Recurvation: When telomes bent down inwards, it is called Recurvation. During this process, the fertile telomes (sporangiophores) were reflexed and sporangia became inverted (Fig.1.13)

Incurvation: This process accounts for the shifting of sporangia from terminal position to the ventral surface of the leaf in ferns (Fig. 1.14).

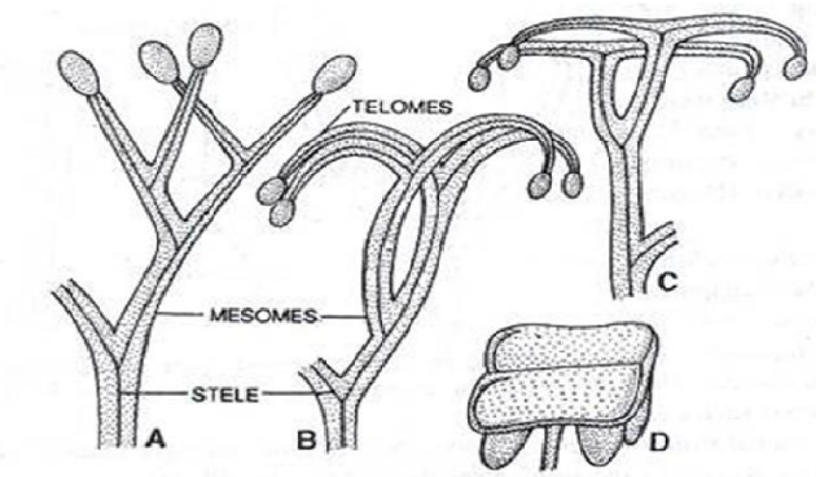


Fig.1.13 Steps in the process of Recurvation

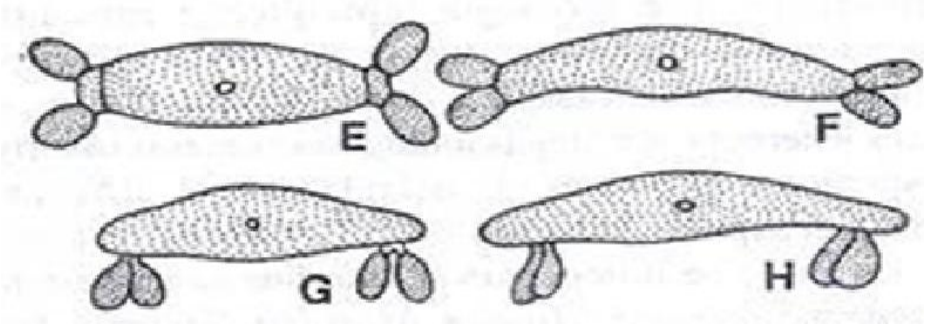


Fig. 1.14.Steps in the process of Incurvation

Merits of telome theory

1. It provides an excellent interpretation of origin and evolution ofsporophyte of land plants.
2. The elementary process proposed by Zimmermann provides a basis of interpretation which removes outstanding morphological difficulties in the lower vascular plant such as the nature of the aerial portion of the plant body of the family Ophioglossaceae and coenopterid ferns.
3. This theory emphasise on the fact that the plant body is an axis with a descending portion, the root, and an aerial portion, the shoot whose appendages are modified parts of the stem.
4. According to Eames, though the theory is built upon structure in the lowest known vascular plants, higher plant can also be safety interpreted in this way. It also tries to connect the fossil and living plants by their phylogenetical relations
5. Bierhorst is of the view that the theory is too simple and easily applicable but unfortunately its excessive use has greatly diminished its value**.**

Demerits of telome theory

1. According to Thomas (1950), the telome theory does not explain the whorled or spiral arrangement of sporangia, which is observed in some ancient and primitive plants.
2. Application of the telome theory to the origin of Lycopsida has been greatly criticised. Andrews (1960) supports this theory to some extent so far as Sphenopsida and Pteropsida are concerned, but for Lycopsida, he may well be quoted that 'Zimmermann' concept for the Lycopsida is, so far as I am aware, purely hypothetical'.
3. According to Bower (1946), this theory does not explain how a telome-like characterized body has been developed. It has been taken for granted by Zimmermann (1930) that a telome type body is 'ready-made'; whereas an fundamental problem is to know how such a unit has acquired its characteristic development so as to take place in Hofmeisterian cycle.
4. This theory does not provide a satisfactory derivation of all leafy structures from branches.
5. Stewart (1964) also criticised the telome theory because it does not explain the derivation of the dictyostelic condition.

1.6 STELAR SYSTEM AND ITS EVOLUTION

The conducting system of pteridophytes consists of xylem and phloem and associated parenchymatous cells, all of which are organized into a **stele**. The term stele has been derived from a Greek word meaning **pillar** or column. The concept of the stele as the fundamental unit of vascular system was put forward by Van Tieghem and Douliot (1886) who proposed and developed Stelar theory. According to the stelar theory the primary structure of the stem and root were fundamentally similar in gross anatomy because both consisted of a central core, the stele, surrounded by the cortex. The term stele was interpreted as the vascular tissue and conjunctive tissues associated with them and the pith and pericycle (if present).The stele of stem was connected with that of leaf by a vascular connection known as leaf trace.

Types of stele in pteridophytes

On the basis of the kind of stellar organization present in different pteridophytes, an evolutionary sequence can be recognized among different groups. The stele in pteridophytes can be differentiated into two major groups

1. Protostele: It is the most simplest and primitive type of stele. In protostele , the vascular bundle is a concentric solid mass and the central core of xylem is surrounded by a layer of phloem and finally surrounded by a layer of pericycle. Jeffrey (1898) named primitive type of stele as protostele**.** It is considered primitive because it is present in some earliest known land plants that appeared about 400 million year ago. The protostele exists in following forms:

a) Haplostele: This is the most primitive type of stele. In this the xylem forms a solid, smooth, and spherical central core which is surrounded by a continuous concentric layer of phloem e.g. *Lygodium*, *Selaginella* (Fig.1.15 A). This particular type of stele has been regarded as the most primitive among the different types.

b) Actinostele : This is the modification of the haplostele and somewhat more advanced in having the central xylem core with radiating ribs and phloem is not concentric but present in between the radiating ribs of xylem e.g. *Psilotum* (Fig.1.15 B). The protoxylem is present at the tips of radiating arms.

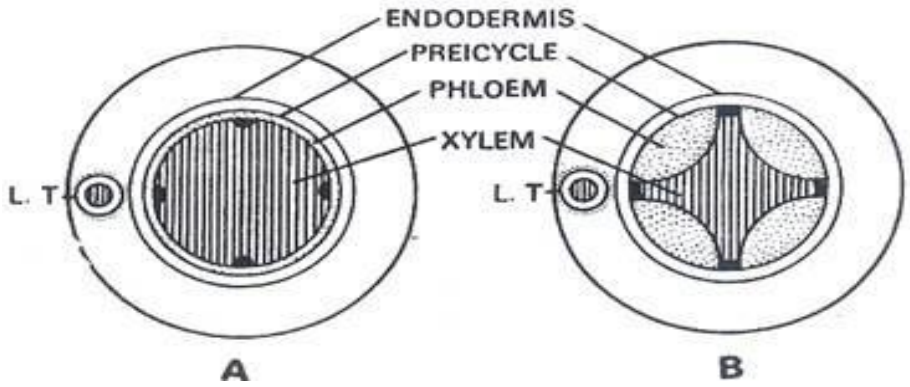
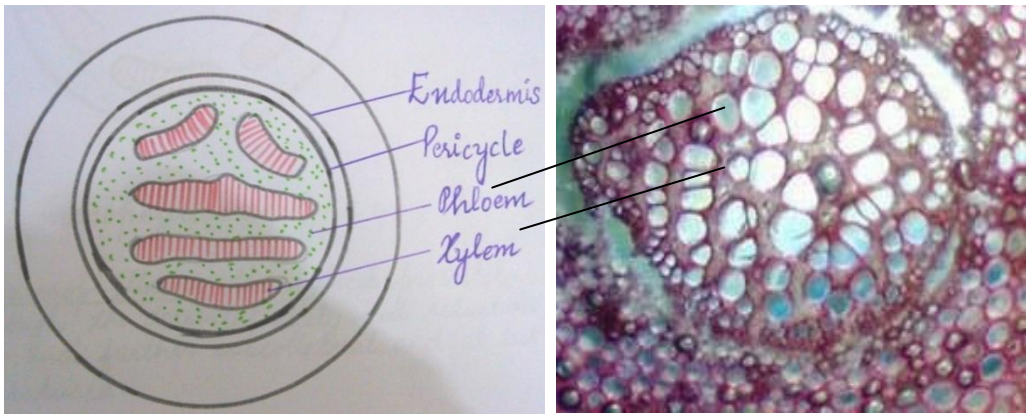


Fig. 1.15. Diagramme showing Haplostele (A) and Actinostele (B).

c) Plectostele: In the stem of some species of *Lycopodium* the solid core of xylem gets broken in a number of plate-like lobes, more or less lying parallel to one another. The phloem alternates with xylem plates e.g. *Lycopodium volubile.* This specialized form of protostele is termed as plectostele (Fig. 1.16)

d) Mixed protostele: In this type, masses of xylem and phloem are uniformly distributed. Scattered groups of xylem are embedded in the ground tissue of phloem e.g. *Lycopodium cernnum* (Fig. 1.16).

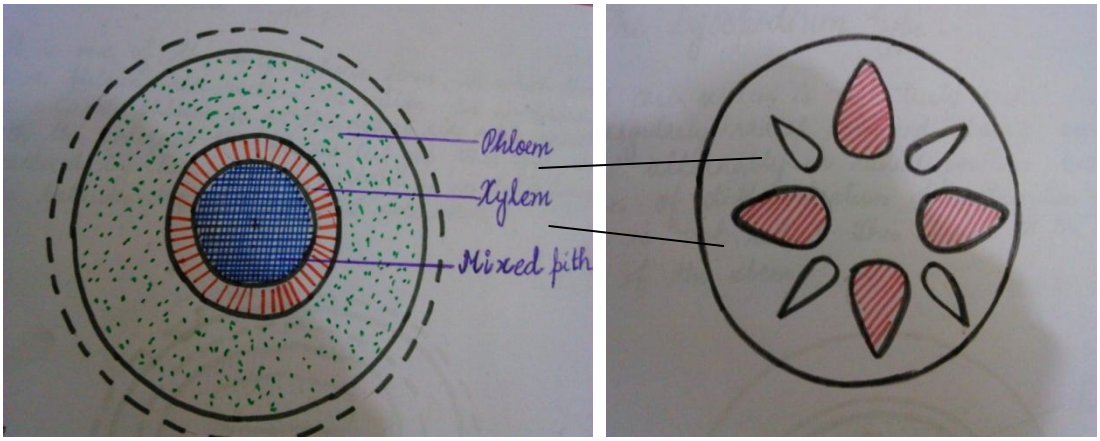
e) Protostele with mixed pith: In the centre there is parenchyma cells associated alongwith the tracheids e.g. *Lepidodendron.* It may be derived from the transformation of the tracheids into parenchyma and may be first step in formation of pith. Such type of protostele is termed as mixed-protostele (Fig.1.17).



Plectostele ***Mixed protostele***

Fig.1.16. Diagramme showing Plectostele and Mixed protostele

f) The radial protostele: This stele consists of radial vascular bundles enclosed by an endodermis layer. This type generally found in root and stem of young stage of some species of *Lycopodium* (Fig. 1.17).



Protostele with mixed pith **Radial protostele**

Fig. 1.17. Diagramme showing Protostele with mixed pith and radial protostele

2. Siphonostele: A kind of stele in which there is pith in the central region is called a siphonostele.This is the modified form of the protostele which has developed central pith hence often called medullated protostele. In this type, xylem is in the form of a hollow cylinder, enclosing a well defined central pith in the centre and surrounded by concentric phloem. This type of stele is thought to have been evolved from a protostele by conversion of treachery elements into parenchyma.

Origin of pith in siphonostele

There is a general acceptance that siphonostele is evolved from a protostele. Two theories have been proposed to explain the origin of pith:

Intra –stelar origin of pith: According to this view, pith has originated as a result of transformation of tracheary elements of the central xylem core into parenchyma. Thus, the pith is totally intra –stelar. This view is supported by Boodle (1901), Gwynne – Vaughani (1908), Bower(1911). e.g. *Osmunda regalis* , *Botrychium ternatum*where tracheids are scattered throughout the pith (mixed pith).

Extra –stelar origin of pith: This hypothesis was supported By Jeffrey (1902, 1910, 1917). According to this view, protostele has transformed into siphonostele due to migration of cortical cells into stelar axis .Openings such as leaf and branch gaps, probably provided passage for invasion of parenchyma .This view derives support from amphiphloic siphonostele that has two endodermal layers, one delimits the stele from the cortex and the other from the pith. Since endodermis is a structure peculiar to cortex, the pith is considered as cortical in origin.

Types of siphonostele

According to the distributional patterns of xylem and phloem, the siphonostele is classified into following two types:

a) **Ectophloic siphonostele**: In this type, the central pith is surrounded by concentric cylinders of xylem and phloem e.g. *Equisetum*. The phloem is present only on the outer side of xylem (Fig.1.18).

b) Amphiphloic siphonostele: In this type, there is pith in the centre . The concentric xylem is surrounded on both the sides (externally and internally) with phloem cylinder which intern is followed by pericycle e.g. *Marsilea* (Fig. 1.18).

In its simplest form, the siphonostele has no leaf gaps. This type of siphostele is termed as cladosiphonic siphonostele e.g. some species of *Selaginella* .On the other hand a siphonostele with leaf gaps is termed as phyllosiphonic siphonostele e.g. *Marsilea.*

c) Eustele: Here the hollow vascular cylinder with central pith gets broken into a number of collateral bundles arranged in a ring. This type is also known as polyfassicular siphonostele e.g. *Equisetum* (Fig.1.19).

d) Solenostele: This is modified form of siphonostele which get perforated by a single leaf gap. The solenostele may be either ectophloic or amphiphloic e.g. ferns (Fig. 1.19).

e) Dictyostele: A dissected siphonostele is known as dictyostele. In this type, the cylindrical stele is interrupted by numerous leaf gaps that overlap each other. In the cross section, the stele appeared as discrete stands of or bundles each with internal xylem and concentric phloem and is called meristele e.g. *Pteris* (Fig.1.19).

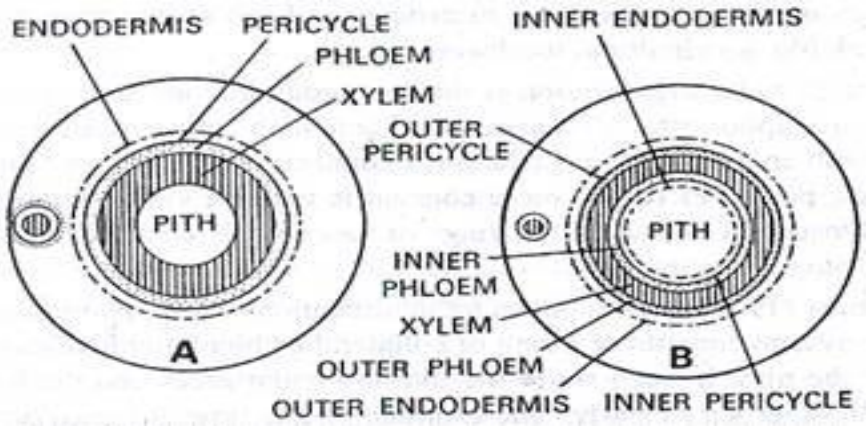
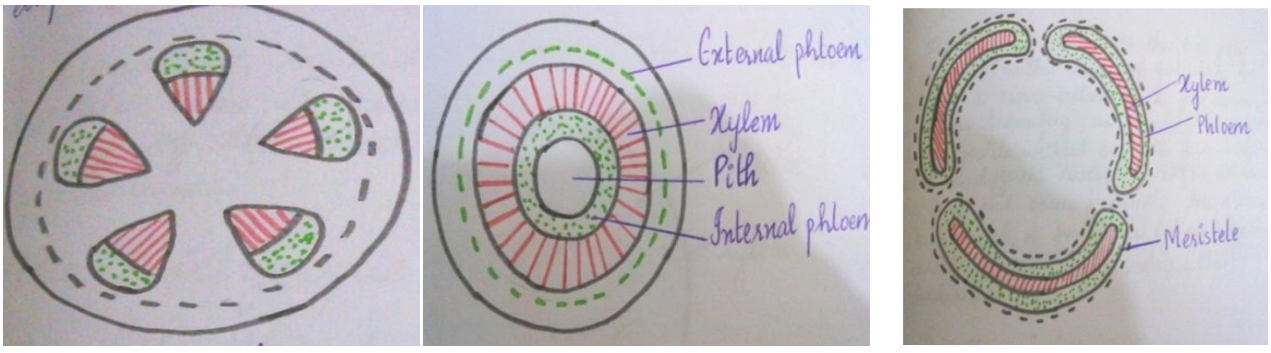


Fig. 1.18.Ectophloic Siphonostele (A) and Amphiphloic Siphonostele (B).



Eustele Solenostele Dictyostele

Fig.1.19. Diagramme showing Eustele, Solenostele and Dictyostele

f) Polycyclic stele: This type of stele is most complex one among all pteridophytes. A typical polycyclic stele possesses two or more concentric rings of vascular tissue in regular rings or cylinders one within another .This may be a solenostele or a dictyostele. Two concentric rings

of vascular tissue are found in *Pteridium aquilinum* and three in *Matonia pectinata* (Fig. 1.20).

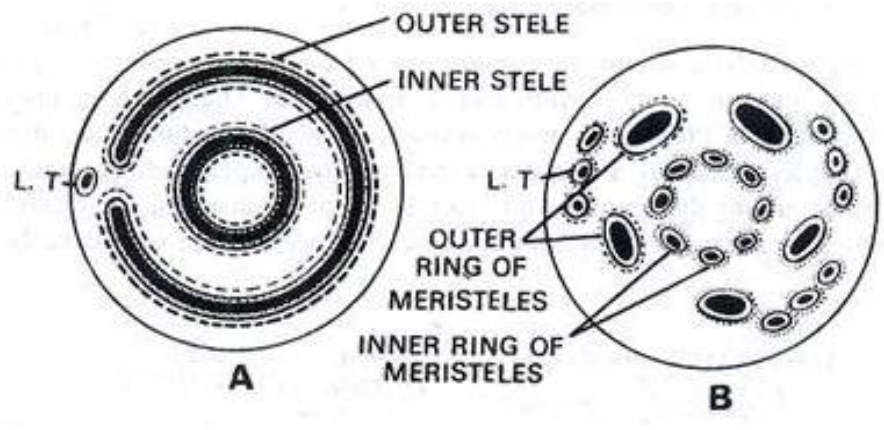


Fig.1.20. Diagramme showing Polycyclic Solenostele (A) and Polycyclic Dictyostele (B).

Evolution of the stelar system

It is now generally held that the simplest type of stele is protostele .It is fundamental type for the vascular plants in general and the pteridophyta in general and all the other types of stele have been derived from it in the course of evolutionary specialization. As far as is known all pteridophytes in the initial (sporeling) stage starts with protostelic stem. It is permanently retained in the adult stem of many living pteridophytes e.g. *Selaginella*, *Lycopodium* etc. A protostele may serve the need of small shoots and also of the larger stems under special circumstances. But where the shoot grows accompanying an increase in size, there is internal differentiation of the stele. The first step is appearance of parenchyma, scattered in the xylem core as described earlier in this unit, and finally a central parenchymatous medulla or pith is developed in the protostele. Such type of stele is called Siphonostele. The method by which medullation came about in a protostele and formed a siphonostele is a debated question and explained by two hypotheses viz. Extra-stelar and Intra-stelar origin of pith. In its simplest form the siphonostele has no leaf gaps e.g. *Selaginella* and known as cladosiphonic siphonostele in contrast with phyllosiphonic condition with leaf gaps. Siphonosteles which are perforated by scattered leaf gaps are known as Solenostele and a siphonostele with more overlapping gaps is known as dissected siphonostele or dictyostele. The final elaboration of the stellar organization in pteridophytes consist in the development of a number of separate steles. Such a stele is known as Polycyclostele. Another modification of siphonostele is the Eustele in which the vascular system consists of collateral vascular bundles.

1.7 HETEROSPORY

Heterospory can be defined as the presence of two types of spores in same the same plant (Fig1.21). The two kinds of spores are different in shape, size, structure and function. Structurally one spore is small and the other type of spore is larger in size. The smaller spores are known as microspore whereas the larger spores are known as megaspores. The microspore is produced in microsporangia in large number and megaspore is produced in megasporangia in small number. This differentiation of spores in size is definitely related to

the distinction of sex of the gametophyte. The smaller spore or microspore on germination leads to male gametophyte and the larger one or megaspore on germination leads to female gametophyte.

Among the pteridophytes heterospory occurs in 9 genera viz. *Selaginella, Isoetes, Stylites , Marsilea, Pilularia, Regnellidium, Salvinia, Azolla and Platyzoma.*

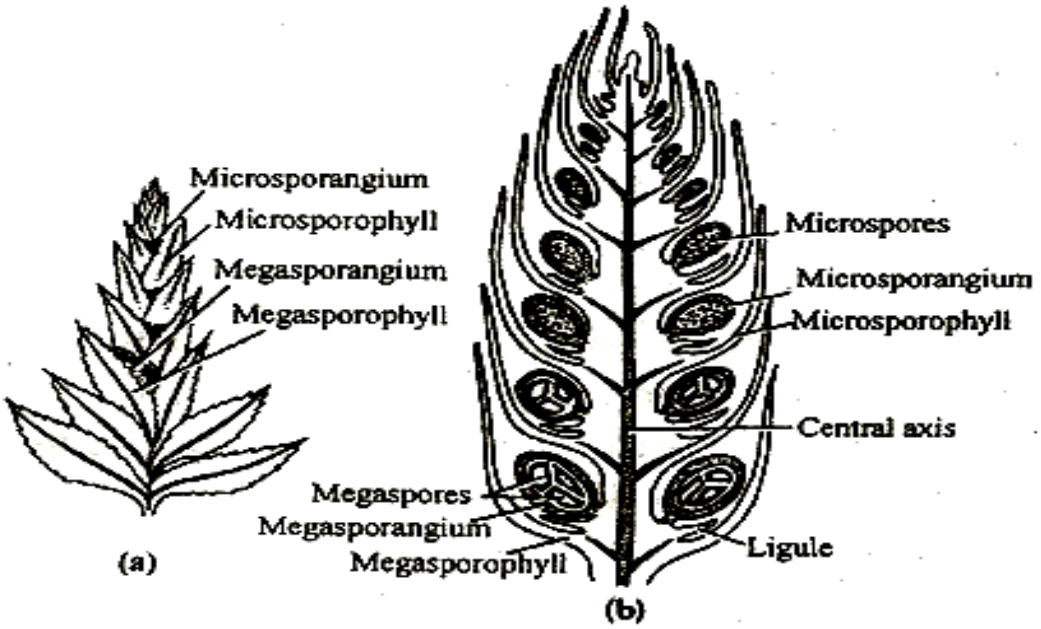


Fig. 1.21.Diagramme showing morphology of heterosporous cone (a) and L.S. of a heterosporous cone (b).

Origin of heterospory

A detailed study of homosporus forms has revealed that heterospory originated due to reduction in number of spores within sporangia. That is if more number of spores are functional than there is more competition for nutrition and limited nutrients are provided to developing spores.In this way microspores are formed, they are smaller in size and more in number.On the other hand, if some of the spore mother cell in a sporangium disintegrates during development, the remaining ones get sufficient nutrients.These are megaspores; they are larger in size but less in number.

Evidences of heterospory

Paleobotanical evidences: These were concluded on the basis that earlier vascular plant were heterosporus eg. *Lepidocarpon, Lepidostrobus* etc. According to Scott (1894) an indication of heterospory can be traced in *Calamostachys binneyana*and *C.casheana*. In former the sporangia were with large number of small spores in tetrads. In later two distinct types of sporangia microspoorangia and megasporangia occurred.A similar disintegration was observed in some species of *Lepidocarpon, Calamocarpon* and *Stauropteris***.**

The above example indicates that-:

1. Heterospory has not only evolved in living forms but was present in the fossil plants.
2. It originated due to integration of spores in a sporangium.

However, the reduction in number of spores or spore mother cell was achieved but it cannot be determined as there is no information regarding the development of sporangia and spore.

Evidences from developmental studies: Developmental studies in pteridophytes, during the formation of sporocytes, meiosis and maturation of spore provide a real insight in the understanding of heterospory. In *Selaginella, Isoetes, Marsilea, Salvinia* etc. early development of microsporangium and magasporangium is similar till the formation of sporocytes.In *Selaginella* all the sporocyte in microsporangia undergoes meiosis as a result a large number of microspores is formed. On the other hand all the megasporocytes except one abort and the surviving magasporocyte undergo meiosis to form four large functional megaspore of same or variable size.

Developmental studies have thus, showed that the process of heterospory becomes operative either before meiosis (e.g. *Selaginella*) or after meiosis (e.g. *Marsilea*).

Evidences from Experimental studies: On the basis of experimental studies on *Selaginella* and *Marsilea* it has been found that heterospory originated due to nutritional factors. It was observed that if the photosynthetic activity of *Selaginella* was slowed down by keeping it in low light intensity, then only microsporangia developed. Due to the low photosynthetic activity, nutrition became a limiting factor and spores could not grow in size. Thus, under such conditions only microspores were produced. Similar experiments were preformed on *Marsilea* by Shattak (1910). In variable conditions of light, temperature and nutrients, he found that in plants growing in favourable conditions the microsporangium contains aborted microspore and microsporangium showing microspore abortion developed spore that were 16 times larger than the original size. In extreme cases of abortion only a single spore survived and looked alike a megaspore and showed all structural features of megaspore.

Under unfavourable conditions of light, temperature and nutrients, he was able to induce the formation of the larger number of smaller spore in megasporangia. However, it was not possible to germinate these altered spores therefore; no conclusive results can be achieved.

Advantage of heterospory

1. Hetrospory expresses sex determining capability of plant. In homosporus species, differentiation of sex takes place at the gametophytic stage, whereas in heterosporus species difference in size of the spore is related to the sex of the gametophyte. A microspore always gives rise to male gametophyte and megaspore gives rise to female gametophyte. Therefore, in heterosporus forms sex can be predicted at the spore stage.
2. The biological significance of heterospory is that in heterosporus forms the development of gametophyte is endosporic (spore germinate within the sporangium)and its nutrition is derived from the sporophyte hence is not affected by the ecological factors as in the case of independently growing gametophytes which has to manufacture not only its own food but also for the developing embryo.
3. It is an evolutionary step towards seed habit.

Heterospory and Seed habit

In seed bearing plants, there are two kinds of spores (microspores and megaspores) which grow to form male and female gametophyte respectively, In these plants the single megaspore

is not shed from the megasporangium but retained within it while still attached to the mother plant. It germinates within the megasporangium producing the much reduced female gametophyte (nucellus) bearing archegonia. Later the nucellus and the gametophyte are protected by a covering known as integument and the whole structure is known as ovule. After fertilization zygote within ovule give rise to the embryo and the rest of the gametophyte including endosperm and integument thickens to form a seed coat This entire structure (integumented ovule) is known as seed.

Thus, the important features leading to the development of seed habit are:

1. The evolution of heterospory i.e. production of two kinds of spores
2. The retention and germination of megaspore to form female gametophyte, fertilization of the egg and embryo formation within the megasporangium.
3. Elaboration of the apex of the megaspore for receiving microspores or pollen grains.
4. Envelopment of the megasporangium (nucellus) by an integument except at the apex thus forming micropyle.

Selaginella shows a remarkable approach to seed habit because of the following features:

1. It is heterosporus.
2. The megaspore starts germinating within the megasporangia and their time of release varies with species.
3. The number of megaspore in *S.rupestris* and *S.monospora* is reduced to one.
4. In *S.rupestris* the megaspore is never shed and the fertilisation and the development of embryo takes place while megaspore is enclosed within the megasporangium.

However the seed development in these species cannot be called as true seed habit because-:

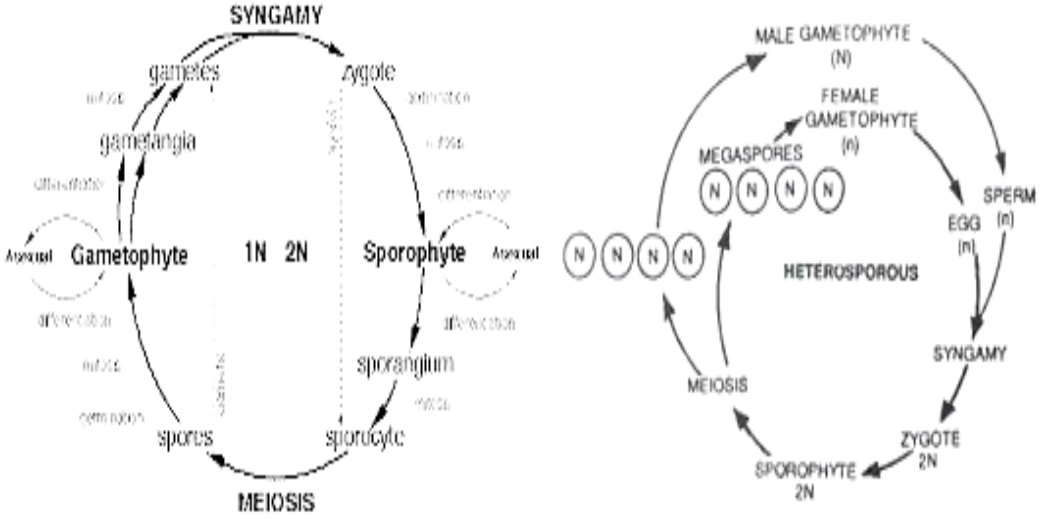
1. The megasporangium is not covered with integuments.
2. The retention of megaspore permanently within the megasporangium has not become established.
3. Histological union between the megaspore and magasporangium is absent.
4. Absence of resting period after the devlopment of embryo.

1.8 LIFE-CYCLE OF PTERIDOPHYTES

The life-cycle of a pteridophyte comprises of two distinct phases or generation, each of which produces other. One phase or generation is **sporophytic** and another is **gametophytic.** The **sporophyte,** is diploid and dominant part of the life-cycle, for it is organised into stem, leaves and roots. It is the part of life-cycle in which vascular tissue is developed. The sporophyte plant develops sporangia within which are diploid cells, called **spore mother cells or sporocytes**. Each spore mother cell or sporocyte divides by **meiotic or reduction division.** As a result of **meiosis,** spores are produced, which are therefore, haploid. In some, members, all spores produced by sporangia are of one type; such a plant is said to be homosporous *(Lycopodium, Dryopteris).* These spore on germination produce the **haploid or gametophyte generation.** These gametophytes are of same kind. The gemetophytic generation is always small, inconspicuous and bears male and female gametes. The male gametes, *i.e., sperms* are produced in large number within the antheridium. The female gamete, *i.e., egg* is generally borne singly within the archegonium. **Fertilization** takes place in presence of water when a

sperm fuses with an egg to produce a diploid *zygote*. The **zygote** germinates to form the new *sporophyte.* The generation is called **sporophytic generation** (Fig 1.22 A and1.23)**.**

In heterosporous pteridophytes, *i.e., Selaginella, Isoetes, Azolla* and *Marsilea,* the spores are of two kinds- the smaller spores termed as *microspores* or *male spores* and are developed in *microsporangia,* while the larger spores are termed as *megaspores* or *female spores* and are formed in *megasporangia.* The microspores on germination produce the male gametophyte on which only the male gametes, *i.e.,* the *sperms* are produced. The megaspore produce the female gametophyte, the fertilization occurs in presence of water resulting in the formation of a diploid cell or *zygote* which in turn develops into a sporophytic generation. Thus, the life cycle of a pteridophyte consists of an alternate succession of heteromorphic sporophytic and gemetophytic generation (Fig. 1.22 B and 1.24).



A B

Fig 1.22 Diagrammatic representation of life cycle of homosporous (A) and heterosporous (b) pteridophyte.

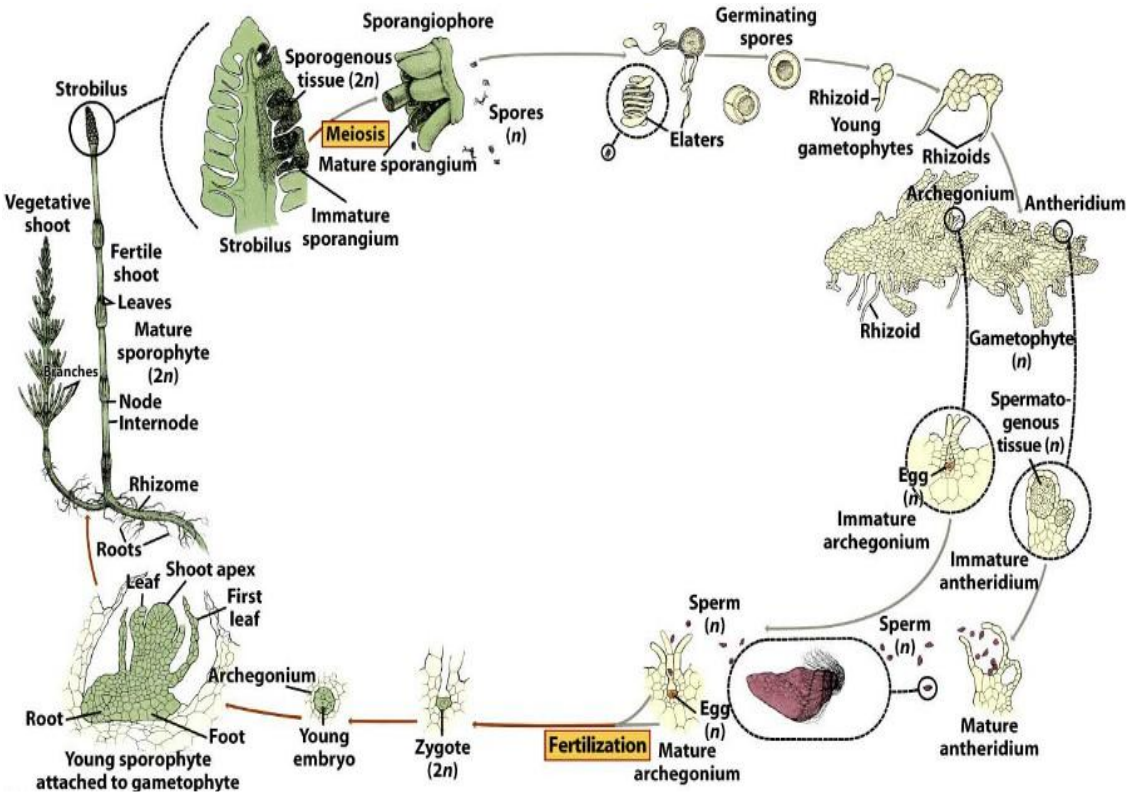


Fig. 1.23.Diagramme showing different stages in Life cycle of a homosporous pteridophyte (*Equisetum*).

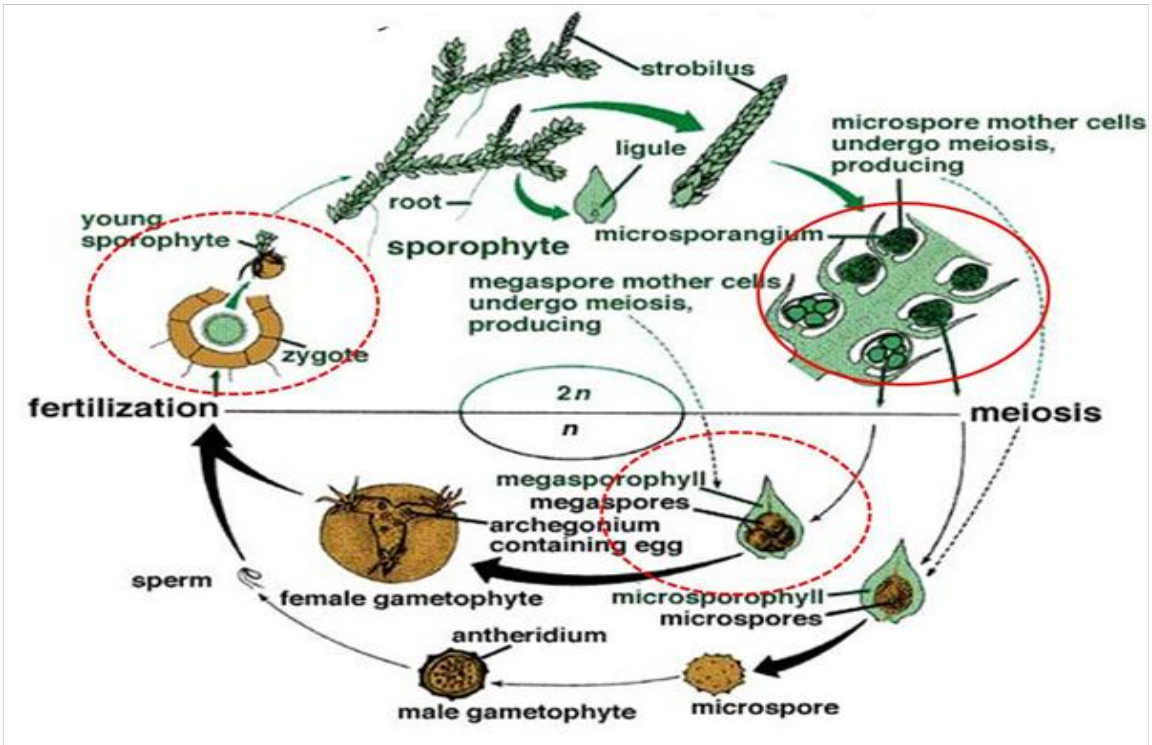


Fig. 1.24.Diagramme showing different stages in Life cycle of a heterosporous pteridophyte (*Selaginella*).

1.9 SUMMARY

Vascular plants are traditionally divided into those that do not produce seeds- vascular cryptogams (pteridophytes) and those that produce seeds- spermatophytes. The modern pteridophytes are remnants of much larger groups that flourished 395 to 260 million years ago. Many groups of pteridophytes became totally extinct and are known only in fragmentary fossil remains.The psilopsids, the club mosses, the horsetails and the ferns are the spore-bearing tracheophytes (due to the presence of trachieds or tracheary elements) and are collectively referred to as lower vascular plants or vascular cryptogams.

In pteridophytes the sporophytic plant body is differentiated into true roots, stem and leaves except some primitive members like *Rhynia*. In some members the branching is dichotomous while in others it is monopodial. On the basis of leaves two main categories have been distinguished; Megaphyllus- with large compound leaves e.g. ferns; Microphyllus- with small leaves like *Lycopodium.* The vascular system varies in different groups. It may be a simple protostele, dictyostele, solenostele or polycyclic stele. The sporophytic plant reproduces asexually by means of spores which are produced in sporangia. Development of sporangia may be eusporangiate (group of initial cell participate) or leptosporangiate (single initial cell participates). Sporangia are borne on stem or leaves or in their axils. Spore bearing leaves are called sporophylls. In some species, sporophyll are clustered to form cone or strobilus e.g. *Equisetum*, while in some other species sporangia are produced within specialized structure called sporocarp e.g. *Marsilea*. In ferns, sporangia are grouped together to form sorus. If all the spores are of same size, the plant is said to be homosporous (e.g. *Lycopodium* and *Equisetum*) and if they are of different size the plant is called heterosporous (e.g. *Selaginella* and *Marsilea*).

The spore on germination gives rise to gametophyte. Gametophyte developing from homospores grows upon the soil and form independent plants therefore known as exosporic. While the gametophyte that develop from the heterospores are for most part retained within the sporangium and are called endosporic. The gametophyte bears sex-organs the antheridia and archegonia. Fertilization in all cases is accomplished by the agency of water and the zygote undergoes repeated divisions to form a new sporophyte. On the basis of International Code of Botanical Nomenclature the pteridophytes were divided into four divisions: Psilophyta, Lycophyta, Sphenophyta and Filicophyta.

There have been much suggestions of the manner in which the terrestrial independent sporophyte of vascular plants may have evolved. A theory which is based primarily upon the studies of the lower vascular plants living as well as fossil, and at the same time is capable of general application to all the vascular plants have been suggested by Zimmermann under the title Telome theory. According to telome theory, the early land plants originated from the green algae and the higher land plants evolved from the earliest land plants like *Rhynia* as a result of few organogenetic processes called Elementary Processes each following its own trend.

As already been stated earlier, the complete life-cycle of pteridophytes consist of two generations which are totally different in their morphology and they alternately produce each

other. The haploid spore on germination gives rise to a relatively small and inconspicuous structure-the prothallus which bears directly the sex-organs. This is the gametophyte or sexual generation. As a result of fertilization a diploid zygote is formed. It enlarged, undergoes a series of division and forms a conspicuous, highly developed plant provided with stem, leaves and roots. After an initial vegetative phase, sporangia develop and spores are liberated. This is the sporophyte or asexual generation. During spore formation reduction division takes place and spore thus formed are haploid. The spore germinates and the life-cycle commence again.

1.10 GLOSSARY

Axis: The main stem of a whole plant or inflorescence.

Binomial nomenclature: The system of classification in which the scientific name of a species is a combination of two names, the first name being the generic name. The second name is referred to botanically as the specific epithet.

Cryptogams: Plants whose sexual reproductive organs are not conspicuous and without stamens, ovaries and seeds. These plants produce spores.

Dichotomous: The type of branching in plants that result when growing point divides into two equal growing points which in turn divide in a similar manner after a period of growth and so on.

Dictyostele: A siphonostele that is broken up by crowed leaf gaps into a network of distinct vascular stands or meristeles, each surrounded by an endodermis.

Ectopholic: A stele with phloem present only on the external side of the xylem.

Fern: Any of numerous flowerless and seedless plants having true roots from a rhizome and fronds that uncurl upward and reproduce by spores.

Fertilization: The union of two similar or dissimilar gametes to form a diploid zygote.

Gametophyte: A gametophyte is a gamete bearing plant. It develops from the meiospores produced by sporophyte by meiosis or reduction division. Gametophyte is a haploid structure.

Habit: The general external appearance of a plant, including size, shape, texture and orientation

Habitat: The place where a plant lives; the environmental conditions of its home.

Heteromorphic: Two stages morphologically different in shape, size, texture and orientation.

Heterospory: The condition of producing two types of spores differing in size.

Homospory: The condition of producing only one type of spores.

Leaf trace: The conducting strand extending from the stele of the stem through the cortex to the base of leaf and connecting the vascular system of both.

Leptosporangiate: Sporangia developing from a single initial cell.

Life-cycle: In most of the plants multicellular diploid sporophyte phase alternates with a multicellular haploid gametophyte phase. This cycle is known as life-cycle or alternation of generation.

Megasporangium: A diploid spore sac containing only large asexual spores or megaspores.

Megaspore: The larger of the two kinds of asexual haploid spores, which produces female gametophyte in heterosporous plants.

Meristele: The vascular part of a dictyostele between two neighbouring leaf gap, appearing in transverse section as separate strands.
Microsporangium: A diploid spore sac containing only small asexual spores or microspore.
Microspore: The smaller of the two kinds of asexual haploid spores, which produces male gametophyte in heterosporous plants.
Monopodial: The mode of stem branching in which the main axis is formed by a single dominant meristem
Order: A group of one or more families sharing common features, ancestry or both
Pinnate: A compound leaf with leaflets arranged on each side of a common petiole or axis
Pteridophyte: Plants having vascular tissue and reproducing by spores
Siphonostele: A medullated protostele.
Sorus: A group of sporangia as in ferns.
Spore: A haploid propagule produced by meiosis in diploid cells of a sporophyte that can germinate to develop a multicellular gametophyte.
Sporophyte: A sporophyte is the diploid multicellular stage in the life cycle of a plant. It develops from the zygote when a haploid egg cell is fertilized by a haploid sperm and each sporophyte cell therefore has a double set of chromosomes. The sporophyte produces spores by meiosis (hence the name sporophyte means spore bearing plant).
Stele: The central vascular cylinder of the axis (stem and root) taken as whole.
Strobilus: A cone like structure consisting of sporophylls or sporangiophores borne close together on an axis.
Vascular: An adjective referring to the conducting tissues (xylem and phloem) in vascular plants.

1.11 SELF ASSESSMENT QUESTIONS

1.11.1 Fill in the blanks:

i. Vascular plants that do not produce seeds are known as_____
ii. Pteridophytes as a group differs from bryophytes having _____
iii. Plants with small leaves are known as _____
iv. Plants producing two types of spores are called _____
vi. Telome theory was proposed by _____

1.11.2. Tick the right answer:

i. Meristele is a part of:
(a) Protostele (b) Solenostele
(c) Dictyostele (d) Polycyclostele

ii. A stele without pith is
(a)Solenostele (b) Siphonostele
(c) Haplostele (d) Dictyostele

iii. Amphiphloic siphonostele has:

(a) Phloem towards inner side of xylem (b) Phloem on both sides of xylem
(c) Phloem surrounded (d) Phloem outside the xylem

iv. The term protostele was given by:
(a) Zimmermann (b) Andrews
(c) Bower (d) Jeffrey

v. Pteridophyta as group resembles bryophyte having:
(a)Presence of vascular tissue (b) archegonia
(c) flowers (d) seeds

vi. A plant in the division Psilophyta has no true
(a) Leaves and roots (b) Gamete
(c) Gametophyte (d) Sporophyte

Answer Keys:

1.11.1. i. Vascular cryptogams; ii. vascular tissue; iii. Microphyllous; iv. Heterosporous; v. Zimmermann

1.11.2. i. (c), ii (c), iii. (b), iv (d), v (b), vi (a)

1.12. REFERENCES

- Andrews, H.N. 1960.*Evolutionary trends in early vascular plants,* Cold Spring Harbor Symposia on Quantitative Biology 24: 217-234.
- Benson, L. 1957. *Plant classification*.Boston
- Bold, H.C.1957.*Morphology of plants*. New York.
- Boodle, L.A.1901Comparative anatomy of the Hymenophyllaceae, Schizaceae and Glecheniaceae .*Ann. Bot*. 15: 703-747.
- Bower, F.O.1911.Medullation in the Pteridophyta.*Ann.Bot.* 25: 537-553.
- Gwynne-Vaughan, D.T. 1908. Observation on the anatomy of solenostelic ferns. *Ann.Bot.* 15: 71-78.
- Jeffrey, E.C.1898. *The morphology of central cylinder in vascular plants*. Rep. Brit. Assoc. Toronto 869-70.
- Linnaeus, C. 1754. *Genera Plantarum*, Holmiae. Shattuk, C.H. 1910. Origin of heterospory in *Selaginella*.*Bot. Gaz*. 49:19-40.
- Smith, R.W.1955. *CryptogamicBotany*. Vol IIMcGraw Hill, New York
- Takhtajan, A.L. 1964. Phylogenetic principles of the system of higher plants.*Bot.Rev*. 79: 1-45.
- Thomas, H.H.1950.The telome theory and the new morphology.*R. Proc. 7th Internat. Bot. Congress, Stockholm.ept.*
- Van Tieghem, P.andH.Douliot1886.Sur la polystelic.*Ann. Sci. Nat. Bot. Ser*. 7(3): 275-322.

- Wilson, C.L. 1953.The telome theory.*Bot.Rev*. 19: 417-437.
- Zimmermann,W. 1930.*Die Phylogenie der Pflanzen,I,* Auflage, Jena.

1.13 SUGGESTED READINGS

- *Biology and morphology of Pteridophytes*. Central Book Depot Allahabad By Parihar,
- N.S.
- *An introduction to Pteridophyta: Diversity and Differentiation*. Vikas Publishing House Pvt Ltd, New Delhi By A.Rashid,
- *A Text Book of Pteridophyta* . Vikas Publishing House Pvt Ltd, New Delhi By Pandey, S.N., P.S. Trivedi and S.P. Misra
- Botany for Degree students: *Pteridophyta*. S. Chand Publications, Meerut By B.R.
- Vashishtha

1.14. TERMINAL QUESTIONS

1. Describe following terms:

(i) Stele (ii) Heterospory (iii) Protostele

2. What is heterospory? Describe briefly the origin of heterospory in pteridophytes.
3. Describe various types of steles studied by you.
4. Describe the term stele.Give an account of evolution of stele in pteridophytes.
5. Describe briefly merits and demerits of telome theory
6. Write notes on:
    a. Advantage of heterospory
    b. Elemantary processes
    c. Amphiphloic siphonostele
7. Differentiate between
    (i) Eusporangiate and leptosporangiate development
    (ii) Homospory and heterospory
    (iii) Megaphyll and microphyll
8. Give main divisions of pteridophyta and describe their salient features.

UNIT-2 STRUCTURE AND REPRODUCTION IN *RHYNIA* AND *SELAGINELLA*

2.1 OBJECTIVES

This unit describes structure and reproduction in *Rhynia* and *Selaginella*. After reading this unit you will be able to:

1. Describe systematic position, habit, habitat and general features of *Rhynia* and *Selaginella*.
2. Explain reproduction in *Rhynia* and *Selaginella.*
3. Understand sporangial development in *Selaginella*.
4. Discuss life cycle in *Selaginella*.

2.2 INTRODUCTION

In the previous unit we have described the general characteristics of pteridophytes. The present unit deals with structure and reproduction of two pteridophytes viz. *Rhynia* and *Selaginella*. *Rhynia* is a fossil plant that lived on the earth in the previous ages. It is a member of family Rhyniaceae and order Psilophytales. We must remember that plants living today are the surviving members of the flora that flourished luxuriantly in the past extending back through millions of year. In the course of evolution the flora on the earth as changed many times so that fragments of many ancient plants were scattered here and therein certain layers of earth' crust. These fragmentary remains preserved in the rocks are known as the fossil. As a representative of fossil plant we have chosen *Rhynia* to describe the structure and reproduction in early land plants.

The second genus *Selaginella* described in the present unit is only living genus of family Selaginaceae. It is markedly heterosporous and possesses ligulate leaves. The main features of this large genus are (i) The sporophyte is herbaceous and shoot is dorsiventral and creeping or erect. The leaves are small and a ligule is present at the base. In many species the root system is produced from rhizophore. (ii) The sporophyte is heterosporous and sporophylls are usually aggregated into strobili. The gametophytes are extremely reduced in size and dioecious. The antherozoids are biciliate. In this unit we will study structure and reproduction in *Rhynia* and *Selaginella*.

2.3 RHYNIA

Systematic Position

Division - Pteridophyta
Class- Psilophytopsida
Order - Psilophytales
Family - Rhyniaceae
Genus - *Rhynia*

Distribution and habitat: The genus *Rhynia,* was named after village Rhynie in Aberdeenshire district of northern Scotland, where the first fossils of the plants were discovered. Two species are described from the red sand stone beds of middle Devonian age by Kidston and Lang in 1917. Some 380 million years ago, *Rhynia,* and other plant grew in

this locality in marshy environment. There is evidence that these plants were growing in peaty habitats near volcanoes, where the atmosphere contained sulphurous vapours and the soil was saturated with acid water from hot springs. The two known species of *Rhynia* are *R. major* and *R. gwynne-vaughanii*. The petrified remains of these plants are found and on the basis of reconstruction the form and structure of these plants have been described.

2.3.1 STRUCTURE OF *RHYNIA*

External features

The sporophyte plant body of *Rhynia* was simple and consisted of a slender, dichotomously branched rhizome, bearing erect, dichotomously branched aerial stems (Fig. 2.1). The aerial branches of *R. major* were about 50 cm in height and 1.5 to 6 mm in diameter, whereas the stems of *R. gwynne-vaughanii* attained a height of 20 cm and were only 1 to 3 mm in diameter. There were no **roots** but from the rhizome grew numerous **rhizoids**. These stems were naked and had no leaves. The aerial branches seem to have terminated finally into *sporangia.* In *R. gwynne-vaughanii*, hemispherical protuberances were present which might have arisen from the lower part of the aerial stems or from the rhizome. The vascular bundles of these adventitious branches were not connected with those of the main stems. It suggests that they were capable of growing into new plants, if detached from the new axis and served as means of vegetative propagation.

Internal features

The internal structure of the rhizome as well as stem was similar. In the centre, a solid central core of vascular tissue was surrounded by cortex. The vascular cylinder was a **protostele (haplostele)**, with a cylindrical mass of xylem, surrounded by a phloem layer (Fig. 2.2 A). The xylem was composed of annual tracheids which were smaller towards the centre. The phloem was composed of elongated thin walled cells, with oblique end walls.Around the stele was a broad **cortex** with no intervening pericycle and endodermis. The cortex was differentiated into an inner and an outer region. The inner cortex was composed of spherical cells and had abundant intercellular spaces. It is presumed that the region of inner cortex was green, and as such has been the chief photosynthetic tissue of the plant. The outer cortex was formed of large angular cells without intercellular spaces, except below the stomata. The outermost layer was the **epidermis**, one cell in thickness and with a thick **cuticle** on its outer surface. In the epidermis of the aerial branches, **stomata**, with two guard cells were present.

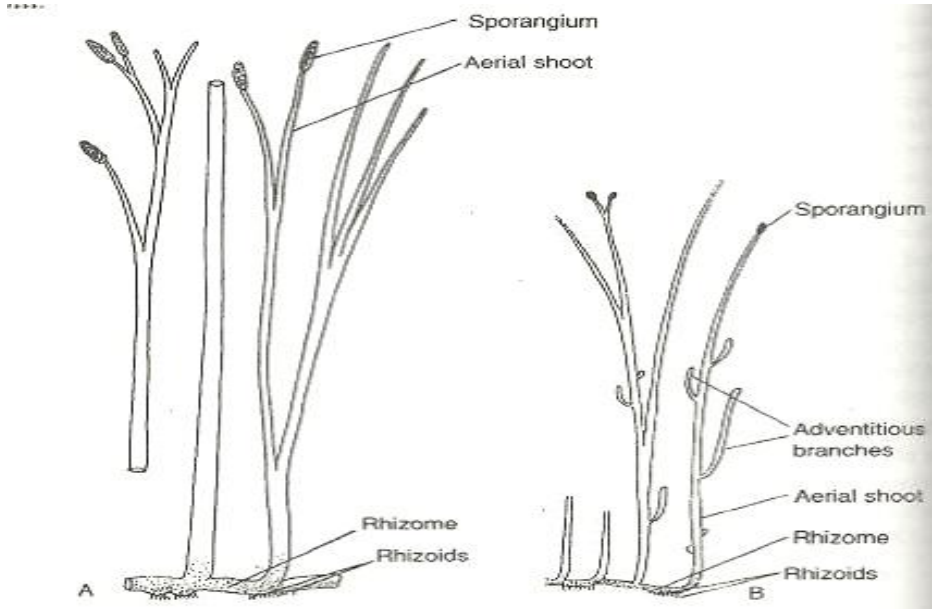


Fig. 2.1. Reconstruction of *Rhynia major* (A) and *R.gwynne-vaughanii* (B).

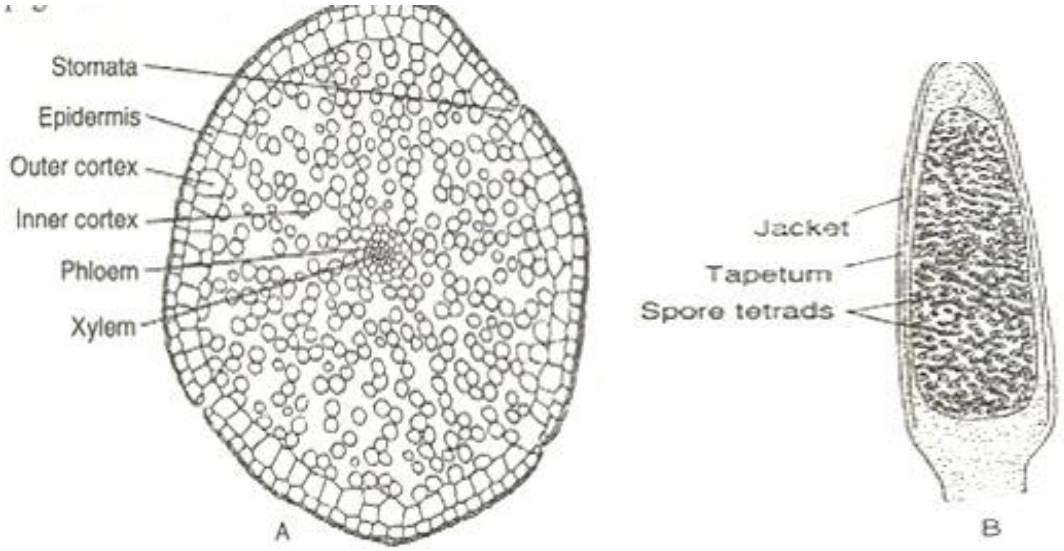


Fig.2.2. *R.gwynne-vaughanii* A- Transverse section of stem and B-longitudinal section of sporangium.

2.3.2 Reproduction in *Rhynia*

The sporangia were cylindrical and borne singly on the tips of some aerial branches. They were large, oval or cylindrical structures with pointed ends. The sporangia had walls several cell layers thick in which the cells of the outermost layer were thick walled and had a heavy cuticle (Fig. 2.2 B). The middle layer was about three cells in thickness and composed of thin walled cells. The inner layer of the jacket composed of small rounded cells and probably functioned as **tapetum**. The sporangial cavity contained numerous spores of same size (homosporous) with cutinized walls. The spores were apparently all alike and were arranged in tetrads. The presence of tetrads in some specimens suggests that they were formed by reduction division and that the plant bearing them represented sporophytic generation. The sporangium was without any specialized mechanism of dehiscence.

The Gametophyte

The spores: The spores were cutinized and were born in tetrads. The spores were 40µto 65µ in diameter. Nothing is known about the gametophyte of *Rhynia* because gametophyte of this fossil plant has never been discovered. Lyon (1957) reported some germinating spores from Rhynie Chert, which show multicellular structures, developing at the ends of germ tubes, that looked like that of *R. major*. These may represent the gemetophytic generation. Merker (1959) has suggested that the underground parts of *Rhynia* might possible be the gametophytes. According to Pant (1962), certain specimens described as *R. gwynne-vaughanii*, may be the gametophytes of *R. major*. However, no conclusive evidence of archegonia or antheridia is known to identify these fossils as gametophytes. *Lyonophyton, a* recently described gametophyte from the Rhynie Chert does not seem to be related to *Rhynia,* but may be the gametophyte of other Rhyniophytes.

Present status of *Rhynia major*

Edwards in 1986 described a new genus *Aglaophyton* to accommodate *R. major* as *Aglaophyton major* and also emended its description as: Plants sporophytes, with a semi-creeping decumbent habit, much shorter than originally described, formed extensive stands of decumbent axes. Rhizome probably surface living, unlikely to have been long creeping as originally described. Maximum height of the plant 18cm or so, dichotomously branched upright axes arise from rhizoid-bearing prostrate axes, upright axes 1.5-6.0mm in diameter, naked, dichotomizing at a wide angle (45-90 degrees) with all axes terminating in sporangia, single sporangia rare. The reconstruction represents two fertile units which resulted from axes growing vertically after they had fallen over, and which then developed swollen areas and rhizoids on their lower surfaces, and eventually produced sporangia. It seems likely that in many cases vertically growing axes fell over and produced rhizoids rather than terminated in sporangia.

The most significant finding of Edwards concerns the structure of the central conducting strand. It consists of three zones, a central region of thin-walled cells, a middle region of thick walled cells, and an outer region of thin-walled cells. There is no indication of differential wall thickenings in the cells of any of these regions and the central strand is interpreted as a conducting strand similar to those found in many bryophytes, the inner two regions being comparable to hydroids and the outer region comparable to the leptoids found in many mosses**.** Edwards laid much stress on the nature of the conducting strands and expressed that this plant exhibits characters intermediate between vascular plants and some mosses and cannot be considered a member of either group. The structures originally interpreted as tracheids in the central vascular strand upon re-examination were found to be conducting tubes without any thickenings associated with tracheids of vascular plants. Since unornamented conducting tubes would be plesiomorphic to the moss lineage directly but does suggest a close relationship. Also the main plant body of *Aglaophyton*is clearly a free living sporophyte (sporangia are attached). Banks (1992) in a reclassification of the early vascular plants placed *Aglaophyton major* (along with nine other genera) in the category of "Aberrant Plants" as they do not fit into the strict definition of Rhyniales which includes mostly dichotomously branching plants with single, terminal sporangia and centrach vascular strands

the tracheids of which were with thickenings. Sharma and Tripathi (2000) after a study of the structure of the sporangium and spores of *A.(R.) major* are of the opinion that these structures are more like those of the other Pteridophytes than in any Bryophyte. Moreover would it be fair and justified to remove this plant only on the basis of a single character (non-vascular tracheids) from the Pteridophytes and ignore all the other characters that it shares with this group?

2.4 SELAGINELLA

Systematic position

Division - Pteridophyta
Class- Lycopsida
Sub-Class - Ligulopsida
Order - Selaginellales
Family - Selaginellaceae
Genus - *Selaginella*

Distribution and habitat: It is a single living genus of family Selaginaceae. It is commonly called "Small Club-Mass'' or "Spike Moss". It comprises about 700 species with world wide distribution and thrive best in relatively moist and shady habitats of the hills. Some species are xerophytic (*S.lepidophylla*), whereas some species (*S. oregana*) are epiphytic and grows on the branches and trunks of moss covered trees. About 58 species have been reported from India (Alston 1945).

2.4.1 Structure of *Selaginella*

External structure

The plant body is sporophytic (2n) which is differentiated into roots, stem and leaves (Fig2.3).The plants show great variation in their morphology. In some species the branching stem is **prostate** creeping along the surface of the ground (*S. kraussiana*) or may be **sub-erect,** (*S.trachyphylla*), or may be **scandent** (*S. willdenovii*). The term is covered with four rows of small leaves. Out of these, two rows of smaller leaves and two of large leaves. These species with **dimorphic** leaves such as *S. kraussiana, S. helvetica, S. lepidophylla, and S. chrysicaulos* were grouped in the sub-genus **Heterophyllum** by Hieronymus (1900)**.** In other species the stem may be **erect** with a spreading mass of foliage uniform in size e.g., *S. spinulosa, S. rupestris, S. pygmaea* and *S. oregano.* Such species with uniform leaves were grouped in the sub-species **Homeophyllum.** The stem, covered with theses green leaves, present a moss-like appearance, hence the plant is called the "**little club moss**".

In some xerophytic species (*S. lepidophylla* and *S. pilifera*) the entire plant assumes a shape of a tight ball during dry periods and again opens up into normal green plant in the presence of water. Such plants are commonly known as **Resurrection plants**.

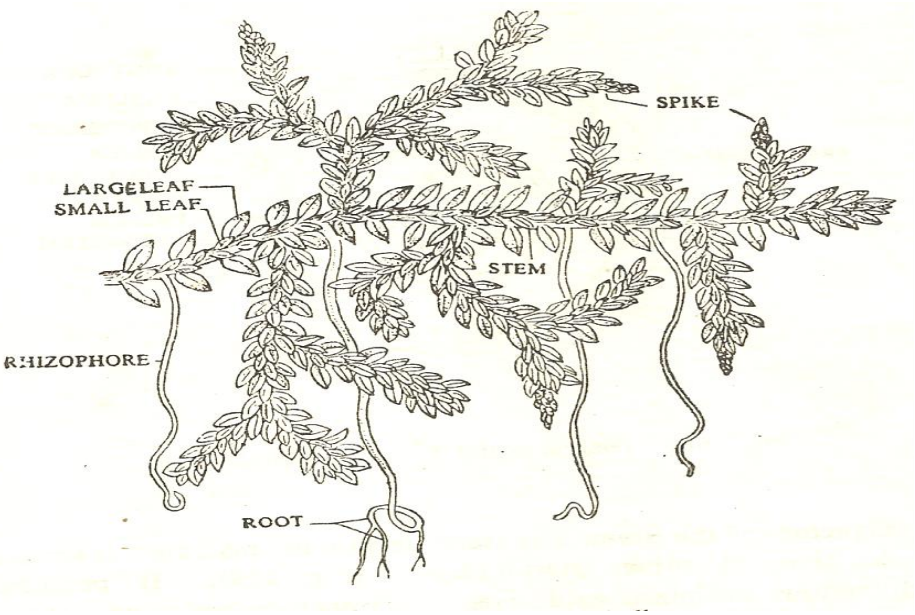


Fig.2.3. External features of *Selaginella*

Leaves: The leaves are small, simple and lanceolate to ovate in form. They are attached to the stem by a narrow insertion. Each leaf has an unbranched vein. Except for some xerophytic species where the leaves are thick and rigid, the leaves are usually thin and delicate. In species of subgenus **Homeophyllum** all leaves are of same size and are arranged spirally on the stem. In subgenus **Heterophyllum** leaves are conspicuously of two types and arranged in pairs. The small leaf of each pair is inserted on the dorsal-side on the stem and larger on the ventral-side. Successive pairs of leaves are so arranged that larger-leaf alternates with a large leaf and small-leaf with a small-leaf.

In *Selaginella,* on the upper or adaxial surface at the base of each leaf there is a small flap-like outgrowth called the **ligule** (Latin *ligula*=little tongue). It is prominent and functional only during the growth of leaf and withers away in the mature leaves. It is characteristic feature of sub- class Ligulosida. The function of ligule is not known but it is said to absorb water. In sporophylls ligule lies between the sporangium and leaf blade.

Stem: *Selaginella* stem is herbaceous, branched, solid and may be prostrate in species of sub-genus heterophyllum while in species referred to subgenus homeophyllum it is generally erect. The stem is dichotomously branched (Fig.2.3). The two branches formed as a result of dichotomy may be equal and continue to grow and undergo further dichotomy, or the two branches of a dichotomy may be unequal i.e.,one of them remains small.

Rhizophore

In many species of *Selaginella*at the place of bifurcation of stem, a leafless, colourless elongated cylindrical structure grow downwards into the ground and produce a tuft of adventitious roots at their tip (Fig. 2.3). This is called the **rhizophore** (Greek *rhiza*= root+phora=bear) by Nageli (1868), and is quite different from the root in that it has no root cap. In some species (*S. kraussiana*) only one rhizophore arises at each branching of the stem while in some other species (*S. martensii*) two rhizophore arise from each branching.

Root

The roots are adventitious and originate from the tip of rhizophores. The roots have root caps and bear root hair. In some cases the root arise only from the places where the stems branch. e.g., *S* . *densa*. The roots are dichotomously branched.

Internal structure

Root: The structure of the root is very simple. It has an outer **piliferous epidermis** which root-give rise to root hairs. This is followed by a several layered parenchymatous-**cortex** a few or several layered outer sclerenchymatous **hypodermis.** In ***S. densa*** the cortex consists of sclerenchymatous cells only (Webster and Sleeves 1963).Usually the **endodermis** is not well defined. Within this lies one to three layered **pericycle.** The root shows a protostelic **monarch** structure; the protoxylem being **exarch.** The xylem is surrounded by phloem in a horse-shoe shape manner (Fig.2.4).

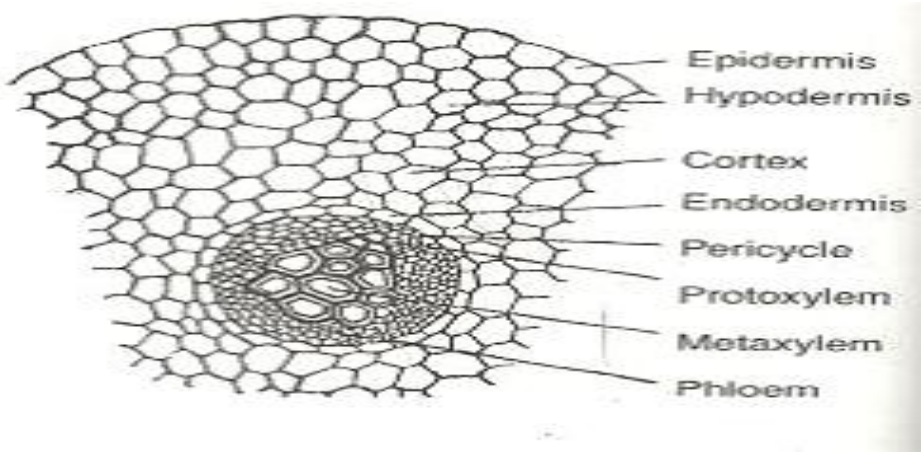


Fig. 2.4. Transverse section of root of *Selaginella*

Stem: The stem, despite its small size, is structurally similar to other pteridophytes. A transverse section of stem shows outermost layer the **epidermis** composed of elongated and pointed (prosenchymatous) cells. The outer wall of epidermal cells is cutinized**.** The stomata are absent**.** A many layered **cortex** lies below the epidermis. Outer part consist of thick walled lignified cells forming a sclerenchymatous cortex while the inner cortex composed of thin walled parenchymatous cells without intercellular spaces (Fig.2.5). In some xerophytic species (*S. lepidophylla*) the entire cortex consists of thick walled sclerenchymatous cells. Most of the species have a well developed stele which is a **protostele**. In some species the stele is siphonostele. The two protoxylem groups lie at the ends of oval mass of metaxylem so the stele is diarch and exarch. The **endodermis** except in some xerophytic species, such as, *S. lepidophylla*and , *S. rupestris*is peculiar in that it is interrupted by the large inter-cellular air-spaces. This is called the **trabeculated-endodermis.** The trabeculae (Latin *trabecule* means little beam) possess band-shaped thickening "**the casparian strips**" characteristics of the endodermis. In some species the stem contains a small centrally-placed stele, in others there are several independent steles. Xylem is solid band-shaped consisting of tracheids only. Duerdon (1929) reported the presence of **true-vessels** in a few species like *S. oregana, S. rupestris* and *S. densa.* Companion-cells are absent in phloem. The pericycle consists of thin-walled parenchymatous cells.

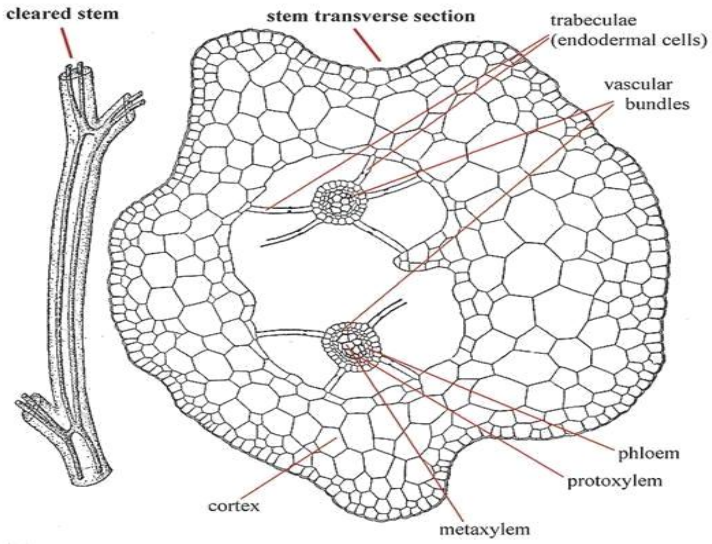


Fig. 2.5.Transverse section of the stem of *Selaginella*

Various stellar modification are found in the different species of *Selaginella.*

1. The xylem become **polystelic** in species with dorsiventral stem (*S. martensii*), as in erect system of *S. spinulosa,* or it may become **endarch** instead of exarch in trailing stems.
2. The stems may, in certain cases, become **polyarch** with a number of protoxylem groups**.** The number of the steles varies from 3-16. Each stele is surrounded by its own trabeculae.
3. Bower (1935) showed that rhizome of *S. laevigatalyalli* shows in young-condition a "**solenoxylic**" structure which is followed by a solenostelewith central pith and further in the upright stems it finally breaks into many **meristeles.**

Rhizophore: The rhizophore displays a root-like structure. It differs from a root with minor differences. The single layered epidermis is composed of thick walled cells followed by several layered hypodermis composed of thick walled cell. The cortex is composed of thin walled parenchymatous cells. The stele is usually protostele. The position of protoxylem varies with the species. In *S.kraussiana, S. poulteri and S. delicatissima,* the protoxylemlies in the centre *i.e.,* **centroxylic.** *S. martensii*shows a monarch and exarch structure. The structure in *S. atrovirdis* may be in the form of a number of strands situated in the crescentric metaxylem. The phloem surrounds the xylem completely (Fig. 2.6).

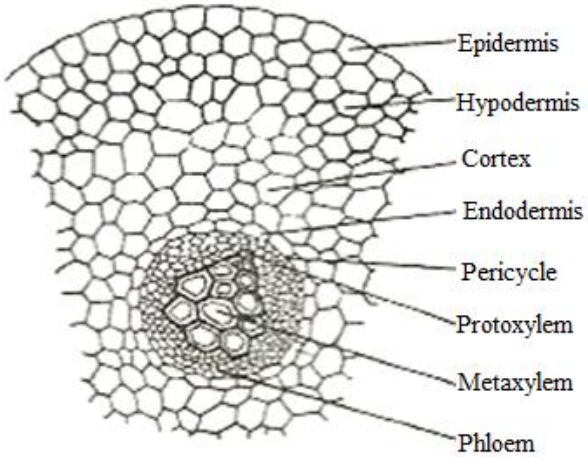


Fig. 2.6. Transverse section of rhizophore of *Selaginella*

Morphological nature of rhizophore

The morphological nature of rhizophore has long been a botanical puzzle. It has been interpreted by different botanists. The following are the three important views which have been advanced from time to time to prove its possible nature:

(1) According to Gibson, Van Tieghem and Uphof (1920) the rhizophore is a **capless-root** because: (i). it is geotropic; (ii). it is leafless and (iii).it exhibit root like structure

(2) Treub(1920), Pfeffer (1871), Bruchmann(1905) and Troll regarded it as a **leafless-shoot due** to the absence of root-cap, root-hairs; its exogenous origin(it formed always from the angle meristem which is present between the two branches of the stem) and it can be developed into leafy shoots under controlled experimental conditions (Bruchmann and Williams 1937).

(3) Williams (1958), Goeble (1930) and Bower (1947) regarded it as an **intermediate structure** between root and shoot and hence an "**organ sui generis" (independent organ).**

Leaf: The leaf displays a simple structure. The cells of the upper and lower **epidermis** contain chloroplasts. The **stomata** are present near the mid-rib only, on the lower epidermis. In between the two layers of epidermis lies that are loose spongy **mesophylls** which is generally not differentiated into palisade and spongy-parenchyma (Fig.2.7). In some species like in *S. lyalli, S.concina* **mesophylls** is differentiated into palisade and spongy-parenchyma. Mesophyll is a mass of green spongy cells forming a loose network with large intercellular spaces. Near the vascular bundle intercellular spaces are absent. According to species, each mesophyll cell has one or more chloroplast with spindle shaped pyrenoid like bodies at the centre. In the centre lies a single concentric **amphicribral-bundle** (a central strand of xylem surrounded by phloem). The vascular bundle is surrounded by a bundle sheath.

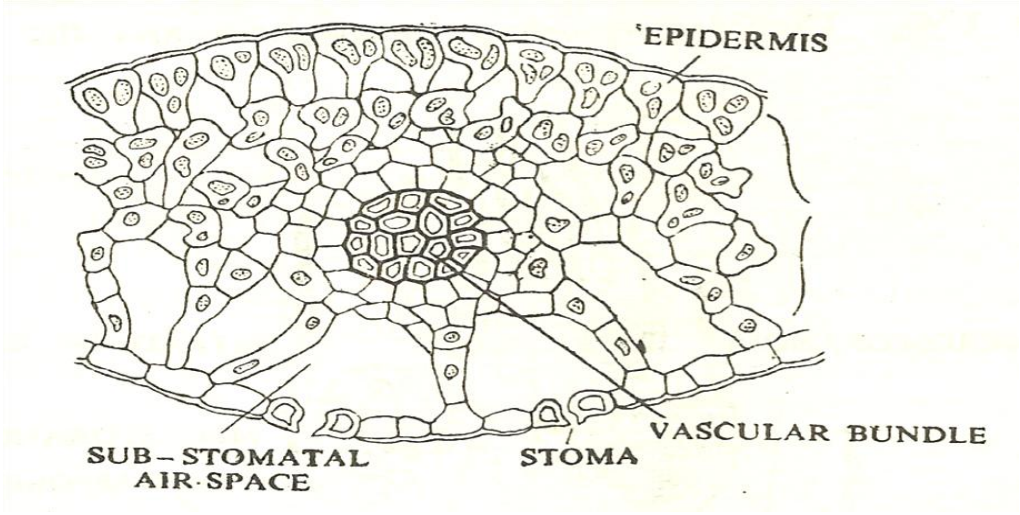


Fig.2.7.A part of transverse section of leaf of *Selaginella*

Ligule: The basal portion of mature ligule is hemispherical and called **glossopodium**. It is composed of thin walled cells. At the base the glossopodium is surrounded by a cup-shaped sheath the glossopodial sheath whose tubular cells are sunken into the leaf. The remaining cells of ligule are more or less cubical and densely filled with protoplast (Fig. 2.8).

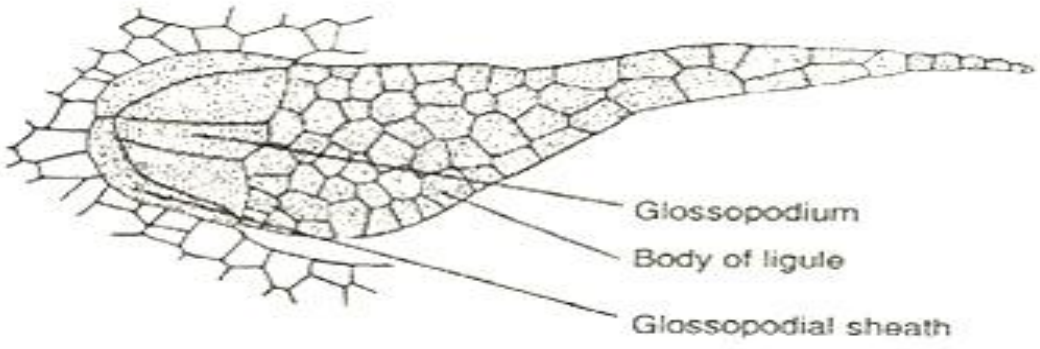


Fig. 2.8.Vertical section of a ligule of *Selaginella*

2.4.2 Reproduction in *Selaginella*

1-Vegetative reproduction: It is of rare occurrence in few species and may take by:

i. **Fragmentation:** The prostate branches under favourable conditions develop roots and break into small fragments each developing into a new plant e.g. *S. rupestris*.

ii. **Bulbils:** Certain species propagate by **Bulbils** or the small **tubers** as in *S. chrysocaulos* and *S. chrysorrhizos.* In the former case the tubers are formed at the surface of the ground and are called "**surface tubers**". In the latter case they are developed underground hence called "**underground tubers**". On the approach of favourable conditions, the tubers grow into new plants.

2-Sexual reproduction

The *Selaginella* plant is a sporophyte and bear spores. The haploid spores in turn produce gametophytes which bear gametes and reproduce by them sexually. The reproductive structure is a compact one and develops at the terminal portions of the branches. It is called a **strobilus** or **spike** and is a **sessile** structure. Usually it tapers towards the apex and length varies from $1/4^{th}$ of an inch to 2-3 inches in different species. *S. patula* and *S. cuspidate* are the two abnormal species, in which the terminal portion of the branch may continue vegetative growth beyond the spike. *S. erythropus,* furnishes an interesting example where the second strobilus is produced on a fertile-branch after an intercalary sterile portion. The strobilus either erect or horizontal. In some cases the strobili, owing to loose arrangement of sporophylls, become inconspicuous.

The strobilus possesses many ligulate **sporophylls** arranged in the form of the cluster each bearing on its upper-side and near its base a small short-stalked **sporangium.** The sporangia, instead of being all alike, are of**two** distinct kinds. These are present on the same strobilus. One type of sporangia contains four large spores and others contain many small spores. The large spores are **megaspores** and sporangium which bears them is the **megasporangium** and the leaf on which it is borne is a **megasporophyll.** Similarly the small spores are **microspores**, their respective sporangium, is the **microsporangium** borne on a **microsporophyll.** Each sporophyll,like the leaf has got a ligule in its axil. This **dimorphic** condition of spores is known as **heterospory** (Fig.2.9).The position of micro and megasporophyll varies according to the species.

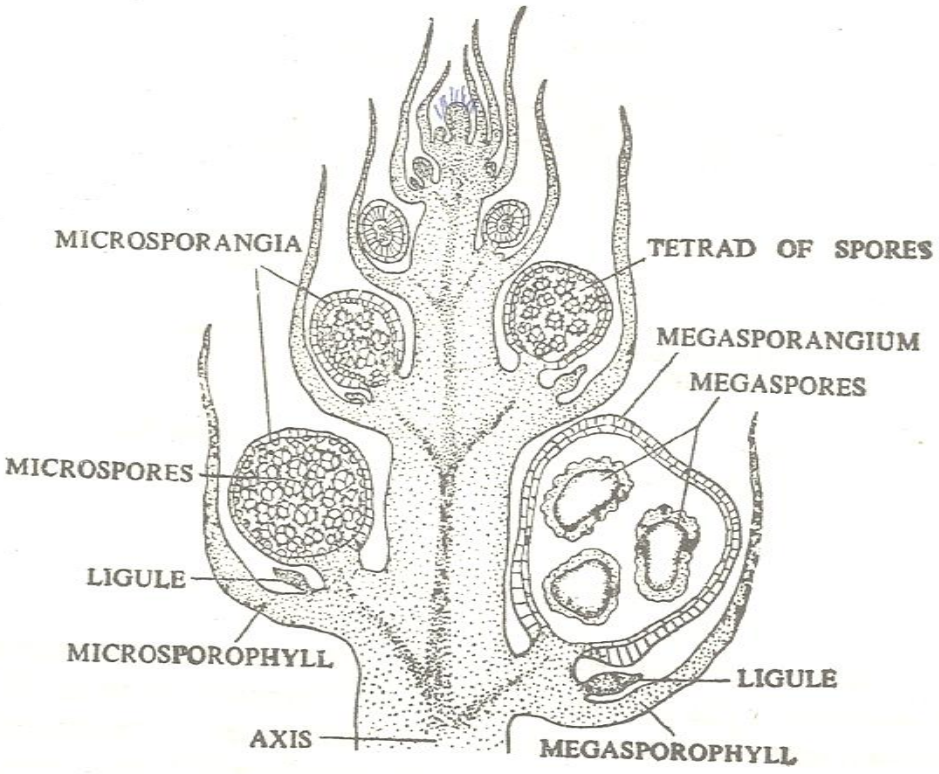


Fig.2.9.Longitudinal section of the strobilus of *S.kraussiana* showing one lower megasporangia and upper microsporangia

Development of sporangia

The early development of both kinds of sporangia is similar upto the spore mother cell stage. They are eusporangiate in development i.e. arising from a group of initials as you have already studied in Unit 1.In most of the cases, the sporangium arises from the cells of the axis, but at maturity the sporangium lie in the axil of the sporophyll. The sporangium initials divide periclinally to form an outer tier of cells, the jacket initial and the archesporial cells. The jacket initial by further division produces a two layered sporangium wall (Fig.2.10) The archesporial cell after numerous divisions produce a mass of sporogenous tissue. Of the two layered jacket the cells in the outer layer become thick walled while the cells in the inner layer remain thin walled. The outermost cells of the sporogenous tissue by periclinal division cut off an outer layer of sterile cells called tapetum. A number of spore mother cells are formed by the last cell division of the sporogenous cells.

In the microsporangium, all the spore mother cells are functional. These cells separate from each other and undergo reduction division to form tetrads of microspores.

In megasporangium, all the megaspore mother cell degenerate before meiosis except one which divides meiotically to form a tetrad of four megaspores. In most of the cases four tetrads are formed in each megasporangium but the number varies in different species.

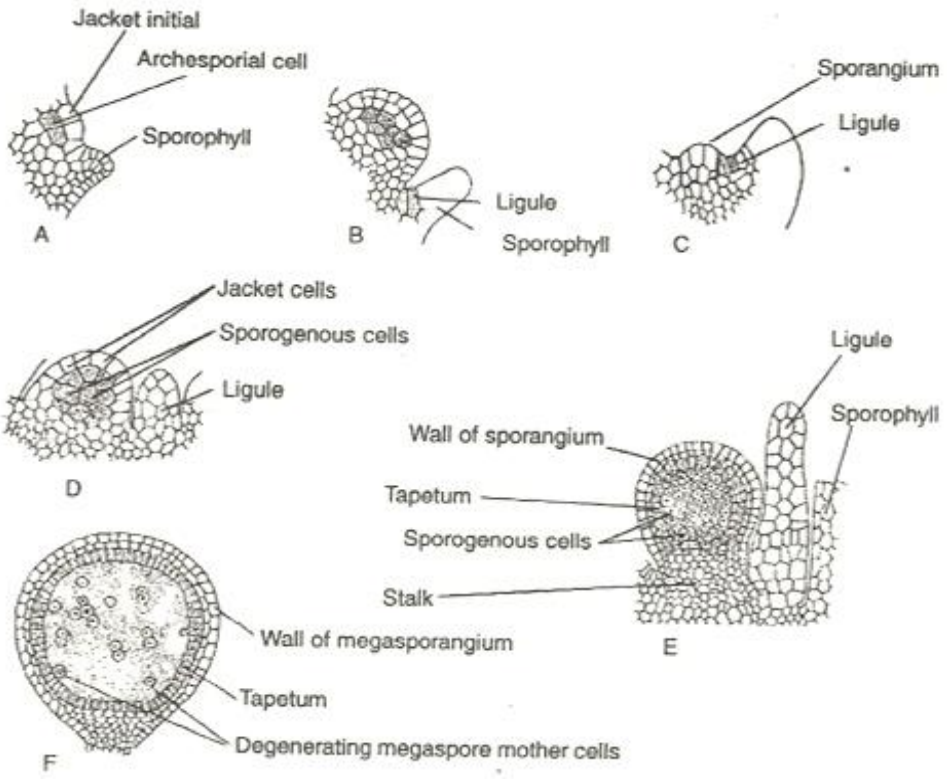


Fig. 2.10.Development of sporangium in *Selaginella*

Structure of mature sporangium: A microsporangium consists of a short stalk and an oval, reniform or spherical capsule which appears red, yellow or brown in colour (Fig.2.11). The body of sporangium has a two-layered wall. The outermost layer consists of columnar cells which becomes thick later on while the inner layer consists of thin walled cells. Within the wall tapetal layer enclose numerous tetrads of haploid microspores.

The megasporangium is larger in size than microsporangium and appears paler, green or whitish in colour. By the enlargement of megaspore, the megasporangium attained a four-lobed structure with each lobe enclosing a megaspore.The wall is similar in structure as described for microsporangium.

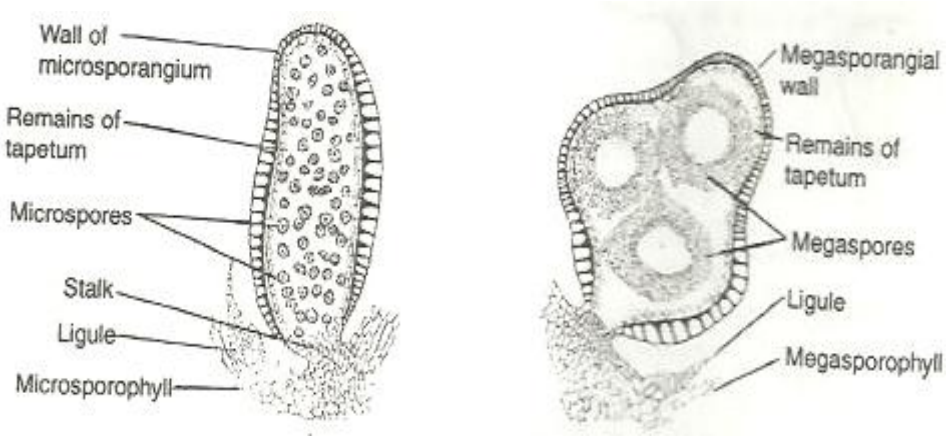


Fig. 2.11.Vertical section of microsporangium (A) and megasporangium (B)

Mechanism of sporangial dehiscence: When mature, the sporangium splits vertically only in the upper part into two valves which gap apart. This is brought about by cohesion owing to differential hygroscopic changes in the apical and lateral part of the sporangial wall. The basal portion (unsplitted) of the sporangium dries up and becomes boat-shaped finally forcing out of spores violently to distance of few centimeters. The liberation of the spores takes place at intervals in small masses. According to Goebel this violent dispersal of spores in an adaptation for cross fertilization in that it helps to bring spores from different plants near each other. This is further proves by the **protandrous** nature of the strobilus.

Germination of spores: Unlike spores of *Lycopodium* which germinate on soil, the spores of *Selaginella* germinate within the sporangium before they are shed from their respective sporangia. The spores of *Selaginella* are peculiar in that they show **intrasporangial germination** and this is called "**precocious germination**" by Bold (1957). The difference in the size of the two spores is associated with the difference in their function. The megaspore develops into a female gametophyte while microspore gives rise to male gametophyte. The microspore, except for its much smaller size (0.015-0.05 mm), and red colour, closely resembles a megaspore. It germinates into a 13-celled male gametophyte **while confined in the microsporangium** thus differing from other pteridophytes. So at the time of liberation, the spores are found in various stages of development.

Germination of Microspore and Development of Male gametophyte: The first division results in the formation of a large and small cell both of which lie within the microspore wall. The smaller-cell corresponds to the vegetative tissue of the fern prothallus and is called **prothallial cell.** The large cell is the mother cell of the antheridium which by further divisions develops a central group of 6-8 primordial cells surrounded by a single layer of **jacket cell** (Fig. 2.12).

According to Millardet, only two inner cells produce the mother cells of the spermatozoids but Pfeffer, on the other hand found that all the primordial cells first form in the antheridium divide again and at length give rise to **antherozoids** *e.g., S.martensi i*and *S. caulescens.* Each cell of the central group is finally transformed into a spirally coiled antherozoid with two flagella, while the jacket-cells disintegrate. The microspores are usually shed sometimes during the development of sperms by rupturing the microsporangia. The spermatozoids move for about 30 or 45 minutes. About three weeks time is sufficient for the germination of the microspore and the ultimate development of sperms. When mature, about 256 sperms lie free in the spore wall which liberates them when it bursts open. The sperms are very minute in size roughly measuring about 0.0125mm. Their cilia are twice big as compared to the body.

Germination of Megaspore and Development of Female gametophyte: The megaspore has more or less the shape of the low broad triangular pyramid with a round base. They are twenty times larger than the microspores. They can easily be seen with the naked eye. Their size ranges from 0.5 mm to 5.0 mm. Each megaspore has a characteristic well marked **triradiate ridge** prolonged into a beak-like portion. It is in this region that the spore ruptures.

Each possesses a very thick, rough, cutinized, sculptured outer wall, the **exospores,** and a delicate **endospore** (Fig. 2.13).

Mostly the megaspore germinates in situ, *e.g.* while still enclosed in the megasporangium. The stage at which megaspores (developing female gametophyte) are shed varies from specie to species. In some cases they are liberated immediately after first division. In *S. kraussiana* they may be shed shortly after the development of first archegonium or in some interesting cases the megaspores are not at all liberated from the megasporangium till fertilization has taken place and a well developed embryo is formed *e.g.*, *S.apoda* and *S. rupestris.*

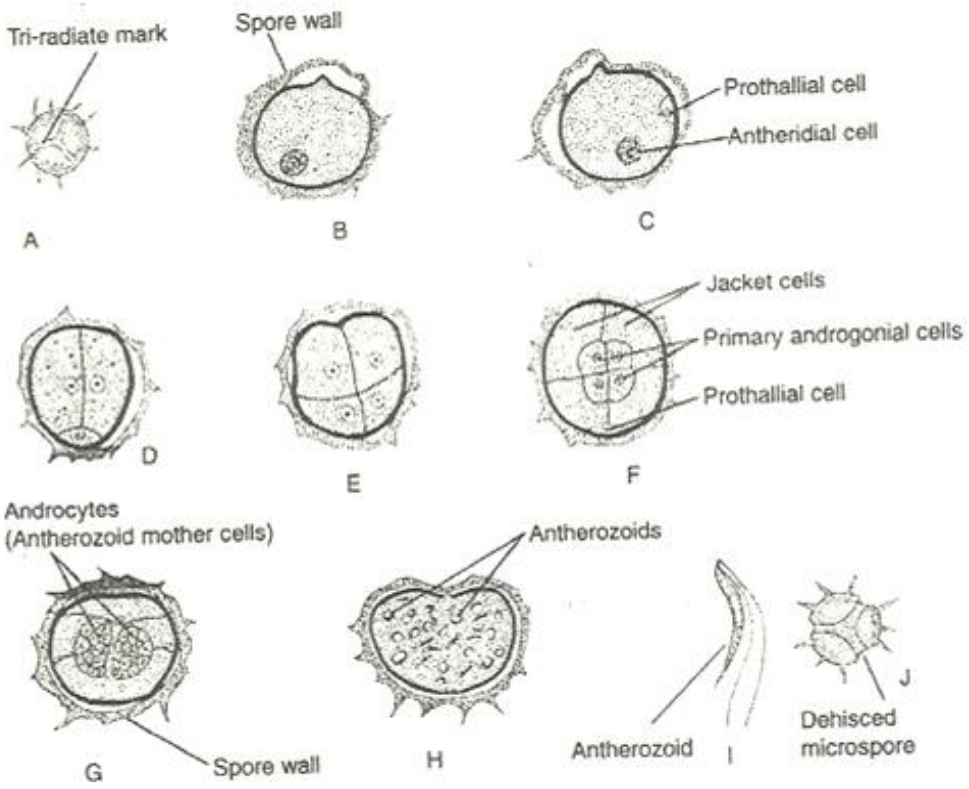


Fig. 2.12, Stages in the development of male gametophyte in *Selaginella*

Campbell (1902) has worked out the development of the female gametophyte in *S. kraissiana. A*ccording to him, the protoplasm contracts to form a small sac-like structure which is accompanied by the rapid expansion of the wall so that the two become separated by a wide space. This is followed by the bursting of the outer-wall into two layers- the **exospores** and **mesospore** which are separated with each other by a **gelatinous membrane.** The megaspore at this stage contains a haploid nucleus which divided producing numerous nuclei around the protoplasmic-layer. At this stage the protoplasm increases nuclei around the protoplasmic-layer. At this the protoplasm increases in size and volume thus establishing contact with the exospores and megaspore obliterating the central vacuole. Wall formation takes place at the beak-like portion in the centre of the triradiate ridge. This results in the development of a small celled meniscus-shaped cellular tissue. This is one-cell thick at the sides, and three-cells thick in the middle and is called the **female prothallus.** Below this there is a large-celled tissue of hexagonal cells called the **diaphragm** formed by free cell

formation. Pfeffer regards them as **secondary prothallium** and compared this tissue with the endosperm of angiosperms.

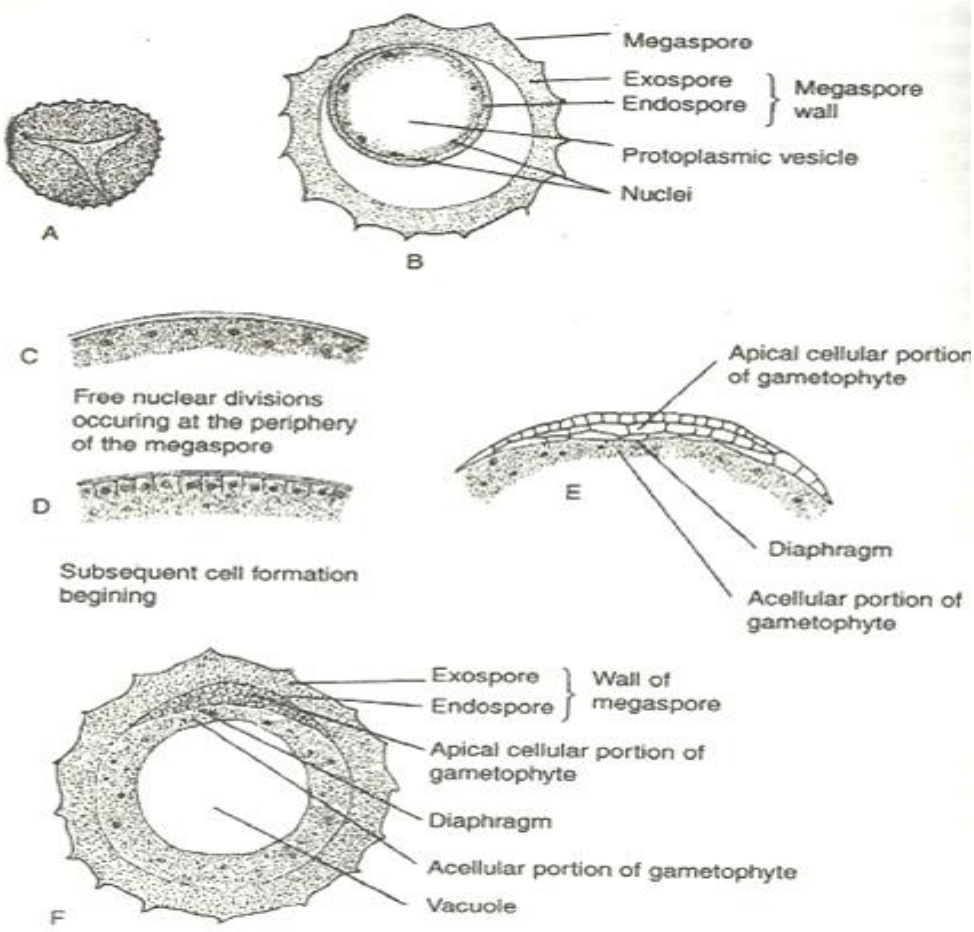


Fig. 2.13 Stages in the development of female gametophyte

Certain superficial cells towards the apical side enlarge and behave as potential **archegonial-initials** and form the archegonia. At this stage the megaspore bursts along the ridge exposing the female prothallus. Soon **vestigial-rhizoids** develop from the three little humps. The archegonial initial divided into two which further divide into four rows of the cells with two cells in each row is formed. The lower-cell divides thrusting a narrow prolongation in between the neck cells. This is separated into a **neck canal cell** and the large cell, the **central cell.** This cell further divides and forms a **venter canal cell** and an **egg** (Fig. 2.14).When the archegonium is mature, the neck canal cells and venter canal cell disorganize forming a mucilaginous product. This oozes out from the neck attracting sperms to the egg. Generally in *Selaginella* the megasporangia break open at this stage thus liberating the female gametophyte which falls to the ground.

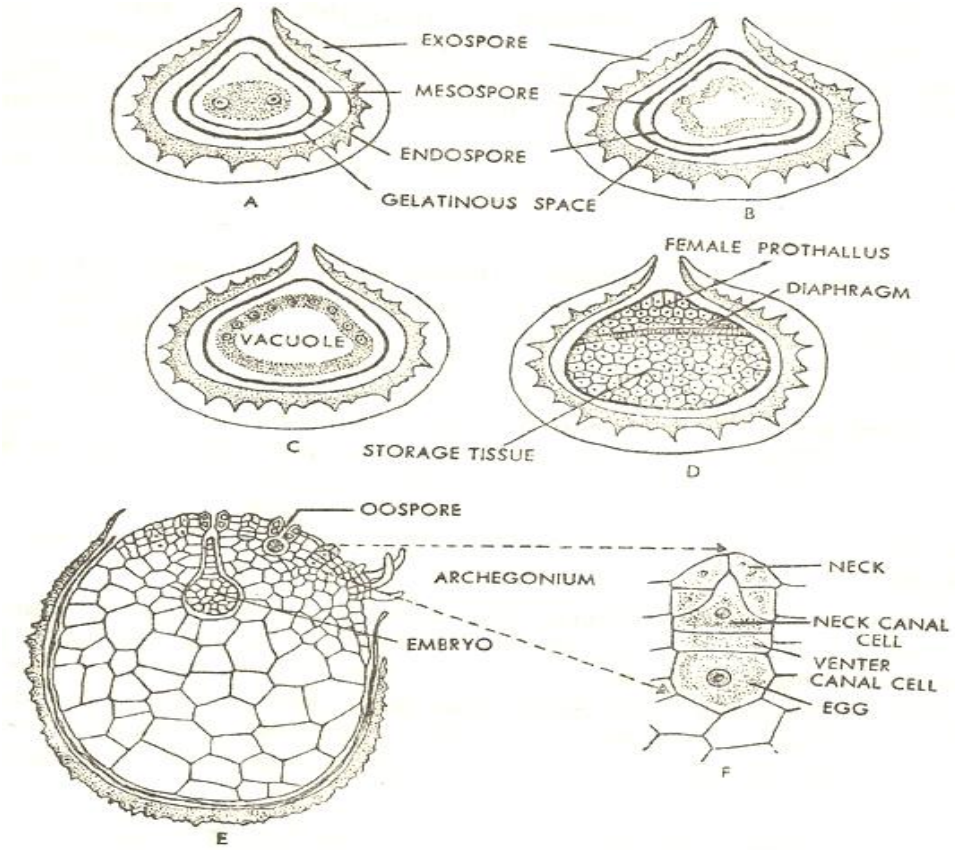


Fig. 2.14 Stages in the development of Archegonium

Fertilization: Usually the male gametophytes are shed from the microsporangium on the ground. Here they complete their development ultimately producing spermatozoids. These are liberated by the decay of the microspore wall. If the microspore or male gametophyte gets a chance to fall near the mature female gametophyte or megaspore and provided moisture is present, the sperms swim from the male gametophyte to enter archegonia. The sperm ultimately fuses with the egg resulting in its fertilization.

But in certain cases, *S. apoda* and *S. rupestris,* showedan approach to the **seed habit**. Here, when a megasporangium is mature, it cracks open, but not sufficiently, to permit the escape of developing female gametophyte. Only one megaspore is formed in each megasporangium. The megasporangia, when mature, burst-open and the developing microgametophytes are thrown out. Some of them shifting down between the sporophytes mat fall into partly-open megasporangia. Now, lying in the megasporangium, the two kinds of gametophytes complete their development. If sufficient water is present, fertilization takes place. The young embryos develop within the wall of the megasporangium and drop out as soon as they develop a root and primary shoot. Later on the opening of megasporangium becomes wider and the megagametophytes with their developing embryos fall to the ground.

This is especially significant since it introduces in the life-cycle a close parallel to the **pollination** and **seed formation** habits found in the spermatophytes. Therefore, when the megaspore, with its newly formed embryonic sporophyte, falls to the ground, it is for all practical purposes a **seed** and hence *Selaginella* approaches the seed habit.

Development of Embryo or Sporophyte: The oospore after fertilization gets surrounded by a wall and becomes a zygote. It divided transversely into two walls, the upper epibasal and the lower hypobasal cell. The epibasal-cell forms the suspensor cell which elongates and pushes the developing embryo down into the gametophytic tissue (Fig2.15). The embryo differentiates into foot, root and primary stem with two lateral cells on either side. Each of the lateral cells give rise to the cotyledon (Fig. 2.15 E and G).The foot serves to absorb the food for the developing embryo from the gametophytic tissue. The foot by its further growth pushes the stem apex to one side so that the axis of embryo comes to lie at right angle to the suspensor (Fig.2.15 G).From inner side of each cotyledon, near to its base develops an outgrowth which develops later into ligule (Fig H). The apical cell of the root cut off cells and and produce a structure that is considered rhizophore (Bruchmann 1912). This primary rhizophore develops the roots. By the outward growth of the stem and the root, the young sporophyte eventually becomes independent of the gemetophytic tissue within the old megaspore wall (Fig.2.16).The young sporophyte remains attached to megaspore for some time and than falls into the ground where primary rhizophore develops roots that grow into the soil and plant starts an independent life.

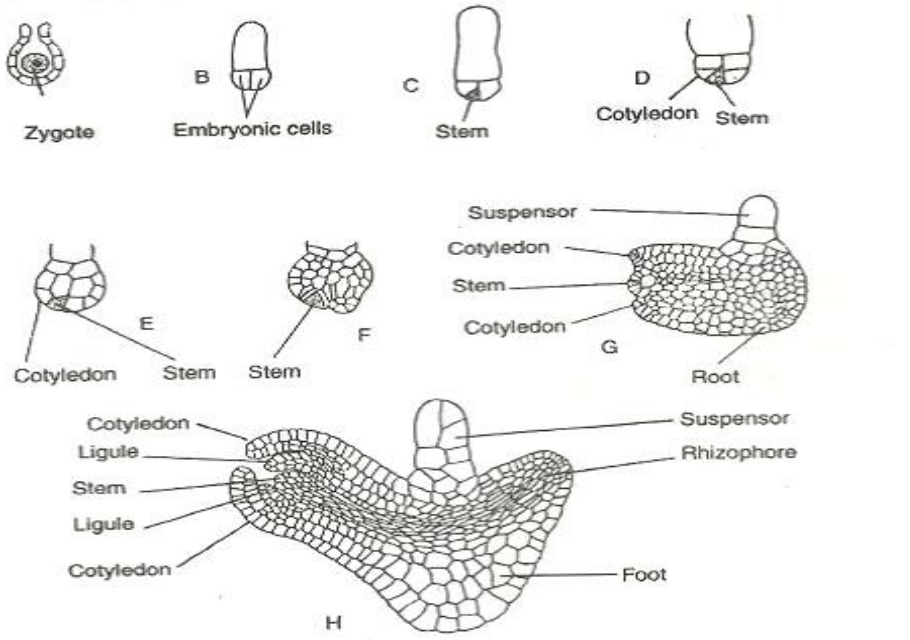


Fig. 2.15- Stages in the development of embryo in *Selaginella*

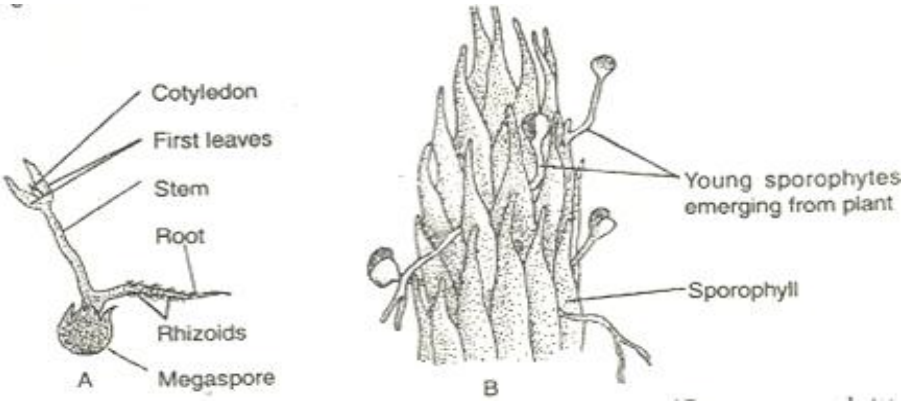


Fig.2.16. Young sporophyte of Selaginellakraussianna still attached to megaspore (A) and young sporophyte protruding from the cone of S. rupestris (B)

Life-cycle of *Selaginella*

In *Selaginella,* the spores are of two kinds- the smaller spores termed as *microspores* or *male spores* and are developed in *microsporangia,* while the larger spores are termed as *megaspores* or *female spores* and are formed in *megasporangia.* The microspores on germination produce the male gametophyte on which only the male gametes, *i.e.,* the *sperms* are produced. The megaspore produce the female gametophyte, the fertilization occurs in presence of water resulting in a formation of a diploid cell or *zygote* which in its turn develops into a sporophytic generation. Thus the life cycle of *Selaginella* consists of an alternate succession of heteromorphic sporophytic and gemetophytic generation (Fig.2.17).

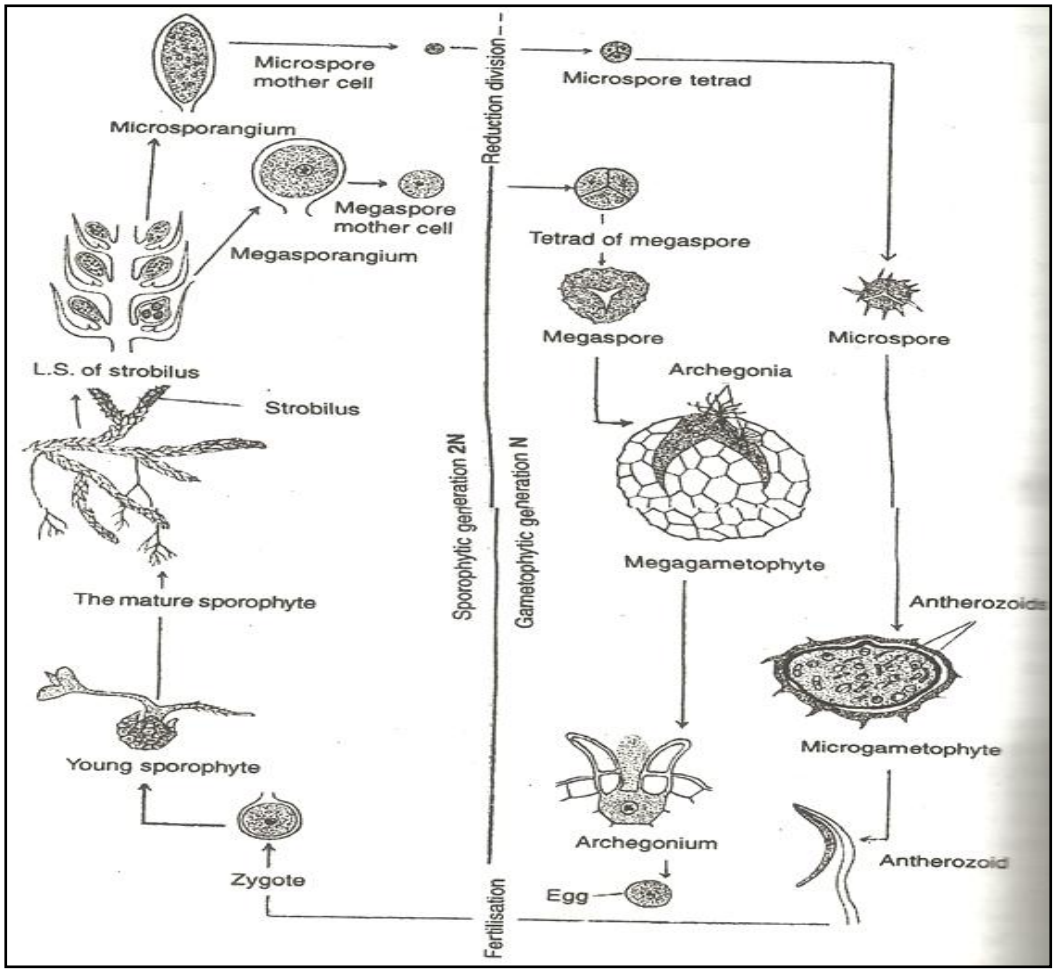


Fig. 2.17 Diagrammatic representation of the life-cycle of *Selaginella*

2.5 SUMMARY

Rhynia with its two species was discovered from the Middle Devonian deposits of Rhynie in Aberdeenshire district of Scotland by Kidston and Lang (1917).The plant body was herbaceous sporophyte with aerial dichotomously branched leafless stem arising from a horizontal rhizome with rhizoids on the lower side. At the tip of axes sporangia were present. The aerial stem of *Rhynia major*were about 50 cm in height and 1.5 to 6 mm in diameter, while the stems of *R.gwynne-vaughanii* attained a height of about 20 cm and were only 1 to 3 mm in diameter.Aerial axes of *R. major* were smooth whereas the aerial axes of *R. gwynne-*

*vaughanii*were with hemispherical humps scattered all over the axes. It had adventitious branches in addition to the normal dichotomies; sporangia and spores were smaller. The gametophyte, it was believed was too delicate to have been preserved during the fossilization process. In 1968 Lemoigne suggested that the hemispherical bulges on the surface of *R. gwynne-vaughanii*were archegonia. The rhizomatous portion represents the gametophyte, while the aerial erect portions represent the sporophyte.

In 1986 Edwards described a new genus *Aglaophyton* to accommodate *R. major* as *Aglaophyton major* and also emended its description as: Plants sporophytes, with a semi-creeping decumbent habit, much shorter than originally described, formed extensive stands of decumbent axes. Edwards laid much stress on the nature of the conducting strands and expressed that this plant exhibits characters intermediate between vascular plants and some mosses and cannot be considered a member of either group.

Selaginella with about 700 species is worldwide in distribution. It is a member of class Lycopsida and order Selaginellales. The plant is the sporophyte and is a delicate herb with adventitious roots.The stem covered with green leaves present a moss like appearance; hence the plant is called the little club moss. The leaves are simple, lanceolate or ovate and ligulate in that they bear aflap like outgrowth at base called ligule. At the place of bifurcation of the stem a leafless, colourless cylindrical structure grows downward. This is known as rhizophore and develops tufts of adventitious roots. The stem is characterized by the presence of trabeculated endodermis. In some species the stem contains a small centrally placed stele, in others there are several independent steles. A section of leaf shows a definite upper and lower epidermis, an usually undifferentiated mesophyll and a central concentric amphicribral vascular bundle. A cross section of root shows an epidermis, cortex and stele. The endodermis in most species is usually not well defined. The stele is monarch and exarch. The phloem more or less surrounds the xylem. Anatomically the rhizome resembles the root and its morphological nature is still in question.

In most species of *Selaginella* the fertile region is well differentiated from the vegetative region as a definite strobilus. In most species the strobili bear both megasporophylls and the microsporophylls, but in some species the strobili may consist of one type of sporophylls. The sporophylls also possess a ligule. Eachsporophyll bears a single stalked sporangium in its axil. The megasporangia and microsporangis are alike in their early development and this continues upto the spore mother cell stage. In those sporangia which are to bear microspore i.e. microsporangia all the sporogenous cells are potential spore mother cells while in those sporangia which are to bear megaspore i.e. megasporangia all megaspore mother cells except one usually degenerate. Both the micro and megasporangia are stalked structure. The megasporangium is larger in size and usually contains four megaspores, while the microsporangium is small and contains numerous small microspores. The microspore germinates to produce male gametophyte which bears antheridia while megaspore germinates to produce female gametophyte which bears archegonium. The antherozoids are set free and they swim to the archegonia in a thin film of dew or rain water. After fertilization the zygote is formed which divide to form embryo. The embryo differentiates into foot, root and primary stem with two lateral cells on either side. Each of the lateral cells gives rise to the cotyledon.

Each cotyledon develops upon its inner side near the base an appendage, the ligule. The young sporophyte is attached for some time to the female gametophyte still held within the megaspore wall. Eventually the stem and the cotyledons grow upward and the rhizophore bend downward and the roots from its apex penetrate the ground.

The life cycle of *Selaginella* consists of an alternate succession of heteromorphic sporophytic and gemetophytic generation

2.6 GLOSSARY

Androcyte: Antherozoid mother cell.
Androgonial cell: Any cell within an antheridium other androcyte or androcyte mother cell.
Antheridium: Male sex organ of cryptogams.
Archgonium: The female sex organ of bryophytes, pteridophytes and gymnosperms.
Axil: It is the junction where a lateral organ such as a leaf joins a main axis like a stem.
Cortex: The ground tissue of stem and root; present between epidermis and the stele.
Cuticle: A waterproofing layer covering the epidermis of aerial plant surfaces.
Dichotomous: The type of branching in plants that result when growing point divides into two equal growing points which in turn divide in a similar manner after a period of growth and so on.
Embryo: An embryo is a multicellular diploid structure in an early stage of embryogenesis or development.
Endodermis: The layer of tissue situated between the cortex and stele.
Fertilization: It is the fusion of gametes to initiate the development of a new individual organism.
Foot: A specialized organ of attachment and of the embryo which absorbs food from the gametophyte.
Gametophyte: A gametophyte is a gamete bearing plant. It develops from the meiospores produced by sporophyte by meiosis or reduction division. Gametophyte is a haploid structure.
Habit: The general external appearance of a plant, including size, shape, texture and orientation
Habitat: The place where a plant lives; the environmental conditions of its home.
Heteromorphic: When the two phases of life-cycle are morphologically different.
Heterospory: Production of two kinds of dissimilar spores differing in size and function in the same species.
Homospory: Production of one kind of similar spores.
Leaf: An outgrowth of the stem usually flat and green; its main function is manufacture of food by photosynthesis.
Life-cycle: In most of the plants multicellular diploid sporophyte phase alternates with a multicellular haploid gametophyte phase. This cycle is known as life-cycle or alternation of generation.
Ligule: A minute appendage of the leaf that is found at the base of the leaf.
Megaspore: The larger of two kinds of spores produced by a heterosporous plant giving rise to the female gametophyte.

Mesophyll: The inner photosynthetic parenchyma of leaf located between epidermal layer and usually differentiated into palisade and spongy parenchyma.
Microspore: The smaller of two kinds of spores produced by a heterosporous plant giving rise to the male gametophyte.
Rhizome: Underground stem distinguished from root by nodes, buds or scale like leaves.
Rhizophore: A specified part of the stem bearing roots.
Spore: A haploid propagule produced by meiosis in diploid cells of a sporophyte that can germinate to develop a multicellular gametophyte.
Sporophyte: A sporophyte is the diploid multicellular stage in the life cycle of a plant. It develops from the zygote when a haploid egg cell is fertilized by a haploid sperm and each sporophyte cell therefore has a double set of chromosomes. The sporophyte produces spores by meiosis (hence the name sporophyte means spore bearing plant).
Strobilus: A cone like structure consisting of sporophylls or sporangiophores borne close together on an axis.
Tetrad: A group of four spores resulting from reduction division of one spore mother cell.
Zygote: The unfertilized egg before it undergoes further differentiation.

2.7 SELF ASSESSMENT QUESTION

2.7.1 Multiple choice Questions:

1. The sporangia of *Rhynia* are:
(i) Apical and homosporous (ii) Lateral and homosporous
(iii) Apical and heterosporous (iv) Lateral and heterosporous

2. *Rhynia* was described by:
(i) Kidston and Lang (ii) J.R. Dawson
(iii) Bierhorst (iv) Mehra

3. The new name for *Rhynia major* is:
(i) *Pteris* (ii) *Notothylus*
(iii) *Horneophyton* (iv) *Agalophyton*

4. Ligule is present in:
(i) *Rhynia* (ii) *Psilotum*
(iii) *Selaginella* (iv) *Lycopodium*

5. In *Selaginella*meiosis occur during:
(i) Spore formation (ii) Gamete formation
(iii) Zygote formation (iv) Sporophyte formation

2.7.2. Fill in the blanks

1. *Selaginella* is a _____ pteridophyte.
2. *Rhynia* is a_____ plant.

3. *R. gwynne-vaughani* is _____ than *R. major*.
4. In *Selaginella* vegetative reproduction takes place by _____.
5. Foot is present in _____of *Selaginella.*
6. Life cycle of *Selaginella* is _____.

Answer keys:

2.7.1.: 1. (i), 2. (i), 3. (iv), 4. (iii), 5. (i)

2.7.2.: 1. Heterosporous, 2.Fossil, 3.Smaller, 4.Tubers/ fragmentation, 5. Embryo, 6. Heteromorphic

2.8 REFERENCES

- Alston, A.H.G. 1945. An enumeration of the Indian species of *Selaginella*.*Proc.National Inst. Sci. India,* XI: 211-236.
- Banks, H.P.1992. The classification of early vascular plants-Revisited.*Geophytology* 22:49-63.
- Bower, F.O. 1947.*Botany of the living plants*.4th ed. London.
- Bower,F.O.1935. *Primitive land plants*.Macmillan London.
- Bruchmann ,H.1905. On the rhizophore of *SelaginellaFlora* 95:150-66.
- Bruchmann, H. 1912. Zur Embryology der Selaginellaceae. *Flora* 104: 180-224.
- Campbell, D.H. 1902. Studies on the gametophyte of *Selaginella*.*Ann. Bot*. 16: 419-428.
- Duerdon, H.1929. Variation in megaspore number in *Selaginella.Ann.Bot* 43:451-457 .
- Edwards.D.S.1986. *Aglaophyton major*, a non-vascular land plant from the Devonian Rhyniechert. *Bot. J. Linn. Soc.* (London) 93: 173-204.
- Goebel, K. 1930. *Organographyof plants* Part. II p.228 (*Selaginella*).
- Hieronymus, G. 1900. Selaginellaceae – In: Engler A. and Prantl K.1902. *Die Naturl. Pflanzenfam.*I.Tell4 Abt. Leipzig.
- Kidston, R. and W.H.Lang. 1917 -1920. On Old Red sandstone plants showing structure from the Rhyniechert bed Aberdeenshire, Part I. *Rhynia Gwynne-vaughanii*Kidston and lang. Trans. Roy.Soc.Edinberg 51: 761-784.
- Lemoigne, Y. 1970. Gametophyte of *Rhynie*.*Bull. Soc. Bot. France* 117: 307-320.
- Lyon, A.G.1957. Germinating spore in Rhyniachert.*Nature* 180:1219.
- Nageli 1868.Entstehung and Wachsthum der WurzelnBeitrz.Wiss*Bot.*vol.IV()
- Pfeffer 1871. Die Entwickelung der KeimesderGattung*Selaginella*.(Hanstein's*Bot* AbhandlungenVol I).
- Pant, D.D.1962.The gametophyte of psilophytales.Proc. *Summer School Botany. Darjeeling* June 2-15 1960, 276-301.
- Sharma, B.D. and R.P.Tripathi 2000.Sporangium of *Aglaophyton (Rhynia) major* (Kidston and Lang) Edwards from Rhyniechert, Lower Devonian.*Phytomorphology* 50: 188-191.
- Treub1877.Recherches sur les organs de la vegetation du *Selaginellamarlensii*Spring. (Musee bot.de LeideVol II)

- Uphof, J.C.T.1920. Contributions towards knowledge of the genus *Selaginella*.The root.*Ann.Bot*.34:493-517.
- Webster,T.R. and T.A.Steeves 1963.Morphological nature of *Selaginella*rhizophore.*Phytomorphology*. 13: 367-376.
- Williams, S. 1958. *Manual of Peridology* 105: 15

2.9 SUGGESTED READINGS

- Biology and morphology of *Pteridophytes.* Central Book Depot Allahabad ByParihar, N.S.
- An introduction to *Pteridophyta: Diversity and Differentiation*. Vikas Publishing House Pvt Ltd, New Delhi ByA.Rashid,
- A Text Book of *Pteridophyta* .Vikas Publishing House Pvt Ltd, New Delhi ByPandey, S.N., P.S. Trivedi and S.P. Misra
- Botany for Degree students: *Pteridophyta.* S. Chand Publications, Meerut By B.R. Vashishtha

2.10 TERMINAL QUESTIONS

1. Describe the given blow-

(i) Rhizophore (ii) Ligule (iii) Microsporangium (iv) Megasporangium

2. Explain the following:

(i) Sporangia of *Rhynia*
(ii) Locality of *Rhynia*
(iii) Stem of *Rhynia*

3. Differentiate between:

i. Heterospory and homospory
ii. Rhizophore and root
iii. *Rhynia major* and *R. gwnnye-vaughani*

4. Define the following:

(i) Sporophyll
(ii) Strobilus
(iii) ligule
(iv) rhizophore
(v) microsporangium
(vi) megasporangium

5.Write short notes on:

i. Vegetative reproduction in *Selaginella*
ii. Gametophyte of*Rhynia*
iii. Sporangium of *Rhynia*

iv. Reseurrection plants
v. Life- cycle of *Selaginella*

6. Draw labeled diagrams to illustrate the structure of the following:
i. T.S. stem of *Selaginella*
ii. T.S. stem of *Rhynia*
iii. L.S.strobilus of *Selaginella*

UNIT-3 STRUCTURE AND REPRODUCTION IN *EQUISETUM* AND *ADIANTUM*

3.1 OBJECTIVES

This unit describes structure and reproduction in *Equisetum* and *Adiantum.* After reading this unit you will be able to:

- Describe systematic position, habit, habitat and general features of *Equisetum* and *Adiantum*
- Explain reproduction in *Equisetum* and *Adiantum*
- Understand sporangial development in *Equisetum* and *Adiantum*
- Discuss life cycle in *Equisetum and Adiantum*

3.2 INTRODUCTION

In the previous unit we have described the general characteristics of pteridophytes. The present unit deals with structure and reproduction of two pteridophytes viz., *Equisetum* and *Adiantum*. Class Equisetopsida contains a single order Equisetales. Found in the Upper Devonian, best in Carboniferous from whence its decline started, until in Triassic it was represented by a few genera. The order contains a single surviving family Equisetaceae and a sole living genus *Equisetum*. ***Equisetum*** (**horsetail**, **snake grass**, **puzzlegrass**) is the only living genus in Equisetaceae, a family of vascular plants that reproduce by spores rather than seeds.

Equisetum is a "living fossil" as it is the only living genus of the entire class Equisetopsida, which for over one hundred million years was much more diverse and dominated the understory of late Paleozoic forests. Some Equisetopsida were large trees reaching to 30 meters tall. The genus *Calamites* of the family Calamitaceae, for example, is abundant in coal deposits from the Carboniferous period.

A superficially similar but entirely unrelated flowering plant genus, mare's tail (*Hippuris*), is occasionally referred to as "horsetail", and adding to confusion, the name mare's tail is sometimes applied to *Equisetum*.

It has been suggested that the pattern of spacing of nodes in horsetails, wherein those toward the apex of the shoot are increasingly close together, inspired John Napier to discover logarithms.

The second genus *Adiantum* comprising of some 200 species, is widely distributed in both tropical and temperate regions of the world. Species of *Adiantum* occur in a wide variety of habitats but they are most abundant in moist and shady places.

3.3 *EQUISETUM*

Systematic Position

Division - Sphenophyta
Class - Calapmopsida
Order - Equisetales
Family - Equisetaceae
Genus - *Equisetum*

Distribution and habitat

Equisetum is almost world-wide in distribution with 15 species and confined to N. Temperate regions, though some are met with in Tropics also, except Australia. From India four species are known *E. arvense, E. diffusum, E. palustre* and *E. ramosissimum*. Species of *Equisetum* are usually known as "horse tails" or "pipes" or "scouring rushes".

Plants are small to large, terrestrial; usually grow in wet or marshy places or in open, sunny sand banks along rivers and margins of lakes.

The genus *Equisetum* is cosmopolitan, being absent only from Antarctica, though they are not known to be native to Australia, New Zealand nor the islands of the Pacific. They are perennial plants, either herbaceous and dying back in winter as most temperate species, or evergreen as most tropical species and the temperate species rough horsetail (*E. hyemale*), branched horsetail (*E. ramosissimum*), dwarf horsetail (*E. scirpoides*) and variegated horsetail (*E. variegatum*). They typically grow 0.2-1.5 m tall, though the "giant horsetails" are recorded to grow as high as 2.5 m (northern giant horsetail, *E. telmateia*), 5 m (southern giant horsetail, *E. giganteum*) or 8 m (Mexican giant horsetail, *E. myriochaetum*), and allegedly even more.

Many species in this genus prefer wet sandy soils, though some are semi-aquatic and others are adapted to wet clay soils. The stalks arise from rhizomes that are deep underground and almost impossible to dig out. The field horsetail (*E. arvense*) can be a nuisance weed, readily re-growing from the rhizome after being pulled out. It is also unaffected by many herbicides designed to kill seed plants. *E. arvense* prefers an acid soil, lime may be used to assist in eradication efforts to bring the soil pH to 7 or 8. Members of the genus have been declared noxious weeds in Australia and in the US state of Oregon.

All the *Equisetum* is classed as "unwanted organisms" in New Zealand and are listed on the National Pest Plant Accord.

3.3.1 Structure of *Equisetum*

External features: The plant body of *Equisetum* is differentiated into stem, leaves and roots.

Rhizome: The *Equisetum* sporophyte develops a usually perennial, much branched underground rhizome. The rhizome produces true roots. The rhizome divided into nodes and internodes; scales present at nodes are fused to form a sheath. From nodes extra axillary branches arise, usually annually to give rise to aerial shoots which are built on the same pattern as the rhizome. It anchors the plant body and act as storage organ. The rhizomes allow survival in harsh environmental conditions.

Roots: The roots are adventitious except the primary root. They arise in whorls from the base of the branch primordia at each node of rhizome. The roots are slender and fibrous, but sometime branched.

Stems: The upright aerial stems exhibit a monopodial branching pattern, having one main axis of growth. Plant body has green, photosynthetic aerial stems, jointed at the nodes, and with vertical ridges or ribs on the internodes. Stems may be simple and unbranched, or bear

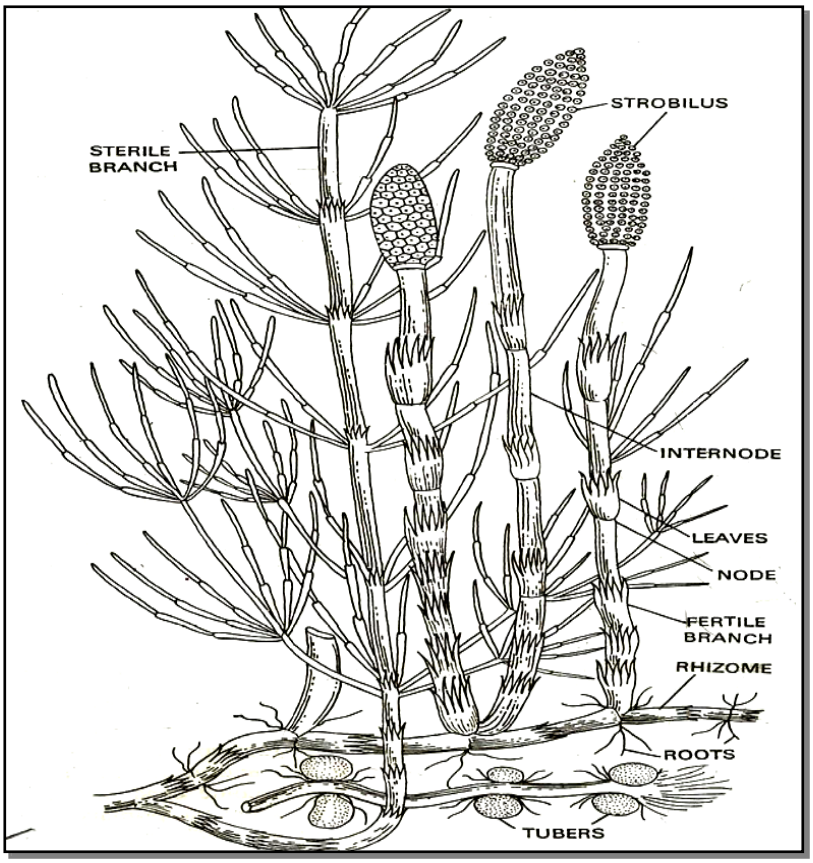


Fig.3.1. *Equisetum*. External features, the sporophyte showing rhizome, roots, tubers

whorls of branches. The reduced leaves contain no chlorophyll, so photosynthesis is carried out by the stems and branches, if present. The aerial stems, which may persist for 1-3 years, arise from perennial, horizontal rhizomes. Stems are impregnated with silica. This gives *Equisetum* a rough texture, and is the source of the common name for some *Equisetum*s, scouring rushes. Beneath the ridges, collenchyma cells, with unevenly thickened primary walls, provide strength to the stems.

Some species of *Equisetum* have dimorphic shoots, with separate, morphologically different fertile and sterile stems. The fertile stems of these species usually lack chlorophyll and branches, and wither soon after spores are shed, while the sterile shoots are photosynthetic and bear whorls of branches. In a few species, like *E. sylvaticum*, the fertile shoot will become green and develop branches after the spores have been shed. Horsetail species with monomorphic shoots have fertile and sterile shoots that look the same. The only difference is that a fertile shoot will bear a strobilus at the top of a simple or branched photosynthetic stem. After spores are shed, the strobilus will wither, but the stem remains functional.

Branches: In some species, whorls of photosynthetic branches arise from each node of the jointed stems, emerging through the base of the leaf sheath.

Leaves: Horsetails leaves were once considered to be microphylls, since each leaf has only one leaf trace, but now horsetail leaves have been shown to be reduced megaphylls. A whorl

of several small, scale-like leaves occurs at each node. The small leaf blades are connate (fused together), except at their tips, and form a sheath around each node with teeth along the upper margin. *Equisetum* produces new branches and leaves from the apical meristem.

Internal features

Stem: The internal structure of the stem, the transverse and longitudinal section passing through the nodes and internodes are studied.

Internal anatomy: To study the anatomy of the node, one has to cut the aerial stem through internode in transverse sections. The outer surface of the stem looks wavy, because of the presence of ridges and furrows.

The stem is covered by a single layered epidermis interrupted by stomata situated in the grooves or furrows. The epidermis is always impregnated with thick layer of silica. The deposition of the silica on the epidermal layer gives the rough appearance to the stem, and therefore, the *Equisetum* plants are also known as 'scouring rushes'. The stomata are found in grooves of the aerial shoots. The development of stomata is peculiar in the sense that initial divides twice by successive longitudinal divisions and in this way the two innermost cells develop into the guard cells, whereas, the two outermost cells develop into accessory cells on being mature of the stomata, the two accessory cells completely overarch the guard cells and the stoma. In majority of the species e.g., *E. hymeale*, *E. ramosissimum* etc., the stomata are sunken, whereas in some other species, e.g., *E. palustre*, *E. pratense* etc., they are situated on the surface of the epidermis. The silica is deposited in the wall of guard cells in transverse-radial bands.

Just underneath the epidermis, there is broad cortex. The cortex consists of mechanical and assimilatory tissue. In the outer cortex, just beneath each of the ridges, there is a strand of sclerenchyma. Usually the sclerenchyma is restricted to the periphery but in *E. giganteum* it extends inward to the endodermis. These columns of sclerenchyma are chief mechanical elements of the shoot. The sclerenchyma strands are also found in the furrows. Here, each strand is situated in between the curved strands of chlorenchyma. The chlorenchyma possess

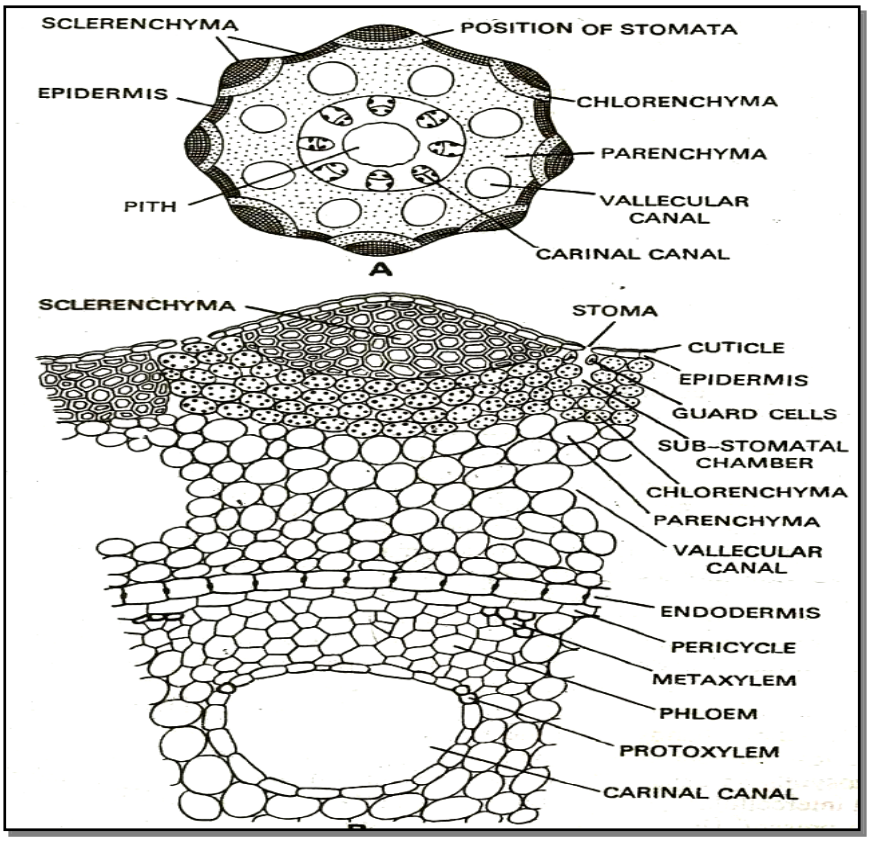


Fig.3.2. *Equisetum*, Anatomy of stem

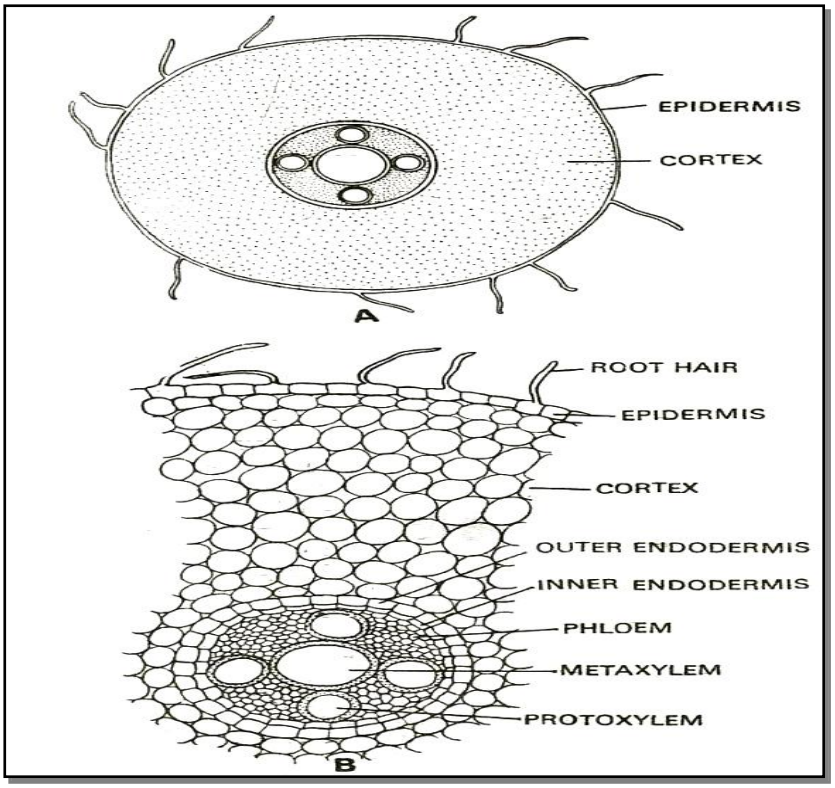


Fig. 3.3. *Equisetum*, Anatomy of root

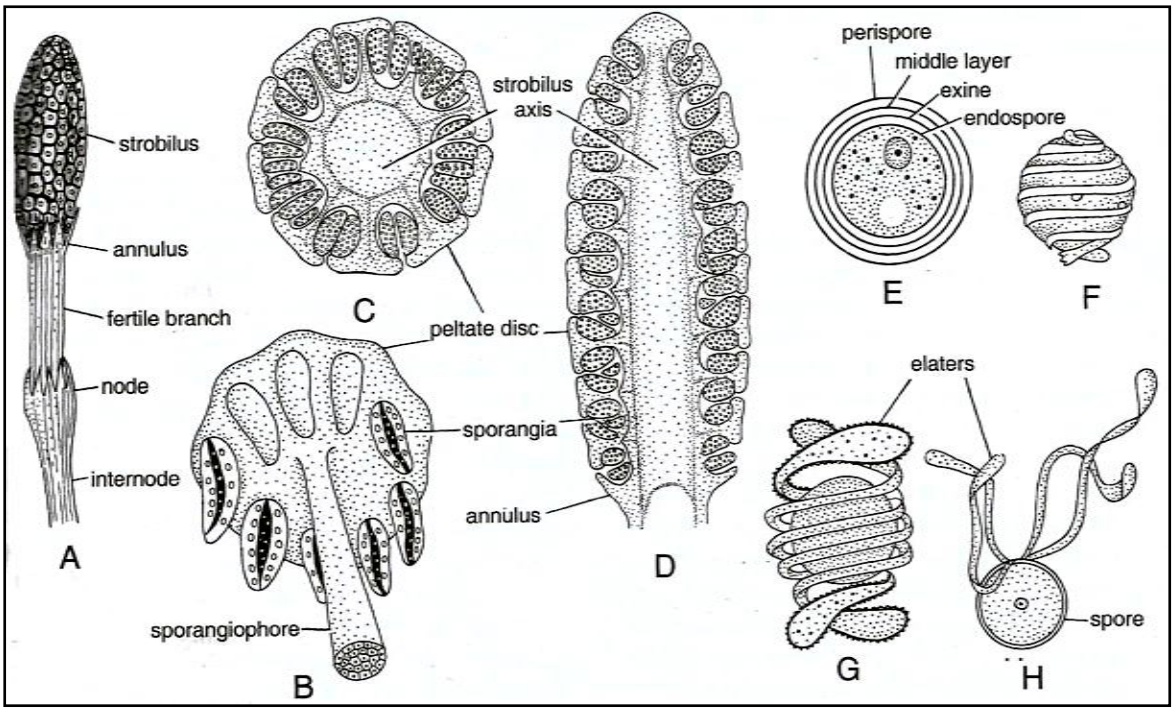


Fig. 3.4. ***Equisetum.*** **Structure of Strobilus: A. fertile shoot, B. Sporangiophore with sporangia, C. T.S. of strobilus, D. L.S. of strobilus, E. T.S. of a spore showing various wall layers, F-G. spores with elaters, H. Spore with free elaters.**

well developed intercellular spaces. These spaces are very much distinct below the stomata. These chlorenchymatous bands are found beneath the sclerenchymatous strands situated underneath the ridges. The ends of the chlorenchymatous bands touch the epidermis in the grooves. Since the leaves are small, scaly and have less number of chloroplasts the chloroenchyma of the cortex of the shoot is the major photosynthetic tissue. The inner cortex is composed of thin walled parenchyma with well developed intercellular spaces. In this region of the cortex the air spaces known as vallecular canals are also present. Usually vallecular canals are found opposite the furrows in the deeper tissue of the cortex. They are alternate to the vascular bundles. These canals are filled up *E. telmateia* with air.

The endodermis is the last layer of the cortex. In *E. arvense*, *E. telmateia*, *E. Palustre* and certain other species, the endodermis surrounds the entire stele. In *E. giganteum*, *E. limosum* and some other species, each vascular bundle is surrounded by separate endodermal layer. In still other cases, e.g., *E. hyemale*, *E. ramosissimum* etc., there is a common internal endodermis inside the ring of bundles delimiting the pith and common outer endodermis found outside the ring of bundles. Just beneath the endodermis a single layered pericycle is found. The pericycle is the outermost layer of the stele.

The vascular skeleton, i.e., stele of *Equisetum* is siphonostelic. The separated vascular bundles are arranged in a ring. The vascular bundles are situated opposite the ridges and alternate to the vallecular canals. The number of bundles varies from species to species. In each internode, as many vascular bundles are found as there are leaves at the node. The vascular bundles alternate to each other in their position in the successive nodes. The

intermodal portions are longitudinally perforate, and each perforation runs the length of an internode. The perforations in the internode are situated above the traces. These perforations are not branch gaps. The vascular bundles are collateral type and resemble to some extent to that of monocotyledons. The vascular bundles contain both metaxylem and protoxylem. A carinal canal is developed in each bundle, because the disintegration of the early formed tracheids of the protoxylem during elongation of the surrounding cells of the internode. The remaining protoxylem elements are composed of few tracheids. These protoxylic elements are found arranged to the margin of carinal canal. The metaxylem elements are found in two groups. The two groups are found arranged on the margin of the carinal canal towards outside. The protoxylem lies in between the two groups of metaxylem. The metaxylem elements are composed of reticulate, scalariform or pitted teacheids. The phloem is composed of sieve tubes and phloem parenchyma. The sieve plates may also be seen. The companion cells are not found. The secondary growth is altogether absent. The central region the stem is occupied by a hollow pith. The carinal canals are filled up with water.

Nodal anatomy: The alternate vascular bundles of the successive internodes are connected each other by short branches and this way a continuous ring of the vascular cylinder is found in the node. Eames (1909) reported that the bundles at the nodes do not have carinal canals. Here, the protoxylem elements are intact and completely occupy the lacuna or carinal canal. At the node, the pith is not hollow and it forms a diaphragm separating the two successive internodes

Rhizome: The anatomy of the rhizome is quite identical to that of the aerial shoot. The assimilatory tissue and the stomata are not found in the rhizome. The mechanical tissue,i.e., sclerenchyma is poorly developed as compared to that of the aerial shoot. In *E. arvense*, pith is solid, whereas in certain other species, the pith and the vallecular canals are very much reduced.

Leaf: The anatomy of the leaf is quite simple. The leaves are uninerved, this means that each leaf contains a single vascular bundle. The vascular bundles of the leaf sheath are simple and collateral. The carinal canals are not found. Individual bundles are surrounded by separate endodermal layers (endodermis). The outer tissues of the leaf sheath are composed of narrow sclerenchymatous bands. These bands of sclerenchyma pass up the leaf ridges and alternate with the strips of chlorophyllous tissue associated with stomata.

Root: The adventitious roots are borne at the nodes of the rhizome and aerial shoots. The anatomy of adventitious roots is quite simple. To study the anatomy the cross sections of the root are required. The outermost layer is known as piliferous layer which bears unicellular hairs upon it. Just beneath the piliferous layer there is a multilayered cortex. In small roots the cortex is divided into two zones. The outer zone is composed of three to four layered lignified exodermis. The inner zone of the cortex consists of thin walled parenchyma with well developed intercellular spaces.

The endodermis is two celled in thickness. The inner layer of the endodermis acts as pericycle. However, the pericycle is absent. The lateral roots originate from the inner layer of the endodermis. In between the two layers of the endodermis, intercellular spaces are found. The Casparian strips are strictly found in the outer layer of the endodermis.

The stele of the root varies in its nature from species to species. It is triarch to hexarch. There is a big central axial metaxylem element surrounded by three to six narrow points of protoxylem. Each protoxylem point is represented by a single tracheid. The tracheids of xylem elements are spirally thickened. The angles between the protoxylem points are completely filled with phloem. The phloem is composed of phloem parenchyma and sieve tubes.

The apical growth: The apical growth of the main aerial shoot and its laterals takes place by means of a single pyramid like apical cell. This apical cell cuts the segments at its three faces.

The segments are cut off regularly. Each segment divides anticlinally forming two upper and lower segments. Both these segments give rise to two tier of cells by successive divisions. The upper tier of the cells develops into the node and the lower into the internode.

In the roots, a young root primordium is differentiated into a group of initials which develop into a root cap and a pyramid like apical cell, which develops into the root proper. Here, the behaviour of apical cell differs from that of the stem that it cuts off segments from all its four faces, whereas, in the stem only three faces of the tetrahedral apical cell cut off the segments. The lateral segments form the tissues of the root proper, and the terminal segment forms the root cap.

3.3.2 Reproduction in *Equisetum*

Equisetum reproduces by vegetative and sexual methods.

1-Vegetative Reproduction

The underground rhizomes of some species of *Equisetum* (*E. arvense, E. telmateia*) form tubers, which help in vegetative propagation. The tubers develop due to irregular growth of some branch buds at the nodes of the rhizome. They are oval (*E. arvense*) or pear-shaped (*E. telmateia*). The tuber has a central parenchymatous region, rich in starch grains, and it is surrounded by 2-3 layers of sclerenchyma. Several collateral vascular bundles are present in the central region. Each bundle is individually surrounded by its endodermal layer. After detachment from the parent plant, the tubers remain in the soil, and on the return of favourable conditions they grow into new plants.

Reproduction by Spores

Equisetum is a homosporous pteridophyte.The spores develop within sporangia borne on sporangiophores. The sporangiophores are aggregated into a compact cone or strobilus.

Position and structure of strobilus: In most species strobili are borne terminally on the vegetative shoots. But in some species (*E. arvense*) they are borne on special fertile shoots which are short-lived and die soon after spores are shed. The strobilus has a central massive axis, called strobilus axis, and a large number of sporangiophores. The sporangiophores project at right angles in successive alternate whorls from the strobilus axis. Each sporangiophore is a stalked structure with a hexagonal peltate disc at its distal end. On the underside of the sporangiophore disc 5-10 sac-like sporangia are borne near its periphery in a ring. The free round apices of sporangia face the strobilus axis.

In some species a whorl of scale-like outgrowths, called annulus, is present at the base of the strobilus. It has been interpreted as the last whorl of scale leaves of the fertile shoot by some, while others consider it of sporangiophoric nature as it bears small sporangia occasionally.

Development of sporangium: The apical growth of the shoot, which is destined to bear strobilus, is slowed down and it assumes a conical shape. This conical apex now functions as strobilus axis. The primordia of sporangiophores are formed on this axis in an acropetal succession, in positions of leaf primordia. Initially, the primordium is hemispherical but soon it becomes peltate due to the formation of a constriction near its base. Sporangia are initiated on the apical dome of the sporangiophore.

The development of sporangium is eusporangiate, i.e., a sporangium develops from a group of initials. Sporangia are initiated near the centre of the apical dome of the sporangiophore. But later the dome expands laterally (due to rapid growth of the central part of the dome) and as such the sporangia are pushed to the margins and finally to the underside of the peltate disc.

The first division of the sporangial initial is periclinal, establishing an outer and an inner daughter cell. The inner daughter cell forms sporogenous tissue by repeated divisions in

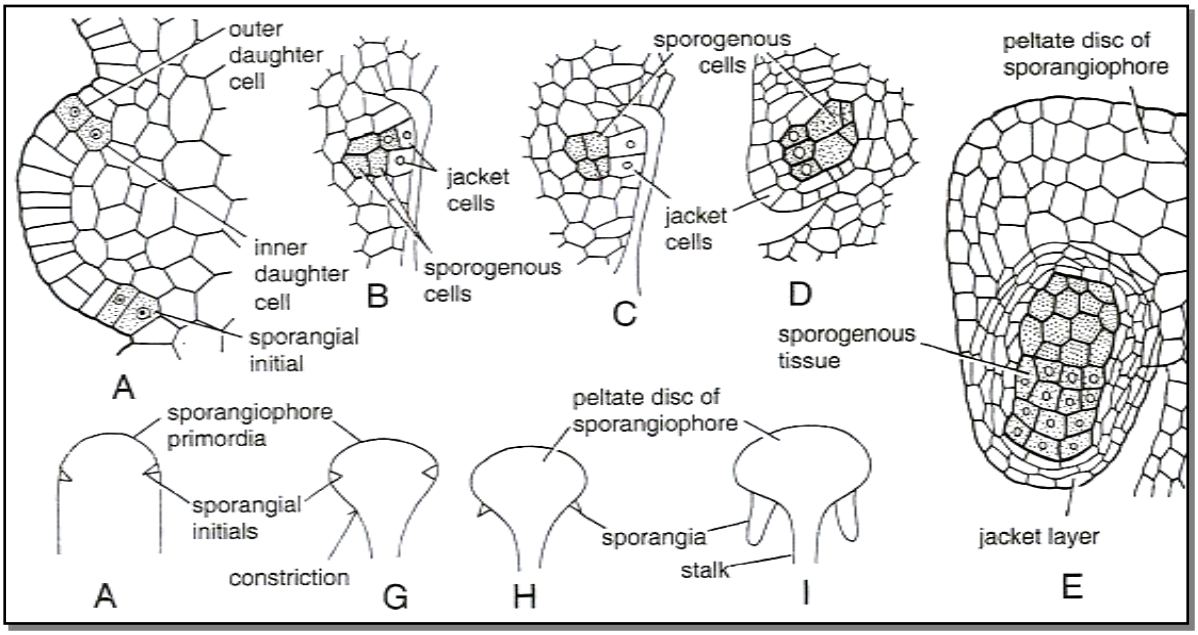


Fig. 3.5. *Equisetum* . Development of sporangium, A-E. Successive stages in the development of sporangium, F-I. showing the gradual shift in the position of sporangia on the sporangiophore

all possible planes, whereas the outer daughter cell divides both anticlinally and periclinally and form 2-7 layered sporangial wall. The innermost layer of the sporangial wall functions as tapetum. The cells of the tapetum are irregular, thick-walled and nutritive in function. The cells of the outer wall layer develop thin bands of helicoid secondary wall thickening, which presumably help in the dehiscence of the sporangium.

As the sporangium matures, all but the two outermost wall layers disintegrate and form a periplasmodial fluid. At this stage, the sporogenous cells separate from each other and function as spore mother cells. Before meiosis, about 30% spore mother cells also disintegrate and form plasmodial fluid. The remaining spore mother cells remain active and float freely in the periplasmodial fluid. Each spore mother cell undergoes a reduction division and forms four spores. The spores soon become spherical.

Structure of the mature sporangium: The mature sporangia are sac-like structures attached to the underside of the peltate disc of the sporangiophore. The wall of the mature sporangium is only two layered. All spores in a sporangium are alike.

Dehiscence of sporangium: As the sporangia mature, the strobilus axis elongates. Consequently, the compactly arranged sporangiophores separate from each other and the sporangia are exposed. As the sporangium dries, the helicoid thickening bands present in the outer wall layer shrink and the sporangium ruptures.

GAMETOPHYTE

The spores of *Equisetum* are spherical, uninucleate and green, they contain numerous chloroplasts. The spore wall is differentiated into four concentric layers, the outermost perispore, the second middle layer, the third exospore and the innermost endospore. The perispore, also known as epispore, splits into four strips or bands. Although these bands are separate from one another, they are attached to a common point on the spore. Initially, these bands are wrapped around the spherical spore but as the spore dries the bands are uncoiled. These bands are known as elaters and they have expanded spoon-like tips. The elaters are hygroscopic and respond to change in humidity. Although their definite function is not known, they probably help in the dehiscence of the sporangium by expanding and contracting. More often they seem to keep spore groups entangled. They also act as parachute and help spores to float in air.

Germination of Spore and Development of the Gametophyte

The spores of *Equisetum* germinate shortly after shedding. They are short-lived and remain viable for 1-48 hours after shedding. Such a short duration of viability of *Equisetum* spores is perhaps due to their high rate of respiration.

The spores germinate on a suitable substratum. They swell by absorbing water and shed the outer coat. The first division of the spore is asymmetrical; it produces a small rhizoidal cell and a larger cell. The former develops into the first rhizoid, whereas the latter eventually gives rise to prothallus. The shape and size of prothallus depends on prevailing conditions; if a large number of spores germinate within a limited space, the prothalli formed are usually filamentous, whereas sparsely germinating spores usually form relatively thick and cushion-shaped prothalli. The cells in the upper part of the prothallus are chlorophyllous and those in the lower portion are colourless. The basal cells in the lower portion give rise to unicellular rhizoids, which help in the attachment of prothallus to the substratum. The upper marginal cells of the prothallus are meristematic. If the growth is uniform along the entire margin, it results in the formation of a circular gametophyte and if growth is more active at certain

points then lobed gametophyte is formed. Mature field grown gametophytes of *Equisetum* are very small, seldom exceeding a few millimeter.

Several studies have shown that prothalli of *Equisetum* are basically monoecious and heterothalic (i.e., dioecious nature) develops only under the influence of adverse environmental conditions.

The spores of *E. debile* germinate densely then they form very small prothalli, which bear either antheridia or archegonia. But when they germinate sparsely, relatively large prothalli are formed, which first bear archegonia and then antheridia. Thus the sex of the prothallus depends upon the conditions available for the germination of spores. Though *E. arvense* is a monoecious species, under adverse conditions prothalli remain unisexual.

Gametophytes of *Equisetum* are rarely seen in nature because of two factors. Firstly, the young gametophytes appear as filamentous algae or moss protonema to the naked eyes and often get obscured by other small plants growing nearby. Secondly, they often die while quite young as a result of drying and in a given season only very few gametophytes attain maturity.

Sex Organs

Both, antheridia and archegonia develop from the superficial meristematic cells of the prothallus. Archegonia are confined to the basal cushion region of the prothallus and antheridia on the lobes of upright branches. Usually archegonia develop before antheridia.

Development of archegonium

Any superficial cell from the margin of the prothallus may function as archegonial initial. It divides periclinally into an outer primary and a central cell. The primary cover cell divides by

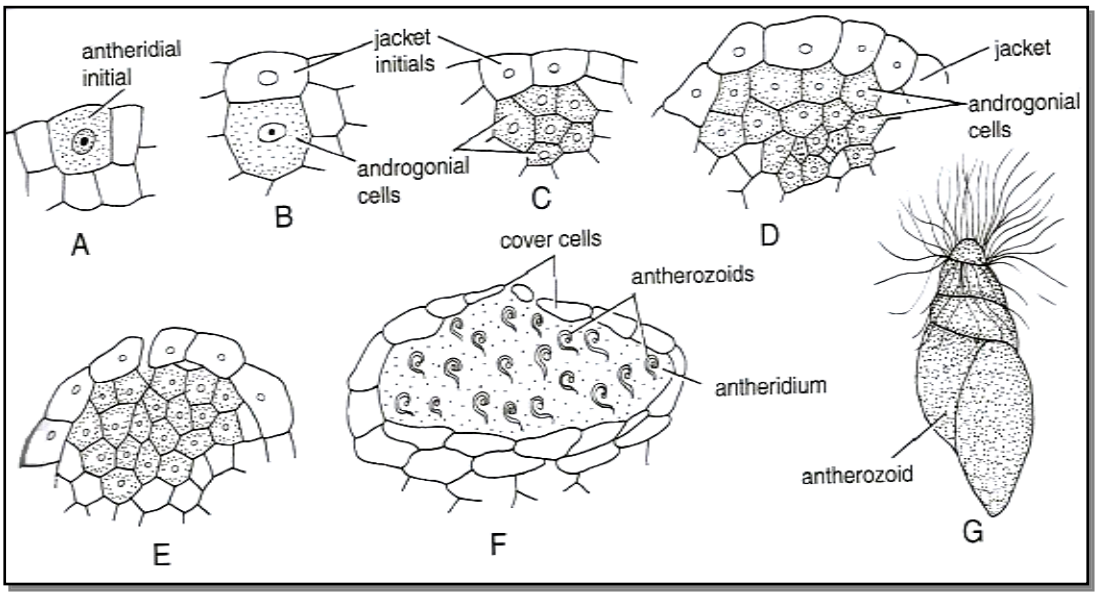


Fig. 3.6. *Equisetum.* A-D. Successive stages in the development of antheridium

two vertical divisions at right angles to each other, forming four primary neck cells. These cells divide further and form 3-4 celled high neck of the archegonium. In the meantime, the central cell divides transversely into a primary neck canal cell and a venter cell. The primary neck canal cell by a further transverse division, gives rise to two neck canal cells. But in some species (e.g.,*E. debile*) the primary neck canal cell does not divide and directly functions as neck canal cells and in *E. hyemale* and *E. ramosissimum* it divides vertically into two boot shaped cells, which are attached at the base of the neck canal.

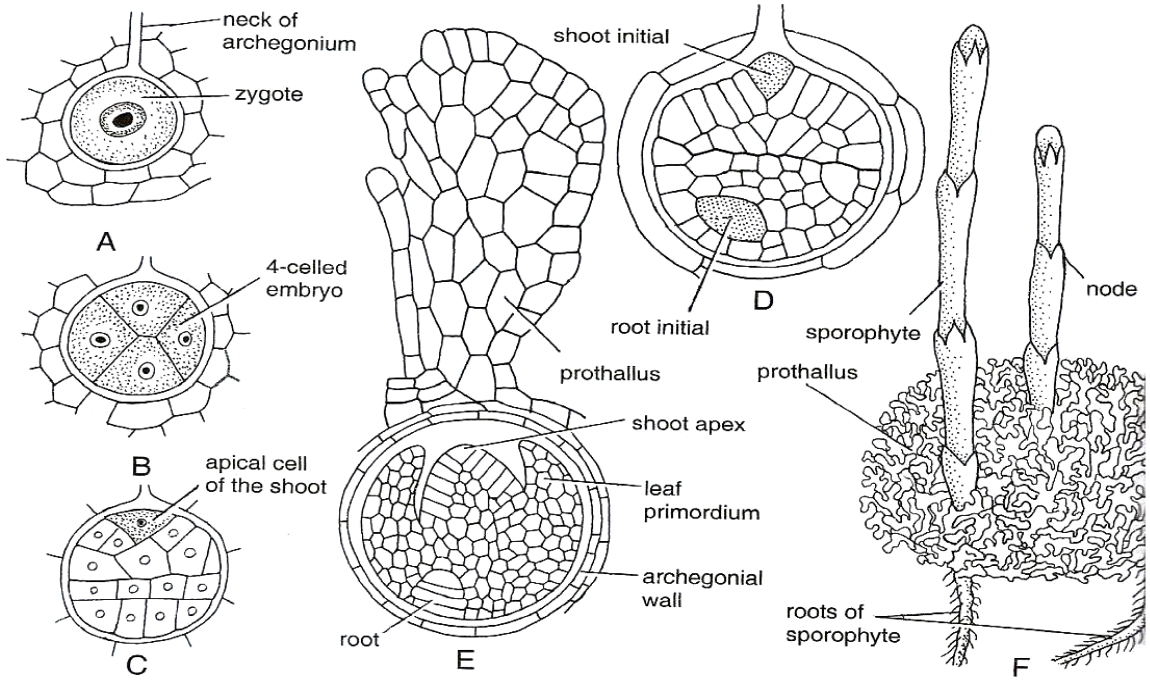


Fig. 3.7. *Equisetum*. Embryo Development. A. L.S. of archegonium showing zygote, B-E. Stages in embryo development, F. Young sporophyte

Mature Archegonium

Mature archegonium has a small neck and a lien base. The neck is made up of tiers of neck cells; each tier usually has four cells. The neck canal has one or two neck canal cells. The swollen basal part of the archegonium a venter canal cell and an egg. The neck of the archigonium usually projects above the surface of prothallus.

Development of antheridium

In monoecious species antheridia develop archegonia. There are usually two types of antheridia viz., projecting antheridia, and embedded antheridia. The projecting antheridia develop on the margins of the prothallus or on the lobes of the upright branches, whereas the embedded antheridia develop in the massive cushion-shaped of the prothallus.

The superficial antheridial initial divides periclinally into an outer jacket initial and an inner androgonial cell. The jacket initial divides only anticlinally and gives rise to a single layered antheridial jacket. A large triangular jacket cell at the apex of the antheridium differentiates into a cover cell or opercular cell. The nucleus of the androcyte progressively changes in

shape to become helicoid. Then each androcyte metamorphoses into an antherozoid. The anterior part of the antherozoid is spirally coiled, and has numerous flagella, whereas the posterior part is somewhat expanded.

Fertilization

Before fertilization, the neck canal cells and venter canal cell disintegrate and form a passage for the entry of antherozoids. The disintegrated mass of these cells contains malic acid, which attracts freely swimming antherozoids towards the neck of the archegonium. Although many antherozoids move towards an archegonium, only one of them swims into it and fuses with the egg. Thus zygote is formed. Usually more than one archegonia are fertilized in a prothallus. In *E.debile* as many as 15 young embryos have been observed in a single prothallus.

Embryo Development

The diploid zygote, formed by the fusion of the male and female gametes, is the mother cell of the next sporophytic generation. It develops into an embryo, which forms a new sporophyte.

The embryogeny of *Equisetum* shows some variations in different species. In most of the species, the first division of the zygote is transverse (i.e., at right angles to the neck of the archegonium), establishing an epibasal and a hypobasal cell. Both of these cells contribute to embryo. Unlike Selaginella and Lycopodium, no suspensor is formed in *Equisetum*. The second division of the zygote is vertical and as the result a four-celled embryo is established All the four cells of the embryo are of different shape and size. In *E. arvense*, the 4-celled embryo divides by a second vertical division at right angles to the first one, thus forming eight cells arranged in two tiers of four each. The largest of the four epibasal cells differentiates as apical cell of the shoot and the remaining three cells form leaf initials. The largest of the hypobasal cells functions as root initial and the remaining three cells give rise to the foot.

Active divisions in the apical cell of the shoot and the root initial results in the establishment the shoot and root. The embryonic root penetrates the prothallus and enters the soil. The first shoot, called primary stem, bursts the neck of the archegonium and grows upright. It is differentiated into nodes and internodes. Each node of the primary stem has only three leaves.

The primary stem shows only limited growth. Its apical growth ceases after 10-15 internodes have been formed. Then a secondary branch develops at of the primary stem from a bud. It has 1-5 leaves at each node. The secondary branch also has limited growth and is replaced by another upright branch arising from its base. This process may be repeated until 3-4 shoots have appeared and finally, a shoot instead of growing in usual upright position, grows horizontally and penetrates the ground forming the first underground rhizome. It is perennial and gives out new aerial shoot.

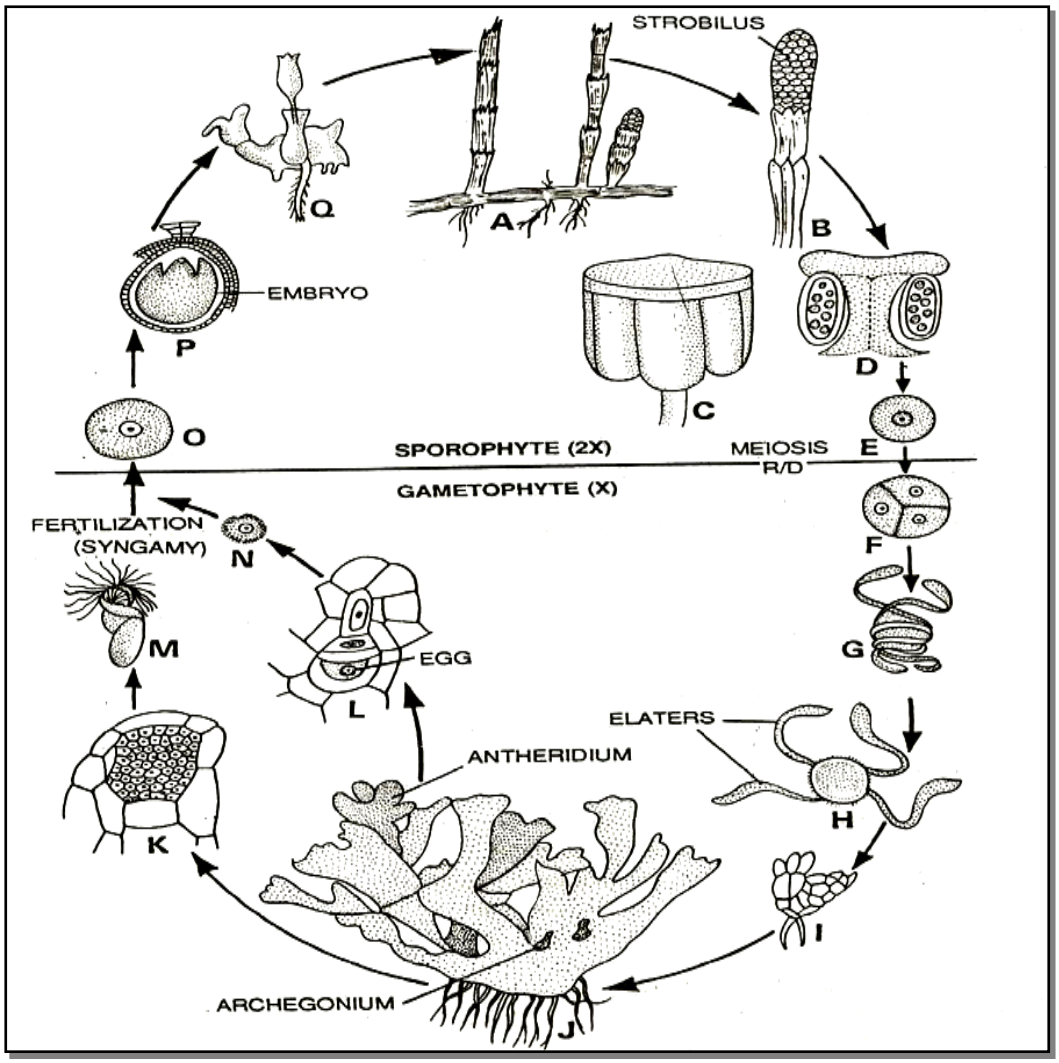


Fig. 3.8. ***Equisetum.*** **Diagrammatic life cycle. A. sporophyte, B. strobilus, C. sporangiophore with sporangia, D. L.S. of sporangiophore showing sporangia and peltate disc, E. spore mother cells, F. spore tetrad, G. spores with coiled elaters, H. spore with uncoiled elaters, I. young prothallus, J. mature prothallus with archegonia and antheridia, K. anthredium, L. archegonium, M. antherozoid, N. egg, O. oospore, P. young embryo, Q. young sporophyte**

3.4 *ADIANTUM*

Systematic position

Division - Filicophyta
Class - Pteropsida
Sub-Class - Leptosporangiatae
Order - Filicales
Family - Polypodiaceae
Genus - *Adiantum*

Distribution and habitat: It is a large genus comprising of some 200 species, widely distributed in both tropical and temperate regions of the world. Species of *Adiantum* occur in

a wide variety of habitats, but they are most abundant in moist and shady places. They occur on wet walls and in shady rock crevices. The common name *'maiden hair fern'* is given to the species of *Adiantum* because of their bright black petioles which resemble with black hair of ladies. Several species of *Adiantum* are commonly grown. The genus is represented in India by 10 species of these Adiantum *caudatum A. Capillus- veneris, A. venustum, A. lunulatum* and *A. athiopicum* are fairly common.

3.4.1 Structure of *Adiantum*

External features

The sporophyte is differentiated into rhizome, roots and leaves. The rhizome is usually subterranean and creeping (*A. Capillus- veneris, A. pectinatum)*, but sometimes it is sub-erect (*A. pedatum*) or erect (*A. caudatum*). It is perennial, dichotomously branched and covered with persistent leaf bases and hairy outgrowths, called ramenta. The rhizome bears leaves on the upper side and roots on the lower side.

The roots are small, adventitious and wiry structures. They form a mass around the subterranean rhizome.

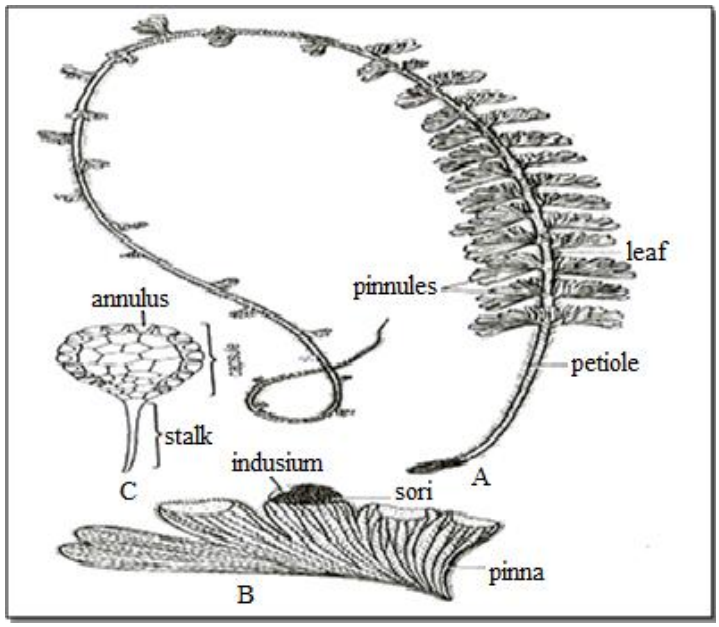


Fig. 3.9. *Adiantum,* A. external morphology, B. pinna, C. sporangium

The leaves or fronds are pinnately compound; they may be simply unipinnate (*A. caudatum*), bipinnate (*A. capillus-veneris*) or 3-4 pinnate (*A. venustum*). The pinnae are alternate or opposite and nearly sessile (*A. caudatum*), shortly (*A. venustum*) or long petiolulate (*A. lunulatum*). The rachis is smooth and naked or villose and its length varies from 3 to 40 cm in different species. In *A.caudatum*, the terminal part of the rachis has only sparsely placed pinnae and produce the apex. The veins are repeatedly forked venules are free, parallel and continue into the indusium.The leaves bear marginal sori covered by reflexed marginal flaps of the leaf.

Internal structure

Root

Internally, the root consists of a single layer of epidermis, a wide cortex, and a central cylinder. Unicellular root hairs are present in the epidermis. The cortex is differentiated into an outer parenchymatous region consisting of 4-6 layers of cells and an inner relatively narrow sclerechymatous region. The central cylinder is surrounded by endodermis and pericycle. The stele consists of central metaxylem tracheids with two radiating arm of protoxylem. A group of phloem cells is present on either side of the xylem plate.

Rhizome

The rhizome shows differentiation into epidermis, hypodermis and ground tissue with many meristeles. The single layered epidermis is covered with thick layer of cuticle. Some epidermal cells give rise to long multicellular hairs. The epidermis is followed by 4-6 layers of sclerenchymatous hypodermis, which provides mechanical strength to the rhizome. The hypodermal cells are, however, not thickened in the young rhizome.

Next to the hypodermis is parenchymatous ground tissue. The structure of the stele not only varies in different species but also within the same species at different stages of development. There is amphiphloic siphonostele with central parenchymatous pith in a young rhizome. As the rhizome becomes older, this stele transforms into a solenostele or dictyostele. Species with long rhizome (*A. pedatum*)characteristically have a solenostele (as leaf gaps do not overlap), but in rhizomes with short internodes the stele is essentially dictyostelic as leaf gaps overlap each other. In such cases several meristeles are found embedded in the ground tissue.

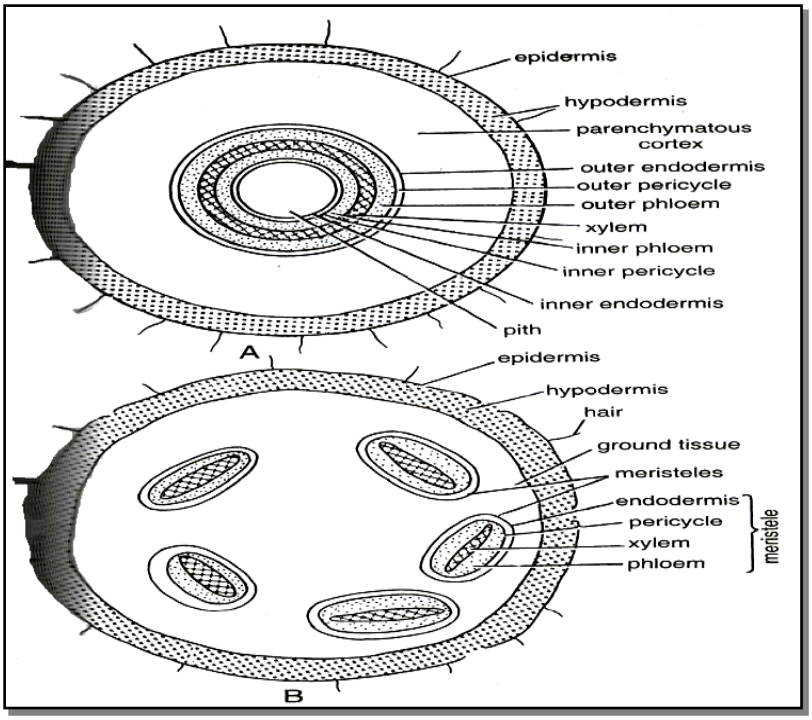


Fig. 3.10. ***Adiantum,*** **T.S. of rhizome, A young rhizome, B mature rhizome**

Petiole

The epidermis is single layered and is covered by a thick cuticle. In some species (*A. caudatum*) epidermal cells form multicellular hairs. The epidermis is followed by a few layers of sclerenchymatous hypodermis, which provides mechanical support to the elongated rachis. Inner to the hypodermis is parenchymatous ground tissue. Some cells of the ground tissue contain dark tannin.

The central part of the ground tissue is occupied by either a single large horse shoe-shaped (*A. phillipense, A. caudatum*) or two arc shaped vascular strands facing each other. In the latter, each strand is surrounded by a layer of endodermis and pericycle. The central part of the strand is composed of xylem surrounded by phloem.

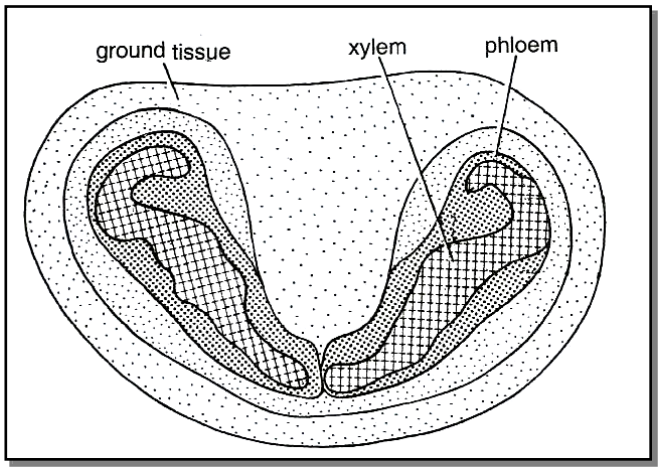


Fig. 3.11. *Adiantum.* T.S. of petiole

Pinna

The epidermal cells of pinna are irregular in outline and contain chloroplasts. Stomata are mostly confined to the lower epidermis. The mesophyll is not differentiated into palisade and spongy parenchyma. But the cells adjacent to the upper epidermis are somewhat columnar and those away from it are irregularly lobed. The vascular bundles are embedded in the mesophyll tissue. Each bundle is surrounded by a sclerenchymatous bundle sheath. The larger veins are concentric, whereas the smaller veins are collateral.

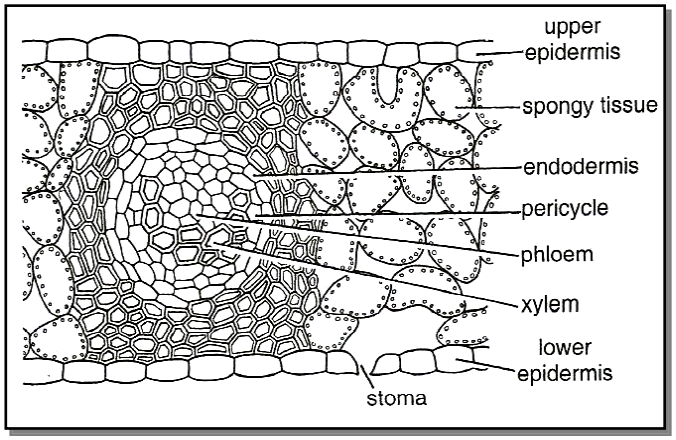


Fig. 3.12. *Adiantum.* T.S. of pinna

3.4.2 Reproduction in *Adiantum*

Spore producing organs: The characteristic of *Adiantum* is the presence of apparently marginal sori which are superficial in origin and covered by a sharply reflexed leaf margin which looks like an indusium because of its membranous nature and brown colour on its maturity. Actually there is no true indusium. The sporangia are inserted upon the distal region of the veins traversing the fertile lobe. The fertile region of the blade itself becomes sharply reflexed and serves as indusium. Each such fertile lobe bears a group of sori situated upon parallel veins. In some cases the sporangia are found spread on to the surface of the blade in between veins.

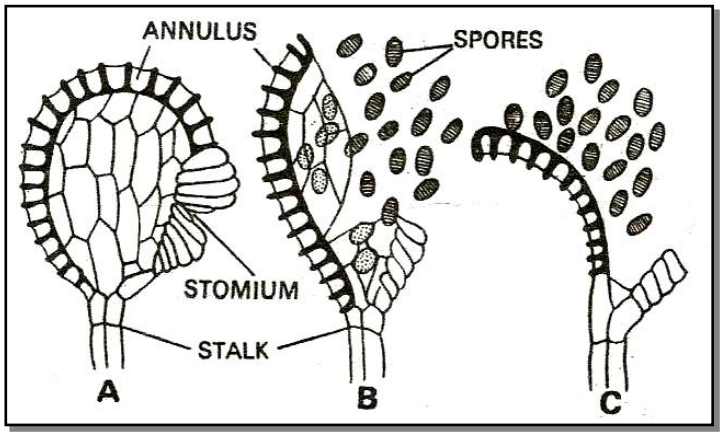


Fig. 3.13. ***Adiantum,*** **A. sporangium, B-C. spores escaping from sporangium**

Development of sporangium: The development of sporangium is of leptosporangiate type. The sporangium develops from a single superficial cell of the placenta. This cell divides by a transverse wall forming two cells. The upper cell divides again by an oblique wall to the first wall. Another oblique division takes place, giving rise to a tetrahedral cell. The cell again divides by a transverse wall. The inner cell is known as archesporial cell. The lower cell of the pair formed by the first division divides several times and develop into the multicellular stalk. The cells surrounding the tetrahedral archesporial cell divide further giving rise to the sporangial wall. Thereafter, the archesporial cell divides to form a tapetal layer of the cells. At the same time it also produces about a dozen spore mother cells. The spore mother cells give rise to spores. Each spore mother cell divides twice developing four spores. During division there is meiosis and the spores are haploid. Usually each sporangium contains 48 haploid spores.

Structure of sporangium: Each sporangium is composed of a multicellular stalk and a capsule. The capsule of this sporangium is of the shape of biconvex lens. The wall of the capsule is composed of a single layer of thin walled cells. A row of specially thickened cells, known as annulus partially surrounds the capsule. At one side of the annulus, there is a stomium composed of thin walled cells. On maturity, the sporangium contains about 32 to 64 dark, ragged walled spores in it

Dehiscence of sporangium: On the maturity of the sporangia, indusium shrivels up and the sporangia are exposed to the outer atmosphere. The sporangium bursts by a special mechanism. The cells of the annulus are thickened in a peculiar way. The inner tangential and

radial walls of the annulus are thick while the outer tangential walls are thin. The bursting of the sporangium is caused by the behaviour of the water in relation to the cells of the annulus. In young sporangia the water glands are present and they remain moist. On the maturity of the sporangia, the sporangia are exposed to dry air and the water is lost from the cells of the sporangia. This way, the thin outer walls of the annulus begin to contract, the stomium opens and the annulus along with some portion of the sporangium turns backward with a jerk throwing the spores out of the sporangium.

The spore: The spores are double walled. The outer wall is thick, ragged and brown in colour. It is known as exine. The inner wall is smooth and thin, and known as intine. Each spore contains a big central nucleus. The gametophytic stage of the fern begins from this spore.

Germination of the spore and development of the prothallus: After their dispersal the spores lie dormant for some time and under favourable conditions of moisture and temperature, they germinate. First of all outer spore wall (exine) breaks and thereafter the intine protrudes out in the form of a green germ tube. Very shortly this tube is cut off by a transverse wall and two unequal cells are resulted. The small colourless cell is known as rhizoidal cell. From this cell a colourless branch grows into the soil and develops a rhizoid. The large green cell elongates and divides transversely several times developing into a filament 3 to 6 cell in length. The terminal cell of the filament known as an apical cell cuts of cells behind it and give rise to this filamentous structure. The apical cell also divides laterally and a flat prothallus is formed. The segments cut off from the apical cell divide again and again developing into the young prothallus. Usually the prothallus is heart-shaped. The prothallus is green and one-celled thick at its margins. In well developed prothalli the central part of the prothallus is more than one cell in thickness. This region is called cushion. Many

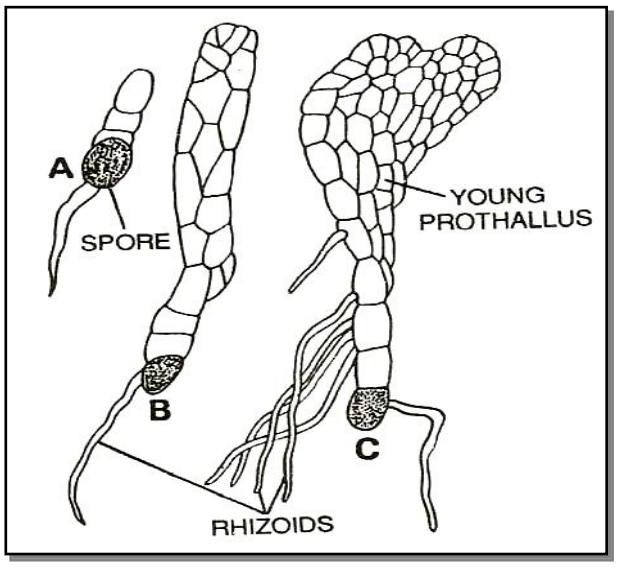


Fig. 3.14. ***Adiantum,*** **Spore germination and development off young prothallus**

rhizoids develop on the underside of the cushion anchoring the prothallus to the soil. The rhizoids also serve as absorbing organs. During the development of the gametophyte the

original apical cell is replaced by a group of marginal initials. The further growth of the prothallus takes place by these initials and ultimately the heart-shaped prothallus is formed.

Structure of prothallus: The prothallus is flat, thin, heart- shaped and green mass of tissue. There is a notch at its posterior end. It is one cell in thickness at its margins, but in the central region, near about the notch, it is many celled in thickness. This region is called the cushion. Several colourless rhizoids are developed from the underside of the cushion. The cells of the prothallus are thin walled. Each cell bears discoid chloroplasts and a nucleus in it. The sex organs (archegonia and antheridia) are confined in the central region of the prothallus. The prothallus is probably 1/8 to 1/3 of an inch diameter. Each prothallus is self supporting. It absorbs water and nutrients from the soil and photosynthesize the food material as the numerous chloroplasts are found in its cells. The prothallus represents the gametophytic generation of the fern as it bears the sex organs upon it.

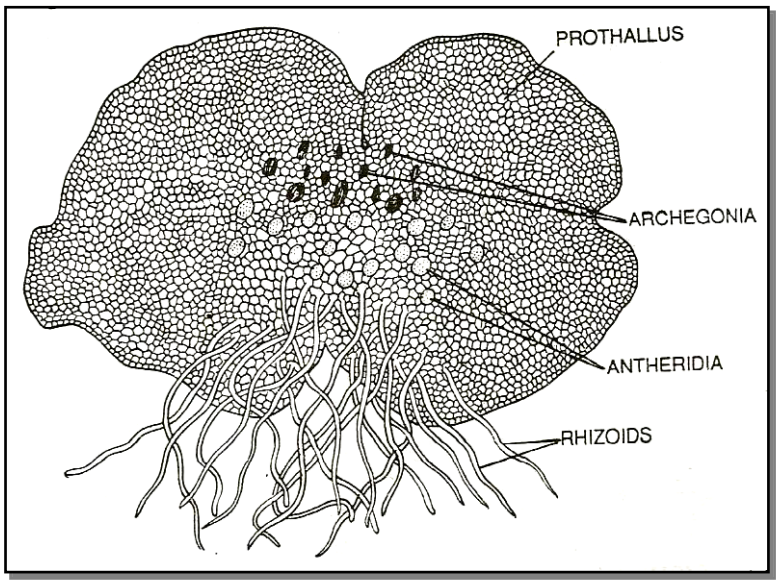


Fig. 3.15. *Adiantum*, Lower surface of prothallus showing antheridia, archegonia and rhizoids

The sex organs: The sex organs develop on the underside of the prothallus (gametophyte). Usually the prothalli are monoecious and bear both male and female sex organs, i.e. antheridia and archegonia. In the normal prothallus the archegonia develop around the notch upon the cushion and the antheridia in the basal central region of the prothallus among the rhizoids. The antheridia develop first and the archegonia later on.

Development of anthredium: One of superficial vegetative cells of the prothallus protrudes out and divides by a transverse wall giving rise to two cells. The terminal cell acts as an antheridial initial. First of all the antheridial initial divides by an oblique funnel-shaped wall with the wide end upwards. By successive such oblique divisions a central cell is formed. This central cell is surrounded by a number of peripheral cells containing the chloroplasts in them of the original initial. The first division is followed by a dome shaped wall across the top of the funnel and thus a central cell is enclosed. Thereafter the upper cell divides by a ring-shaped wall. This way, the semispherical antheridium is composed of two ring cells, a cap cell and a central cell. The central cell divides further irregularly, and about

thirty two cells known as antherozoid mother cells (androcytes) are produced. Each antherozoid mother cell (androcyte) metamorphoses into a multiciliate antherozoid. The nucleus of each androcyte is transformed into a tapering spiral of three turns. At the posterior end of this spiral structure a vesicle of cytoplasm is attached. At the anterior end there is an elongated blepharoplast bearing a group of very long flagella. By means of flagella the antherozoids can swim in the water film.

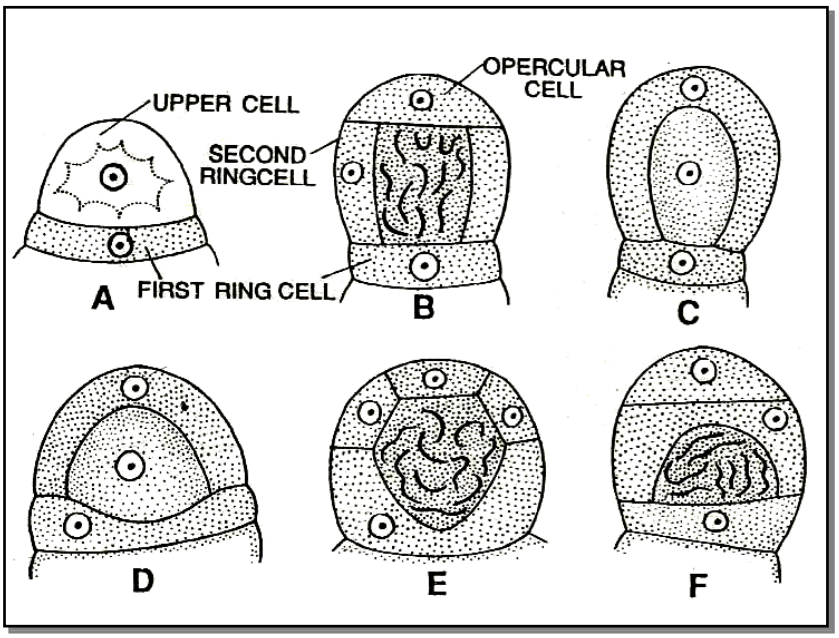


Fig. 3.16. Adiantum, A-F. stages in the development of anthredium

Dehiscence of anthredium: The water is essential for this process. When the mature anthredium comes in contact with the water, the walls of the androcytes situated within the mature antheridium become mucilaginous and swell and with, the result the lid cell of the antheridium is thrown off. The antherozoids are ejected out. Each antherozoid is still within a thin membranous cell wall, which very soon dissolves in the water and the anthrezoid is free in the water.

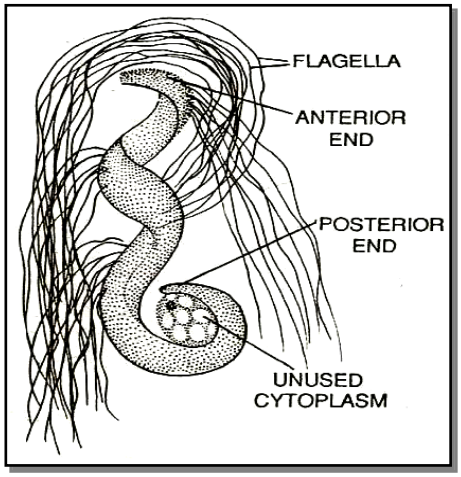


Fig. 3.17. *Adiantum*, A single spermatozoid with flagella and unused cytoplasm

Development of archegonium: The archegonium develops from a single superficial cell of the prothallus, known as the archegonial initial. The initial divides into three cells by two transverse walls. Of these three cells the lower one is the basal cell which forms the wall around the venter. The remaining two cells are the central cell and the cover cell. The cover cell divides vertically twice forming four neck initials. Each neck initial divides transversely developing four vertical rows of the cells of the neck. The neck is 5 to 7 cells in height. The central cell grows up between the neck cells. This divides several times transversely producing a narrow neck canal cell, a ventral canal cell and an egg or oosphere. The neck canal cell may or may not divide further into two cells. The neck is sharply curved. The two rows of the neck of the convex side contain 5 to 7 cells, whereas the rows of concave side have only four cells and thus the neck is strongly curved.

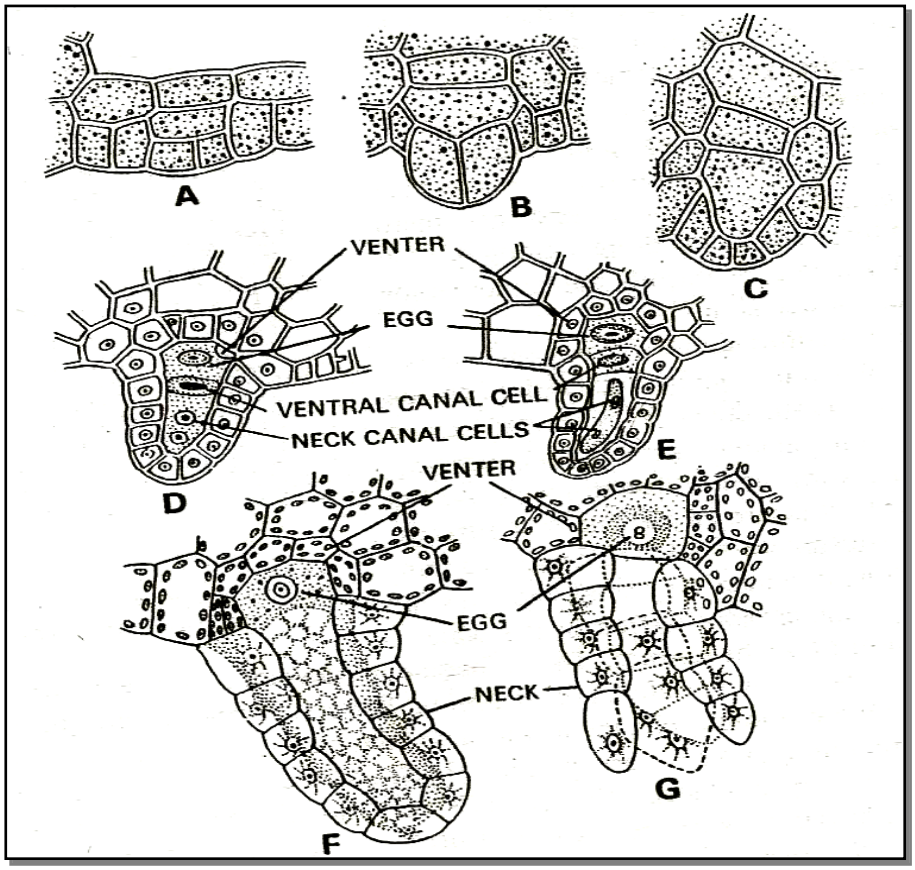


Fig.3.18. ***Adiantum*****, Development of Archegonium. A-C. Early stages of development, D. the venter contains an egg, E. the neck and venter canal cells, F. the cells have been disorganized, G. archegonium opens**

Structure or archegonium: The archegonium is flask-like, elongated structure consisted of a venter embedded in the tissues of the prothallus and a sharply curved neck which projects outside the tissues of the prothallus. The curved neck consists of four vertical rows of cells. The archegonium with its neck and venter contains an axial row of cells. The lowermost cell found within the venter is the oosphere or ovum, above to it there is a ventral canal cell and thereafter a long neck canal cell which is generally binucleate. Prior to fertilization the neck canal cell and the ventral canal cell break down into a mucilaginous

substance. This mucilaginous material swells and forces its way outside the neck. This way an opening is caused at the apex of the neck and the antherozoids enter through this opening to reach the oosphere.

Fertilization: The water is an essential factor for this process. Ordinarily the prothalli receive water by rain. The mature archegonium probably secretes malic acid, which attracts the swimming antherozoids towards it. The antherozoids swim down the neck canal through the mucilage and one of those penetrates the oosphere at a hyaline receptive spot. Soon after the entrance of the antherozoid in the egg the two male and female nuclei are fused together and the fertilizations is affected. The oosphere secretes a wall around it and becomes oospore. Several archegonia of a single prothallus may be fertilized but ultimately only one oospore develops into the complete sporophyte.

The embryo and its development: Immediately after fertilization the zygote divides by a vertical wall, forming two cells. Soon after second and third divisions take place at right angles to each other resulting in an octant or a group of eight cells. Four of the cells of the octant found towards the apex of the prothallus form the epibasal half and the remaining four cells the hypobasal half. The epibasal cells produce the axis and the first leaf of the young sporophyte. The hypobasal half produces the primary root and the foot.

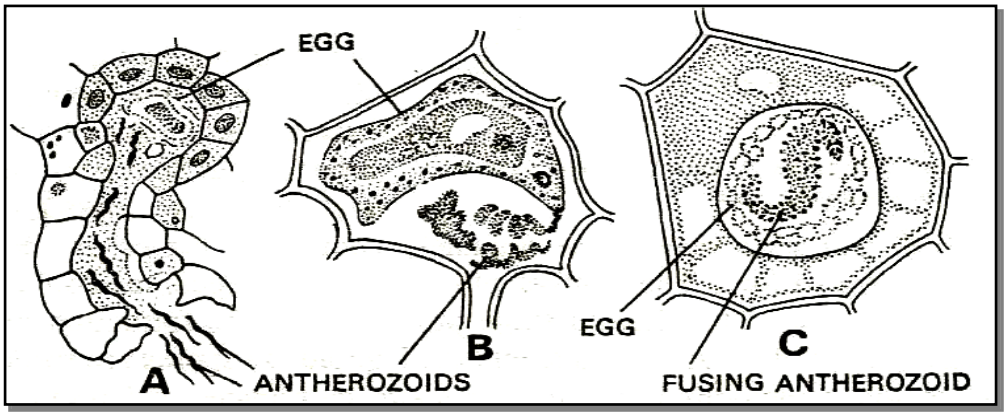


Fig. 3.19. ***Adiantum,*** **Fertilization. A. spermatozoids entering the neck of archegonium, B. single spermatozoid entering the egg nucleus, C. union of spermatozoids with egg nucleus**

The foot acts as haustorium and remains embedded in the venter. It absorbs nourishment for the young sporophyte from the prothallus and soil unless and until it becomes independent The primary root dies soon and the adventitious roots develop. The prothallus disintegrates very soon. As soon as the first leaf becomes able to synthesize the food, the prothallus disappears. The first leaf of the young sporophyte is generally small and two-lobed. Soon after other larger· leaves develop which are dichotomously forked. Only after the formation of the fifth and sixth leaves, the pinnately compound leaves are developed.

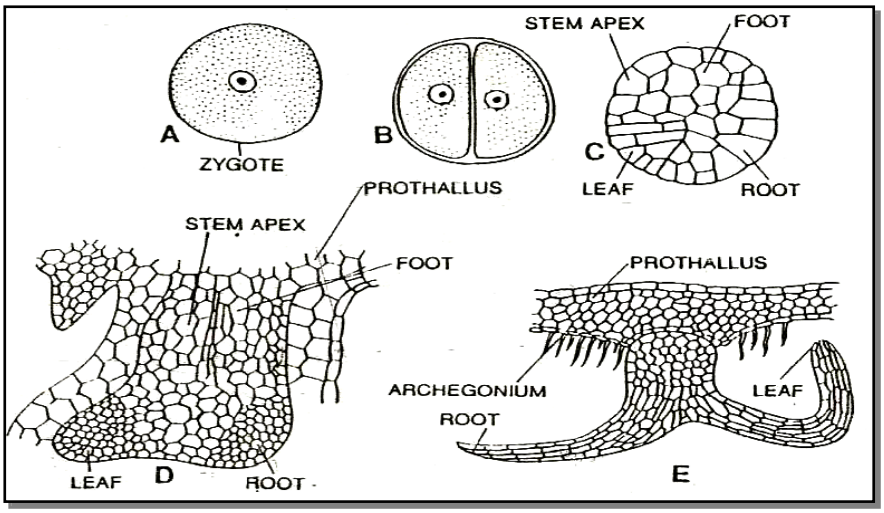


Fig. 3.20. ***Adiantum,*** **A-E stages in the development of the embryo.**

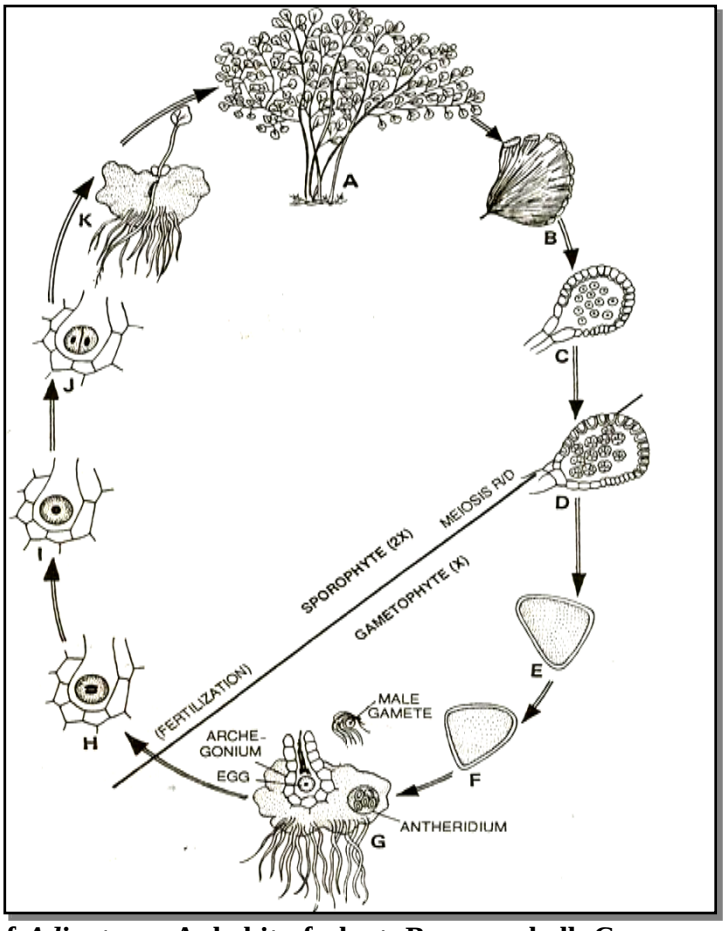


Fig. 3.21. Life cycle of *Adiantum*, A. habit of plant, B. sporophyll, C. sporangium with spore mother cells, D. sporangium with spore tetrads, E. Spore, F. geminating spores, G. Prothallus with antheridia and archegonia, H. Fusing male and female nuclei, I. Oospore, J. embryo, K. prothallus with young sporophyte

Alternation of generations: The number of chromosomes becomes doubled, i.e., diploid (2x) after fertilization is over. This diploid stage prevails upto the formation of spore mother cells. Meiotic division takes place at this stage and the haploid (x) spores are formed. The spores are the beginners of the gametophytic stage. The spore germinates and prothallus is formed.The antheridia and archegonia develop on the prothallus. The antherozoid and ovum fuse and fertilization is effected. The zygote is the beginning of the sporophytic stage. The sporophyte gives rise to gametophyte (prothallus) and again by the process of the union of the gametes the sporophytic stage is attained. This way, it may be said that the fern exhibits an alternation haploid (gametophytic) and diploid (sporophytic) generations.

3.5 SUMMARY

Equisetum is herbaceous and is commonly known as horse tail. Plant body is provided with prostate rhizome and erect branches that are branched at three levels. Different species can be arranged in a reduction series. Stem which is hollow can be distinguished into nodes and internodes. Leaves are microphyllus, simple isophyllus, extremely reduced and forms sheath around the stem. Tubers may also be formed on the nodes of the stem. Sporophylls are arranged in compact strobili or cones at the end of the erect branches. Four to six sporangia are borne transversely to the cone axis on the peltate sporangiophores. *Equisetum* reproduces by vegetative and sexual methods. In Vegetative reproduction the underground rhizomes of some species of *Equisetum* (e.g., *E. arvense, E. telmateia*) form tubers, which help in vegetative propagation. The tubers develop due to irregular growth of some branch buds at the nodes of the rhizome. They are oval (*E. arvense*) or pear-shaped (*E. telmateia*). The tuber has a central parenchymatous region, rich in starch grains, and it is surrounded by 2-3 layers of sclerenchyma. Several collateral vascular bundles are present in the central region. Each bundle is individually surrounded by its endodermal layer. After detachment from the parent plant, the tubers remain in the soil, and on the return of favourable conditions they grow into new plants. In reproduction by spores, the spores develop within sporangia borne on sporangiophores. The sporangiophores are aggregated into a compact cone or strobilus.

Adiantum is also herbaceous having upright or creeping scaly rhizome. Leaves are arranged spirally or alternately on the rhizome. Leaves are circinately coiled in young condition. Petioles are shining black and long blade of leaflets may be entirely or repeatedly branched, delicate in texture. The forking veins transverse the blades. Usually veins are free but in some species they are anatomising forming reticulum e.g., maiden hair fern. Sori appears to be marginal but actually the sporangia are borne on the lower surface of leaves near the margin and are covered by sharply reflexed leaf lobes. The characteristic of Adiantum is the presence of apparently marginal sori which are superficial in origin and covered by a sharply reflexed leaf margin which looks like an indusium because of its membranous nature and brown colour on its maturity. Actually there is no true indusium. The sporangia are inserted upon the distal region of the veins traversing the fertile lobe. The fertile region of the blade itself becomes sharply reflexed and serves as indusium. Each such fertile lobe bears a group of sori

situated upon parallel veins. In some cases the sporangia are found spread on to the surface of the blade in between veins.

3.6 GLOSSARY

Androcyte: Antherozoid mother cell.
Androgonial cell: Any cell within an antheridium other androcyte or androcyte mother cell.
Antheridium: Male sex organ of cryptogams.
Archegonium: The female sex organ of bryophytes, pteridophytes and gymnosperms.
Axil: It is the junction where a lateral organ such as a leaf joins a main axis like a stem.
Cortex: The ground tissue of stem and root ; present between epidermis and the stele.
Cuticle: A waterproofing layer covering the epidermis of aerial plant surfaces.
Dichotomous: The type of branching in plants that result when growing point divides into two equal growing points which in turn divide in a similar manner after a period of growth and so on.
Embryo: An embryo is a multicellular diploid structure in an early stage of embryogenesis or development.
Endodermis: The layer of tissue situated between the cortex and stele.
Fertilization: It is the fusion of gametes to initiate the development of a new individual organism.
Foot: A specialized organ of attachment and of the embryo which absorbs food from the gametophyte.
Gametophyte: A gametophyte is a gamete bearing plant. It develops from the meiospores produced by sporophyte by meiosis or reduction division. Gametophyte is a haploid structure.
Habit: The general external appearance of a plant, including size, shape, texture and orientation
Habitat: The place where a plant lives; the environmental conditions of its home.
Heteromorphic: When the two phases of life-cycle are morphologically different.
Heterospory: Production of two kinds of dissimilar spores differing in size and function in the same species.
Homospory: Production of one kind of similar spores.
Leaf: an outgrowth of the stem usually flat and green; its main function is manufacture of food by photosynthesis.
Life-cycle: In most of the plants multicellular diploid sporophyte phase alternates with a multicellular haploid gametophyte phase. This cycle is known as life-cycle or alternation of generation.
Ligule: A minute appendage of the leaf that is found at the base of the leaf.
Megaspore: The larger of two kinds of spores produced by a heterosporous plant giving rise to the female gametophyte.
Mesophyll: The inner photosynthetic parenchyma of leaf located between epidermal layer and usually differentiated into palisade and spongy parenchyma.
Microspore: The smaller of two kinds of spores produced by a heterosporous plant giving rise to the male gametophyte.
Rhizome: Underground stem distinguished from root by nodes, buds or scale like leaves.

Rhizophore: A specified part of the stem bearing roots.
Spore: A haploid propagule produced by meiosis in diploid cells of a sporophyte that can germinate to develop a multicellular gametophyte.
Sporophyte: A sporophyte is the diploid multicellular stage in the life cycle of a plant. It develops from the zygote when a haploid egg cell is fertilized by a haploid sperm and each sporophyte cell therefore has a double set of chromosomes. The sporophyte produces spores by meiosis (hence the name sporophyte means spore bearing plant).
Strobilus: A cone like structure consisting of sporophylls or sporangiophores borne close together on an axis.
Tetrad: A group of four spores resulting from reduction division of one spore mother cell.
Zygote: The fertilized egg before it undergoes further differentiation.

3.7 SELF ASSESSMENT QUESTION

3.7.1. Multiple choice questions:

1. *Equisetum* is commonly called as:
(i) Homosporous (ii) Spike
(iii) Heterosporous (iv) Horse tail

2. Sporangia develop in *Equisetum* on:
(i) Upper surface of sporophylls (ii) Sporongiophores
(iii)Vegetative leaves (iv) Upper surface of sporophylls

3. In Foot of Equisetum the endodermis is :
(i) Present (ii) Absent
(iii) Two layered (iv) Multi layered

4. Vascular canal in *Equisetum* is situated:
(i) Below the ridges (ii) Below the furrows
(iii) Below the ridges and furrows (iv) Between the pith and the epidermis

5. Presence of air cavities in the stem of Equisetum indicate:
(i) Xerophytic feature (ii) Hydrophytic feature
(iii) Mesophytic feature (iv) Haplophytic feature

6. If sporangia are developed from a single initial cell, the development of sporangia is designated as
(i) Eusporangiate (ii) Leptosporangiate
(iii) Monosporangiate (iv) Polysporangiate

7. Which type of venation is characteristic of fern?
(i) Parallel (ii) Reticulate
(iii)Dichotomous (iv) Open furcate

8. A plant showing vascular tissues but not producing seeds belongs to:
(i) Gymnosperms (ii) Pteridophytes
(iii)Bryophytes (iv) Angiosperms

9. In ferns meiosis takes place during:
(i) Germination of spores (ii) Formation of spores
(iii) Formation of Gametes (iv) Formation of Archegonium

10. The major role in the dehiscence of a fern sporangium is played by its:
(i) Sorus (ii) Tapetum
(iii)Indusium (iv) Annulus

3.7.2. Fill in the blanks

1. Spores of *Equisetum* are unique in having _____
2. *Equisetum* belongs to *sub* division_____
3. On the outer walls of epidermis of *Equisetum* there is deposition of _____
4. The stem of *Equisetum* have _____ and _____ in outline.
5. Water filled canals in the vascular strands of *Equisetum* are _____
6. Fern prothallus is _____
7. The spore produced by the fern represents_____ stage
8. There are _____ vertical rows of cells in the neck of the archegonium in fern
9. In ferns the stem is generally modified into_____
10. In fern's sporangia the _____and _____ walls of annulus cells are thickened.

Answer Keys:

3.7.1: 1. (iv), 2.(ii), 3. (iii), 4. (ii), 5. (ii) 6. (ii), 7. (iv), 8. (ii) 9. (ii), 10. (iv)

3.7.2: 1. Elaters, 2. Sphenopsida, 3. Silica 4, Ridges and grooves, 5.Carinal canal,
6. Haploid, 7. Gametophytic stage, 8. Four, 9.Rhizome, 10. Inner/Radial

3.8 REFERENCES

- Alston, A.H.G. 1945. An Enumeration of the Indian species of *Adiantum*. *Proc.National Inst. Sci. India*, XI: 211-236.
- Banks, H.P.1992. The Classification of early Vascular Plants-Revisited. *Geophytology* 22:49-63.
- Bower, F.O. *1947. Botany of the Living Plants*. 4th ed. London.
- Bower,F.O.1935. *Primitive Land Plants*. Macmillan London.
- Bruchmann ,H.1905. On the Rhizophore of *Adiantum Flora* 95:150-66.
- Campbell, D.H. 1902. Studies on the Gametophyte of *Adiantum*. *Ann. Bot*. 16: 419-428.
- Goebel, K. 1930. *Organography of plants* Part. II p.228 (*Adiantum*).
- Lemoigne, Y. 1970. Gametophyte of *Equisetum*. *Bull. Soc. Bot. France* 117: 307-320.
- Lyon, A.G.1957. Germinating spore in Rhynie chert.*Nature* 180:1219.

- Pant, D.D.1962. The Gametophyte of Psilophytales. *Proc. Summer School Botany. Darjeeling* June 2-15 1960, 276-301.
- Sharma, B.D. and R.P.Tripathi 2000. Sporangium of *Aglaophyton (Equisetum) major* (Kidston and Lang) Edwards from Rhynie chert, Lower Devonian. *Phytomorphology* 50: 188-191.
- Uphof, J.C.T.1920. Contributions towards knowledge of the genus *Adiantum*. The root. *Ann.Bot*.34:493-517.
- Williams, S. 1958. *Manual of Peridology* 105: 15

3.9 SUGGESTED READINGS

1. *Biology and Morphology of Pteridophytes*. Central Book Depot Allahabad, Parihar, N.S.
2. *An Introduction to Pteridophyta: Diversity and Differentiatio*n. Vikas Publishing House Pvt Ltd, New Delhi, A.Rashid,
3. *A Text Book of Pteridophyta*, Vikas Publishing House Pvt Ltd, New Delhi, Pandey, S.N., P.S. Trivedi and S.P. Misra
4. Botany for Degree Students: Pteridophyta. S. Chand Publications, Meerut, B.R. Vashishtha

3.10 TERMINAL QUESTIONS

Q.1. Describe in detail the Gametophytic generation in *Equisetum*

Q.2. Explain:
(i) Sporangia of *Equisetum*
(ii) Locality of *Equisetum*
(iii) Stem of *Equisetum*

Q.3. Write a detailed account of the structure of the cone in *Equisetum*

Q.4. Define the following:

(i) Strobilus
(ii) Rhizophore
(iii) Microsporangium
(iv) Megasporangium

Q. 5. Write short notes on:
(i) Vegetative reproduction in *Equisetum*
(ii) Gametophyte of *Equisetum*
(iii) Sporangium of *Equisetum*
(iv) Life- cycle of *Adiantum*

Q. 6. Draw labelled diagrams to illustrate the structure of the following:
(i) T.S. stem of *Adiantum*
(ii) T.S. stem of *Equisetum*
(iii) L.S. strobilus of *Adiantum*

Q.7.Write short notes on:
(i) Indusium
(ii) Sorus
(iii) Root of Fern
(iv) Fern Prothallus

Q.8. Describe the development of reproductive structure in *Adiantum*
Q.9. Describe the life cycle of *Adiantum*
Q.10.How is it advantageous to the reproduction of a fern to have its sex organs on the underside of its prothallus. Explain

UNIT-4 STRUCTURE AND REPRODUCTION IN *MARSILEA AND AZOLLA*

4.1 OBJECTIVES

This unit describes structure and reproduction in *Marsilea* and *Azolla.* After reading this unit you will be able to:

- Describe systematic position, habit, habitat and general features of *Marsilea* and *Azolla*.
- Explain reproduction in *Marsilea* and *Azolla.*
- Understand sporangial development in *Marsilea* and *Azolla.*
- Discuss life cycle in *Marsilea* and *Azolla.*

4.2 INTRODUCTION

In the previous unit we have described *Equisetum* and *Adiantum*. The present unit deals with structure and reproduction of two other important pteridophytes viz., *Marsilea* and *Azolla.* The order marsileales is a small group of heterosporous leptospororangiates. These are mostly aquatic or semiaquatic plants and are commonly known as water ferns. The soporophyte has a branched creeping rhizome which bears roots and upright leaves at intervals. Young leaves show circinate vernation. The plants are heterosporous and both microsporangia and megasoporangia occur within a specialized structure called sporocarp. Marsileales include a single family marsileaceae with three genera viz., *Marselia, Piluria* and R*egnellidium.*

The order salviniales include two genera of water ferns viz., *Azolla* and *Salvinia.* The sporophytic plant body of these ferns is soft and herbaceous and floats on the surface of the permanent water bodies forming dense mats. The stem is represented by a horizontal rhizome. It is covered with two (*Azolla*) and four (*Salvinia*) rows of leaves. True roots are present in *Azolla* but they are absent in *Salvinia* and instead one of the ventral leaves becomes dissected and appears root like. The members are heterosporous and sporangia are borne within a special fruiting body called sporocarps. The sporocarp bears either microsporangia or megasporangia. The spores along with the cytoplasm of degenerating tapetal cells form small units called massulae.

4.3 MARSILEA

This order includes a single family, Marsileaceae. The family includes the living genera- *Marsilea, Pilularia* and *Regnellidium.* They are heterosporous aquatic ferns. The sporangia of these are produced within special structures known as sporocarps. Each sporocarp possesses many sori which bear microsporangia and megasporangia. The sori are gradate, i.e., the oldest sori are found at their terminal end of the receptacle and youngest at the base.

Systematic Position:

Division:	Filicophyta
Class:	Pteropsida
Sub class	Leptosporangiopsida
Order:	Marsileales
Family:	Marsileaceae

Genus: *Marsilea*

Distribution and habitat

There are about 65 species of *Marsilea* distributed all over the world. They are found in tropical regions, such as Africa and Australia. Gupta and Bhardwaja (1957) have recorded about ten species of *Marsilea* from our country. About six species of *Marsilea* are known to occur in the United States. They are hydrophytic or amphibious plants. They grow rooted in the mud of marshes and shallow pools. *Marsilea vestita* and some other species grow in shallow ponds. A single plant of *M. vestita* may grow in all directions until it covers an area twenty-five metre or more in diameter. In *M. vestita* and most of other species the sporocarps develop to maturity only on the plants that are not submerged. *M. minuta* and some other species produce sporocarps in the aquatic habitat; on the other hand *M. aegyptiaca* never produces the sporocarps in the aquatic habitat. An Austraian species *M. hirsuta* can survive in dry conditions throughout the year.

The Indian species recorded by Gupta and Bhardwaja (1957) are as follows-

1. *M. quadrifolia; M. minuta; M. aegyptiaca; M. brachypus; M. gracilenta; M. poonensis; M. rajasthanensis; M. brachycarpa; M. Condensate, M. coromandelica*

4.3.1 Structure of *Marsilea*

External Features: The plant body is divided into:

The Stem

The species of *Marsilea* possess a rhizome which creeps on or just beneath the surface of the soil. The rhizome is slender, branched and possesses nodes and internodes. The leaves are borne alternately along the upper side of the rhizome usually at the nodes. One or more adventitious roots come out from each node on the underside of the rhizome. The rhizome is dichotomously branched and is capable of indefinite growth in all directions and covers an area of more than twenty-five metres in diameter.

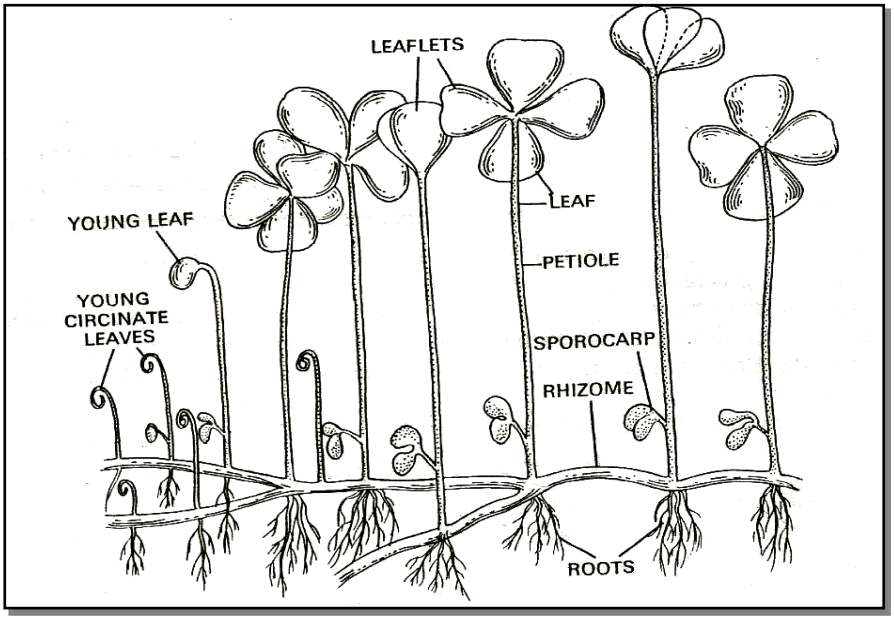


Fig. 4.1. ***Marselia:*** **A sporophyte with sporocarps, rhizome, leaves and roots**

The Leaves

The leaves are borne alternately along the upper side of the rhizome at the nodes. The leaves possess circinate vernation typical of most Filicales (ferns). The young parts of the leaves of *M. minuta* and others are covered with numerous multicellular hairs. The leaves of submerged plants possess long flexible petioles and leaf lamina that float on the water surface.

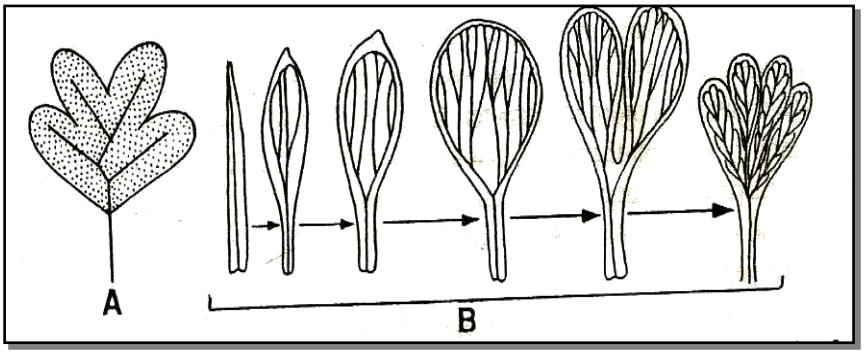


Fig. 4. 2. ***Marselia:*** **A. Leaf showing arrangement of leaflets, B successive types of juvenile leaves of *Marselia***

When the plants grow on mud or marshy places, the leaves get shorter and the petioles erect and stouter which spread the leaves in the air. The leaves are compound. The lamina of each leaf is divided into four leaflets pinnae arising from the apex of the petiole. Division of a leaf-blade into four leaflets results from two dichotomies arising in close succession to each other. According to Puri and Garg (1953) the leaf of *Marsilea* consists of a single leaflet bearing four pinnules and not of four leaflets. The veins of each pinna are dichotomously branched and have numerous cross connections resulting in a close reticulum of veins. The shape of pinnae varies from obovate to obcuneate. The margin also varies from entire to crenate, e.g., *M. minuta* or from crenate to lobed as in *M. aegyptiaca* a xerophytic form. The leaflets may be once or twice deeply lobed dichotomously, e.g., in *M. macrocarpa* and *M. biloba*. In *M. minuta,* the pinnae become coarsely toothed. At night the pinnae of aerial leaves become folded upwards and exhibit the sleeping movement.

The sporocarps are borne on short peduncles near the base of the petiole. In majority of cases the peduncle or stalk of the sporocarp is unbranched and bears a single sporocarp at its apex. *Marsilea quadrifolia* possesses dichotomously branched peduncle, which bears two to five sporocarps. In *M. polycarpa* single dichotomously branched peduncle bears about 6 to 26 sporocarps.

Roots

One or more adventitious roots are borne at each node on the underside of the rhizome. The adventitious roots may arise even from internodes, e.g., in *M. aegyptiaca*. In *M. minuta* the roots may develop laterally. Dr. Pande (1923) pointed out that the roots of *M. minuta* secrete carbonic acid and because of this secretion the roots could penetrate the shells of pond snails.

Internal features

Rhizome

The rhizome of *Marsilea* possesses an amphiphloic siphonostelic vascular cylinder. The outermost layer is the, single layered epidermis without any stomata. The cortex is differentiated into outer and inner cortical regions. The outer cortical region consists of compact parenchymatous tissue. This region may be one to several celled in thickness. Just beneath this the cortical region contains large lacunae or air spaces (aerenchyma). The lacunae are separated from each other by one layered parenchymatous septa. This region may be considered the middle cortex. Internal to this region the inner cortex is found. This consists of a sclerotic zone. The cells consisting this region are thick-walled sclerenchymatous cells (fibres). Beneath this region the cortex again consists of compact parenchymatous tissue acting as storage tissue containing starch in them. Some of the tannin cells may be found in this innermost region.

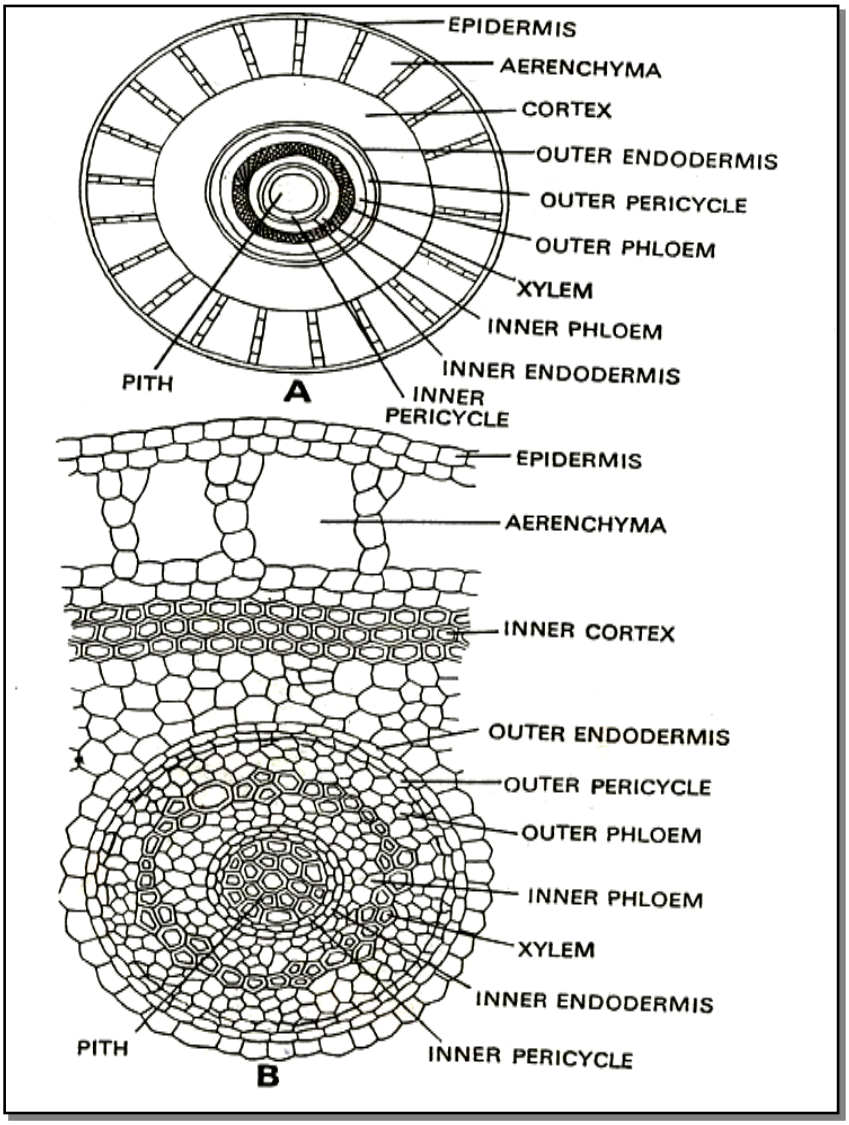


Fig. 4.3. ***Marselia:*** **Anatomy of rhizome (diagrammatic). (A). T.S of rhizome, (B). T.S. of rhizome (detailed)**

The stele is amphiphloic siphonostele. All species possess the siphonosteles externally and internally limited by a single layered endodermis. Just beneath the outer endodermis there is a single layered pericycle. In the centre is the pith whose structure depends upon environmental conditions. In submerged species, the rhizomes possess usually parenchymatous pith, whereas the plants growing on mud have a more or less sclerenchymatous pith. Outside the pith there is a single layered inner endodermis, inner pericycle and then inner phloem in a continuous succession. Thereafter, there is a ring of xylem which is surrounded by the successive rings of outer phloem, outer pericycle and outer endodermis. In *M. quadrifolia* there is no definite protoxylem but in *M. vestita* there are well defined protoxylem groups which are exarch. This way, the continuation of different tissue in the amphiphloic siphonostele is as follows-outer endodermis, outer pericycle, outer phloem, xylem, inner phloem, inner pericycle and then inner endodermis.

Petiole

The outermost layer is single layered epidermis. Just beneath the epidermis there is hypodermal layer. Then there is outer cortex constituting of large air spaces or lacunae (aerenchyma) separated from each other by septa. The inner cortex is composed of compact parenchymatous cells. In this region some of the tannin cells may be present here and there. In the central region of the petiole there is stele which is more or less triangular in outline. The stele is surrounded by a single layered endodermis. It possesses V-shaped mass of xylem with the exarch protoxylem. The two arms of V are quite separate and somewhat curved from each other. The V-shaped mass of xylem is surrounded by phloem and single layered pericycle successively. The ends of each arm of V-shaped xylem are protoxylem groups whereas the middle regions of the arms of V consisted of large tracheids representing the metaxylem groups. The opening of the V is always towards· the axis, i.e., adaxial side.

Leaflet

The leaflet is bounded by two upper and lower epidermal layers. In the case of floating leaves the stomata are confined to the upper surface but in the case of the plants growing in mud and moist soil, the leaves are aerial, and the stomata are found on both the upper and lower surfaces. Just beneath the upper epidermis there is mesophyll differentiated into palisade and spongy tissues. The vascular bundles are concentric, i.e., xylem elements are surrounded by phloem. On the outside of the vascular bundle there is single layered endodermis. Towards lower side there are big air spaces separated by septa.

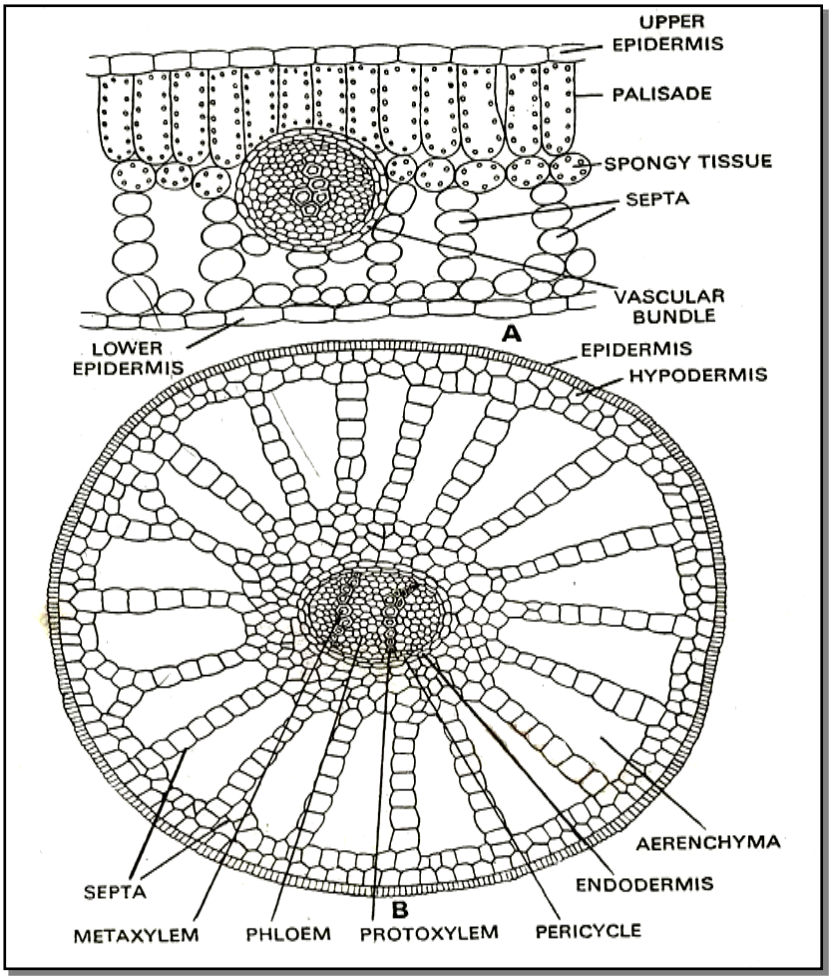


Fig. 4.4. ***Marselia:*** **A. T.S. of a portion of leaflet, B. T.S. of petiole**

Root

In the transverse section of the root, the epidermis, cortex and stele may be seen. The epidermis is single layered and composed of thin-walled parenchymatous cells. The cortex of the root is differentiated into two regions. The outer region consists of large air spaces or lacunae separated by septa from each other; the inner zone of the cortex consists of a few layers of sclerotic cells. Inner to the cortex there is single layered endodermis. Just beneath the endodermis there is single layered pericycle. In the centre of the stele there is typical diarch and exarch structure with a diametric plate like strand of xylem. The phloem bands are found on either side of the xylem plate.

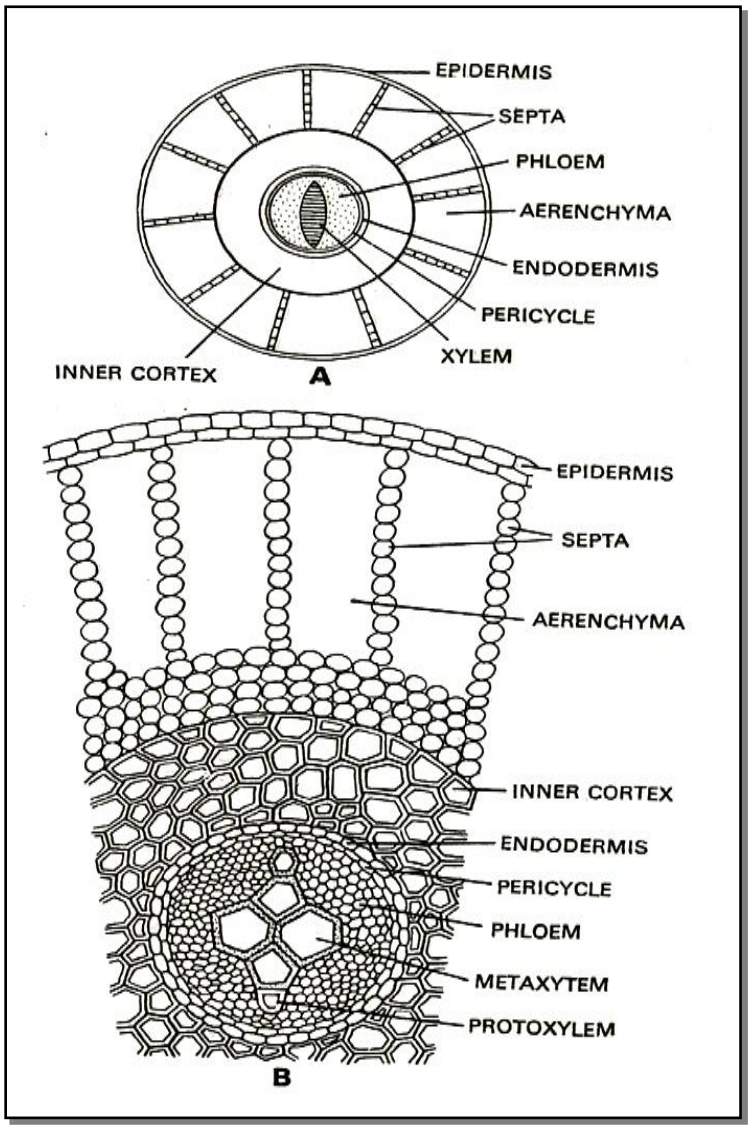


Fig. 4.5. ***Marselia:*** **Anatomy of root. (A). T.S. of root (diagrammatic), (B). T.S. of a portion of a root (detailed)**

4.3.2 REPRODUCTION IN *MARSILEA*

The reproduction in *Marsilea* takes place by vegetative and sexual methods

1-Vegetative Propagation

The vegetative reproduction takes place by means of specially developed structures known as tubers. In the dry conditions certain branches develop from the rhizome, which swell because of the storage of food material and are known as tubers. These tubers survive in the unfavourable and drought conditions and on the return of favourable conditions they germinate into new plants, e.g., *M. hirsuta.*

2-Sexual Reproduction

The plant is a sporophyte. It bears the special structures known as sporocarps which contain micro and megasporangia in them. It is heterosporous. The sporocarps are borne on short peduncles above the base of the petiole. In most cases the peduncle is unbranched and bears a single sporocarp at its apex. In *M. quadrifolia* the peduncle is dichotomously branched and bears 2 to 5 sporocarps.

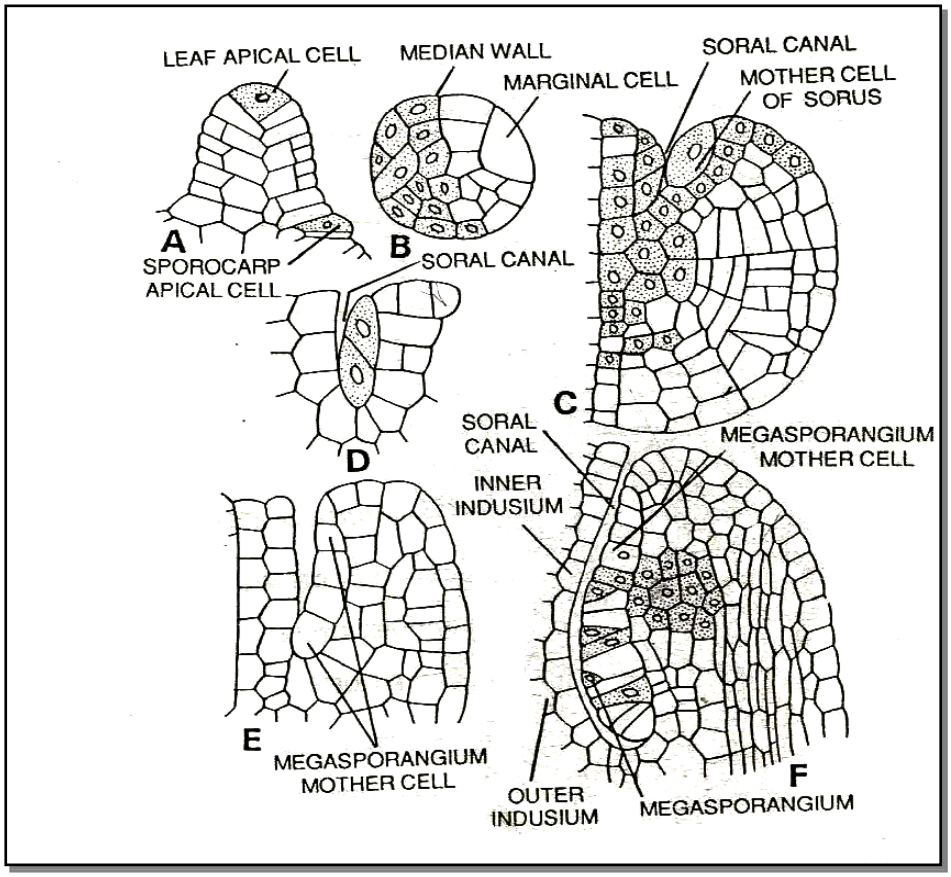


Fig. 4.6. ***Marselia:*** **Development of Sporocarp. A. young leaf, B. T.S. of a young sporocarp, C development of one half of leaf, D-F. stages of development of sorus and soral canal**

The sporocarps may be oval or bean-shaped. In the earlier stages of its development it is soft and green but later on it becomes sufficiently hard and brown in colour. In majority of the species of Marsilea near the point of attachment of the stalk or peduncle at the base, there are usually one and sometimes more protuberances in the median plane. Such protuberances consist of one or two teeth and raphe. The raphe is found laterally fused to base of the sporocarp at the end of the peduncle. In certain species the raphe is not found, where the sporocarp is directly attached to the end of the peduncle, e.g., *M. polycarpa, M. caribaea* and others. Beyond the raphe two teeth or projections are found. These teeth are unequal in size. The lower tooth is stouter than the upper one. In some species the teeth are very prominent, e.g., *M. vestita* while in other species they are altogether absent.

The vascular supply of the sporocarp consists of a main vein along the narrow side facing the peduncle from which numerous lateral veins perpendicular to the main vein (dorsal bundle) are given off. These lateral veins are given off alternately right and left. Each lateral vein

divides dichotomously about middle of its base and the apex. A receptacle develops at the region where each lateral vein forks dichotomously. The receptacles of one valve alternate with those on the opposite valve of the sporocarp. A flap like outgrowth two-celled thick extends like a hood over the entire receptacle. Each receptacle projects· inward from the wall of the sporocarp.

Development of Sporocarp

The sporocarp of Marsilea develops from a marginal cell of a very young leaf. This marginal cell is situated on the inner face of the leaf and is being differentiated only after the apical cell of the leaf has cut off 6-8 segments. The marginal cells of the sporocarp initials divide and make a mass of undifferentiated cells which become curved so that the distal end gets directed horizontally. As the distal part enlarges to form the sporocarp two rows of soral mother cells appear on the ventral side, arising directly from the marginal cells of the earlier stage. Later the marginal cell and their derivatives are pushed downwards to the lower surface and slightly towards the median line due to unequal growth of the cells. As increase in diameter continues the cells lateral to the soral mother cells grow more rapidly than the developing sorus with the result that the sporangial mother cells become burried. Simultaneously each sorus towards the median line a small cresent shaped depression appears on the side facing downwards which deepens quickly with the growth of tissue around the sorus. These depressions become spaces above and around the sori opening to the outside by the small pores, which are called the soral canals. The soral canals appear linear in the longitudinal section and crescent-shaped in cross section. Each soral canal is lined on its central face by an indusium of which two layers may be recognized, i.e., outer indusium and inner indusium. In each soral canal the receptacle of the sorus faces the indusium, and sporangia arise on the receptacle in acropetal succession. The first sporangial initials appearing at the tip of the receptacle develop into megasporangia whereas the other initials appearing along the sides produce microsporangia. Lateral to the sori the massive tissue of the sporocarp develops and forms the massive outer wall which ultimately closes the soral canals, and the sori are completely enclosed within the sporocarp.

Internal Structure of the Sporocarp:

Transverse Section

The following tissues are seen in the transverse section. Outside the sporocarp there is a very thick wall consisting of three layers. The outermost layer is known as epidermis which consists of broad and columnar cells. The epidermis is interrupted by a number of stomata. Below the epidermis there are two hypodermal layers. The outer hypodermal layer consists of elongated thick-walled cells, while the lower hypodermal layer consists of elongated and palisade like cells. In the inner region of the sporocarp only two chambers of sori are seen surrounded by separate indusia. The dorsal bundles are also seen. Each sorus possesses a receptacle which bears either micro or megasporangia.

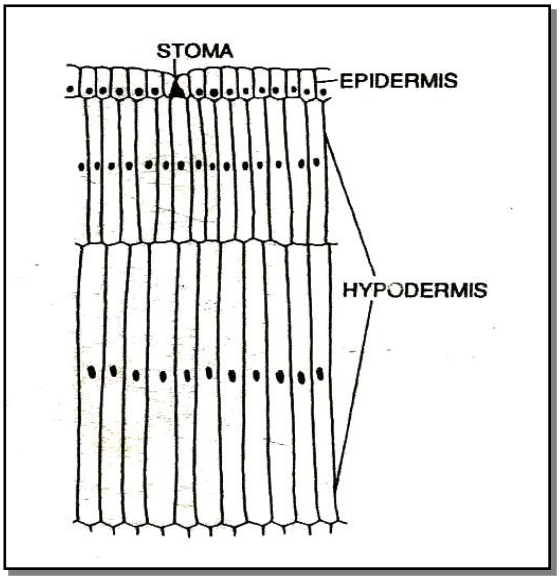


Fig. 4.7. ***Marselia:*** **portion of a transverse section of wall of sporocarp**

Longitudinal Section

The structure of the wall of sporocarp and the gelatinous ring is the same as in transverse section. In the interior of the sporocarp there are two alternating rows of sori each surrounded by a two layered indusium. A placental branch goes to each sorus from the lateral bundles. The receptacle bears a single megasporangium at the tip and the microsporangia on the lateral sides. Each megasporangium contains a large single megaspore while the microsporangium contains many small rounded microspores.

Dorsiventral Section

The structure of the outer wall of the sporocarp and gelatinous ring is the same as seen in transverse and longitudinal sections. Below the outer wall a continuous gelatinous ring is found. Within the sporocarp there is a group of sori. Each sorus appears to be formed in a cavity and is surrounded by a delicate, membranous indusium. The sorus contains micro and megasporangia. The megasporangia may easily be seen if the sporocarp is cut dorsiventrally somewhat to one side of the median line of the sporocarp, whereas, the microsporangia may be easily seen if the section of the sporocarp is cut in the same plane but slightly farther away than the previous one.

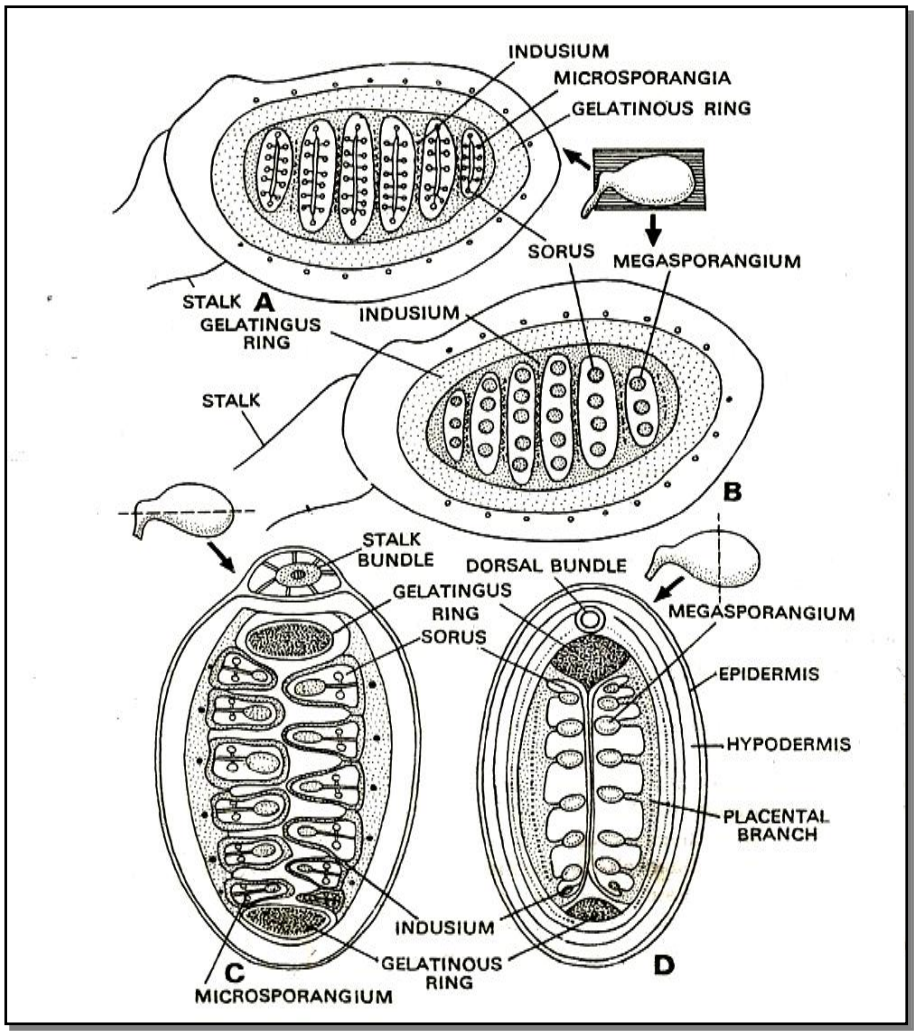


Fig. 4.8. ***Marselia:*** **structure of sporocarp. A. section cut in dorsiventral plane somewhat to one side of the median line showing microsporangia, B. section cut in dorsiventral plane showing megasporangia, C. section cut in longitudinal section showing sori containing micro and megasporangia, D. Transverse section of sporocarp**

Morphological Nature of the Sporocarp

Various interpretations have been given by different workers with regard to the morphological nature of the sporocarp. There ae two main hypotheses

1. Leaf-segment or laminar hypothesis and 2. Petiolar hypothesis

The sporocarp of *Marsilea* has been interpreted as a lateral modified segment of the leaf. According to Bower (1926), Busgen (1890), Campbell (1905), leaf segment or laminar hypothesis the sporocarp has been interpreted homologous with a modified fertile segment from the lower part of a leaf. Petiolar or whole leaf hypotheseis Johnson (1898, 1933) has interpreted the sporocarp to be homologous with an entire leaf. The argument for the latter interpretation by Johnson is that the apical growth of a sporocarp resembles to that of an

entire leaf rather than to of a leaflet or leaf segment. The leaf segment or laminar hypothesis is supported by several workers and seems to be more correct.

Leaf segment or laminar hypothesis

The vascular supply to the peduncle of the sporocarp and the vascular supply to the interior of the sporocarp prove that the sporocarp is a modification of leaf segment (pinna) rather than that of an entire leaf. The advocates of the leaf segment theory interpret it in various ways. Bugen (1890) interpreted that the sporocarp has been resulted from the opposition of two leaflets (pinnae), whereas Bower (1926) and Campbell (1905) interpreted that the sporocarp has been resulted from a single pinna by its enfolding. Puri and Garg (1953) interpreted that the sporocarp has been resulted from the enfolding of a pinna with several pinnules each with a marginal sorus. The presence of single dorsal main vein in the sporocarp and the single bundle in the peduncle indicate clearly that the sporocarp has been derived from a single pinna. It has been argued by Bower (1908, 1926) the ancestors of Marsileales were probably ferns with a gradate sorus surrounded by an involucroid indusium and not Schizaeaceae. In Schizaeaceae the sporangia are borne singly and develop simultaneously whereas in Marsileales the sporangia are borne in sori of a gradate type in which the sporangia at the apex of a receptacle develop earlier than those at the base of the receptacle.

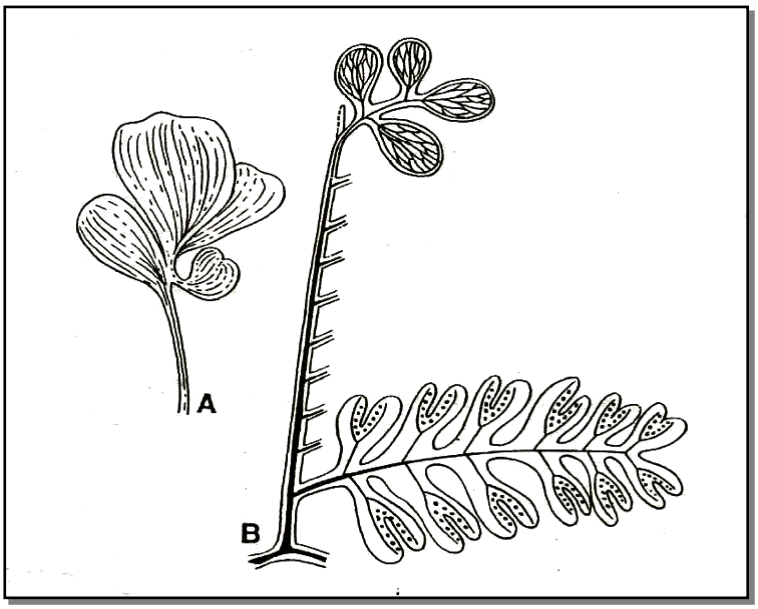


Fig. 4.9. ***Marselia:*** **A. abnormal leaf of *M. hirsute* showing conditional transitional to sporocarp, B. Simple case with single fertile leaflet at the base to develop into sporocarp.**

This way the relationships of the Marsileales appear to be more with the homosporous leptosporangiate ferns. There is no evidence that the heterospory of Marsileales arose earlier of the evolution of sporocarp. In all other ferns there is homospory and this point indicates that the origin of heterospory is somehow or other connected with evolution of the sporocarp.

Liberation of sori from the sporocarp: The outer wall of the sporocarp is extremely hard and strongly resistant to mechanical injury and drying out. In natural conditions the sporocarp may burst even two or three years later its formation. The spores within the sporocarp may remain viable 20 to 30 years and sometimes upto 50 years. The sporocarp may easily be germinated by injuring it on the ventral median line and keeping it in the water. The water enters to the interior of the sporocarp. Within half an hour the gelatinous ring imbibes water and becomes swollen with the result the sporocarp bursts into two valves from its ventral margin. As more water is imbibed the gelatinous ring protrudes out of the sporocarp. This gelatinous ring bears sori and is known as sorophore. The sori are attached to the gelatinous sorophore by their ends. As the sorophore expands and pushes out, it pulls out the sori, which are attached to it by their ends. Usually the attachment of the gelatinious ring breaks down from the ventral side of the sporocarp and the dorsal part of the side of the sporocarp and the dorsal part of the ·gelatinous ring remains attached by one end to the sporocarp. The gelatinous sorophore bears two alternating rows of soral sacs one on either side of it. A fully elongated sorophore is a long gelatinous cylinder 15 to 20 times longer than the length of the

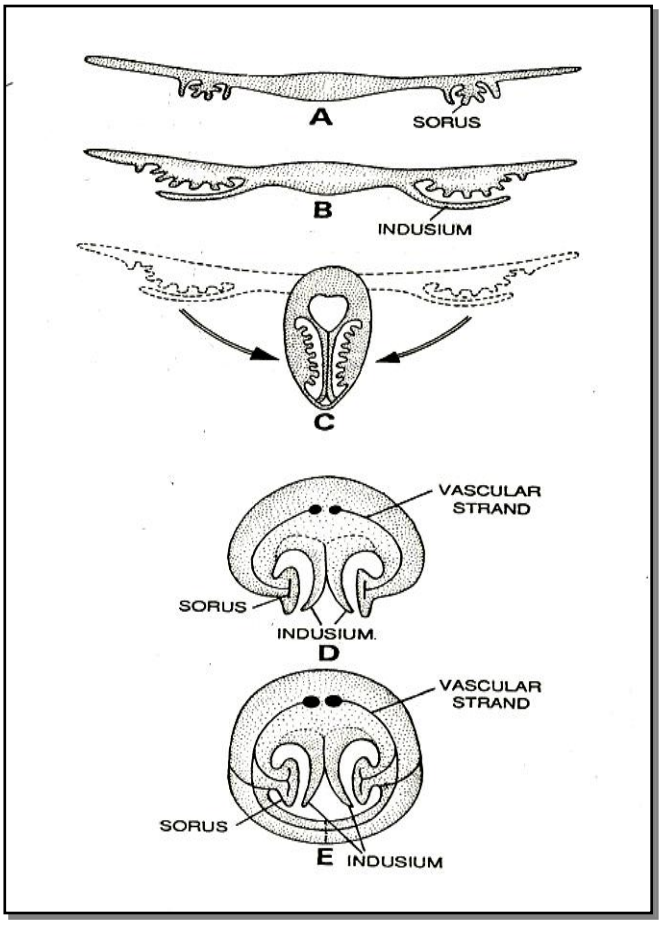


Fig. 4.10. ***Marselia:*** **Morphological nature of sporocarp, A-C Smith's concept of Morphological nature of sporocarp, D-E Eames concept of Morphological nature of sporocarp**

sporocarp. At the tip of the sorophore there are certain small gelatinous projections, also alternate with one another. They are the rudimentary sori which could not develop. The gelatinous ring elongates and straightens and becomes a worm-like structure. At the time of their separation from the gelatinous ring the ventral ends of the sori are torned off and sporangia with spores escape from the ventral ends of the sori. The indusia and the jackets of sporangia become gelatinized and the spores are liberated. The germinating spores and the developing gametophytes remain embedded in the gelatinous matrix up to their maturity.

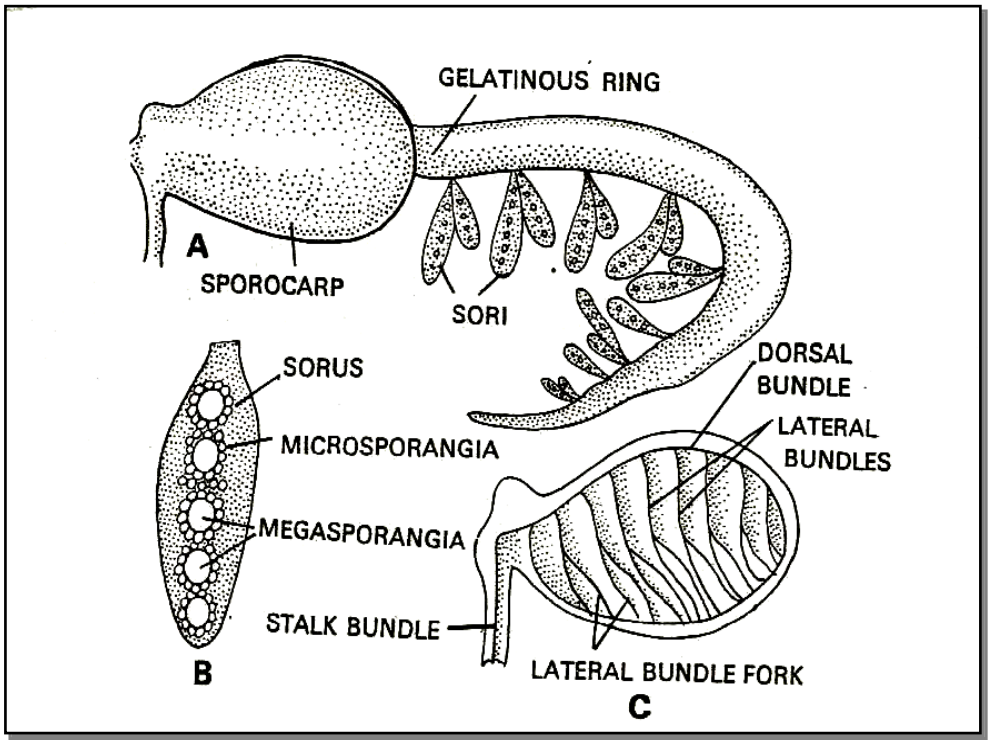


Fig. 4.11. ***Marselia:*** **A. extrusion of the gelatinous ring and sori, B. sorus surrounded by indusium, C. vascular supply of the sporocarp in lateral view**

Development of Sporangia

The development of micro and megasporangia is of leptosporangiate type. The leptosporangiate differ from other ferns in having a sporangium with a jacket layer one cell in thickness. There are a definite number of spores within a sporangium. The sporangium develops from a single initial cell and the tapetum differentiates from a single internal cell of a developing sporangium.

One of the superficial cells acts as a sporangial initial. The sporangial initial divides periclinally producing two cells, the inner cell and the outer cell. The inner cell does not divide further whereas the outer cell forms the entire sporangium, its stalk and its contents. The outer cell divides thrice by successive diagonal divisions giving rise to a tetrahedral apical cell. The apical cell cuts of two segments on each of its three sides giving rise to a stalk and basal wall cells of the sporangium. The apical cell divides periclinally producing an outer cell, the jacket initials and an inner archesporial cell. The jacket initials divide anticlinally

and give rise to the jacket layer of the sporangium. The archesporial cell divides periclinally and produces tapetal initials which divide both by anticlinal and periclinal divisions and give

rise to two or three layered tapetal layer. After forming the tapetum the remaining archesporial cell, which acts as primary sporogenous cell divides 3 or 4 times successively giving rise to 8 or 16 spores mother cells. Each spore mother cell divides meiotically producing a tetrad of 4 haploid spores. This way, in both types of sporangia, i.e., micro and mega sporangia about 32 or 64 young spores are formed.

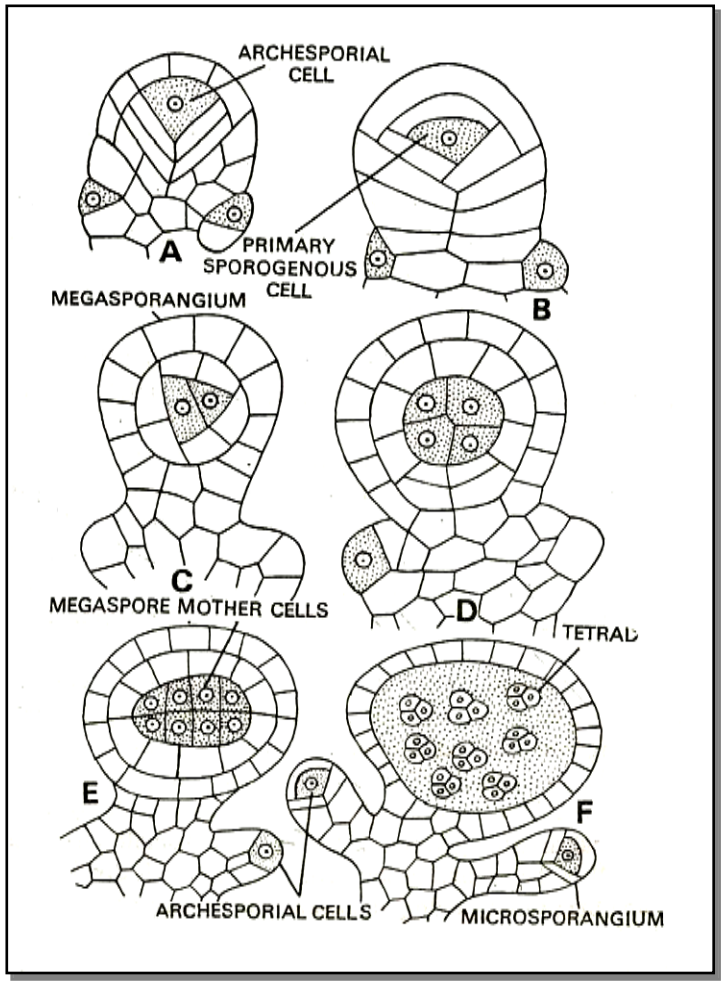


Fig. 4.12. ***Marselia:*** **Successive stages in the development of sporangia, A-F micro and mega sporangia**

The development in the micro and mega spoiangia is alike up to the formation of a one celled thick layer, two-celled thick tapetal layer and 32 to 64 young spores.

In mega sporangium only one of the spores matures and the remaining spores disintegrate and contribute to multinucleate plasmodium formed by disintegration of the tapetum. As only one megaspore survives it becomes quite large in size and thick walled as in other heterosporous pteridophytes.

In microsporangium generally all young spores mature so that each microsporangium contains 32 or 64 microspores.

The jacket layer of both the sporangia of *Marsilea* is a thin walled homogeneous structure without any indication of the formation of annulus. Comparatively the stalk of microsporangium is longer than that of mega sporangium.

The Spores

There are two kinds of spores found in micro and mega sporangia, known as microspores and megaspores.

The Microspores

A microspore is globose in shape with small pyramid-like apex. Each spore shows a faintly developed tri-radiate ridge. It possesses a large central nucleus and a large number of small starch grains scattered throughout the cytoplasm. There may be one or two nucleoli in the big nucleus. The spore wall is quite thick. The endospore is surrounded by epispore and endospore.

Development of Male Gametophyte

The germination of microspore takes place quite rapidly and at ordinary room temperature the microspore develops into a fully mature micro gametophyte within 12 to 20 hours. First of all the starch grains of the microspore migrate to the periphery of the cytoplasm and the nucleus generally shifts to the broad side of the microspore. The microspore for the first time divides by an asymmetrical wall forming two unequal cells, a small lenticular or prothallial cell and a large apical cell. The large apical cell contains granular contents and it divides further. According to Belajeff (1898) and Campbell (1892), the apical cell cuts off a basal cell but this is very much doubted because of the lack of evidence in support of it The apical cell, immediately after its formation divides diagonally to the prothallial cell producing two antheridial initials. According to Sharp (1914) both the antheridial initials then cut off the first jacket cell by a curved wall diagonally formed to the wall of previous division. The jacket cell in each antheridium does not divide again. The curved sister cell divides by a periclinal division giving rise to two cells, a small inner cell and a large outer cell. The small inner cell is the second jacket cell. The outer cell divides periclinally forming the third jacket cell and the primary androgonial cell. The primary androgonial cell divides four times in a series giving rise to 16 androcytes. Simultaneously the prothallial cell distintegrates completely and the jacket cell disintegrate partially. The two androcyte masses lie within the old spore wall.

The androcytes are metamorphosed into antherozoids. Shortly before the antherozoids are mature, the spore wall bursts and the antherozoids are liberated in the water. The antherozoids are liberated by the disintegration of the jacket cell of each antheridium.

Structure of Antherozoid

The antherozoids of *Marselia* have many coils, sometimes a dozen or more. They are cork screwlike in shape.

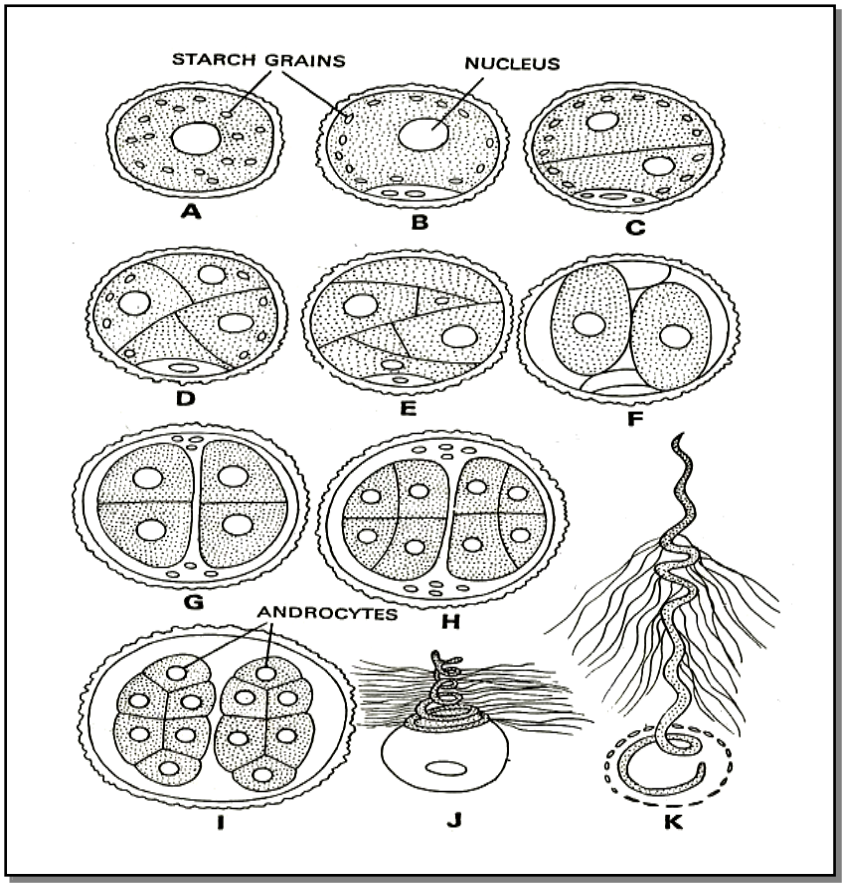


Fig. 4.13. ***Marselia:*** **A-I, successive stages in the development of microgametophyte, J, antherozoid shortly after escape from microspore, K, mature elongated antherozoid**

Usually the upper three or four coils consist of blepharoplast and do not bear any flagella. The broad posterior coils bear 50 to 60 flagella. At the posterior end a globular vesicle is found which contains the cytoplasm.

The Megaspore

The megaspore is ellipsoidal and possesses a small projection at the anterior end. The mucilaginous spore wall is quite thick around the megaspore but thin at its protuberant anterior end. In the remaining part of the megaspore the middle spore wall layer is much thicker and provided with radial fibrils. The anterior protuberant portion contains densely granular cytoplasm and a nucleus. The remaining basal protoplast contains a large number of starch grains scattered throughout the cytoplasm.

Development of Megagametophyte

The development of Mega gametophyte or female gametophyte is somewhat slower than that of male gametophyte. The megaspore begins to germinate immediately after its formation and the mega gametophyte reaches to its maturity at ordinary room temperature within 14 to 22 hours.

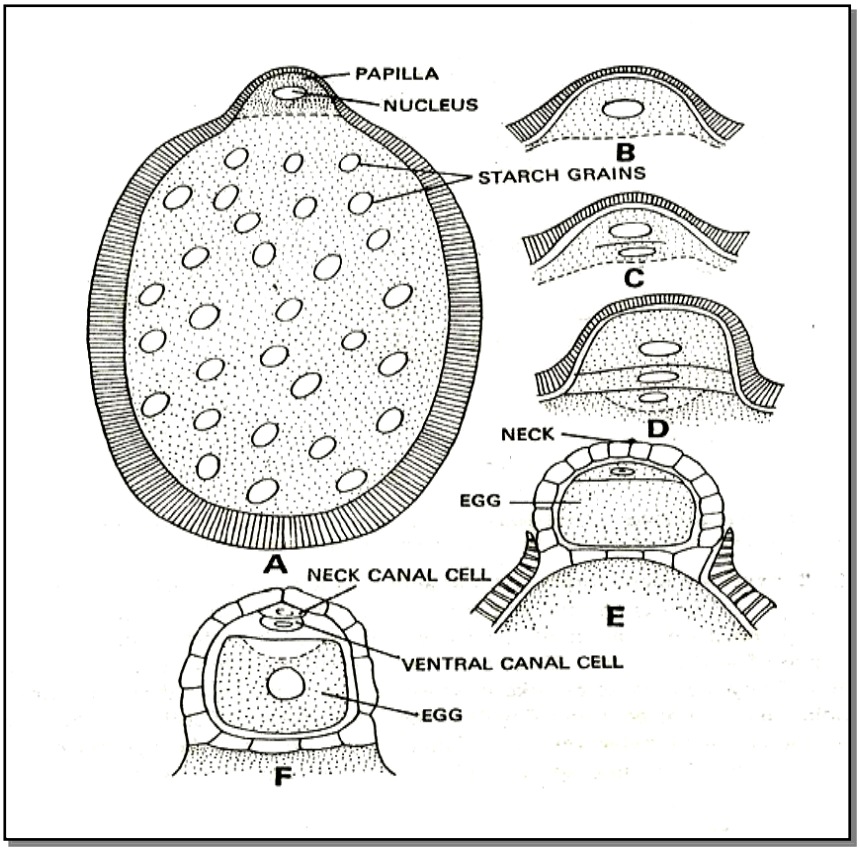


Fig. 4.14. ***Marselia:*** **A, L.S. of mature megaspore, B-E, successive stages in the development of megagametophyte and archegonium, F, mature archegonium**

It has been observed in *Marsilea vestita* that as soon as the spore begins its germination, the nucleus becomes spherical and at the antherior end, the granular cytoplasm increases in amount. According to Campbell (1892), about two or three hours later of the beginning of the spore germination, the nucleus divides which is soon followed by a transverse division. This transverse wall develops in between the denser cytoplasm of the protuberance and the remaining watery cytoplasm. The small cell lies within apical protuberance. The lower large cell is nutritive or prothallial cell and occupies the remaining large portion of the megaspore. The large prothallial cell is quite vegetative and does not divide further. This large cell functions as store house of food material. The small cell situated within the apical papilla develops into the gametophyte proper. The nature of the small cell is somewhat doubtful. Sometimes this has been interpreted an archegonial initial but it is much more probable that the apical cell bears four cutting faces, three lateral and one basal. Each of these cuts a single segment at each face before it acts as an archegonial initial. All the four segments divide by anticlinal divisions several times giving rise to a one-celled thick vegetative tissue. According to Campbell (1892) and Strasburger (1907) the archegonial initial divides periclinally forming a primary cover cell and central cell.

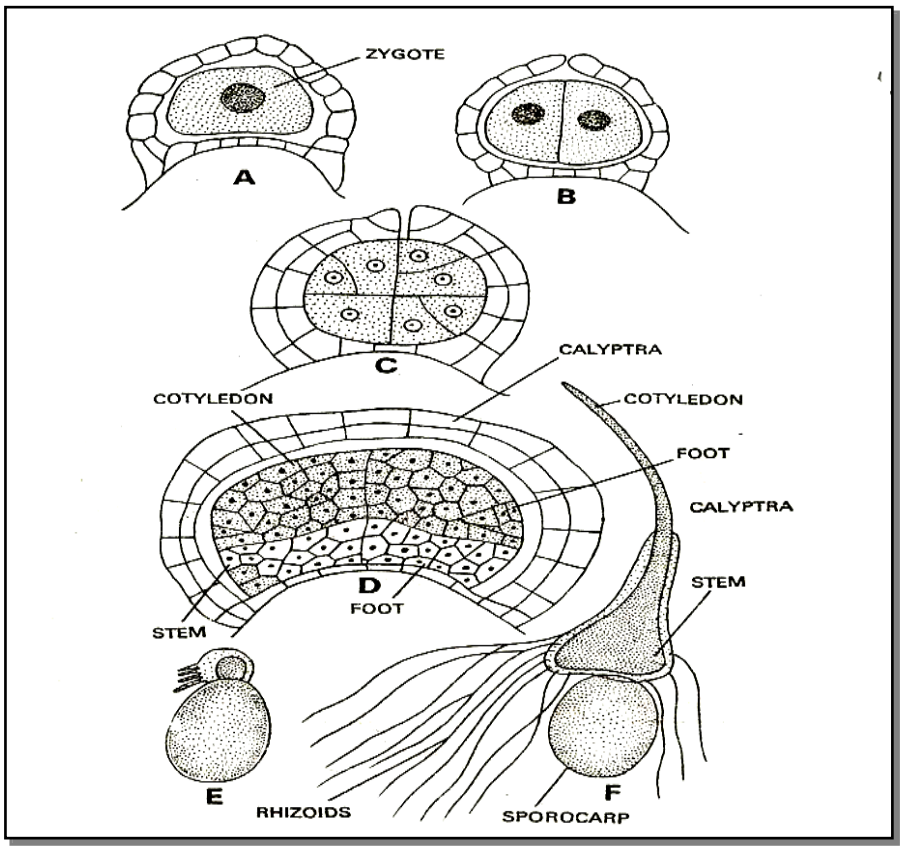


Fig. 4.15. ***Marselia:*** **A-D, successive stages in the development of the embryo, E, sporocarp with young embryo, F, more advanced stage of the embryo in median longitudinal section**

The primary cover cell further divides by two successive anticlinal divisions forming four quadrately arranged neck initials. Each neck initial divides by an oblique wall forming a short neck comprised of two tiers of four cells each. Simultaneously, the central cell divides into two cells, a small primary canal cell and large primary venter cell. Strasburger (1907) reported that in *M. drummondiiand* and some other species the primary canal divides producing two small canal cells. In all species the primary venter cell divides into two cells, a small venter canal cell and a large spherical oosphere or egg. On the maturation of the archegonium the neck canal cell or cells and the venter canal cell disintegrate and the archegonial neck remains open.

A mature mega gametophyte is surrounded by a broad, ovoid gelatinous zone in which there in a watery funnel shaped opening directly upon the archegonium. A large number of antherozoids swim about the funnel shaped opening. Some antherozoids enter the gelatinous envelope, some reach the neck of the archegonium and others fail to do so. Many of the antherozoids die and their uncoiled elongated, none-motile bodies may be seen in the gelatinous envelope whereas the living actively swarming antherozoids may be seen in the gelatinous envelope coiled and moving. This way, the active and living antherozoids may be easily differentiated from the dead antherozoids which have become non-motile and inactive.

Fertilization: Many antherozoids are attracted towards the funnel shaped structure of mega gametophyte. The antherozoids enter gelatinous envelope and reach to the archegonium.

Only one antherozoid enters the egg's cytoplasm anteriorly, but later on its orientation becomes reversed (Atkinson, 1943) and it penetrates the egg nucleus posterior end forward. *Marsilea drummondii* shows parthenogenesis. Strasburger (1907) stated that the megaspore on germination produced a diploid (2x) mega gametophyte which without fertilization developed into a sporophyte.

Development of Embryo

In *Marsilea* the development of the embryo proceeds with great rapidity and only two to four days old sporophyte possesses the first leaf several millimetres long. In *Marsilea vestita* the zygote divides for the first time after fertilization only two or three hours later. The zygote divides first by a vertical division. Thereafter the two daughter cells divide vertically in a plane perpendicular to that of first division (Campbell, 1892). This way a four-celled embryo is formed. Two sister cells of outer side develop into cotyledon and stem and the other two of inner side develop into the foot and root of the embryo. The adjoining cells of the mega gametophyte divide periclinally forming a two to three celled thick calyptra. Simultaneously, many superficial cells on the side of the calyptra facing downwards send out the rhizoids. For the first four or five days, the growth of the calyptra keeps pace with that of the embryo but later on the cotyledon and the primary root penetrate through the calyptra are going upward and the other downward respectively.

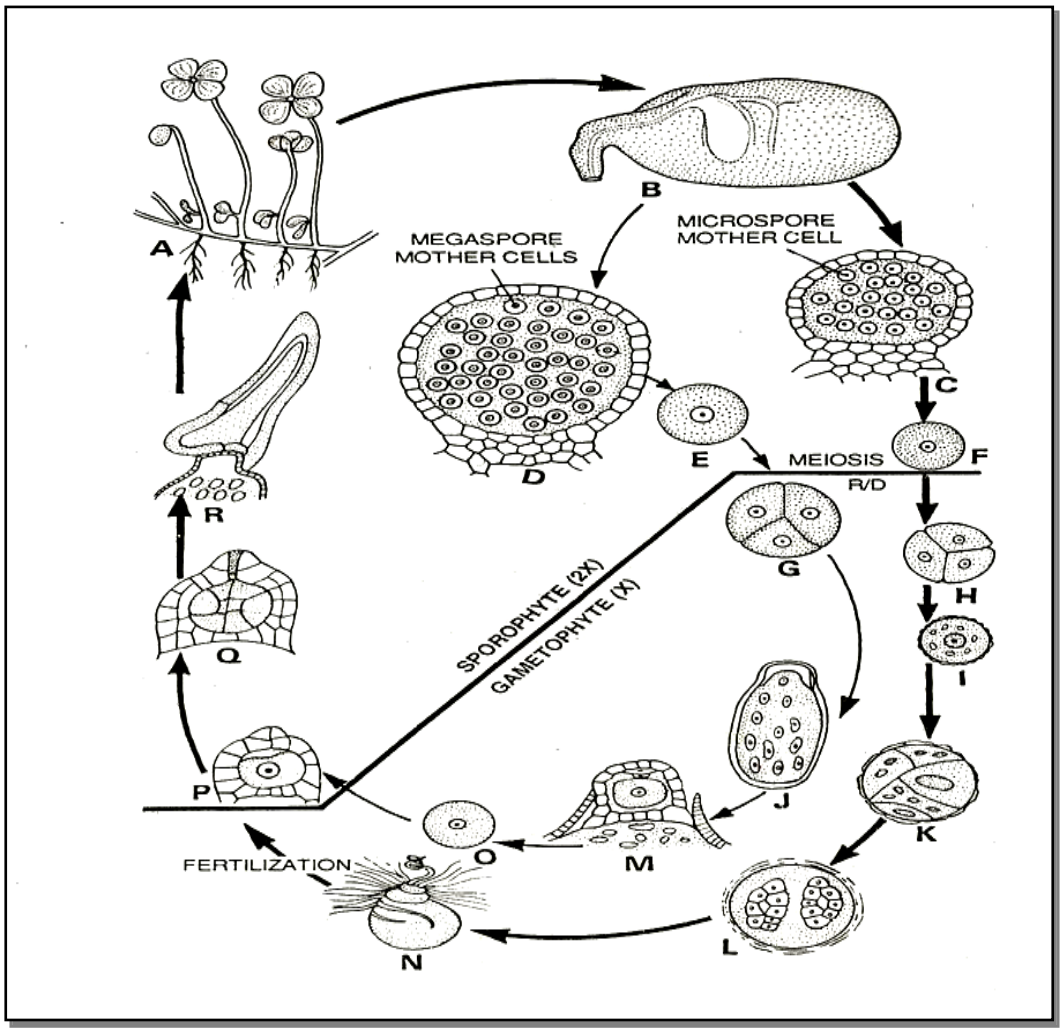


Fig. 4.16. *Marselia:* Life Cycle. A, plant with sporocarps, B, a sporocarp, C, microspore mother cells within microsporangium, D, megaspore mother cells with Megasporangium, E, megaspore mother cells, F, microspore mother cells, G, megaspore tetrad, H, microspore tetrad, I, microspore, J, megagametophyte, K-L, formation of microgametophyte, M, archegonium with egg, N, antherozoid, O, egg, P, oospore, Q, early stages of embryo formation, R, young sporophyte

4.4 AZOLLA

Systematic Position

Sub division: Pteropsida
Class: Leptosporangiatae
Order: Salviniales
Family: *Azolla*ceae
Genus: *Azolla*

Distribution and habitat

The order Salviniales includes two genera of water ferns viz., *Azolla* and Salvinia. The sporophytic plant body of these ferns is soft and herbaceous and floats on the surface of permanent water bodies forming dense mats. The stem is represented by horizontal rhizome. It is covered with two (*Azolla*) or four (Salvinia) rows of leaves. True roots are present in *Azolla*, but they are absent in Salvinia and instead one of the ventral leaves becomes dissected and appears root-like. The members are heterosporous and sporangia are borne within special fruiting bodies, called sporocarps. The sporocarp bears either microsporangia (microsporocarp) or megasporangia megasporocarp). The spores along with the cytoplasm of degenerating tapetal cells form small units, called massulae.

The genus *Azolla* is represented by six species, which are confined to the tropical subtropical regions of the world. They are small moss-like floating plants, forming a dense covering on the surface of permanent ponds. Mature plants of *Azolla* impart characteristic reddish colour to the pond. The genus is represented in India by 3 species, of these *A. pinnata* and *A filiculoides* are widely distributed throughout country and *A imbricata* is confined to the Eastern Himalayas.

A. pinnata is small, 1.5-2.5 cm long, with a +/- straight main axis with pinnately arranged side branches, progressively longer towards the base, thus roughly triangular in shape; the basal branches themselves becoming pinnate and eventually fragmenting as the main axis decomposes to form new plants. Roots have fine lateral rootlets, giving a feathery appearance in the water. Leaves minute, 1-2 mm long, overlapping in two ranks, upper lobe green, brownish green or reddish, lower lobe translucent brown; minute, short, pillae, +/- cylindrical unicellular hairs often present on the upper lobes. When fertile, round sporocarps 1-1.5 mm wide can be seen on the underside at the bases of the side branches. The leaves often have a maroon-red tinge and the water can appear to be covered by red velvet from the distance. *A. pinnata* is locally distributed in its native range of Africa and Madagascar, India, Southeast Asia, China and Japan, Malaysia and the Philippines, the New Guinea mainland and Australia (Croft, 1986). The native ranges of the three subspecies are given in USDA-ARS (2005) as:

tropical Africa, southern Africa and Madagascar for subsp. africana; tropical Asia, China and Japan for subsp. asiatica; and Australia and New Caledonia for subsp. *pinnata*. *A. pinnata* is a floating aquatic fern, found on the surface of small, still ponds or backwaters without wave action, at low to middle altitudes. It becomes especially abundant in water with high nutrient levels, such as ponds in cattle paddocks and farm ponds, where it can completely cover the water surface. It has the ability to survive on moist soil in and around rivers, ditches and ponds which may allow the plant to survive low water levels and periods of drought. In New Guinea the altitudinal distribution falls into two distinct ranges: lowland populations at 3-60 m altitude; and highland populations at 1000-3000 m altitude. However, there is no obvious difference between plants from the highlands and those from the lowlands (Croft, 1986).

4.4.1 Structure of *Azolla*

Sporophyte

External features

The sporophytic plant body is small and herbaceous and consists of a horizontal rhizome which bears leaves and roots.

The rhizome is thin and delicate and floats horizontally on the water surface. It is pinnately branched, the branches are extra-axillary. On the lower side of the rhizome long adventitious roots are present. The roots are usually close to the point of branching and are pendent in water. The rhizomes as well as its branches are covered with minute (0.5 mm or less) leaves. They are borne in two alternate overlapping rows on the dorsal surface of the rhizome. Each leaf is divided into two almost equal lobes. The upper (aerial) lobe is several cells thick, green and photosynthetic. It is somewhat obliquely placed and touches water only on one edge. The lower (submerged) lobe is one cell thick and nearly colourless; it is probably concerned with the absorption of water.

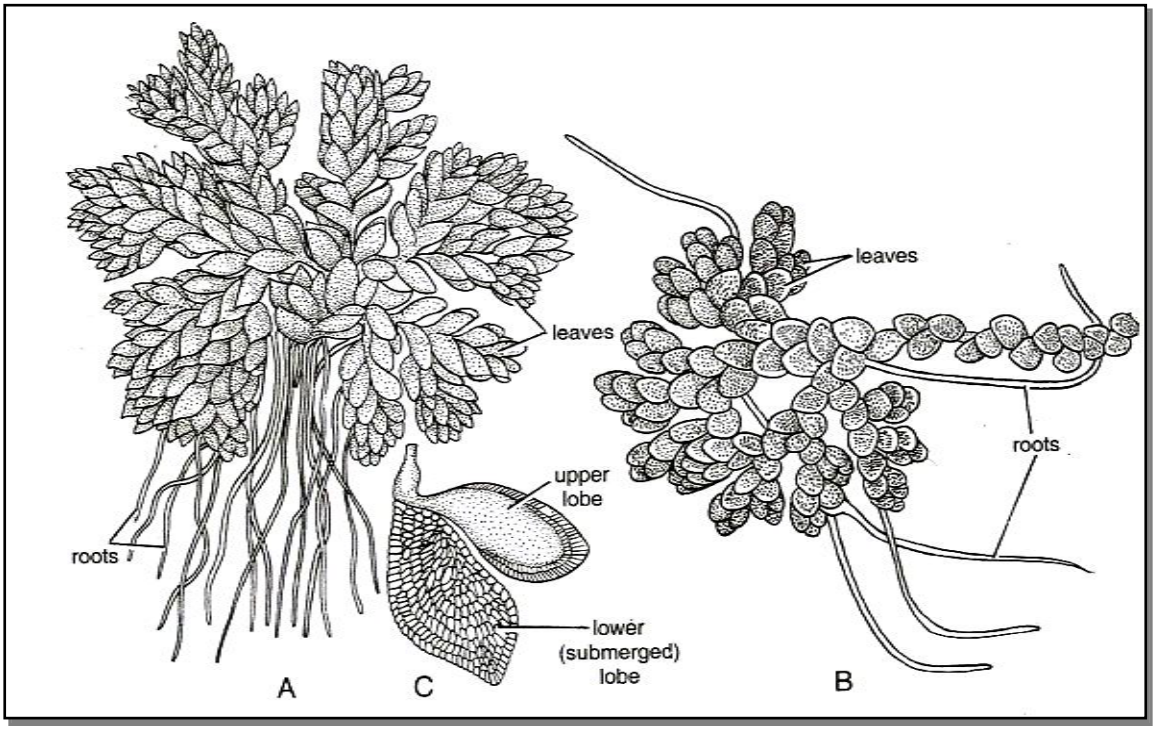


Fig. 4.17. ***Azolla:*** **External morphology, A,** ***microphylla,*** **B,** ***filiculoides, C, leaf***

Internal Structure

Rhizome

A transverse section of the rhizome shows a single layered epidermis, a cortex consisting of 5-8 layers of large parenchymatous cells, and a central stele. The stele is surrounded by a single layer of endodermis, followed by a layer of pericycle. The vascular tissue is greatly reduced. In young stems the stele is essentially protostelic but mature stems have ectopholic siphonostele with typical leaf branch traces. The leaf and branch gaps are of non overlapping type. The xylem consists of only few tracheids and is separated from the phloem by thin layer of parenchyma. The leaf trace forks dichotomously before entering into the leaf; one branch enters the upper lobe and other the lower lobe.

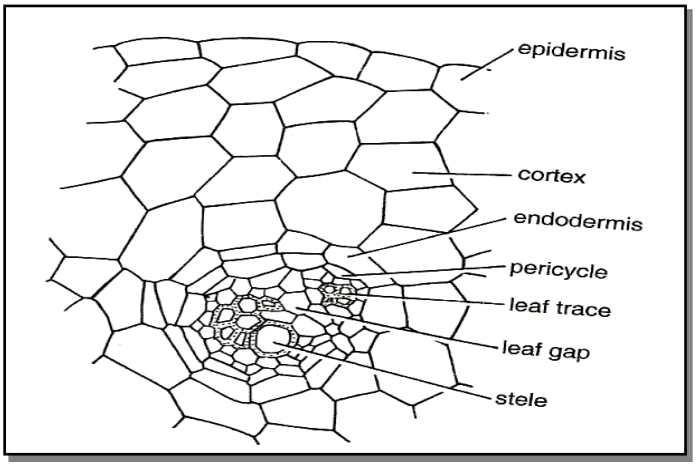


Fig. 4.18. ***Azolla:*** **Transverse section of rhizome**

Root

The epidermis of the root is composed of a single layer of small cells. The cortex is made up of two layers of large thin walled parenchymatous cells; outer layer has nine cells and the inner only six cells. Inner to the cortex, there is a single layer of endodermis, followed by a layer of pericycle. The endodermal and pericycle layers consist of 6 cells each. The xylem is represented by two centrally placed metaxylem tracheids surrounded by four small peripheral groups of protoxylem elements. The phloem consists of only few cells present on either of the metaxylem elements.

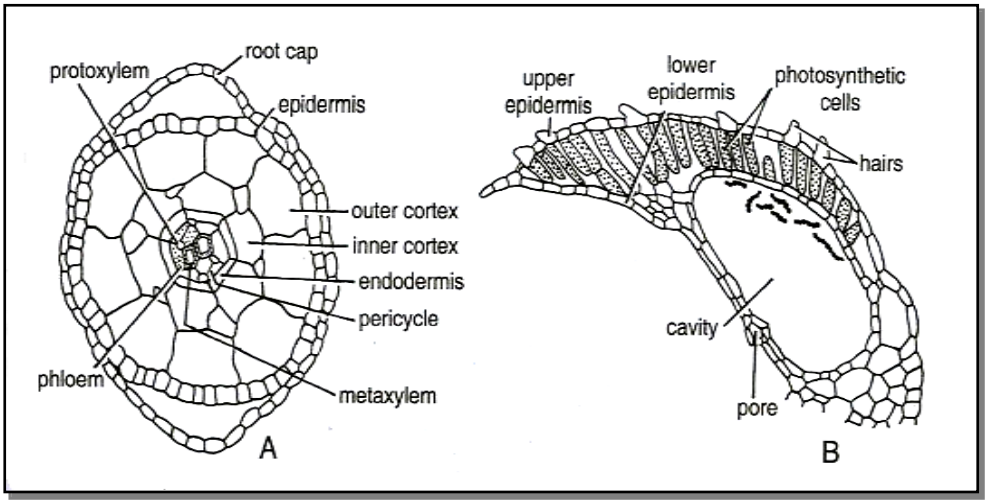


Fig. 4.19. ***Azolla:*** **A, transverse section of root, B, Transverse section of leaf**

The Leaf

The upper green photosynthetic lobe of the leaf is many cells thick in the central region. The cells of upper epidermis give rise to a tuft of unicellular bi-celled hairs which trap considerable amount of air. This prevents leaves from wetting. Stomata are present in both the upper and lower epidermal layers. The mesophyll is composed of columnar palisade-like photosynthetic cells with intercellular spaces in between them. The upper lobe has a large cavity at its base, opening externally by a circular pore. The cavity contains *Anabaena Azollae*, a blue-green nitrogen fixing alga.

The lower submerged lobe of the leaf is only one cell thick, colourless and non-photosynthetic.

4.4.2 Reproduction in *Azolla*

Azolla reproduces vegetatively and by spores.

1-Vegetative Reproduction

Vegetative propagation takes place by fragmentation. The lateral branch separates from the main axis due to the formation of an abscission layer at its base. It grows into an independent plant.

Reproduction by Spores

Azolla is a heterosporous fern and spores are borne within specialized fruiting bodies, called sporocarps. The sporocarps of *Azolla* are dimorphic; those bearing microsporangia (i.e., microsporocarps) are large and spherical and those with megasporangia (i.e., megasporocarps) are much smaller and ellipsoid or flask-shaped. According to Pfeiffer (1907), the sporocarps of *Azolla* are potentially bisporangiate (i.e., each sporangium is capable of producing both mega-and microsporangia), but during their development either microsporangia or megasporangia abort.

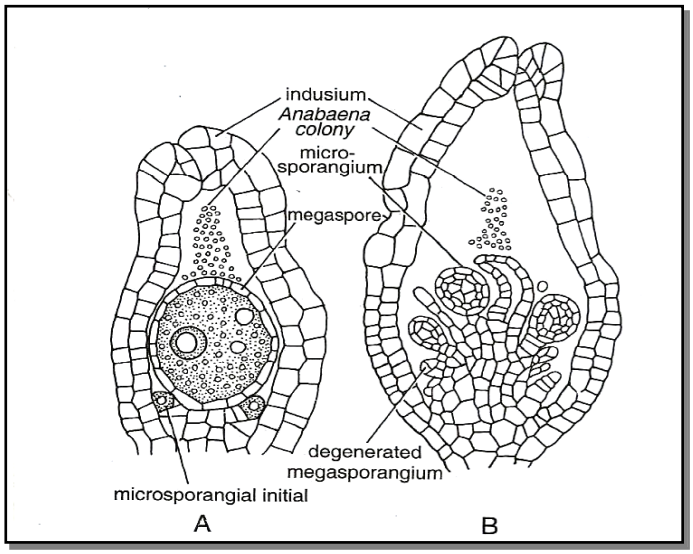


Fig. 4.20. *Azolla:* sporocarps; A, L.S. megasporocarp, B, L.S. microsporocarp

Position of Sporocarps

Sporocarps are borne on the lowermost leaf of a lateral branch. Development of the lower submerged lobe of the fertile leaf stops when its primordium is 2-4 celled Subsequently, each cell of the leaf primordium develops into a sporocarp. Thus each lateral branch bears 2-4 sporocarps depending upon the number of cells in the lower lobes of the leaf primordium. The upper lobe of the fertile leaf forms a hood like covering around the sporocarps.

Development of Mega and Microsporocarps

In both types of sporocarps mega sporangium is always the first to be formed. Micro sporangial initials arise from the stalk of mega sporangium. If the latter matures micro sporangial initials degenerate, and a mega sporocarp containing a single mega sporangium is formed. But if the mega sporangium degenerates then the micro sporangial initial develops further form micro sporocarps.

The fertile leaf initial divides anticlinally. The upper lobe initial undergoes normal anticlinal and periclinal divisions, while the lower lobe initial, after a few divisions, directly gives rise megasporangial initial. The involucre, which covers the sporocarp, develops from the upper lobe.

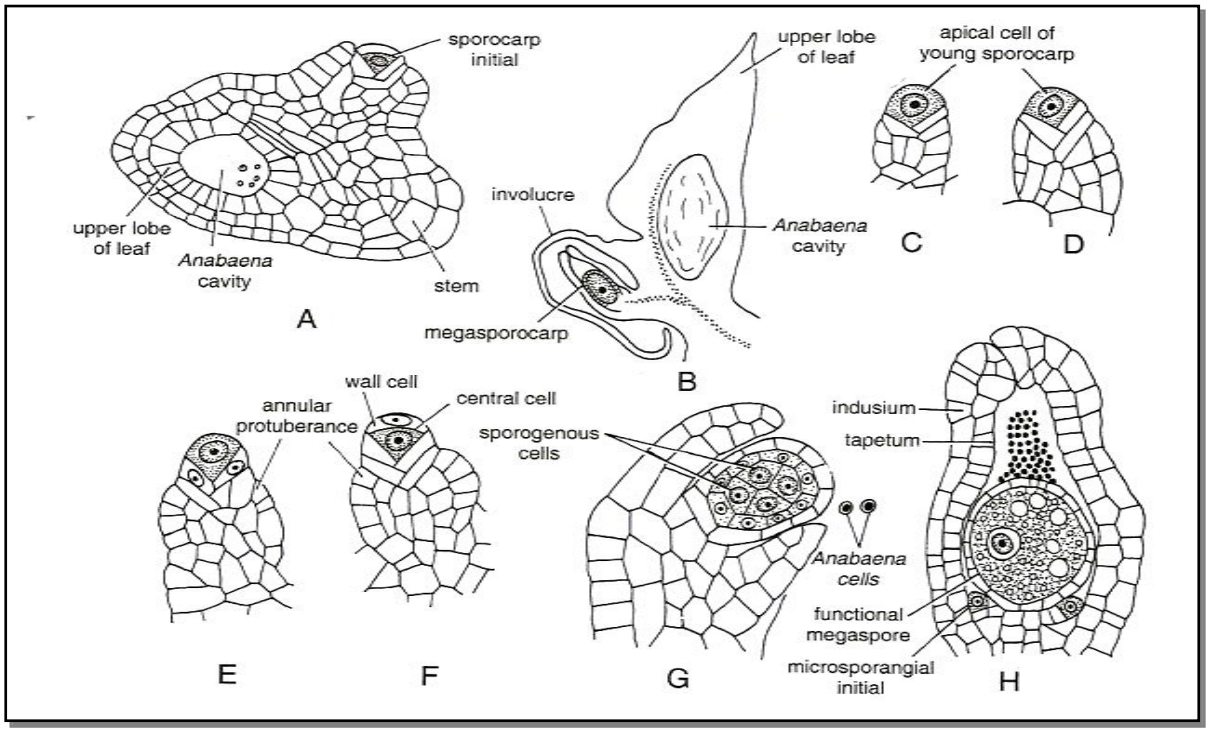


Fig. 4.21. ***Azolla:*** **Development of megasporocarp and Megasporangium, A, T.S of young fertile leaf showing sporocarp initial, B, L.S. megasporocarp enclosed by involucres, C-H, stages in the development of Megasporangium**

The mega sporangium develops from a single initial cell, thus the development is of leptosporangiate type. First few divisions in the sporangial initial are oblique and intersecting and a result a dome-shaped apical cell is formed. The lateral derivatives of the apical cell give to the stalk. After a few cells of the stalk have been cut off, a distal periclinal division occurs

in the apical cell forming a central cell surrounded by a single layered wall. Meanwhile, the stalk cells of the sporangium, by divisions and enlargement, form a short, annular protuberance around the base of the apical cell. This protuberance gradually grows, becomes 2-layered and forms the indusium. It surrounds the sporangium completely, except for a small opening at the tip. The upper part of the indusium of the megasporocarp becomes quite hard due to lignification and deposition of tannins. After dehiscence, the lower portion of the indusium decays while the upper hard portion persists as a cap till it is pushed aside by the developing embryo.

The central cell cuts off a layer of tapetum by periclinal divisions and functions as sporogenous cell. The number of cells in the tapetal layer increases by repeated anticlinal divisions.

The sporogenous cell divides transversely and then by two vertical divisions at right angles to each other, gives rise to 8 megaspore mother cells. By this time, the wall of the densely cytoplasmic tapetal cells dissolves and their cytoplasm intermingles to form multinucleate periplasmodium. Later, the walls of the megaspore mother cells also dissolve, and the rounded cells become surrounded by periplasmodium. Each megaspore mother cell undergoes meiosis giving rise to four megaspores, thus there are 32 megaspores in a megasporangium. Of these, only one is functional while the rest degenerate at various stages of development. The vacuolated periplasmodium, surrounding the degenerating megaspores, gradually hardens to form a honey comb- like structure, called float corpuscles or massulae, at the distal end of the megaspore. It is believed by some workers that the massulae serve as swimming apparatus and provide buoyancy to the large megaspore. But as the megaspore remains at the bottom of the pond until the development of female gametophyte, this view does not seem to be convincing. The miccrosporangial initials arise from the stalk of the megasporangium. Its development dependent upon complete degeneration of the megaspores. Once the development of microsporangial initials starts, additional initials appear in basipetal succession and thus at maturity as many as 120 or more microsporangia develop in a sporocarp.

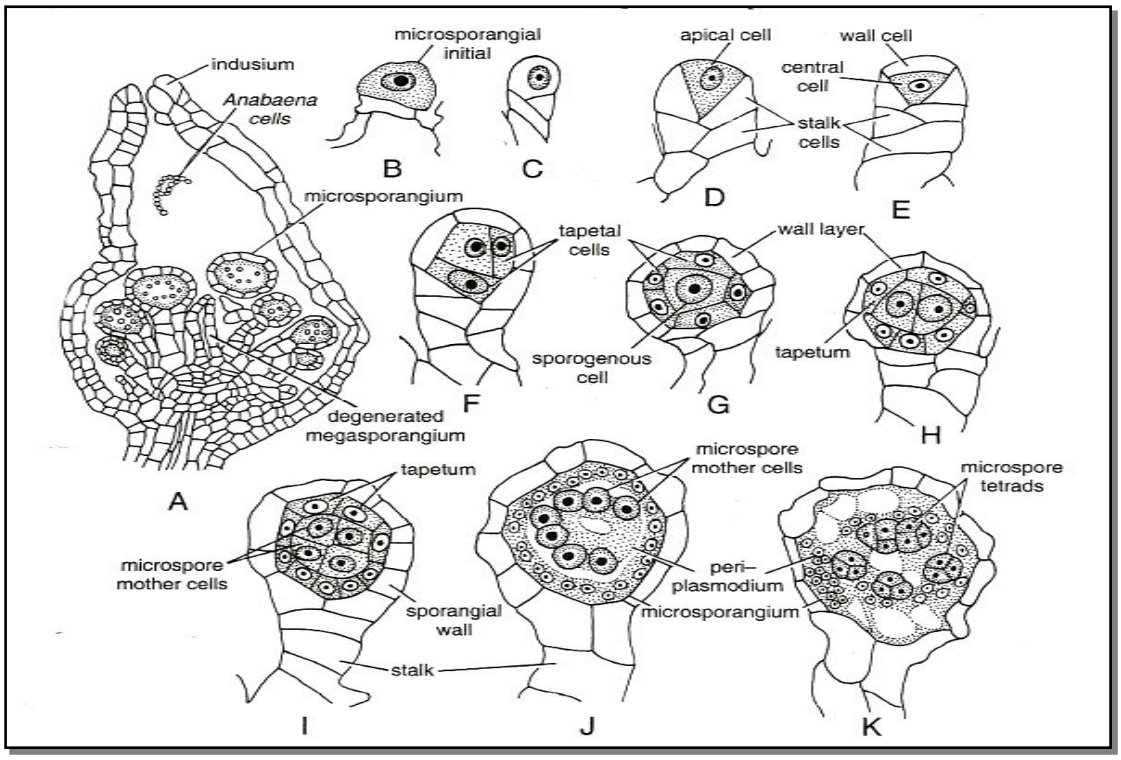


Fig. 4.22. ***Azolla:*** **development of microsporangium, A, L.S. of sporocarp showing degenerating megasporangium and developing microsporangia, B-K, successive stages in the development of microsporangium**

The rnicrosporangial initial undergoes two oblique intersecting divisions, differentiating an apical cell with three cutting faces. The cells cut laterally function as stalk cells. A number of divisions occur in the stalk cells resulting in the formation of an elongated filament which is two cells broad. The apical cells undergo two oblique and one periclinal divisions giving rise to to a single layered sporangial wall and a centrally situated cell developing sporogenous tissue.

The central cell divides periclinally separating a parietal tapetal layer and a sporogenous cell. The latter by four successive divisions forms 16 microspore mother cells. Initially, the tapetal layer divides anticlinally forming many small uninucleate tapetal cells but gradually, their radial walls dissolve to give rise to a multinucleate periplasmodium. Meanwhile, the spore mother cells undergo meiosis, each forming a microspore tetrad. Thus in a microsporangium there are 64 microspores derived from 16 microspore mother cells.

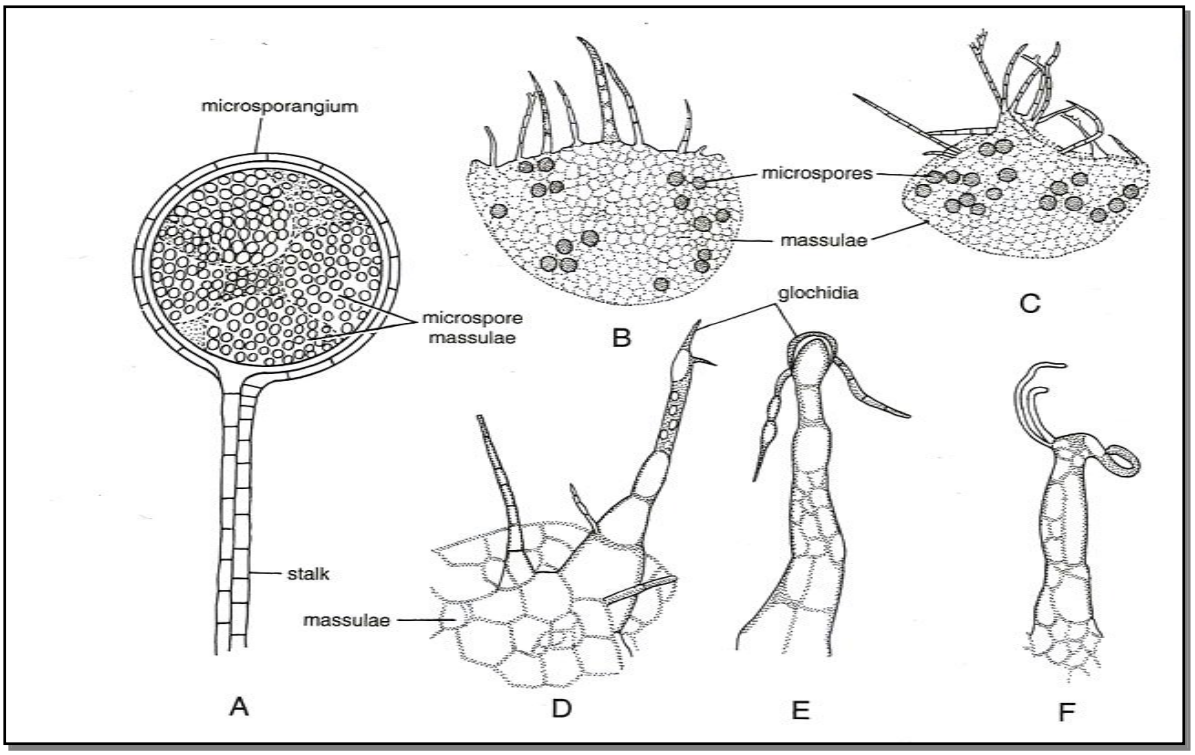


Fig.4.23. ***Azolla:*** **Microsporangium, A, stalked microsporangium showing massulae, B-C, massulae with microspores, D-F, various forms of glochidia**

As the microsporangium matures, the microspores move towards the periphery and the periplasmodium organises into four or more massulae each with many peripherally situated glochidia, which are hardened cytoplasmic simple or branched strands. The massulae, when set free in water, get themselves attached to the rugged surface of the megaspore with the help of glochidia.

Both, the mega- and microsporocarps sink to the bottom of the pond. The massulae are set free after the death and decay of the sporocarp wall.

Gametophyte

Female Gametophyte

The megaspore is the mother cell of the female gametophyte. The first division of the megaspore is asymmetrical establishing a small lenticular cell and a large basal cell. Although the basal cell becomes multinucleate after repeated nuclear divisions and is full of starch grains, it does not take part in the formation of the gametophyte. The upper cell divides repeatedly and forms a hemispherical cushion-shaped non-chlorophyllous female gametophyte. Archegonia develop from archegonial initials which differentiate near the centre on the surface of the gametophyte. The archegonial initial divides periclinally into a central cell and a primary cover cell. The latter divides by two vertical walls at right angles to each other forming four neck initials. These cells by further transverse divisions give rise to 3-4 cells high neck of the archegonium. Meanwhile, the central cell divides transversely into a small primary neck canal cell and a large primary venter cell. The primary mature archegonium thus has a short neck and swollen venter. The neck has four vertical rows of

cells with 3-4 cells in each row. The narrow neck canal is occupied by a single (or rarely two) neck canal cell. The venter has a venter canal cell and a large egg.

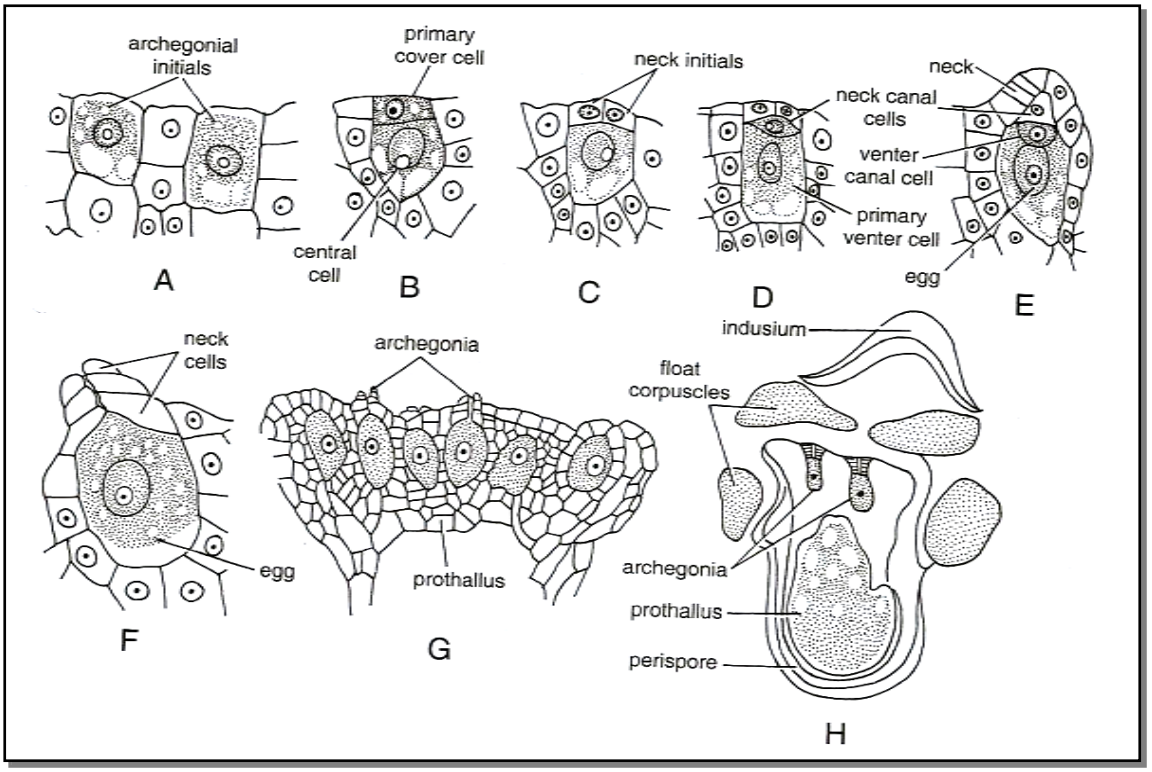


Fig. 4.24. ***Azolla:*** **A-F, Stages in the development of archegonium, G, L.S. prothallus with several archegonia on upper surface, H, archegonia just before fertilization**

Male Gametophyte

The microspore is the mother cell of the male gametophyte. It germinates within the massula at bottom or on the surface of the pond. The germinating spore absorbs water due to which outer spore wall ruptures along the triradiate ridge and inner spore wall protrudes in the form of a papilia. The papilla is cut off near its base by a transverse wall. The outer cell divides by two periclinal walls and thus three cells are established in the outer protruded papilla. Meanwhile, the basal cell also divides asymmetrically forming a small prothallial cell. Of the three cells formed in the papilla, the apical and basal cells do not divide further and eventually function as jacket cells. The central cell, however, by two periclinal divisions forms two more jacket cells. One of these jacket cells divides further. Thus five jacket cells are formed which surround the central cell. The latter divides repeatedly forming eight spermatocytes. Each spermatocyte eventually metamorphoses into an antherozoid. Thus the mature male gametophyte consists of eight antherozoids surrounded by five jacket cells. The gametophyte remains embedded in the outer of massula and is released when massula softens.

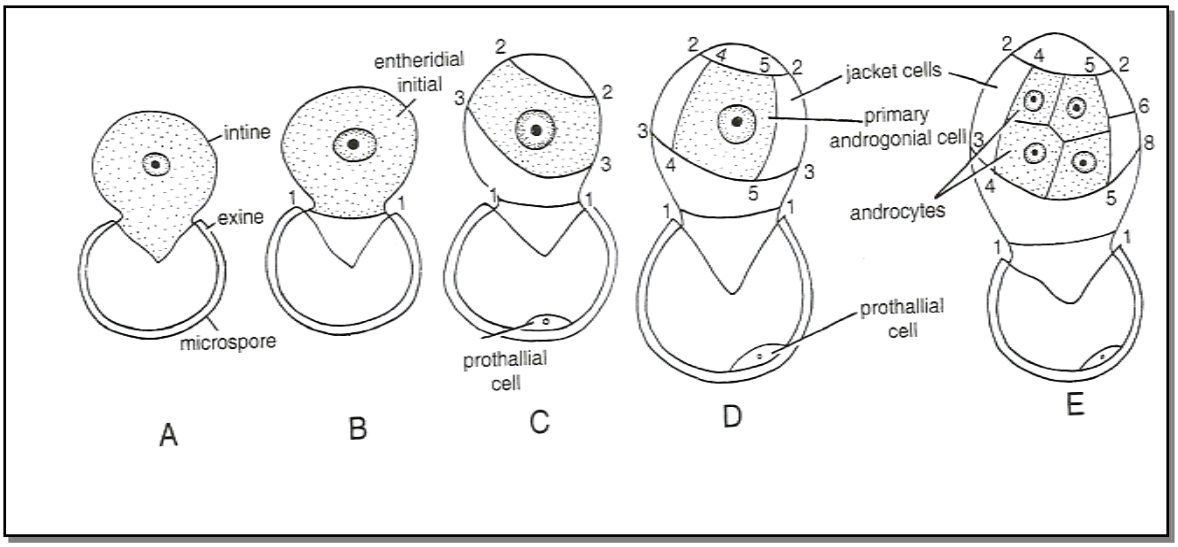


Fig. 4.25. ***Azolla:*** **stages in the development of male gametophyte**

Embryo

The zygote, formed by the fusion of male and female gametes, enlarges considerably within the venter of archegonium. It divides transversely, followed by a vertical division, thus a quadrant is formed. The derivatives of the two epibasal cells give rise to the leaf and stem and those of the hypobasal cells form primary root and foot. The leaf and stem develop more rapidly than the primary root.

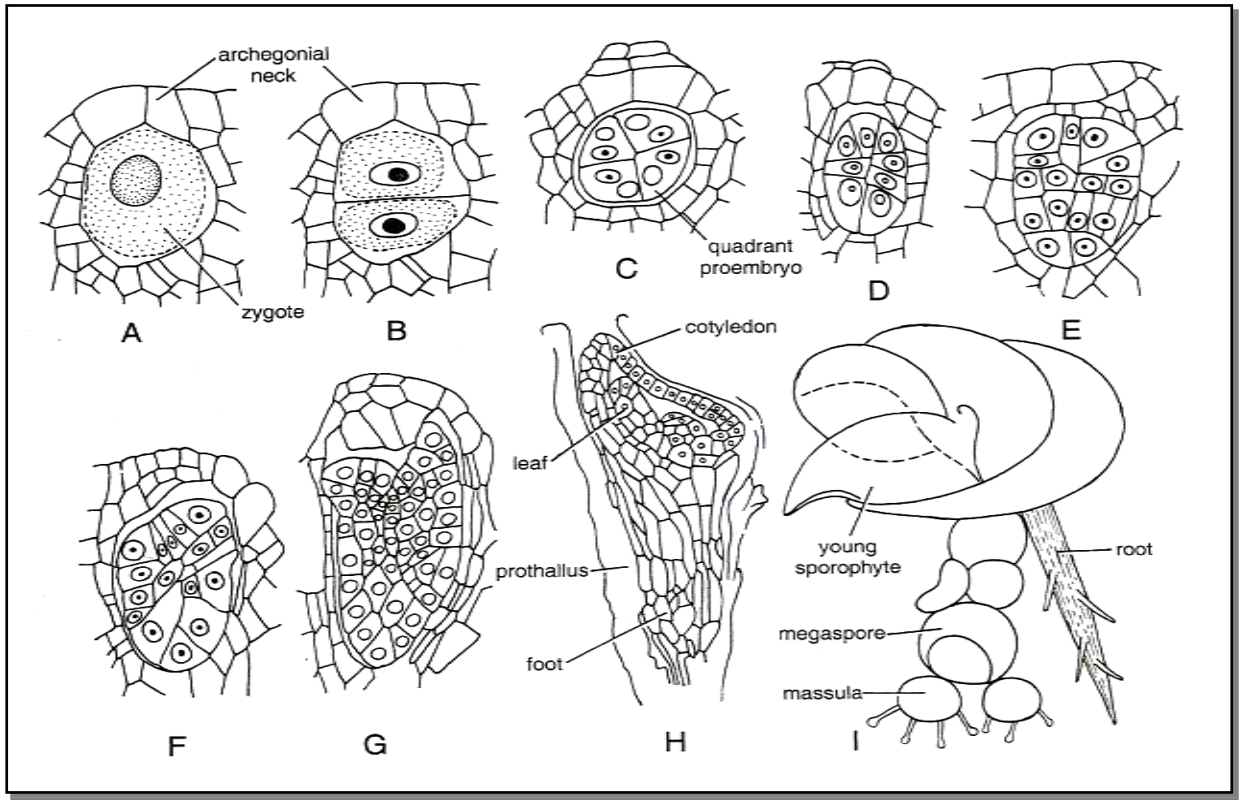


Fig.4.26. ***Azolla:*** **Embryogeny; A, zygote, B-F, stages in the development of embryo, G-H, L.S. young embryo, I, young sporophyte**

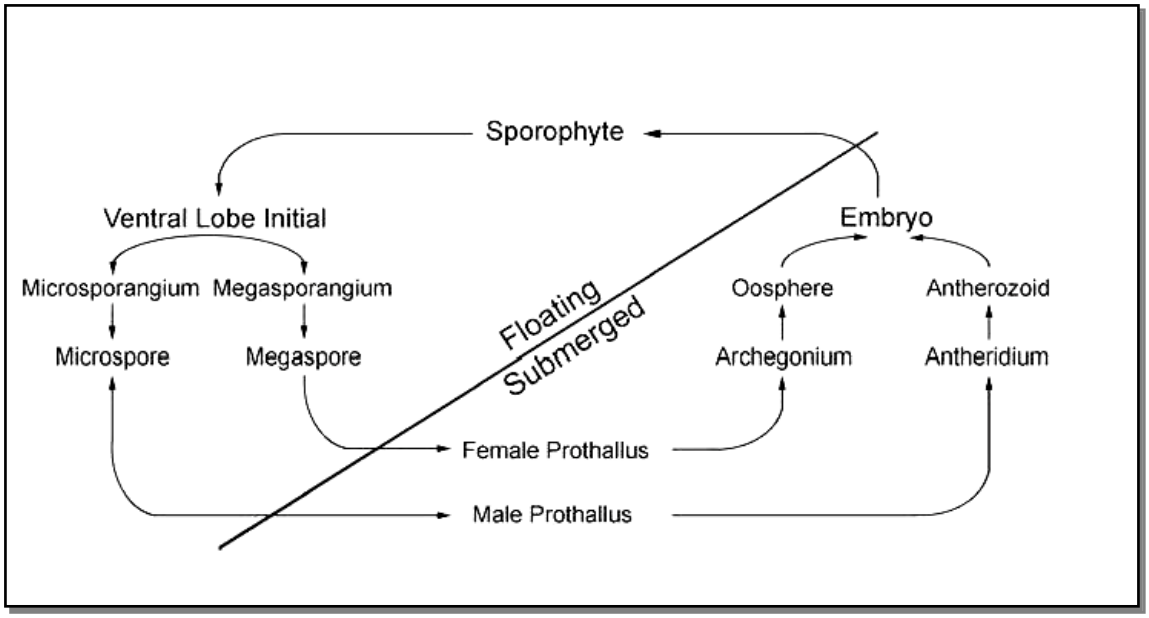


Fig. 4.27 Azolla. Life Cycle

4.5 SUMMARY

Pteridophyta (*pteron* = feather, *phyton* = plants) are the most primitive vascular plants and are also known as 'vascular cryptogams'. They are vascular, spore bearing plants and include ferns and fern-allies. They were the first vascular plants to grow on the surface of earth and began their life period from leafless and rootless individuals (with photosynthetic stem and rhizoids performing the function of roots) in the Silurian and Devonian periods. The pteridophytes are a paraphyletic group of seed plants and consist of four groups: Lycopods, *Equisetum,* Psilotaceae and Ferns (Qiu & Palmer, 1999). They played an important role in establishing the early land flora as they emerged shortly after the evolution of land plants and are much larger than bryophytes (Kenrick & Crane, 1997). They spread rapidly along the shores and river banks and due to the absence of any kind of disturbance in the new habitats along with having a simple genetic makeup, a very rapid evolution was stimulated and witnessed among these land invaders. With this rapid rate of evolution, by the approach of carboniferous period most of the forests of the earth's surface were dominated by members of pteridophytes mainly including large sized trees with secondary growth. However, with the upheavals in the evolutionary period majority of this arboreal vegetation including many tall trees representing several genera and species had perished and in the modern period form the major carboniferous coal reserves of the world. The pteridophytic ancestors of the present day vegetation of ferns and fern allies are the plants which evolved the seed habitat and passed on this characteristic to the present day vegetation and hence, the pteridophytes could be genuinely considered as the forefathers of the present day vegetation.

Pteridophytes grow luxuriantly in moist tropical forests and temperate forests and their occurrence in different eco-geographically threatened regions from sea level to the highest

mountains are of much interest (Dixit, 2000). Though they have been largely replaced by the spermatophytes in the modern day flora, they continue to occupy an important and crucial position in the evolutionary history of the plant kingdom. India has a rich and varied pteridophytic flora due to its diversified topography, variable climatic conditions and its geographical position with several migration-flows of species of different phytogeographical elements meeting in different parts of the Country. They occur in a variety of habitats like terrestrial (*Equisetum, Selaginella*), aquatic (*Azolla, Marsilea*), epiphytic (*Lepisorus, Drynaria)* and *lithophytic (Psilotum, Adiantum).*

Pteridophytes form a major part of the flora next to the angiosperms in the species diversity rich region like India. Their life cycle shows alteration of generations with sporophyte being the dominant phase. The sporophyte of pteridophytes is generally differentiated into root, stem and leaves. The primary root is short lived and is usually replaced by adventitious roots. The stem is usually branched and the branches do not arise in the axil of the leaves. The leafy branch of the fern is called a 'frond' and the small leaflets that make up the whole frond are termed as 'pinnae'. The leaves may be simple *(Equisetum*), simple and sessile *(Selaginella, Lycopodium)* or large and pinnately compound *(Dryopteris, Adiantum).* The vascular system consists of xylem (composed of tracheids, true fibres and vessels absent) and phloem (consisting of only sieve tubes). They have an affinity for the sheltered places under the forest canopy along creeks and streams and other sources of permanent moisture.

4.6 GLOSSARY

Androcyte: Antherozoid mother cell.
Androgonial cell: Any cell within an antheridium other androcyte or androcyte mother cell.
Antheridium: Male sex organ of cryptogams.
Archegonium: The female sex organ of bryophytes, pteridophytes and gymnosperms.
Axil: It is the junction where a lateral organ such as a leaf joins a main axis like a stem.
Cortex: The ground tissue of stem and root ; present between epidermis and the stele.
Cuticle: A waterproofing layer covering the epidermis of aerial plant surfaces.
Dichotomous: The type of branching in plants that result when growing point divides into two equal growing points which in turn divide in a similar manner after a period of growth and so on.
Embryo: An embryo is a multicellular diploid structure in an early stage of embryogenesis or development.
Endodermis: The layer of tissue situated between the cortex and stele.
Fertilization: It is the fusion of gametes to initiate the development of a new individual organism.
Foot: A specialized organ of attachment and of the embryo which absorbs food from the gametophyte.
Gametophyte: A gametophyte is a gamete bearing plant. It develops from the meiospores produced by sporophyte by meiosis or reduction division. Gametophyte is a haploid structure.
Habit: The general external appearance of a plant, including size, shape, texture and orientation

Habitat: The place where a plant lives; the environmental conditions of its home.
Heteromorphic: When the two phases of life-cycle are morphologically different.
Heterospory: Production of two kinds of dissimilar spores differing in size and function in the same species.
Homospory: Production of one kind of similar spores.
Leaf: an outgrowth of the stem usually flat and green; its main function is manufacture of food by photosynthesis.
Life-cycle: In most of the plants multicellular diploid sporophyte phase alternates with a multicellular haploid gametophyte phase. This cycle is known as life-cycle or alternation of generation.
Ligule: A minute appendage of the leaf that is found at the base of the leaf.
Megaspore: The larger of two kinds of spores produced by a heterosporous plant giving rise to the female gametophyte.
Mesophyll: The inner photosynthetic parenchyma of leaf located between epidermal layer and usually differentiated into palisade and spongy parenchyma.
Microspore: The smaller of two kinds of spores produced by a heterosporous plant giving rise to the male gametophyte.
Rhizome: Underground stem distinguished from root by nodes, buds or scale like leaves.
Rhizophore: A specified part of the stem bearing roots.
Spore: A haploid propagule produced by meiosis in diploid cells of a sporophyte that can germinate to develop a multicellular gametophyte.
Sporophyte: A sporophyte is the diploid multicellular stage in the life cycle of a plant. It develops from the zygote when a haploid egg cell is fertilized by a haploid sperm and each sporophyte cell therefore has a double set of chromosomes. The sporophyte produces spores by meiosis (hence the name sporophyte means spore bearing plant).
Strobilus: A cone like structure consisting of sporophylls or sporangiophores borne close together on an axis.
Tetrad: A group of four spores resulting from reduction division of one spore mother cell.
Zygote: The fertilized egg before it undergoes further differentiation.

4.7 SELF ASSESSMENT QUESTION

4.7.1 Multiple Choice Questions:

1. Which one is Heterosporous:
(i) *Marselia* (ii) *Equisitum*
(iii) *Rhynia* (iv) *Lycopodium*

2. Sporocarp is present in:
(i) *Psilotum* (ii) *Marselia*
(iii) *Rhynia* (iv) *Equisitum*

3. Amphiphloic siphonostele is found in :
(i) *Lycopodium* (ii) *Psilotum*
(iii) *Marselia* (iv) *Equisitum*

4. Sporocarps are arranged in *Marselia* on:
(i) Below the ridges (ii) Base of petiole
(iii) Rhizome (iv) None of the above

5. Sporophore is found in:
(i) *Adiantum* (ii) *Marselia*
(iii) *Azolla* (iv) *Equisetum*

6. Azolla is found in:
(i) Ponds (ii) Permanent ponds
(iii) Rivers (iv) None of the above

7. Each sporocarp in *Azolla* represents a:
(i) Sori (ii) Reticulate venation
(iii)Dichotomy (iv) Sorus

8. The spore bearing structures of *Azolla* are known as:
(i) Cylindrical Column (ii) Sporocarps
(iii)Archegonium (iv) Angiosperms

9. In ferns meiosis takes place during:
(i) Germination of spores (ii) Formation of spores
(iii) Formation of Gametes (iv) Formation of Archegonium

10. The major role in the dehiscence of a fern sporangium is played by its:
(i) Sorus (ii) Tapetum
(iii)Indusium (iv) Annulus

4.7.2 Fill in the blanks

1. *Marselia* belongs to subdivision _____
2. *Marselia* has two types of spores, thus it is _____
3. Raphe is the part of *Marselia* _____
4. Young leaves of *Marselia* show_____
5. The veins of *Marselia* leaves are usually _____ branched
6. In *Azolla* the branches of the _____arise outside the axil of the leaf
7. The _____ of *Azolla* leaf is concerned with the absorption of water
8. The archegonial initial divides periclinally into the _____ a _____
9. The _____ of *Azolla* is thin and delicate and floats on the surface of water
10. The sporophytic plant body of *Azolla* is _____and ____and consists of horizontal rhizome

Answers Keys:

4.7.1: 1. (i), 2.(ii), 3. (iii), 4. (ii), 5. (ii) 6. (ii), 7. (iv), 8. (ii) 9. (ii), 10. (iv)

4.7.2: 1. Pteropsida, 2. Heterosporous, 3. Sporocarp 4, Circinate vernation 5.Dichotomously

6. Rhizome, 7. Lower thin lobe, 8. Central cell / primary cover cell, 9.Rhizome,
10. Small /herbaceous

4.8 REFERENCES

- Basak B, Pramanik AH, Rahman MS, 2002. Azolla (*Azolla pinnata*) as a feed ingredient in broiler ration. *International Journal of Poultry Science* 1:29-34.
- Exell AW, Wild H, 1960. *Flora Zambesiaca*, Vol. 1. London, UK: Crown Agents for Oversea Governments and Administrations.
- Gopal GV, 2000. *Azolla pinnata* r.br. Pteridophyte; Salviniales (Azollaceae) in the management of lake agro ecosystem. In: Ramachandra TV, Rajasekara Murthy C, Nhalya, N, eds. Proceedings of Lake 2000. *International Symposium on Restoration of Lakes and Wetlands,* 27th to 29th November 2000, Indian Institute of Science, Bangalore. India.
- Hall JW, 1969. Studies on fossil Azolla. *American Journal of Botany*, 56:1173-1180.
- Johns RJ, 1991. *Pteridophytes of Tropical East Africa*. Kew, UK: Royal Botanic Gardens.
- Kaur H, 2001. Biomass production of Azolla pinnata R. BR. in contaminated soils of Punjab (India). *5th International Biomass Conference of the Americas,* Florida 2001.
- Konar RN, Kapoor RK, 1974. Anatomical studies on *Azolla pinnat*a. *Phytomorphology,* 22:211-223.
- Konar RN, Kapoor RK, 1975. Embryology of *Azolla pinnata. Phytomorphology*, 24:228-261.
- Kundu AL, Chatterjee BN, 1985. Azolla as a substitute of nitrogen fertiliser for rice. *Oryza*, 22(2):119k-119m
- Loyal DS, 1974. Chromosome size and structure in some heterosporous ferns with a bearing on evolutionary problems. In: Kachroo P, ed. *Advancing Frontiers in Cytogenetics*, 293-298.
- Loyal DS, Gollen AK, Ratra R, 1982. Morphological and cytotaxonomic observations on Azolla pinnata. *Fern Gazette*, 12:230-232.
- Moore AW, 1969. Azolla: biology and agronomic significance. *Botanical Review*, 35:17-35.
- Owen SJ, 1997. *Ecological weeds on conservation land in New Zealand: a database.* Wellington, New Zealand: Department of Conservation.
- Ramakrishnan S, Gunasekaran CR, Vadivelu S, 1996. Effect of bio-fertilizers Azolla and Azospirillum on root-knot nematode, Meloidogyne incognita and plant growth of okra. *Indian Journal of Nematology*, 26(2):127-130; 9 ref.
- Reed CF, 1965. Distribution of Salvinia and Azolla in South America and Africa in connection with studies for control by insects. *Phytologia*, 12:121-130.
- Satapathy KB, Chand PK, 1984. Studies on the ecology of *Azolla pinnata* R. Br. of Orissa. *Journal of the Indian Botanical Society*, 63:44-52.
- Srivastava ON, Amarjeet Singh, 1984. Biomass production of *Azolla pinnata* at Ranchi. *Indian Journal of Ecology*, 11(2):337-338

- Takara J, 1981. Insect pests on Azolla pinnata at Bangkhen, Thailand. *International Rice Research Newsletter,* 6(4):12-13
- Tewari JP, Kalpana Singh, Pragati Srivastava, 2001. Inhibition of cucumber green mottle mosaic virus by extract of some ferns. *Journal of Living World,* 8(1):28-32; 8 ref.
- Thakar NA, Patel CC, Patel HR, 1988. Effect of extracts of *Azolla pinnata* on egg hatching of root knot nematodes Meloidogyne incognita and M. javanica. *Madras Agricultural Journal,* 75(7-8):297-299; 6 ref.
- Thomas KJ, 1976. Observations on the aquatic vegetation of Trivandrum, Kerala. Aquatic weeds in S. E. Asia. *Proceedings of a Regional Seminar on Noxious Aquatic Vegetation, New Delhi* 1973. W. Junk. The Hague Netherlands, 99-102
- USDA-ARS, 2005. *Germplasm Resources Information Network (GRIN).* Online Database. National Germplasm Resources Laboratory, Beltsville, USA
- USDA-NRCS, 2004. *The PLANTS Database,* Version 3.5. Baton Rouge, USA: National Plant Data Center.
- Wall H, 1994. *Water Facts - Control of Azolla (Red Water Fern).* Queensland, Australia: Rural Water Advisory Services, Department of Natural Resources.

4.9 SUGGESTED READINGS

- *Biology and Morphology of Pteridophytes*. Central Book Depot Allahabad, Parihar, N.S.
- *An Introduction to Pteridophyta: Diversity and Differentiation*. Vikas Publishing House Pvt Ltd, New Delhi, A.Rashid,
- *A Text Book of Pteridophyta*, Vikas Publishing House Pvt Ltd, New Delhi, Pandey, S.N., P.S. Trivedi and S.P. Misra
- *Botany for Degree Students: Pteridophyta*. S. Chand Publications, Meerut, B.R. Vashishtha

4.10 TERMINAL QUESTIONS

1. Describe the internal structure of the stem of *Marselia*
2. Describe the life cycle of *Marselia* with special reference to its reproductive structures
3. Write a detailed account of the TS of petiole of *Marselia*
4. Write a note on the morphology of the sporocarp of *Marselia*
5. The hard coat of the sporocarp of *Marselia* completely encloses the megasporangia and yet it is not called a seed. Explain
6. Describe the morphology of sporophyte of *Azolla*
7. Describe the structural peculiarities of the leaves of *Azolla*
8. Describe the development of reproductive structure in *Azolla*
9. Describe the development and structure of male and female gametophyte of *Azolla*
10. Draw a labelled diagram of the LS of the microsporocarp of *Azolla*

BLOCK- 2: GYMNOSPERMS

UNIT-5 GENERAL CHARACTERS, CLASSIFICATION, ECONOMIC IMPORTANCE AND DISTRIBUTION OF GYMNOSPERMS IN INDIA

5.1- OBJECTIVES

After reading this section you will know, how to-

- Explain and define the meaning of gymnosperms.
- Describe the characteristic features of gymnosperms.
- Distinguish and identify the gymnosperms in your surroundings.
- Classify the gymnosperms.
- Analyze the distribution and economic importance of gymnosperms.

5.2-INTRODUCTION

"Some seeds are enclosed in a pod, some in a husk, some in a vessel, and some are completely naked". -Theophrastus

In a process of evolution (Telome theory), stellar system, heterospory and seed habit. You learnt that, in some pteridophytes such as, *Selaginella*, there is a remarkable approach to also the seed habit characteristics and thus, it becomes evident that pteridophytes have considerable advance towards the formation of seed in few species. In this link, there is next the previous unit you have studied the characteristic features of pteridophytes, their origin group of plants which have complete seeds, although the seeds are naked *i.e.* are not covered by the fruit wall or ovary wall, such plants are called gymnosperms.

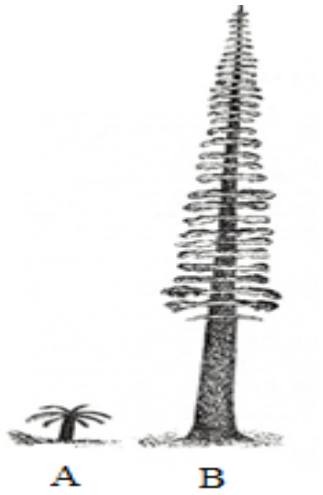


Fig. 5.1 Diagrammatic representation of the habit and comparative size of a Cycad (A) and a Conifer (B) - after Chamberlain (1935).

The term gymnosperm was given by Theophrastus in his book ***"Enquiry into Plants"***(300 BC).It is derived from two Greek words, "***gymnos*"** means naked and **"*sperma*"** means seeds. Gymnosperms and angiosperms are two groups of seed plants(Spermophyta). The former are naked seeded plants in which ovules are not enclosed by ovary wall, born freely on **open megasporophylls**, whereas in later, ovules are born in the **closed megasporophylls** and are completely enclosed within the ovary. Due to this reason(protected seed) angiosperms are considered to be advancedthan gymnosperms. As **gymnosperms** do not possess ovary, hence they don't produce fruits, whereas angiosperms possess ovary and produce fruits.

The first glimpse of this group shows that there are two distinct lines, namely the **Cycadophytes**and the **Coniferophytes**(Fig.5.1).The former can easily be distinguished by some simple characters such as, **palm like tree habit, unbranched stem with long and large compound leaves**, whereas the latter has **cone shaped plant body, tall and profusely branched stem with acicular leaves.**

Of the living and fossil gymnosperms, Cycadales and Ginkgoales are very ancient, for this reason and with some other primitive characters, these members are called **"living fossils".** They include 11 genera with limited distribution in the tropical and sub-tropical parts of the world.

The second important group of gymnosperms is Coniferales. This group is most conspicuous, grows in nearly all parts of the world especially dominated in the Northern Hemisphere. Conifers are represented by nearly 50 genera with wide distribution in the temperate and sub-temperate parts of the world.

The next and most interesting group of gymnosperms isEphedrales consisting of only three genera with great difference in their morphology and reproductive biology. One of the notable members *Ephedra* is found in the arid regions and can be identified by its shrubby leafless appearance. *Gnetum* is a woody liana and *Welwitschia* is underground perennial plant with two persistent leaves.

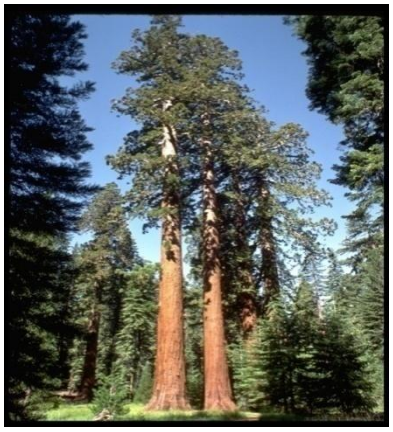


Fig. 5.2 Californian sequoia *(Sequoia semipervirens*)

You will be surprised to know that on one hand, the tallest tree known to plant kingdom belongs to gymnosperms- the Red wood plant or *Californian sequoia* (Fig. 5.2). The tree reaching a height of nearly 112 m into the sky and attaining a girth (diameter) of 15 m,is as tall as a 36 storey building (seeLaetsch,1979). While on the other hand the smallest gymnosperm is a cycad, *Zamia pygmaea* (Fig. 5.3)in which the leaves are only 4 to 5 cm long and it attains a height of 25 cm only.

Goebel has rightly called gymnosperms as "phanerogams without ovary". Gymnosperms act as connecting link between pteridophytes and angiosperms. In plant kingdom the angiosperms have occupied the highest status whilethe position of gymnosperms is just before them. This is because of following reasons:

1. Gymnosperms have slow growth rate.
2. They lack vegetative means of reproduction such as cutting, layering, etc.
3. The means for dispersal of seeds of gymnosperms are very limited such as only by wind and man.
4. The seeds fail to grow under varied habitats (*e.g.* water).
5. Vessels are absent in xylem (except members of Gnetales) and companion cells are absent in phloem (except members of Gnetales).
6. There are less chances of self-fertilization because the cones are unisexual. Bisexuality is absent in gymnosperms.
7. A large amount of pollen is lost because of wind pollination**.**
8. Reduced chances of dispersal because their ovules and seeds are unprotected and they lack fruits.
9. Fertilization occurs through pollen tubes.

Fig. 5.3 *Zamia pygmaea*

5.3 GENERAL CHARACTERS

5.3.1 The Plant Body (The adult sporophyte)

5.3.1.1Geographical Distribution

Some groups of gymnosperms are entirely extinct, some groups are with primitive features and exist in both living and fossil states while some other are living gymnosperms that are distributed throughout temperate, tropical and even in arctic zones. Most of them are evergreen xerophytes.

5.3.1.2 External Features

1. Gymnosperms are middle sized trees (*Cycas*) to tall trees (*Pinus*) and shrubs (*Ephedra*). They are rarely woody climbers (*Gnetum montanum*). Herbs are not present in the gymnosperms.
2. The most massive (thick) and among the oldest, is *Sequoiadendron gigantium*(Big tree; Fig. 5.4) popularly known as Redwood tree or Father of forest. It attains 100 m height, 15 meters girth of trunk and live for more than 4000 years.
3. Plants that are visible, are sporophytic generation (2n). These plants have slow growth rate. These are commonly of moderate size. But conifers are tall trees with graceful branches and foliage and present a conical appearance.

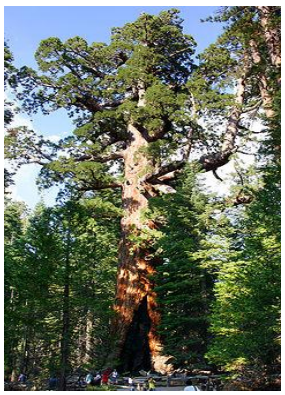


Fig. 5.4 Sequoiadendron gigantium

4. Usually tap root system is present but in some forms **symbiotic relationship** is foundbetween roots and algae in **coralloid roots of *Cycas*** (Fig. 5.5) and between roots and fungi in **mycorrhiza roots of *Pinus***(Fig. 5.6)**.**
5. The stems are aerial, erect, branched (unbranched in *Cycas* and *Zamia*) and woody. In *Pinus* branches are of two types *i.e.* **dimorphism**:-
   a) **Long shoots or branches of unlimited growth.**

b) **Dwarf shoots or branches of limited growth** that on their apices bear cluster of variable number of needle shaped leaves, **collectively known as spur.**

Fig. 5.5 Coralloid roots of Cycas

Fig. 5.6 Mycorrhiza roots of Pinus

6. Plants may possess one kind of leaves *i.e.* **monomorphic** or two kinds of leaves *i.e.* **dimorphic**:-
   a) Foliage leaves (evergreen simple or compound).
   b) Scale leaves (minute and deciduous).
7. Leaves may vary in size from a minute scale leaf to a large and more than 2 meters long megaphylls of some cycads.
8. Venation may be reticulate (*Gnetum*) or parallel (*Welwitschia*) or dichotomous (*Ginkgo*).

5.3.1.3 Internal Features

1. Internal features of roots are like to dicotyledons. Vascular cylinder in roots is diarch to polyarch. Xylem is exarch and roots show secondary growth.
2. In *Cycas***, a broad blue green zone called as algal zone, occurs in the middle cortex of coralloid roots**. The cells of this zone are not organized and are inhabited by the blue green algae *Anabaena cycadacerum* and *Nostoc*.
3. Vascular bundles of stems are collateral, endarch,open and are arranged in a ring. Secondary growth is also present. Secondary wood may be**monoxylic** (well developed pith and cortex) or **pycnoxylic** (much reduced pith and cortex). In cycads (*Cycas*) monoxylic wood is present while in others (*Pinus, Taxus*) it is pycnoxylic.
4. **Xylem lacks vessels and phloem lacks companion cells.**
5. **Secondary vasculature may be monoxylic (single layer of cambium) or polyxylic (several successive layers of cambium).**
6. Thick layer of cuticle and sometimes an additional layer of wax are present on leaves. Stomata are present in deep cavities.Mesarch xylem and transfusion tissues are present. Mesophyll may be differentiated into palisade and spongy parenchyma (*Cycas*) or may be made of only one type of cells (*Pinus*).

The following key may be used in the identification of the gymnosperms.

- Trees or shrubs are usually resinous.
- Herbs (annual) are completely absent.
- Ovules naked, not enclosed in an ovary.
- Cones unisexual, rarely bisexual.
- Leaves needle shaped or scale like, linear, pinnate, rarely fan shaped or oblong, elliptic mostly evergreen.

5.3.2 Life Cycle

5.3.2.1 Reproduction

1. **Vegetative reproduction** is altogether absent in gymnosperms except in ***Cycas***. *Cycas* do propagate through **bulbils**, which you often see in gardens, nurseries or at your homes in the pots; all are clones of mother plant.
2. **Sexual reproduction** is advanced *i.e.*, **oogamous** type**.** Plants are heterosporous *i.e.* producing microspores and megaspores. Both **monoecious** and **dioecious** types of plants are found in gymnosperms (Fig. 5.7 & 5.8).
3. In most of the gymnosperms, reproductive organs are arranged in the form of compact **cones** called as **strobili.** Male cones are**microsporangiate** and female cones are called as **megasporangiate**.
4. **Male cones are short lived** and smaller than **female cones** (except in *Cycas*). **Female cones are long lived.** Male cones consist of central axis with spirally arranged **microsporophylls** whereas female cones are made up of central axis with spirally arranged **megasporophylls.** However, in *Cycas*, megasporophylls are loosely arranged and donot form a cone.
5. **Microsporangia** are borne on the **lower surface of microsporophylls.** They may be numerous and grouped in **sori** (*Cycas*) or reduced to two (*Pinus*).
6. **Megasporangia or ovules are naked and are borne on theupper surface of megasporophylls.**Ovules are covered by a single integument which is differentiated into fleshy outer sarcotesta, stony middle sclerotesta and fleshy inner sarcotesta.

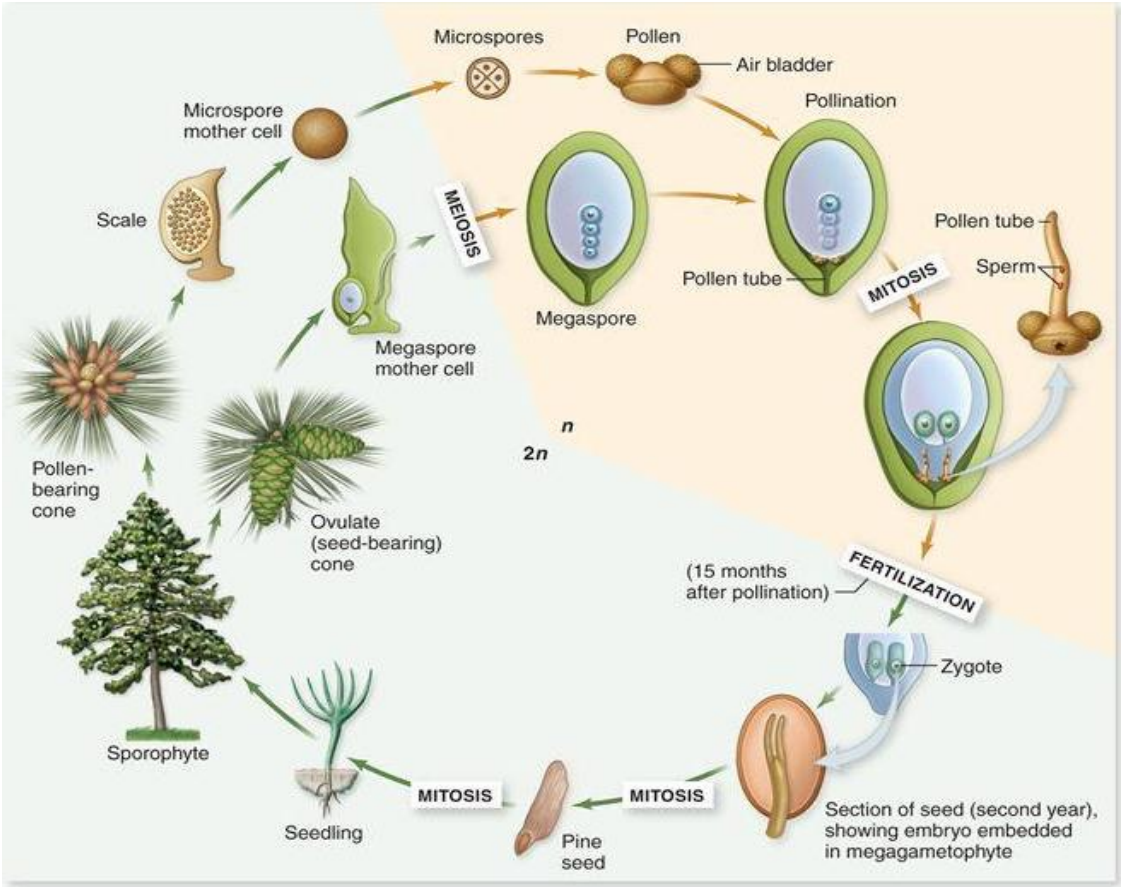


Fig.5.7 *Pinus* sp. Diagrammatic life-cycle

5.3.2.2 The Gametophyte

1. Gametophytic generation (n) is much reduced. The first male gametophytic cell is microsporeor pollen grain. The first female gametophytic cell is functional megaspore.

2. Microspores are endosporic and partially complete their development in microsporangium and the remaining in the pollen chamber of the ovule. At the time of discharge the pollen grain bears only one prothallial cell (*Cycas*) or two prothallus cells (*Pinus*). Thus pollen grains of *Cycas* are liberated at the three celled stage whereas those of *Pinus* at four celled stage.

3. Female gametophyte possesses two or more archegonia. Each archegonium has single cell and a ventral canal cell. Neck canal cells are absent.

4. Pollination takes place by means of wind by the direct contact of pollen grains with the ovules.

5. At the time of fertilization male and female gametes fuse and result in the formation of zygote.

5.3.2.3 The Embryo (The young sporophyte)

1. In living gymnosperms (except *Gnetum*) the early embryogeny takes place by free nuclear divisions after which wall formation starts and embryo become cellular.

2. Embryo gets differentiated into suspensor, radical, hypocotyle, plumule and cotyledons.

3. Polyembryony (development of several embryos in one seed, out of which only one survives) is of common occurrence in *Pinus.*

4. The zygote is meroblastic *i.e*. only basal part develops into an embryo, whereas upper and middle parts do not participate in embryo formation.

5. Endosperm develops before fertilization and is haploid.

6. The number of cotyledons may be one or two or whorl of many.

7. Seeds of all gymnosperms except those of *Cycas* and *Ginkgo* undergo a resting period.

8. The germination of the seed is epigeal (cotyledons come above ground).

9. The alternation of generation is *heterologous.* Gametophytic generation (n) is reduced and dependent upon the sporophytic generation.Sporophytic generation (2n) is dominant and independent (Figs 5.7 & 5.8).

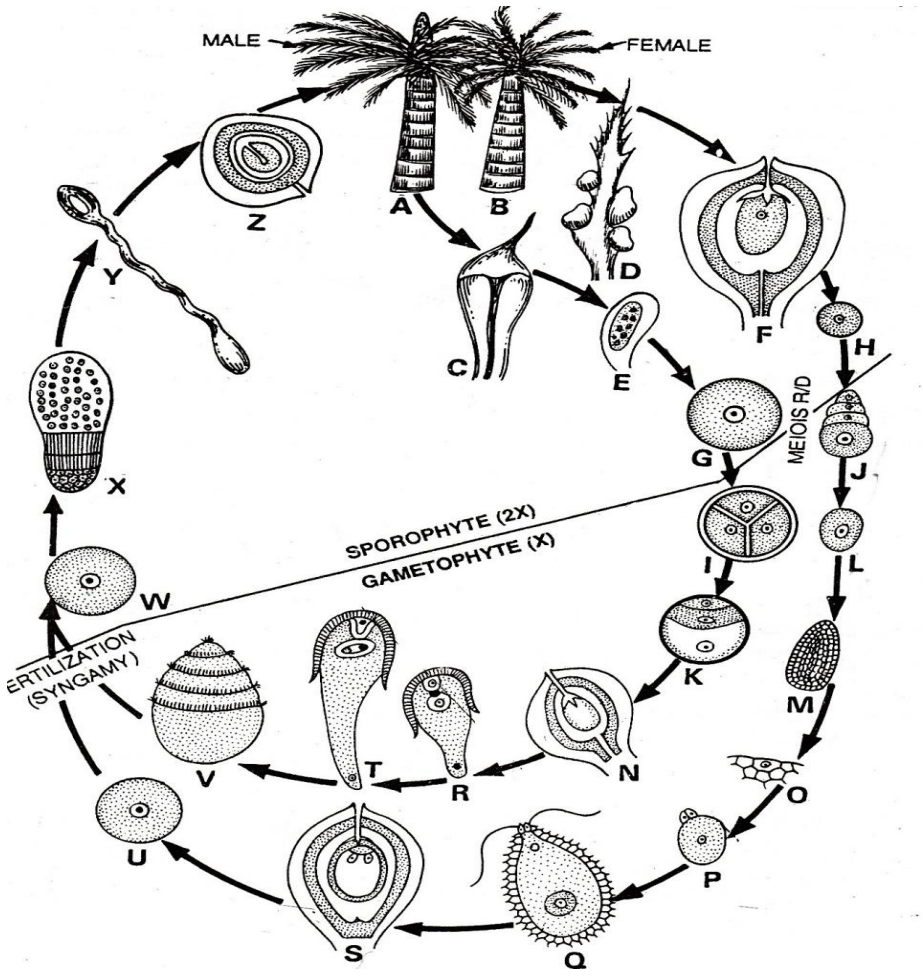


Fig. 5.8 Cycas sp. Diagrammatic representation of life cycle; A.Male plant, B.Female plant, C.Microsporophyll, D. Female strobilus, E. Microsporangium, F. Ovule, G. Microspore mother cell, H. Megaspore mother cell, I. Microspore tetrad, J. Megaspore linear tetrad, K. Male gametophyte, L. Megaspore, M. Female gametophyte, N. Ovule, O. Archegonial initial, P. Young archegonium, Q. Mature archegonium, R. Germinating pollen, S. Germinating pollen in pollen chamber, T. Germinating pollen, U. Egg, V. Spermatozoids, W. Oospore, X. Young embryo, Y. Embryo, and Z. Seed.

5.3.3 Affinities

Gymnosperms constitute a heterogeneous plant group. They resemble **pteridophytes** and **angiosperms** on one hand whereas differ from these groups in some aspects.

5.3.3.1 Resemblances with Pteridophytes

1. Both show **heterologous alternation of generation**.
2. In both sporophytes are distinguished into root, stem and leaves.
3. Both possess **megaphyllous leaves**.
4. Both possess a well marked vascular system.
5. Both lack vessels in the xylem and companion cells in the phloem.
6. Both have **mesarch bundles** in their leaves.
7. Many pteridophytes are **heterosporous**like the gymnosperms.
8. Both possess endosporic gametophyte.

9. In both, gametophytes are highly reduced.
10. The male gametes of Cycads and *Ginkgo* are motile like those ofpteridophytes.
11. In both, female sex organs are archegonia.
12. In both, a distinct embryo develops after fertilization.
13. Embryogeny is **endosporic** in many pteridophytes and all gymnosperms.

5.3.3.2Differences between Gymnosperms and Pteridophytes

1. Gymnosperms are commonly large sized trees, shrubs or rarely climbers whereas pteridophytes are smaller in size and are herbaceous.
2. Gymnosperms have tap root system whereas pteridophytes have adventitious root system.
3. The stems of gymnosperms are aerial whereas the stem of pteridophytes is mostly underground rhizome.
4. All gymnosperms are heterosporous whereas most of pteridophytes are homosporus.
5. In all gymnosperms pollen tube develops as a result of germination of pollen grain, while in pteridophytes pollen tube is not formed.
6. In gymnosperms megaspores remain permanently in the megasporangium whereas in pteridophytesthey are shed from the sporangium.
7. Megasporangium in gymnosperms is protected by an integument which is not found in pteridophytes.
8. Neck canal cells are absent in the archegonial neck of gymnosperms but are present in pteridophytes.

5.3.3.3 Resemblance with Angiosperms

1. Both have well developed and long lived sporophytic generation.
2. Both include trees and shrubs.
3. Sporophytes of both are differentiated into root, stem and leaves.
4. In both the groupsroot system is well developed.
5. The angiosperms and gymnosperms (except Gnetales)possess vessels in xylem and companion cells in the phloem.
6. Both have heterosporous sporophytes and endosporic gametophytes.
7. In both pollen grains grow into pollen tubes.
8. In most of gymnosperms and all angiosperms the male gametes are non motile.
9. In both nucellus is surrounded by integument to form ovule.
10. In both male gametophytes are highly reduced.
11. In both embryogeny is endosporic.
12. In both seeds develop from the ovule.

5.3.3.4 Differences between Gymnosperms and Angiosperms

1. Gymnosperms are not herbaceous whereas majority of angiosperms are herbaceous.
2. Majority of gymnosperms are perennials whereas angiosperms may be annual, biennial or perennial.
3. In angiosperms, xylem possesses vessels and phloem has companion cells, whereas in gymnosperms (exceptGnetales)xylem is devoid of vessels and phloem lacks companion cells.

4. Gymnosperms are unisexual and may be monoecious or dioecious whereas angiosperms may be bisexual as well as unisexual, monoecious ordioecious.
5. Reproduction by vegetative means is very rare in gymnosperms whereas the method is very common in angiosperms.
6. The reproductive organs in gymnosperms are commonly called as conesor strobiliwhereas the reproductive organs in angiosperms are known as flowers.
7. In gymnosperms ovules are naked whereas in angiosperms they are enclosed within ovary.
8. Gymnosperms possess the archegonia whereas the angiosperms lack archegonia.
9. In gymnosperms endosperm develops before fertilization and is haploid (n) whereas in angiosperms it develops after fertilization and is triploid (3n).
10. Gymnosperms donotexhibit double fertilization which is commonly found in Angiosperms.
11. Polyembryony is mostly found in gymnospermswhereas it is not common in angiosperms.
12. In gymnosperms zygote shows free nuclear divisions whereas in angiosperms free nuclear divisions are absent.
13. In gymnosperms, seeds are exposed and fruits are not formed whereas in angiosperms seeds are enclosed in ovary and fruits are formed.

The above resemblances and differences between gymnosperms and other vascular plants show a close resemblance between them but also support that gymnosperms are an independent assemblage of plants that have certain characters peculiar to them alone. Thus gymnosperms occupy an intermediate position between pteridophytesand angiosperms.

5.4 CLASSIFICATION (BY D.D. PANT)

After the recognition of gymnosperms in 1827 by Robert Brown, different positions have been assigned to gymnosperm (group) by different workers, these are Bronganiant (1843) Bentham and Hooker(1862-1883), Van-Tieghem(1898), Englar1897), Coulter and Chamberlain(1910), Chamberlain(1935), Arnold (1948), Delevoryas (1963), Cronquist*et al*. (1966), Sporne (1965) &Bierhorst (1971).

What is classification?
Classification is scientific arrangement of organisms in a hierarchical series of groups. The **smallest group** is the **species**. Similar species are grouped together in a **genus**. In the same fashion the genera are grouped into **families**, families into **orders**, orders into **classes,** classes into **divisions** or phyla and then finally into **kingdoms**. The kingdom is the **highest taxonomic rank.**

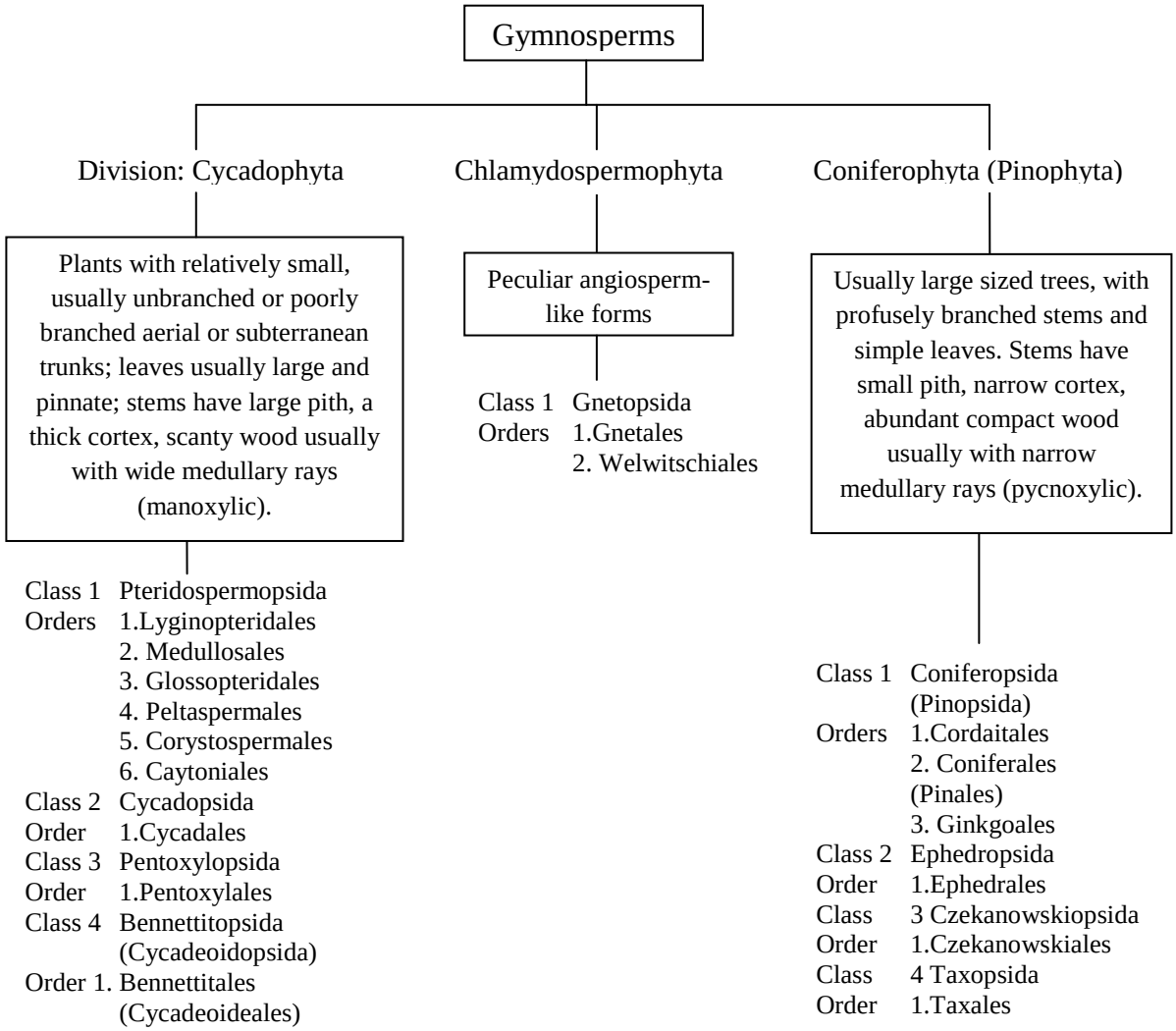
Actually, Pant (1957) **has modified Arnold's (1948) system of classification** and has proposed a new scheme to classify gymnosperms. The important modifications purposed by Pant (1957) in the Arnold's system of classification are:-

1. The rank of divisions has been suggested for Cycadophyta, Chlamydospermophyta and Coniferophyta.
2. Suffixes for each class and order have been used strictly according to the recommendations of **International Code of Nomenclature** for algae, fungi, and plants (**ICN**).

3. In class Pteridospermospsida orders like Glossopteridales, Peltaspermales, Corystospermales and Caytoniales have been included.
4. Under division Coniferophyta, a new class Ephedropsida, with order Ephedrales has been included.
5. For genus *Czekanowskia*, a new order Czekanowskiales and class Czekanowskiopsida has been framed.
6. The division Chlamydospermophyta has been placed in between Cycadophyta & Coniferophyta.
7. The order Pentoxylales has been included in class Pentoxylosida under division Cycadophyta.

The International Code of Nomenclature for algae, fungi, and plants (**ICN**) is the set of rules and recommendations dealing with the formal botanical names that are given to plants, fungi and a few other groups of organisms. It was formerly called the International Code of Botanical Nomenclature (**ICBN**); the name was changed at the International Botanical Congress in Melbourne in July 2011 as part of the Melbourne Code.

Now, according to the syllabus, we will study the classification of gymnosperms as given by **D.D. Pant (1957).**Pant's scheme of classification is as follows:



5.5-ECONOMIC IMPORTANCE

The gymnosperms are an economically important group of plants spread all over the globe, primarily in the temperate (colder) and at higher elevations in the tropics (warmer) regions. **The trees are used for landscaping, timber, building constructions, resins and for manufacture of paper and board. They are also used in medicines, perfumes, varnishes and as essential oils.** The following headings give a brief account of the economic uses of various gymnosperms (for details see Maheshwari& Singh 1960; and Bhatnagar&Moitra, 1997).

Wood

The coniferous wood is generally light coloured, straight grained and light weighted wood, which you might have observed in carpentry shops or in any pine forest. Such wood takes a good polish and paints easily. It bears good nail taking properties and takes a good finish with sharp tools. These properties make the wood used widely for cabinet and furniture making and interior decoration.

The wood of *Pinus* spp. (Pine) is used for making cheap furniture, packing cases agricultural implements, fencing poles, crates, doors, frames, toys, general mill work, etc.

Cedrusdeodara (Cedar or deodar) yields the strongest Indian timber. The heart wood is strongly scented and resistant to insect and fungal attacks. It is widely used for making railway sleepers and carriages. In North India it is chiefly used for making window panes, doors, furniture, electric poles, for flooring in houses, building models, boats, storage vats and also for battery separators.

Resin

Resins are plant exudates secreted in specialized ducts. These largely come from conifers as a result of tapping. They are insoluble in water and soluble in organic solvents and find a lot of use in varnishes, paints, medicines and in paper sizing. Various kinds of resins and their source are given below:

Rosin: It is obtained as a residue after the distillation of pine oleo-resin or turpentine. Turpentine is chiefly tapped from different species of *Pinus e.g., P.roxburghii, P.wallichiana, P.kesiya* and *P. merkusii*. Rosin is used in paper sizing, varnish making, enamels and in the preparation of plasters and ointments.

***Copal*:** Copal is tapped from *Agathisaustralisas* a "green gum" or "candle gum". It is used in spirit varnishes, in making linoleum, preparation of plastics, polishes and the articles for which rosins are used.

Canada balsam: Canada balsam is obtained from *Abiesbalsamina*. It has a high refractive index as that of glass and is used as a mounting medium for microscopic objects and as a cement for lenses in optical work.

Essential oils

Various kinds of essential oils are obtained from different species of coniferous plants. An essential oil obtained from *Cedrusdeodara* is used in perfumery and in medicines to cure bronchitis, tuberculosis, skin diseases and gonorrhea. Turpentine oil is a very popular

essential oil obtained from several species of *Pinus*. Species of *Cupressus*(fir) and *Juniperus* (Juniper) furnish essential oils which are used in making incense sticks and perfurmary.

Paper

Paper is made from wood pulp of some Indian species of coniferous plants like species of *Picia, Pinus, Abies, Cryptomeria* and *Gnetum*. Various species of *Pinus* provide newsprint almost all over the world.

Food

The stem and seeds of *Cycas* yield a starch "Sago" or "Arrowroot" Seeds of *Pinusgerardiana* (Chilgoza) andother species of*Pinus*are edible and nutritive. Young leaves and strobiliof*Gnetumgnemone* are cooked as vegetable.

Medicines

Various gymnosperms yield essential oils and resins that possess medicinal properties. Resin obtained from*Cycasrumphii* is applied to ulcers. The wood of *Cedrusdeodara* possesses diuretic and carminative properties and is used in curing pulmonary disorders, piles and rheumatism.

The oleo-resin of *Pinus* is used in gonorrhoea. Seeds of *P.gerardiana* yield oil which is applied as dressing to wounds and ulcers. The leaves of *Taxusbaccata* (Yew plant, Thuner) are used in asthma, bronchitis, epilepsy and for indigestion. The alkaloid ephedrine extracted from green branches of *Ephedra*spp. is used against asthma, hay fever and bronchial inflictions. The seed juice of*Ephedra* is used to cure respiratory problems.

Ornamentals

Several species of *Cycas* are widely grown as garden plants and for decorative purpose.

Thuja (biota, morpankhi) and species of *Juniperus*(juniper), *Cupressus* (cypress), *Araucaria* (christmastree) *Pinus* (pine), *Ephedra*(joint-pine, joint-fir), *etc*. are grown as ornamentals.

Besides, all these uses, the coniferous forests provide a cool and soothing climate suitable for health.Several health resorts and sanitoria run in the hills under the shadows of pine trees where hundreds of people and patients go every year for recreation and treatment.

5.6 DISTRIBUTION OF GYMNOSPERMS IN INDIA

The total number of living gymnosperms in world is approximately 72 genera and 725 species. M.B.Raizada and K.C. Sahni (1960) reported 16 genera and 53 species from India.Maheshwari listed only 14 genera. This lesser representation is due to the fact that gymnosperms are mainly dwellers of temperate regions and in India; such a climate is present only inthe Himalayas. They form extensive dense forests and grow luxuriantly in various Himalayan ranges.

There are 6 living orders of gymnosperms and out of them 4 are represented in India. These are Cycadales, Coniferales, Ephedrales and Gnetales. *Ginkgo biloba* (living fossil-Ginkgoales) is cultivated at many places in India but it originally belongs to China.

Cycadales - Members of this order are tropical dweller. One of the living members, *Cycas*has 6 species distributed in India (Fig. 5.9). Out of the six species two are commonly grown in the Indian gardens.

Cycasbeddomei : Restricted to dry hills of Cuddapah in the Andhra Pradesh.

C. circinalis : Found wild in the dry deciduous forests of south India.

C. pectinata : Grows wild in several parts of eastern India.

C. rumphii : Grows in Andaman& Nicobar Islands.

C. revoluta : It is a Japanese species, now cultivated as an ornamental plant in Indian gardens and is propagatedvegetatively by means of bulbils.It is represented only by female plants, in India.

C. siamensis **:** Distributed in Siam, Burma, Cochin and Yunnan and grown in India as an ornamental plant.

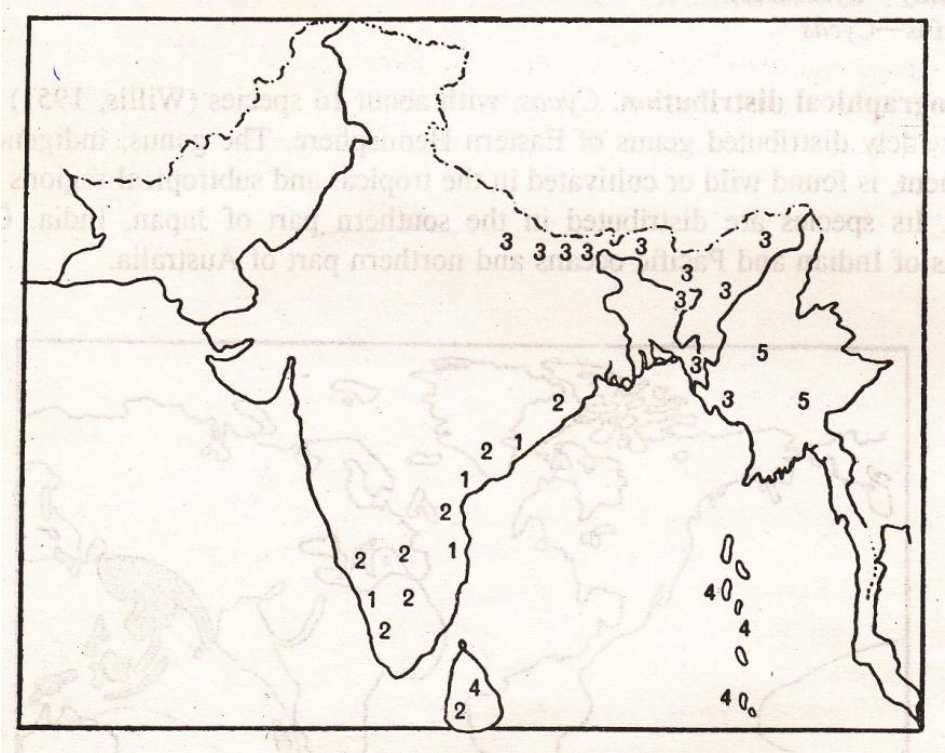


Fig. 5.9.Map showing distribution of Cycas in India and adjacent countries; 1.C. beddomei, 2.C. circinalis, 3.C. pectinata, 4. C. rumphii, and 5. C. siamensis

Coniferales - The order Coniferales is a large order represented by 11 genera in India. These include *Abies, Cedrus, Cephalotaxus, Cupressus, Juniperus, Larix, Picea, Pinus,Podocarpus, Taxus, and Tsuga.* **All of them except *Podocarpus*are found to the Himalayas, s**ome of them occur in both the Eastern and Western Himalayas, whereas others are restricted in distribution. **The distribution is governed mainly by altitude.** The important Indian species with their distribution are as follows:

i. ***Pinus*** is among the common gymnosperms and its species are distributed from Eastern to Western Himalayas (Fig. 5.10).

Pinusroxburghii : Grows luxuriantly at 1000 ma.s.l. in Western Himalayas.

P.wallichiana : Grows at 2,500 m a.s.l. in Western Himalayas.

P. kesiya : It also known by its synonyms as *P. insularis*or *P. khasyana.* It *g*rows luxuriantly in Eastern Himalayas. In Khasia and Chitagong hills from 800 to 1600 m a.s.l.

P. armendii : Grows luxuriantly inArunanchal Pradesh upto 1500m a.s.l.

P.gerardiana : W. Himalayas from 1800 to 3000 m a.s.l. It forms forests in Kilba and Rampur Bushair (H.P.) and extends uptoKishtwar valley but not to Kashmir.

P. merkusii : In India, it occurs mainly in the Eastern part of Anjaw district of Arunachal Pradesh which is neighboring to the India–Myanmar Pine Forests Eco-region.

ii. ***Abies***: In India, *Abies* has four species out of which *A.pindrow* and *A. spectabilis* grow in Western Himalayas. These two species also grow along the higher ranges of Western and Central Himalayas2300-4000m a.s.l.

iii. ***Tsuga*** trees attain a diameter of 6 meters and grow abundantly at 2,750 meters in Darjeeling.

iv. ***Cedrusdeodara*** is the only Indian species that grows in Western Himalayas between **1200-3300 meters. It grows to huge size and may attain an age of 704 yrs.**

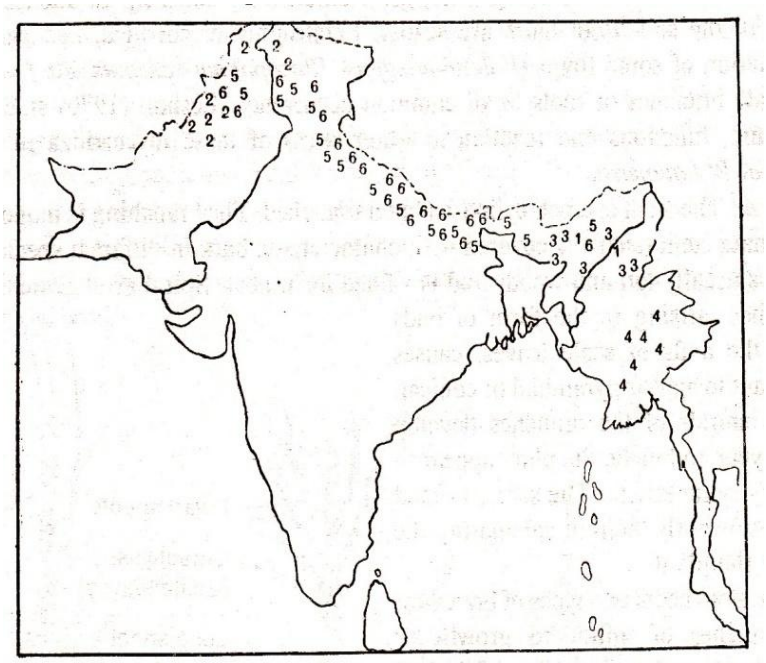


Fig. 5.10.Map showing distribution of Pinus in India and adjacent countries; 1.P. armendii, 2.P. gerardiana, 3.P. kesiya, 4.P. merkusii, 5. P. roxburghii, and 6. P. wallichiana

v. ***Cupressustorulosa*** grows along with*Cedrusdeodara* but also grows elsewhere throughout the outer and middle ranges of Himalayas fromChamba (H.P.) to the Aka hills (NEFA) at 1,800 to 2,800 m.*Cupressussempervirens andCupressusfuniberus* is cultivated as ornamentals inIndian gardens.

vi. *Cephalotaxus*is represented by *C.mannii* and *C. griffithii*in India. Both grow in Eastern Himalayas and **are small trees,** 1500-1800m.

vii. *Juniperus*is represented by 6 species that grow in higher attitudes in the inner valleys of Eastern and Western Himalayas. They **grow above the tree limit** in the sub alpine and alpine regions.

*J. communis*isabout 0.6 m high and forms more and less compact patches of few square meters at 2,900m to 4,250 m a.s.l. in the Garhwal Himalayas.

J. wallichiana with low spreading branches is 30 cm to 1.5 m high and forms dense patches upto 0.2 hectare in extent at 2,900 to 4,200 m.

J. recurva and*J. squamata*grow from 2,300 to 4,900 m in Eastern Himalayas.

*J. macropoda*grows from 3,000 to 3,600 m in Ladakh and Kumaun and from1,500 to 4,300 m in Alaknanda valley (Uttarakhand).

J.coxii grows at higher attitudes in both the Western & Eastern Himalayas.

viii. ***Larixgriffithiana* is the only deciduous conifer of India** that grows in Sikkim and through Chumbi Valley of Tibet to Bhutan and the Mishmi hills of NEFA, usually above 3,000 m.

ix. ***Podocarpus***has two Indian species:-

P. neerifolia grows wild in the Andaman Islands and in Eastern Himalayas. It is a graceful tree growing up to 900 m. It is commonly found in the evergreen climax forests.

*P.wallichaina*occurs from Nilgiri south wards and in Assam. It is the only Conifer occurring in Nicobar Island.

x. ***Taxusbaccata*** grows in the Westernas well as in Eastern Himalayas. **It loves moist and shady places above 2000 m**. It grows all along the Khasi-Jaintia and Naga hills.

xi. ***Cryptomeria japonica*** is **native of Japan** and **was introduced** into India in the nineteenth century. Now it has become **naturalized in Western Himalayas**.

xii. ***Thujaoccidentalis*** is cultivated as an ornamental plant in North India.

xiii. ***Araucaria cookii***and*A. cunninghamii*are cultivated as ornamental plants in North India.

Ephedrales: The genus *Ephedra* is represented by 6 species in India(Fig. 5.11), which are erect or climbing shrubs or perennial herbs. These species occur as following.

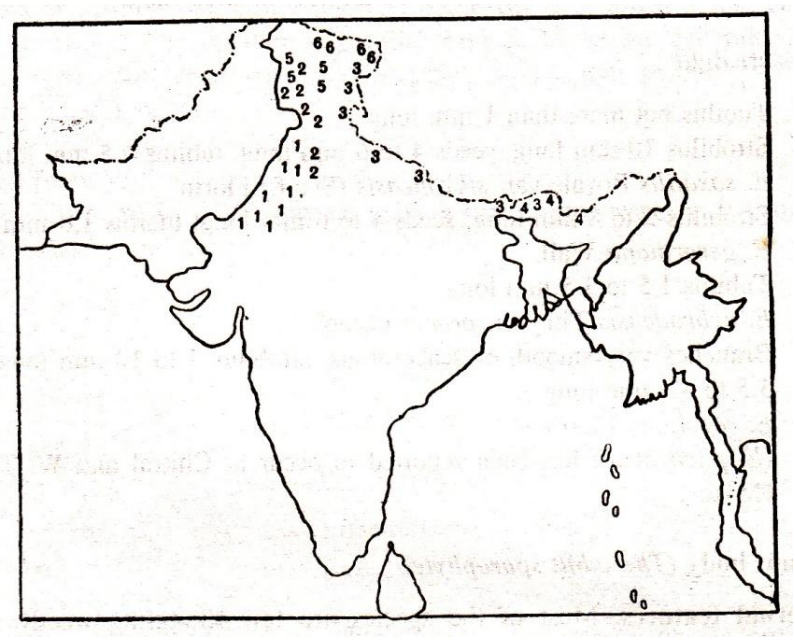


Fig. 5.11.Map showing distribution of Ephedra species in India and adjacent countries; 1.E. foliata, 2.E. intermedia, 3.E. gerardiana, 4.E. saxatilis, 5. E. nebrodensis, and 6. E. regeliana

Ephedra foliata : From Sind, Punjab and Rajasthan.
E.intermedia : Grows in Kashmir, Punjab, Himachal Pradesh and Uttarakhand.
E.gerardiana : Grows in dry alpine and temperate Himalaya in Sikkim and Kashmir.
E. saxatilis : Grows in Sikkim.
E. nebrodensis : High altitudes in the Himalayas.
E.regeliana : Drier parts of Rajasthan.

Gnetales: It is represented by single genus *Gnetum*, grows in various parts of India.Five species have been reported which are:

G.ula : Very common in the evergreen forests of Western Ghats, Andhra Pradesh and Orissa.
G.contractum : It grows in NilgiriHills and Kerala and is a scandent shrub.
G.montanum : Grows wild in Assam, Sikkim and some parts of Orissa.
G.lattifolium : Grows in the Andaman Islands.
G.gnemon: Is an erect shrub that grows in the rain forest of Eastern parts of India.

5.7 SUMMARY

In this unit we have discussed the meaning of gymnosperms, their characteristic features and affinities with previous (pteridophytes) and latter(angiosperms) groups. We also learnt how the gymnosperms are classified according to Pant, how they aredistributed on the globe and what is their economic importance? So, let us sum it up in key points:

1. Gymnosperms are naked seeded plants.

2. They all are woody, perennial, xerophytes and evergreen.
3. Morphologically there are two distinctlines, *i.e.*palm shape (Cycads) and conical shape (Conifers) plant body.
4. Plants possess tap root system but in some plants additional symbiotic relationship is found between roots and algae in coralloid roots (*Cycas*) and between roots and fungi in mycorrhiza roots(*Pinus*).
5. Plants may be monomorphic (having one kind of leaves) and dimorphic (two kinds of leaves).
6. Vascular cylinders of roots arediarch to polyarch. Xylem is exarch.
7. Secondary wood in stems may be manoxylic (*Cycas*) or pycnoxylic (*Pinus*).
8. Xylem lacks vessels and phloem is devoid of companion cells except Ephedrales. Xylem of stem is usually mesarch or endarch.
9. Leaves possess thick cuticle, sunken stomata, mesarch xylem, transfusion tissue and may possess resin passage or latex tubes.
10. Plants are heterosporous. Both dioecious and monoecious plants are found.
11. Male cones are usually short lived and smaller while female cones are long lived and larger than the male cones.
12. Microsporangia (male spore bearing organs) are borne on the lower surface of microsporophylls while megaporangia (ovules) are produced on the upper surface of the megasporophylls.
13. Pollination is anaemophilous, *i.e.* takes place by means of wind.
14. Zygote development is meroblastic, *i.e.* only the basal part develops into an embryo, the upper and middle parts donot participate in the formation of embryo.
15. Mature embryo is divided into root, stem and leaves.
16. Polyembryony (development of several embryos in a seed) is common feature of *Pinus.*
17. In gymnosperms, endosperm develops before fertilization and is haploid.
18. Since ovules are naked and are not surrounded by ovary, true fruits like that of angiosperms, are not formed.
19. The germination of seed is epigeal.
20. Alternation of generation is heterologous and sporophytic generation is dominant and independent.
21. Economically gymnosperms are considered an important group which are the source of food, timber, paper, pulp, resin and drugs.
22. The important drug ephedrine obtained from green branches of *Ephedra* is widely used in cold, asthma, bronchitis, etc.

5.8-GLOSSARY

Adventitious : Found in an unusual place *e.g.* adventitious roots.

Alternation of generation: The occurrence in one life differently produced, usually an alternation of a sexual with asexual form.

Asexual : Having no sexual organs.

Cambium : The tissue from which secondary growth arises in stem.

Cone : The male or female flowers of gymnosperms with a central axis and spirally arranged sporophylls.

Coralloid : Branching like a coral *e.g.Cycas* roots
Cortex : The extrastelar fundamental tissue of the sporophyte.
Diarch : With two xylem and two phloem bundles.
Dichotomous : Repeated forking.
Dioecious : Having male and female sexes on different individuals.
Embryo : A young organism in early stages of development.
Endodermis : Innermost layer of cortex in plants.
Endosperm : The nutritive tissue of seed.
Epidermis : The outermost protective layer of stem.
Erect : Directing upwards.
Evolution : The gradual development of organisms from pre existing organisms since the dawn of life .
Exarch : With protoxylemtowards periphery.andmetaxylemtowards the centre.
Fertilization : The union of male and female nuclei.
Fossil : Petrified plant parts found in rocks.
Gametes : Sexual cells.
Gametophyte : The gamete forming phase in alternation of plant generations, sexual generation of plants.
Habitat : The locality or external environment in which a plant lives.
Haploid : Having x number of chromosome (n).
Heterosporus : Producing two kinds of spores, *i.e.* Microspores and Megaspores.
Leaf gap : Gap in vascular cylinder of a stem in parenchymatous region associated with leaf traces.
Leaf let : Individual unit of a compound leaf; pinna.
Life-cycle : The various phases through which an individual species passes to maturity.
Megasporophyll: A fertile leaf developing megasporangia.
Mesophyll : The internal parenchyma of a chlorophyllous leaf.
Mid-rib : The large central vein of a leaf.
Monoecious : With sex organs on one gametophyte.
Mycorrhiza : Association of fungal mycelium with roots of a higher plant.
Ovule : The megasporangium of seed plant.
Palisade : Arrangement of opposed elongated cellular structures.
Pinnate : A compound leaf having leaf lets on each side of an axis or mid rib.
Pollen : The powder produced by anthers consisting of pollen grains.
Pollination : Transference of pollen grains from anther to ovule.
Polyembryony: Formation of several embryos in one ovule *e.g.Pinus*.
Rachis : The axis bearing leaf-lets.
Resin : An acidic excretion product of certain plants.
Root : Descending portion of plant, fixing it in soil and absorbing moisture and nutrients.
Shoot : Stem of a vascular plant derived from the plumule.
Spore : A highly specialized reproductive cell of plants.
Tracheid : One of the cells with spiral thickenings or bordered pits, conducting water and solutes, and forming woody tissue.

Vascular bundle: A group of special cells consisting of two parts, xylem and phloem.
Vertical : Standing upright.
Xylem : Lignified portion of vascular bundle.

5.9 SELF ASSESSMENT QUESTIONS

5.9.1 Very short answer questions

1. Which is the most important character of Gymnosperms?
2. Who called Gymnosperms as "Phanerogams without ovary"?
3. In which group of plants seeds are formed but fruits do not formed?
4. Which plant is known as 'Sago palm'?
5. Whichgymnosperm is called as 'living fossil'?
6. Terpentine is obtained from which plant?
7. 'Chilgoza' is obtained from?
8. Ephedrine drug is obtained from which plant?
9. The female gametophyte in gymnosperms after fertilization is called as?
10. Canada balsam, a mounting substance is obtained from?
11. Which is the biggest tree in gymnosperms?
12. Name the smallest gymnosperm?
13. Name the tallest gymnosperm?

5.9.2 Multiple choice questions

1. Gymnosperms differ from angiosperms in:

(a) Presence of naked seeds and lack of vessels (b) Presence of seeds and vessels
(c) Having abortive seeds. (d) Having tracheids

2. Xylem of gymnosperms lack:

(a) Tracheids (b) Xylem fibres
(c) Xylem parenchyma (d) Vessels

3. Endosperm in gymnosperms is formed:

(a) At the time of fertilization (b) Before fertilization
(c) After fertilization (d) Along with development of embryo

4. The resin ducts of a gymosperm stem is an example of:

(a) Intercellular space (b) Schizogenous cavity
(c) Lysigenous cavity (d) Big vessels

5. The characterstic features of the stomata in gymnosperms are:

(a) That they are deeply sunken in pits (b) That they are subsidiary cells
(c) That they are ordinary cells (d) that they are specialized cells

6. Which of the following statement is not correct for the gymnosperms;

(a) Leaves are compound
(b) Naked seeds are formed
(c) Xylem is made up of tracheids
(d) Xylem is made up of vessels

7. The smallest known gymnosperm is:
(a) *Cycas revolute*
(b) *Zamia pygmaea*
(c) *Pinus insularis*
(d) *Ginko biloba*

8. Red wood tree is:
(a) *Cedrus*
(b) *Sequoia*
(c) *Pinus*
(d) *Metasequoia*

9. Dry fruit "Chilgoza" is the seed of:
(a) *Cedrus deodara*
(b) *Cycas revoluta*
(c) *Pinus gerardiana*
(d) *Zamia pygmaea*

10. "Sago" is obtained from:
(a) *Cycas*
(b) *Pinus*
(c) *Ephedra*
(d) *Gnetum*

11. Terpentine is obtained from:
(a) *Cycas*
(b) *Pinus*
(c) *Ephedra*
(d) *Ginkgo*

12. Ephedrine is obtained from:
(a) *Cycas*
(b) *Pinus*
(c) *Ephedra*
(d) *Cedrus*

13. Timber is obtained from:
(a) *Cycas*
(b) *Cedrus*
(c) *Ephedra*
(d) *Zamia*

14. Which of the following condition found in *Cycas* is also found in *Pteris*:
(a) Naked ovule
(b) Circinate vernation of leaves
(c) Presence of coralloid roots
(d) Presence of secondary growth

15. Fruits are not formed in gymnosperms because:
(a) They are seed less plants
(b) They are not pollinated
(c) They have no ovary
(d) The process of fertilization doesnot take place in them

16. In which of the following features do gymnosperms resemble angiosperms:
(a) Presence of vessels in the wood
(b) Mode of fertilization
(c) Nature of endosperm
(d) Presence of ovule

5.9.3 Fill up the blanks:

1. Ephedrine is obtained from . . . . . .
2. Taxol is obtained from . . . . . .
3. Sago is obtained from . . . . . .
4. "Chilgoza" is the seed of . . . . . .
5. Living fossil is . . . . . .
6. Naked seeds are found in . . . . . .
7. Vessels are absent in the xylem of . . . . . .
8. Companion cells are absent in phloem of . . . . . .
9. Ovary is absent but seeds are formed in . . . . . .
10. Gymnosperm which provide good timber is . . . . . .
11. Water is not required for fertilization in . . . . . .
12. Mycorrhiza is found in . . . . . .
13. Polyembryony is common in many of . . . .
14. Endosperm is . . . . . in gymnosperms.

5.9.1 Answer key: 1. Naked ovule, 2. Goebel, 3. Gymnosperm, 4. *Cycas*, 5. *Cycas*, 6. *Pinus*, 7. *Pinusgerardiana*, 8. *Ephedra*, 9. Endosperm, 10. *Abies balsamea*, 11.*Sequioadedron gigantium*, 12.*Zamia pygmaea*, 13. *Sequioadedron sempervirens.*

5.9.2 Answer key: 1.a, 2. d, 3. b, 4. b, 5.a, 6. d, 7. b, 8. b., 9. c, 10. a, 11. b, 12. c, 13. b, 14. b, 15. c, 16. d.

5.9.3 Answer Key: 1.*Ephedra*, 2. *Taxus*, 3.*Cycas*, 4.*Pinusgerardiana*, 5. *Cycas*,6. Gymnosperms, 7. Gymnosperms, 8. Gymnosperms, 9. Gymnosperms, 10. *Cedrusdeodara*, 11.Gymnosperms, 12.*Pinus*, 13.Gymnosperms, 14.Haploid.

5.10- REFERENCES

- Arnold, C.A. (1948), "Classification of gymnosperms", *Botanical Gazette*, Vol. 110,pp.2-12.
- Bhatnagar, S.P. andMoitra, A. (1997),*Gymnosperms*.New Age International (P) Limited, New Delhi.
- Bentham, G. and Hooker, J.D, (1862-1883),*GeneraPlantarum*. L. Reeve& Co., London.
- Bierhorst, D.W. (1971),*Morphology of vascular plants*, Mac. Millan Co., New York.
- Brongniart, A. (1843),*Enumeration des genres de plantes*, Paris.
- Chamberlain, C.I. (1935),*Gymnosperms-structure and evolution*, Chicago.
- Coulter, J.M. and Chamberlain, C.I. (1910),*Morphology of Gymnosperms*. Chicago.
- Cronquist, A., Takhtajan, A. and Zimmermann, W. (1966),On the higher taxa of Embryophyta. *Taxon*.Vol. 15(4), pp.129-134.
- Devevoryas, T. (1963),*Morphology and evoloution of fossil plants*,Hott, Rinehart & Winston, New York.
- Engler, A. and Prantl, K. (1897),*Die naturlichenPflanzenfamilien*,NachtragzuTeilen2-4.
- Laetsch, W.M. (1979),*Plants: Basic concept in Botany*, Scott Foresman& Co, USA.

- Maheshwari, P. and Singh, H. (1960), Economic importance of conifers.*J. Univ.Gawhati (Sci)*, Vol. 11,pp.1-28.
- Raizada, M.B. andSahani, K.C. (1960), Living Indian Gymnosperms, *Indian forest records: Botany*,Vol. 5 (2), Manager of Publications, NewDelhi
- Sporne, K.R. 1965. *The morphology of Gymnosperms*. London.
- Hort, A. 1916. *Theophrastus: Enquiry into Plants*,
- Pant, D.D. 1957. The classification of gymnosperms plants.*Palaeobotanist*, Vol. 6(1), pp**.**188-203.
- Van Tieghem, Ph. 1898. *Elements de Botanique*. Ed. **3:** Paris.
- Zimmermann, W. (1952).The mainresults of the Telometheory.*Palaeobotanist*, Vol. 1, pp. 456-470.

5.11 SUGGESTED READINGS

- *Botany for Degree Students -Gymnosperms*: P.C. Vashishta, A.K. Sinha and A. Kumar (1976).
- *College Botany. Vol. 2* : H.C. Ganguly and A.K. Kar (1999).
- *Gymnosperms- Structure & Evolution*: C.J. Chamberlain (1935).
- *Gymnosperms* : P.C. Vashishta (1976).
- *Gymnosperms of India and Adjacent countries*: K.C Sahni (1990).
- *Gymnosperms*: S.P BhatnagarandAlok. Moitra (1997).
- *Gymnosperms: A Treatise :* O.P. Sharma (1980).
- *Indian Gymnosperms in Time and Space*: C.G. K. Ramanujan (1979).
- *Living Indian Gymnosperms* : M.B. Raizada and K.C. Sahani, (1960).
- *A Text Book of Botany* : V. Singh, P.C. Pande and D.K. Jain (2008).
- *The Moropology of Gymmosperms*: K.R. Sporne (1991).

Important website and links

- http://biology.clc.uc.edu/courses/bio106/gymnospr.htm(accessed on March, 2015).
- http://www.biologyreference.com/Gr-Hi/Gymnosperms.html#ixzz3VIBvPMJk (accessed on March, 2015).
- http://www.conifers.org (accessed on March, 2015).

5.12-TERMINAL QUESTIONS

5.12.1- Long answer type questions:

1. Describe the silent features of gymnosperms and give the general outline classification of this group.
2. Write a note on classification of gymnosperms given by D.D.Pant (1957). What is criterion of this classification?
3. Write explanatory note on gymnosperms of Himalaya.
4. Describe the affinities of gymnosperms with other groups.
5. Discuss in brief about the affinities of gymnosperms.
6. Write the characteristic features of Coniferales and their distribution in India.

7. Writes short notes on the canada balsam,copal, resin androsin.
8. Why the gymnosperms are considered as connecting link between pteridophytes and angiosperms.
9. Write brief account on distribution of gymnosperms studied by you in India.

5.12.2 -Short answer type questions

1. List the xerophytic characters of gymnosperm.
2. What is manoxylic wood and how it differs from pycnoxylic wood?
3. Write a short note on the economic importance of gymnosperms?
4. Write a short note on Cycadales and Ephedrales.
5. Write the characteristic features ofConiferales and their distribution in India.
6. Write a short note on medicinal and ornamental value of gymnosperms in your syllabus.
7. Differentiate the coralloid roots and mycorrhiza roots.

UNIT 6: STRUCTURE AND LIFE HISTORY OF *CYCAS*

6.1- OBJECTIVES

After reading this unit you will be able to:

- Identify and describe the morphology of *Cycas*.
- Distinguish the species of *Cycas* from one another.
- Learn the internal structure of*Cycas* and will relate it to other gymnosperms and angiosperms.
- Rewrite the life-history of *Cycas.*
- State the economic importance of *Cycas.*

6.2-INTRODUCTION

" The Cycads of today may rightly be called **"living fossils**" because they come down from the remote past with so little change that if a man from Cretaceous is brought today, he would very easily recognize the modern living forms of today" (Seward, 1933).

In the previous chapter you have studied the characteristic features of Gymnosperms, their classification, distribution and economic importance. You also gained knowledge, that Gymnosperms have two clear-cut lines of evolution one is represented by palm tree like habit and another by its conical shaped plant body. The former line is kept under the group Cycads and later as Conifers. Now, in present chapter we will study the structure and life-history of one of the living Cycads*i.e. Cycas*.

6.2.1 Systematic Position

Cycas, commonly called as "Sago palm" is the most widely distributed genus of the order Cycadales. The systematic position of the genus is as follow;

Division : Gymnospermae
Class : Cycadopsida
Order : Cycadales
Family : Cycadaceae
Genus : *Cycas*

Cycas revoluta, a native of China and Japan is commonly cultivated in Indian gardens. It has a graceful palm like tree like appearance (1.8 to 6 m high). The plant has usually a tuberous stem which on maturity is unbranched, erect, columnar and bearing at the apex a crown of large compound foliage leaves in apparent whorls. The stem of *Cycas revoluta* has medullary rays that contain "sago starch grains", hence the plant is called "Sago palm".

6.2.2 Geographical Distribution

The genus *Cycas* consists of 16 species distributed all over the world. It is found wild or cultivated in the tropical and sub-tropical regions of Eastern Hemisphere. *Cyca srevoluta*, a native of China and Southern Japan is common and the most widely cultivated of all Cycads.In our country, *Cycas* species are commonly found in Orissa, Bengal, Assam, Tamilnadu, Karnataka and Andaman. The genus is represented by six species which are as:

1. *Cycas circinalis* (Crozier Cycas): Distributed in dry deciduous forests of Western Ghats, Orissa and Srilanka.
2. *Cycas siamensis* (Siam Cycas): Distributed in Siam, Burma, China and Yunnan. It is grown in India as ornamental plant.

3. *Cyca spectinata* (Nepal Cycas): Distributed in Nepal, Sikkim, Someshwer hills in Bihar, Assam, Manipur and Bangladesh.
4. *Cyca srumphii* (Rumphius Cycas): Distributed in Andaman-Nicobar Islands, Srilanka and Malaya. It is cultivated in Indian gardens.
5. *Cycas beddomei* (Madras Cycas): Distributed in Tamilnadu, Calicut and Eastern Andhra.
6. *Cyca srevoluta* (Sago Cycas): It is native of China and Southern Japan. It is the most commonly cultivated species of Indian gardens.

Key to the identification of Indian species of *Cycas* species:

A. Margin of leaflets flat.
   i. Trunk swollen at the base, leaflets not more than 8 mm broad; carpophylls pectinate along the margins……..*C. siamensis.*
   ii. Trunk not swollen at the base
      a. Leaflets 12-16 mm broad; blade of the carpophyll ovate lanceolate, teeth small……..*C. rumphii*.
      b. Leaflets 5-10 mm broad; blade of the carpophyll broadly arbicular, long acuminate and deeply pectinate……..*Cyca spectinata*.
      c. Leaflets usually not more than 12 mm broad, carpophyllss pinous, toothed along the margins……..*C. circinalis*.

B. Margins of leaflets revolute.
   i. Small palm like tree, blade of carpophyll pectinate……..*C. revoluta*.
   ii. Small shrub, stem about 15 cm high, blade of carpophyll dentate to ovate……..*C. beddomei*.

6.3-CYCAS

6.3.1-Structure

6.3.1.1 General morphology

Cycas is a palm-like evergreen plant and before the anatomical studies of the stem of *Cycas*

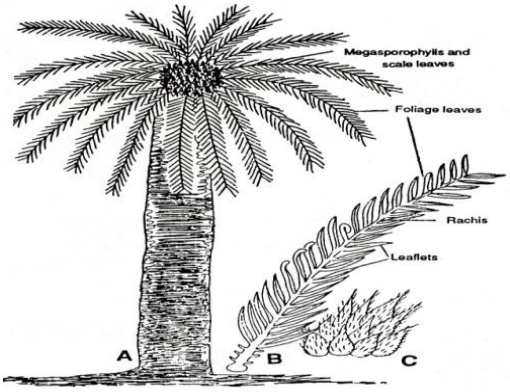


Fig. 6.1.Cycas: **A. a female plant, B. a foliage leaf, and C. scale leaves**

revoluta by Brongniart (1829), the *Cycas* was actually considered a palm. The plant body consists of a columnar aerial trunk with a crown of pinnately compound leaves at its top (Fig 6.1). According to Eichler (1889), Coulter and Chamberlain (1910), Schuster (1932) and others, a tap root system persists in the adult plant but studies of Worsdell (1906) states that the tap roots are soon replaced by the adventitious roots.

A. Roots

Roots in *Cycas* can be differentiated into two types *i.e.* normal tap-roots and coralloid roots.

i. Normal tap-roots: These are positively geotropic, grow deep into the soil, and possess no root hairs. The function of these roots is to fix the plant in the soil, and to absorb the water and other minerals.

Fig. 6.2.Cycas; arrow indicating coralloid roots at base of stem above ground

ii. Coralloid roots: The normal roots develop some lateral branches near the ground surface. These lateral roots get infested with bacteria, fungi as well as algae. After infestation the roots grow first horizontally in the soil and become swollen at their tips. They divide and re-divide repeatedly (dichotomously) to form big bunches of greenish or brownish structures which are **coral like** in appearance. These are called coralloid roots (Fig. 6.2& 6.6A). These roots come out in the air from the ground surface and are phototrophic. Coralloid roots are found more in the young plant than the old.

Corals are animals (marine invertebrates), they do not make their own food, as plants do. Corals have tiny, tentacle-like arms that they use to capture their food from the water and sweep into their inscrutable mouths. Most structures that we call "coral" are, in fact, made up of hundreds to thousands of tiny coral creatures called polyps. Corals are sessile, which means that they permanently attach themselves to the ocean floor, essentially "taking root", like most plants do. We certainly cannot recognize them by their faces or other distinct body parts, as we can most other animals.

B. Stem

The stem is thick, woody and usually unbranched (Fig. 6.1A). Young stem is tuberous (found under the soil surface) while mature stem is columnar, erect and stout. The aerial part of the trunk remains covered by thickarmour of large and small rhomboidal leaf bases. These occur regularly in alternate bands (Fig. 6.3). The larger leaf bases are the bases of foliage leaves while the smaller ones represent the bases of scaly leaves. By counting the number of the crowns of leaves and megasporophylls produced every year the age of the plant can be calculated.

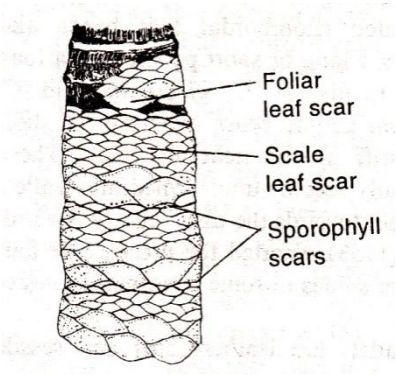


Fig.6.3. Old stem of Cycas showing armour of leaf bases

Among all *Cycas*species, *C. media* is the tallest attaining a height upto 20 meter (Schuster, 1932). Regarding the age of the *Cycas*, the plant can survive for long period, as much as 100 years in case of species like *C. circinalis* (Brandis, 1907), if allowed to grow undisturbed.

C. Leaves: Two types of leaves are present in *Cycas i.e.* green, assimilatory foliage leaves and scaly leaves or cataphylls.

i. Assimilatory fronds or foliage leaves (Fig. 6.1 B): A crown of spirally arranged leaves is present around the stem apex which makes the *Cycas* plant look like a palm or tree fern. These leaves are green coloured, large, pinnately compound, showy, thick and leathery. They possess long or short petiole with a strong rachis. Petiole bears two rows of stiff spines which gradually transform into leaf-lets towards the upper side of the leaf. The rachis is strong and act as central axis for many leaflets. Leaflets are leathery, stiff and sessile with narrow base. Single midrib is present in each leaflet. The size and numbers of leaflets vary in different species. Leaflets of young leaves show circinate venation (Fig.6.4).

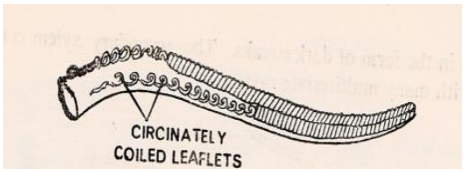


Fig.6.4. A young leaf showing circinate vernation

A leaf may reach upto 3 meters in length in some species of *Cycas*. Leaves are attached to the stem by transversely expanded rhomboidal leaf bases.

ii. Scaly Leaves: These are dry, brown coloured, triangular with their one end pointed (Fig 6.1 C). They are present at the stem apex after the crown of foliage leaves and remain covered with many ramental hairs.

6.3.1.2 Vegetative Anatomy

A. Roots

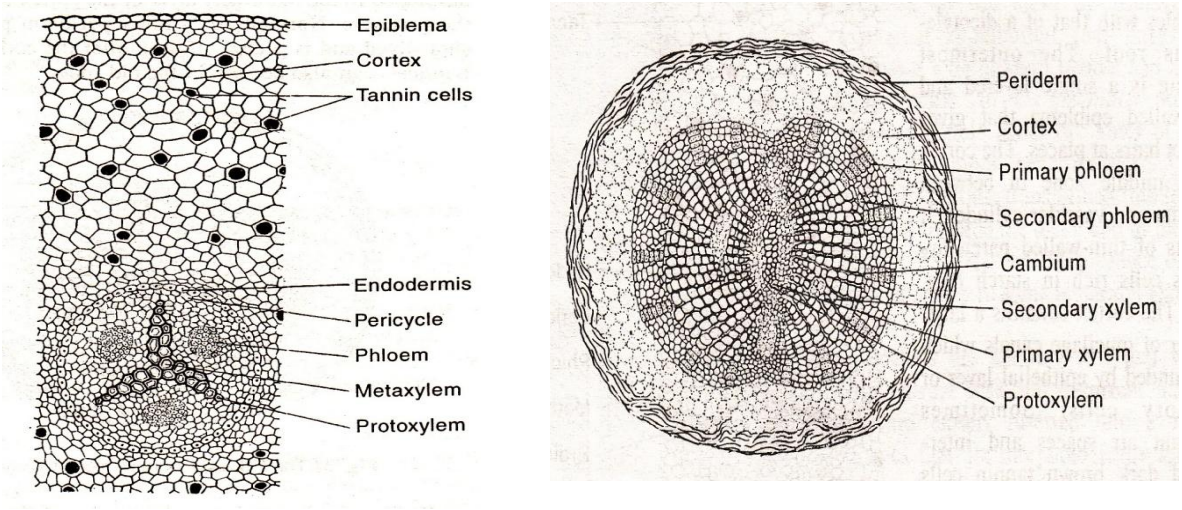
i. Normal Root (Young): It is circular in outline and resemble with dicotyledons rootin structure (Fig 6.5 A).

a**. Epiblema-** Outermost layer is called epiblema or exodermis. It is single layered and thin walled.Some cells of the layer give out root hairs. It surrounds the large region of cortex.

b. **Cortex**- Cortex is made up of parenchymatous tissue. The cells of this tissue are thin walled, almost round in shape with many intercellular spaces. Cortex cells remain filled with starch. Besides these, some tannin filled cells, mucilage cells and sometimes sphaeraphidesare also present in the cortex. It is delimited by endodermis.

c. **Endodermis**- Endodermis is single layered like the epiblema. Casparian strips are present in the barrel shaped cells of the endodermis. It is followed by pericycle.

d. **Pericycle-** It is multilayered region. The cells of pericycle contain abundant starch grains.



A **B**

Fig. 6.5.A. T.S. of normal young root of Cycas, B. T.S. of normal old root of Cycas

e. **Vascular system** -Xylem and phloem bundles in the roots are radially arranged *i.e.* on different radii. The roots are usually diarch but sometimes it shows tetrarch to polyarchcondition. Theprotoxylem consists of spiral tracheids while the metaxylem consists of scalariformtracheids. Vessels are absent.

Phloem consists of sieve tubes and phloem parenchyma. Phloem is present alternate to the xylem groups**.**

Pith is generally absent.

ii. Normal Root (old) showing secondary growth: The older roots undergo secondary growth (Fig 6.5 B). The cambium cuts secondary phloem towards the outer side and secondary xylem towards the inner side. After sometime the pericycle cells also become meristematic and form a complete cambial ring. The secondary xylem consists of radial rows of tracheids separated by parenchymatous cells. Outside the secondary phloem are present the region of the crushed primary phloem in the form of dark streaks. The secondary xylem is manoxylic with many multiseriate rays.

Periderm starts to develop in the cortex of old roots. Some of the cells of the outermost cortical region start to become meristematic and function as cork cambium. These cut cork towards outerside and secondary cortex towards inner side.Often two periderm layers are seen in the roots of *Cycas*. One of them developed in the outermost layer of cortex below the epidermis and the other in pericycle. Normally, only inner periderm persists while the outer periderm is short lived. Cork cells are dead and full of suberin.

Epiblema is ruptured and there are no root hairs in the older roots.

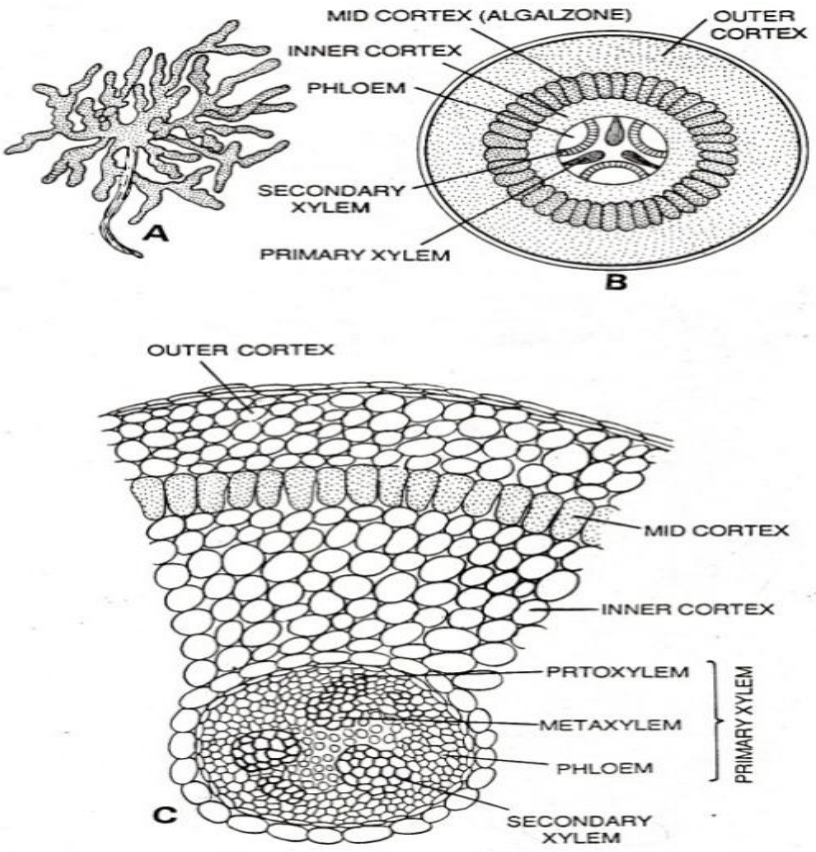


Fig. 6.6. Cycas; A. Coralloid roots, B. T.S. of coralloid root, C. T.S. of coralloid root (detailed structure)

iii. Coralloid root: The internal structure of the coralloid roots is similar to that of normal roots but they differ with normal roots in having poorly developed secondary tissue or none. The cortex is differentiated into three distinct zones (Fig. 6.6 B-C), which are-

a. The **outer cortex** composed of **polygonal** cells.
b. The **inner cortex** of thin walled **parenchymatous**cells.
c. The **middle cortex** forming the **algal zones**.

Algal zone is usually one cell wide, made up of loosely connected thin walled and radially elongated cells. Each cell has a single nucleus and cytoplasm. It has large intercellular spaces. These intercellular spaces are occupied by certain algae, some fungi and few bacteria. Following members have been reported from the algal zone of the coralloid roots of *Cycas*.

Anabaena cicadae (Spratt, 1911).
Nostocpunctiforme (Winter,1935).
Oscillatoria (Fritsch, 1945).
Azotobactor (Life,1901).
Pseudomonas radicicola (Life, 1901).
Some fungi (Life, 1901).

Due to the presence of Cynophycean members and some nitrogen fixing bacteria, the function assigned to the coralloid roots in *Cycas* is mainly the **nitrogen fixation** (Pant, 1973).

Endodermis, pericycle and vascular bundles are similar as in case of normal roots.The xylem is exarch and triarch.

B. Stem

i. Young Stem

Like root, the stem of *Cycas* also resembles internally with a dicotyledonous stem (Fig.6.7). It shows the following anatomical features:

a. Epidermis- It is the outermost layer consisting of compactly arranged thick walled cells. Due to the presence of many persistent leaf bases the epidermis is discontinuous and ruptured.

b. Cortex- It consists of thin walled, parenchymatous cells which are densely filled with starch grains. It is very large, and contains numerous mucilaginous canals lined by many radially elongate epithelial or secretory cells. Mucilage canals of the cortex are connected with medullary rays.**Starch in the parenchymatous cells of the cortex is the source of "sago".**

c. Endodermisand pericycle are not distinct.

d. Vascular cylinder- It consists of numerous vascular bundles arranged in a ring. Each vascular bundle is conjoint, collateral, open and endarch. The xylem consists of tracheids and xylem parenchyma.Protoxylem has tracheids with spiral thickenings while the metaxylem has scalariform thickenings with bordered pits. **There are no vessels**.Outside the xylem is the phloem which consists of sieve tubes and phloem parenchyma. **Companion cells are absent.**

Between the xylem and phloem lies the **primary cambium.** Primary cambium remains active only for short period. It is soon succeeded by another ring of **seconadary cambium**

somewhere in the cortex. These successive rings of cambium form 2-14 different vascular rings showing **polyxylic condition** in the **old stem.**

Many broad and well developed medullary rays are present between the vascular bundles.

These are large, well developed, parenchymatous and contain many mucilage canals.

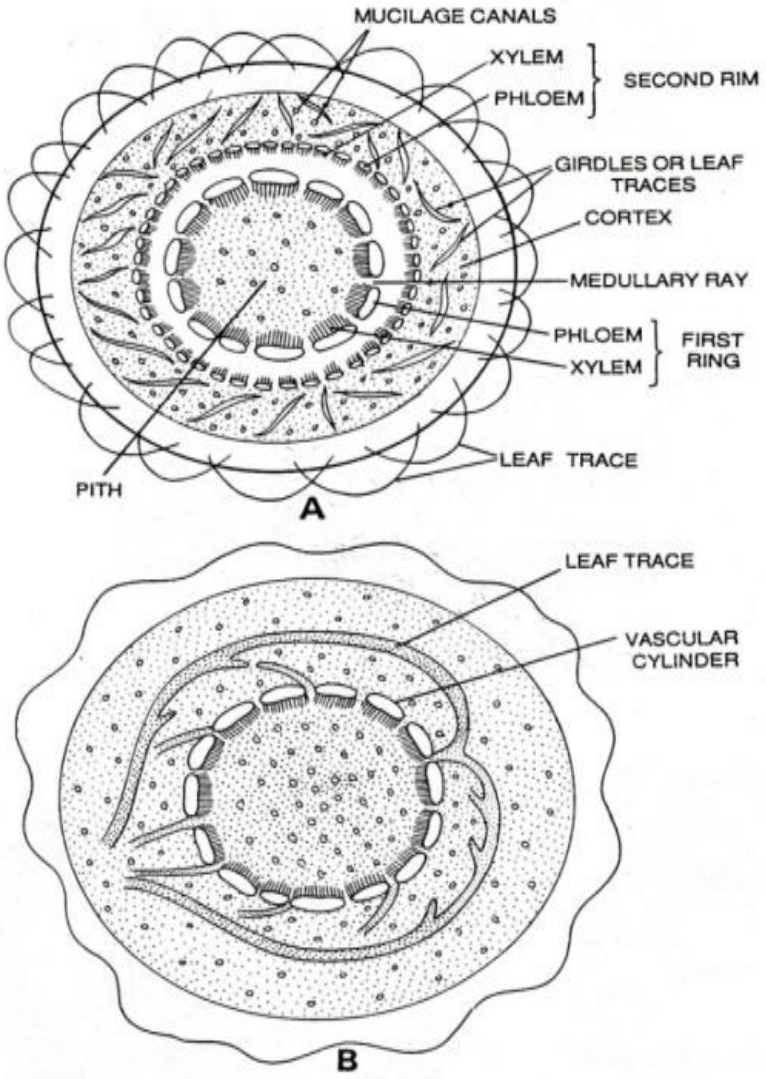


Fig. 6.7.Anatomy of Cycas stem; A. T.S. of Stem, B. T.S. of stem showing origin of leaf traces from vascular cylinder

e. Leaf Traces-A striking feature of *Cycas* is girdling of stem (Fig. 6.7 B). It is caused by large number of leaf traces. The leaf traces are

f. Scattered in the cortical region of the stem and constitute the vascular supply to the leaves from the main vascular cylinder. There are usually four leaf traces for each leaf. Two out of these four, are direct traces while remaining two are girdle traces. The direct traces develop from the vascular cylinder lying in front of the leaf base while the girdle traces develop from the vascular cylinder lying opposite to that of direct traces. They produced together and curve soon in opposite directions, and girdling round the vascular cylinder they enter in the leaf base. At the time of their entrance in the petiole, the leaf trace bundles subdivide and form many petiole bundles.

ii. Old stem

The secondary growth in the stem begins early. In the beginning *Cycas* is monoxylic*i.e.* containing a single ring of vascular bundles but the older stems showing polyxylic condition, *i.e.* several rings of vascular bundles (Fig. 6.8 A).

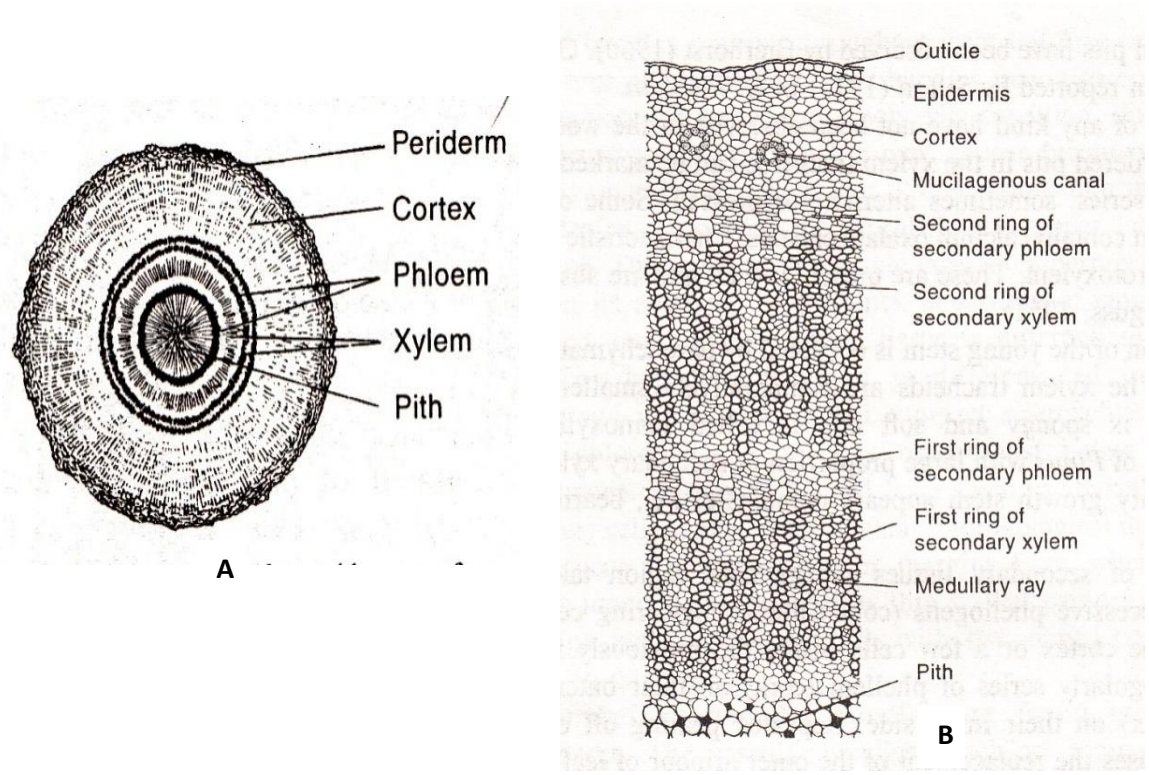


Fig.6.8. A. T.S. of an old stem of Cycas showing polyxylic condition, B. A part enlarged showing two secondary wood rings

Secondary growth is initiated by the activity of inter and intrafascicular cambia. Both cambia unite and form a cambium ring that cuts of secondary xylem towards inner side and secondary phloem towards outer sides. After a shortwhile this cambium ring stops functioning and a second cambium develops in the parenchymatous cortex. This cambium ring also behaves in the similar fashion. In this way as many as 14 rings of vascular tissue may develop showing polyxylic condition (Fig. 6.8 B).On the outer region of cortex the cork cambium also develops and cuts cork towards outer side and secondary cortex towards inner side.

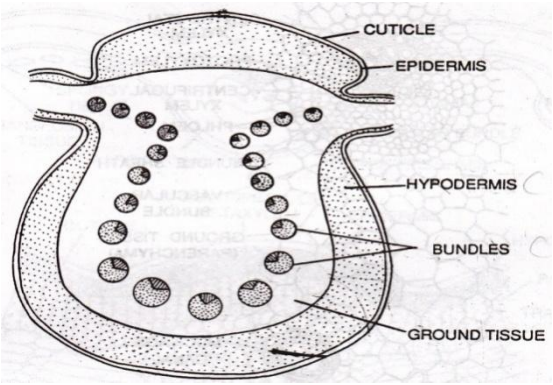


Fig.6.9. An outline diagram of T.S. of rachis showing the arrangement of vascular bundles (Ω).

C. Leaf

i. Anatomy of Rachis

It is a biconvex or roughly cylindrical structure in the transverse section (Fig.6.9). Two arms are present on the rachis, one on each side. These are the bases of the leaflets which arise from the rachis. Following structures are seen in transverse section.

a. **Epidermis**-Epidermis is outermost layer.It is heavily cuticularised and consisting of thick walled cells. Stomata are sunken and irregularly arranged on its upper as well as lower sides.
b. **Hypodermis**- Below the epidermis is present hypodermis.It is differentiated into outer green chlorenchymatous region and inner thick walled lignified layers of sclerenchyma.
c. **Ground Tissue**- Below the sclerenchyma a thin walled parenchymatous zone is present. In this region a number of many mucilaginous canal and vascular bundles are found. The number and arrangement of mucilage canals have no definite relation with that of vascular bundles.
d. **Vascular Bundles**- Vascular bundles are arranged in the shape of inverted Greek letter Omega (Ω)or horse shoe.Towards the tip of the rachis the bundles are arranged in C-shaped manner and their number is comparatively less. Each vascular bundle is more or less oval, conjoint, collateral, and open.

Each vascular bundle is surrounded by a thick walled layer called bundle sheath.Sometimes crystals of calcium oxalate are present in these cells.Inside vascular bundle the xylem is present towards inner side and consists of tracheids and xylem parenchyma. Cambium separates the xylem from phloem. **Vessels are absent.** The xylem is diploxylic*i.e.*two types of xylem is present in two patches, endarch (centrifugal) xylem and exarch(centripetal) xylem. Both xylems are separated by some parenchymatous cells. Phloem, present towards the outer side of the vascular bundle, consists of sieve tubes and phloem parenchyma. **Companion cells are absent.**

The vascular bundles show differences in their structures at the base, middle and apex of the rachis. Near the base vascular bundles are endarch. In the middle of the rachis these appear diploxylic and at the base of rachis vascular bundles becomeexarch.

ii. Anatomy of leaflet

Cycas leaflets are large, tough, thick and leathery (Fig. 6.10 A). In a vertical section the leaflet is differentiated into swollen mid rib portion and two lateral wings (Fig. 6.10 B). A transverse section of leaf-let shows following characters(Fig. 6.10 C).

a. **Epidermis**. The epidermis is single layered and is covered by thick layer of cuticle. Upper epidermis is a continuous layer while lower epidermis is non-continuous. Many sunken stomata are present here. Each stomata is made up of two guard cells that are surrounded by a pair of subsidiary cells. The stomata open outside into a**epistomal cavity** (external air cavity) and inside into a **hypostomatal chamber** (internal air cavity or sub-stomatal) Fig. 6.10 D.

b. **Hypodermis:** A single layered thick hypodermis is present on the inner side of upper and lower epidermis. Cells of hypodermis are sclerenchymatous. In the middle region it becomes two or three layered thick. Hypodermis is followed by zone of chlorophyllous mesophyll cells.

The features of special interest of xerophytic adaptation of *Cycas* leaf are as;

- Presence of cuticle.
- Presence of thick walled epidermis.
- Hypodermis is thick walled and present below epidermis.
- Presence of sunken stomata.Only on the ventral (lower) side
- The midrib is unbranched.
- Presence of transfusion tissue.

c. **Mesophyll**- A well developed mesophyll tissue is present in *Cycas* leaflets. It is differentiated into palisade and spongy parenchyma.**Palisade tissue** is present in form of continuous layer below the sclerenchymatoushypodermis. Cells are radially elongated and filled with chloroplasts. **Spongy parenchyma** is present only in the wings, directly above the lower epidermis. The cells are oval, filled with chloroplasts and loosely arranged having many intercellular spaces filled with air.

d. Transfusion tissue- It consists of two small groups of short and wide tracheid-like cells with reticulate thickenings or bordered pits on their walls. These cells were named as **transfusion tissue by Von Mohl** (1871), and were **first discovered by Frank** (1864). This tissue is present in both the wings (blades) just in between the palisade and spongy parenchyma.The function of transfusion tissue is supposed to help in water conduction.

e. Vascular bundle- A **single and largevascular bundle** is present in the mid rib portion of the leaflet. It is surrounded by a jacket of thick-walled cells.The vascular bundle is conjoint, collateral, open and diploxylic. The centripetal xylem is present on the upper surface of the leaf while the centrifugal xylem is present towards lower leaf surface. Phloem is present on the lower surface of the leaf. It is arc shaped and separated by cambium. Phloem consists of sieve tubes and phloem parenchyma. Companion cells are absent.

The portion of the mid rib in between the palisade layer and lower hypodermal region is filled with parenchymatous cells. Some of these cells contain oxalate crystals.

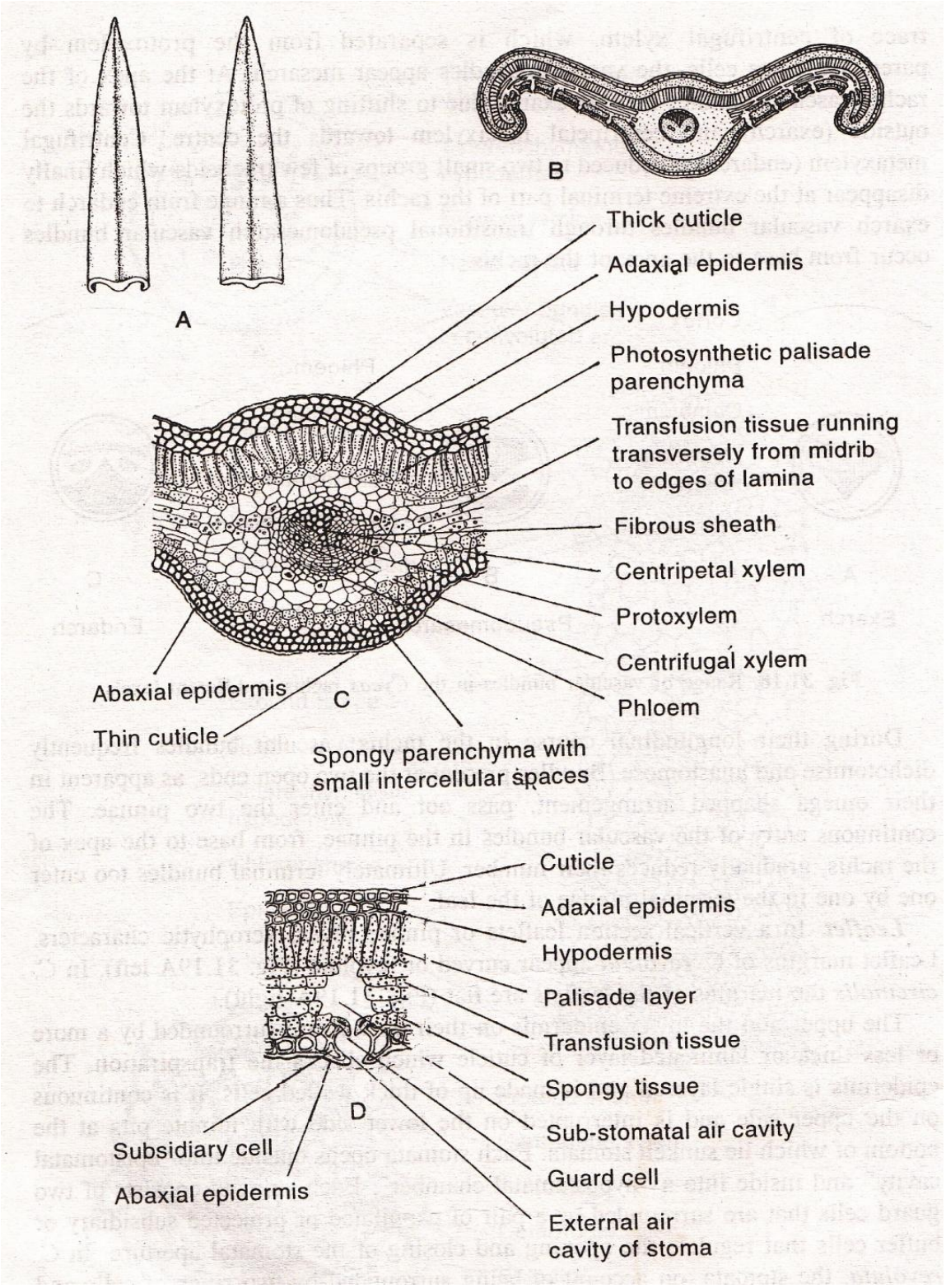


Fig. 6.10. A .Diagram showing the leaflets of *Cycas revoluta* and *C. circinalis*, B. Outline diagram of leaflet of *Cycas revoluta*, C. Enlarged view of middle portion of Cycas leaflet, D.Position of stomata showing external and sub-stomatal air cavity

6.3.2-Life History

6.3.2.1 Vegetative Reproduction

The easiest way to vegetative propagation in *Cycas* is **bulbil** (Fig.6.11). It is more or less an oval structure with a broad base narrowing towards the apex. Many scaly leaves are spirally and compactly arranged over a dormant stem in a bulbil. On detachment from the stem, a bulbil starts to germinate by producing roots from the lower side and leaf towards upper side.**A bulbil from male plant will develop only into male plant while from female plant will form only female plant because *Cycas* is dioecious**.

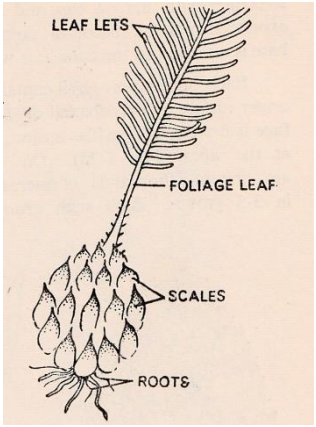


Fig.6.11.A single bulbil

6.3.2.2 Sexual Reproduction

Cycas plant is heterosporous and strictly dioecious*i.e.* male and female sex organs are born

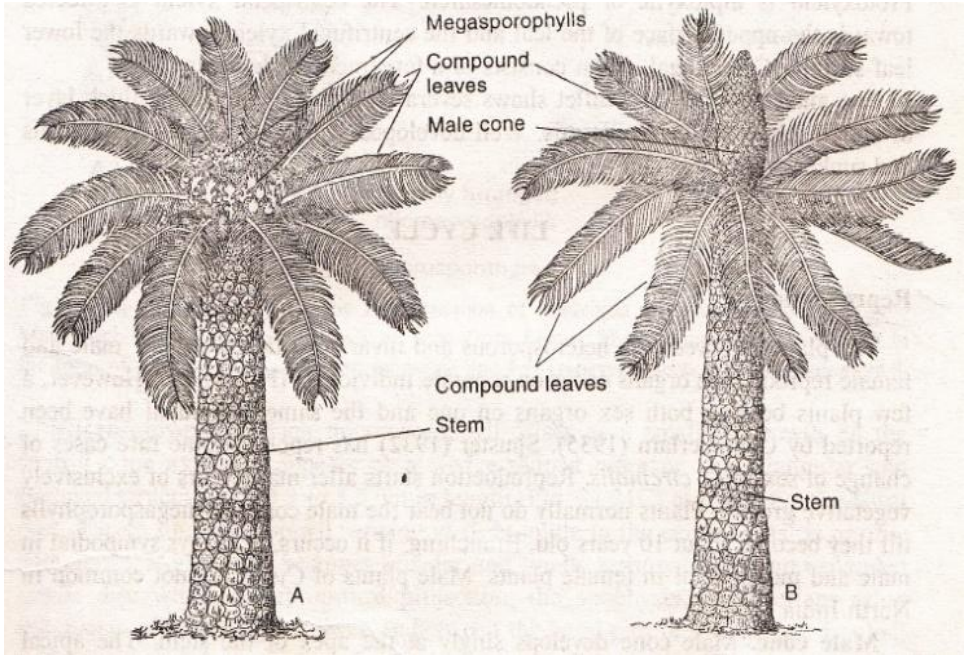


Fig.6.12. Cycas, A.Female plant, B. Male plant

on separate plants (Fig.6.12). Plant of *Cycas* is sporophytic (2n) and the sexual reproduction is oogamous. After many years of vegetative growth the plant starts to form sex organs. Generally,Cycads of more than 10 years of age produce the sex organs (Chamberlain, 1935). The male plants develop, male cone or male strobili bearing microsporophyll while female plants produce a loose collection of megasporophylls. The male cone is terminal while the megasporophylls are produced in succession with the leaves at the apex of the stem.

A. Male Reproductive Organs

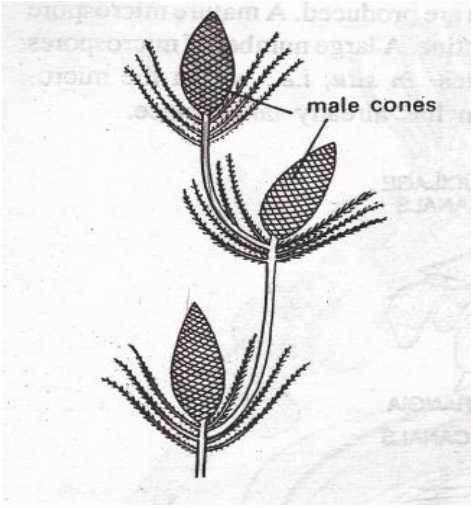


Fig.6.13.Cycas: Sympodial branching in male plant

i. Male cone: The male cone or strobilus is a large, conical or ovoid, compact, solitary and shortly stalked structure which is normally terminal. The plant is **sympodial**, *i.e*. the cone is pushed to lateral side and the stem continues to grow (Fig.6.13).The strobilus sometime reachesupto 0.5 meter in length. Male cones of *Cycas* are among the **largest cone** in the plant kingdom (Fig 6.14). In the center of the cone is present a cone axis.

ii. Microsporophyll- The arrangement of microsporophylls on cone axis is spiral.These unite to form a cone. Each microsporophyll is a flattened, leaflike, woody and brown coloured structure with narrow base and expanded upper portion (Fig. 6.15 A). The terminal sterile

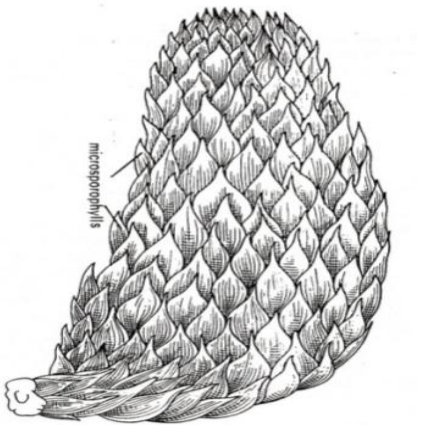


Fig.6.14.Cycas, male cone

part is called **apophysis**. Narrow base is attached to the cone axis with short stalk. Each microsporophyll contains two surfaces *i.e.* an adaxial or upper surface and an abaxial or lower surface.

iii. Microsporangia: On the abaxial surface thousands of microsporangia are present in groups(Fig 6.15A& 6.16 A). Each group is called a sorus(Fig 6.15 B). Each sorus is made up of 3-5 microsporangia(Fig 6.15 C), which in turn bears thousands of microspores. In between the sori(plural of sorus) many hair like structures occur. These hairs are very soft.

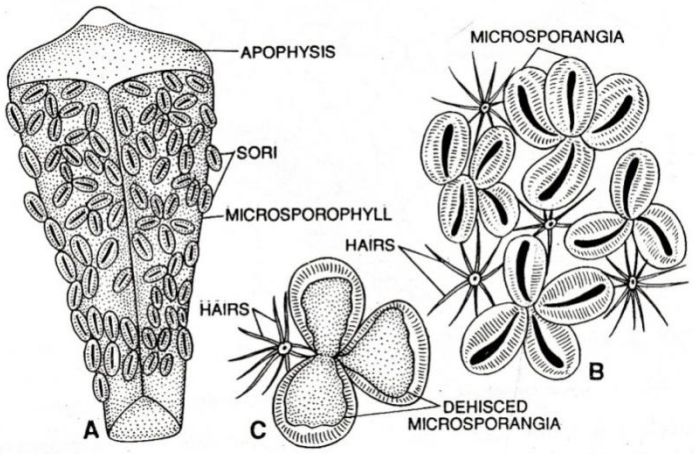


Fig. 6.15.A. Microsporophyll, B. Microsporangia and, C. Dehisced microsporangia

iv. Microspores: Each microspore or pollen grain is rounded or boat shaped, unicellular and uninucleate structure surrounded by an outer thick exine and inner thin intine(Fig. 6.16 C-E). Cytoplasm surrounds the centrally situated nucleus. A large vacuole is also present.

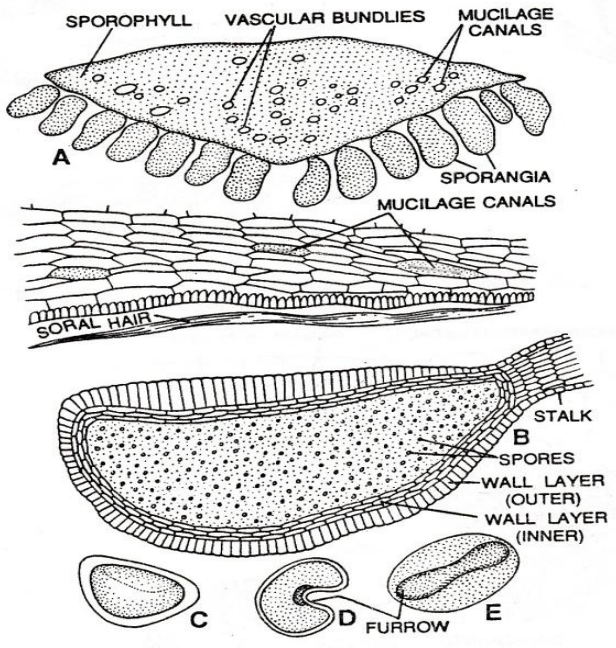


Fig.6.16. A. T.S. of microsporophyll showing sporangia on its lower surface, B. Enlarge view of microsporangium, C-E.mature spore released from microsporangium

v. Development of microsporangium: The development of microsporangium is of eusporangiate type. They are formed from a group of hypodermal cells called archesporiuminitials. Few initials divide periclinally to form outer primary wall cells and

inner primary sporogenous cells. Primary wall cells divide and redividepericlinally as well as anticlinally to form 5-7 cell thick wall of sporangium while primary sporogenous cells divide to form many sporogenous cells. By further division the sporogenous cells develop into microspore mother cells. The latter divide reductionally to form haploid microspores or pollen grains arranged tetrahedrally. The tapetum, which is utilized for the spore formation, develops either from the outermost layer of the sporogenous tissue or from the innermost layer of the wall tissue. Microspores are the first cell of the male gametophyte having haploid number of chromosome. The whole process is shown diagrammatically in Fig. 6.17 A-E.

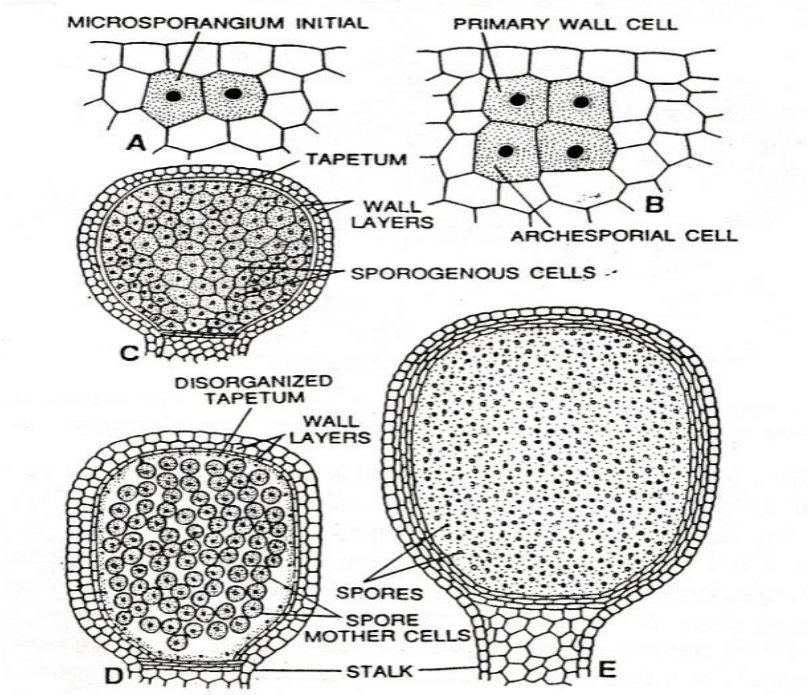


Fig. 6.17.A-E, stages in development of microsporangium

A fully mature microsporangium looks like a short stalked oval sac (Fig. 6.16 B) and dehisce by longitudinal slits. Shedding of the pollen grains starts from the top of microsporangium and proceeds towards the base.

B. Female Reproductive Organs

Female reproductive organs are present in the form of megasporophylls.True female cone is absent in *Cycas* because megasporophylls never aggregate to form a compact structure.

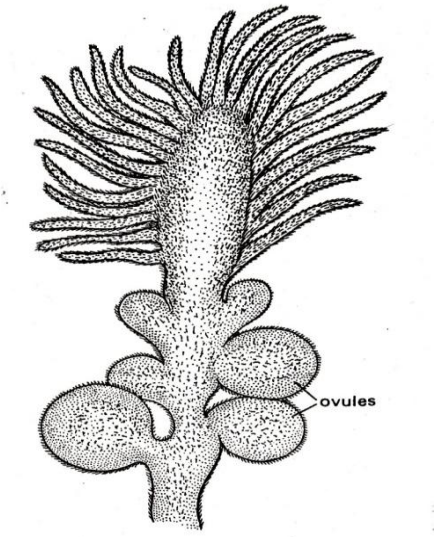


Fig.6.18.*Cycas revoluta,* Megasporophyll

i. Megasporophylls - Megasporophylls are spirally arranged at the apex of the stem but in very large number and thus appear like a rosette (Fig. 6.12 A). These are usually produced only once in a year in *Cycas*. The female plant of *Cycas* is monopodial and megasporophylls are born in acropetal manner which are covered with yellow or brown wooly hairs.

Each megasporophyll is a flat body consisting of an upper dissected or pinnate leaf portion, middle ovule bearing portion and proximal petiole (Fig. 6.18).The middle part is comparatively wider than petiole and bears two pinnate rows of ovules, the number of which varies between 2-12. The ovules are green when young but at maturity they are fleshy and bright orange or red coloured structure.

ii.Ovule: The ovule of *Cycas* isthelargest ovules amongst the living gymnosperms measuring about 7 cm. in length in some species.

iii. Structure of ovule: Ovule of *Cycas* is naked, orthotropous, unitegmic and shortly stalked.It is the largest ovule in plant kingdom which can be seen by naked eyes (Fig. 6.18).

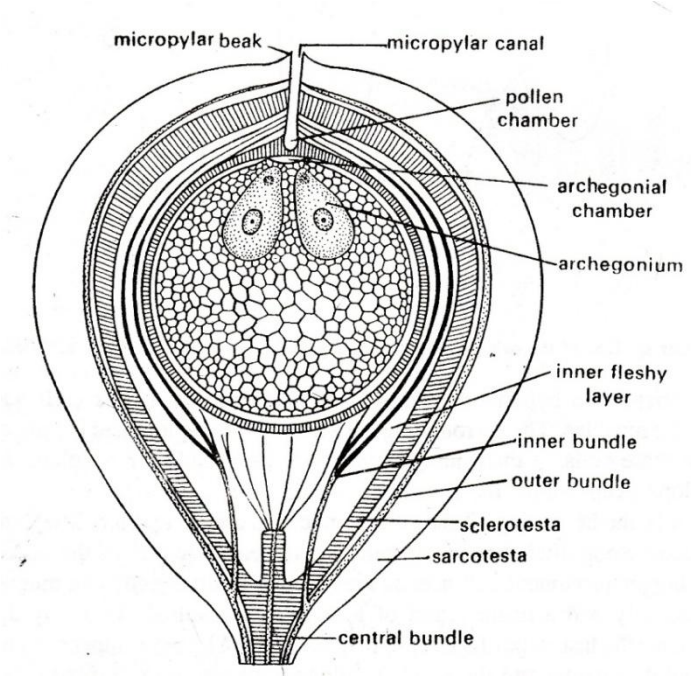


Fig. 6.19.V.S. of ovule showing internal structure before fertilization and its vascular supply

vertical section of the ovule (Fig 6.19) shows micropylar beak, three layered integument, a nucellus and female gametophyte.The single integument is very thick and covers the ovule from all the sides except a mouth like opening called micropyle.

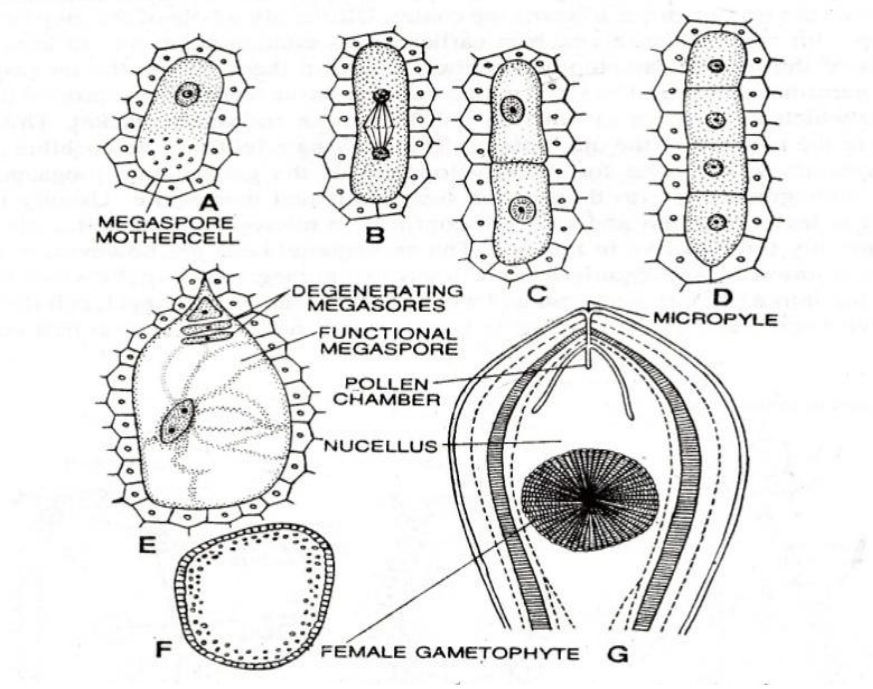


Fig. 6.20.Development of female gametophyte, A-D. Stages in the formation of linear tetrad, E.lower cell of linear tetrad develops into a megaspore, F. free nuclear division, G. cellular female gametophyte.

Integument of *Cycas* ovule is divided into three layers: o**uter fleshy layer (sarcotesta); middle stony layer (sclerotesta) andinner fleshy layer (inner sarcotesta).**

The nucellus grows out into a beak like portion called nucellar beak. The latter protrudes into the micropylar canal. Certain cells at the top of the nucellus dissolve and form a cavity like structure called pollen chamber. Pollen grains are received in the pollen chamber after pollination. Within the nucellus is present an enlarge megaspore or the embryo-sac. The endosperm is formed by the repeated divisions of the megaspore nucleus followed by free cell formation. Just below the pollen chamber is present an archegonial chamber where 3-6 archegonia are present.

iv. Formation of megaspore

In the central region of the nucellus, the nucleus of one of the cell enlarges, become different from other cells. It has dense cytoplasm and prominent nucleus.This cell is called as megaspore mother cell. It undergoes two divisions. The first division is reductional and transverse while the second is followed by mitotic and transverse division. Thus each megaspore mother cell form four megaspores which are arranged in a linear tetrad (Fig.6.20 A-D). Out of these four megaspores, the upper three, present towards the micropyle end, degenerate, leaving behind only a lowermost functional megaspore or embryo sac cell. This is the first cell of the female gametophyte.

Gametophytes

A.Male gametophyte: Microspore is the **first cell of male gametophyte** as mentioned

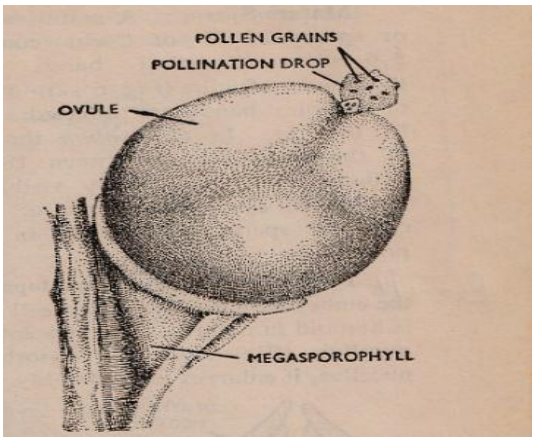


Fig. 6.21. An ovule with pollination drop and pollen grain (after Pant, 1973)

earlier. The development of microspore is partly completed in the microsporangium and partly in the ovule.

i. Gametophyte Development (Before Pollination): The microspore starts germination *in situ i.e.* while still inside the microsporangium. The microspore nucleus divides into two and ultimately two unequal cells are formed. The smaller one is called prothalial cell while the larger one represents the antheridial cell. The former does not divide further.The latter (*i.e.*antheridial cell) divides to form a generative cell near the prothallial cell and a large tube

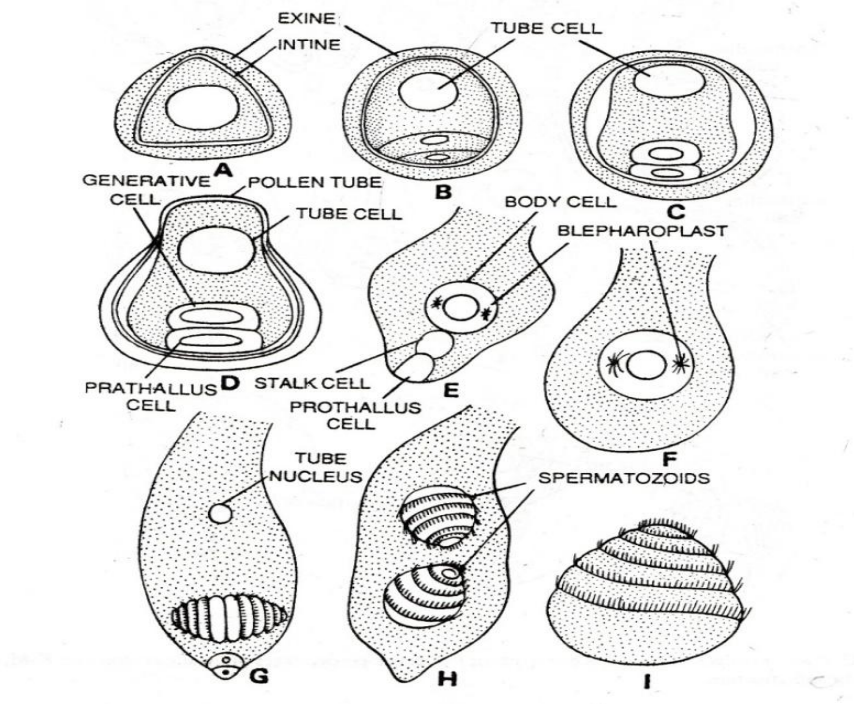


Fig. 6. 22. Cycas; A-G. Successive stages in the development of male gametophyte, H. two spermatozoids, I. one mature spermatozoids.

cell. The shedding of the microspores takes place at this three celled stage (*i.e.*prothallial cell, generative cell and tube cell).

ii. Pollination:-In *Cycas*pollination is **anemophilous***i.e.*the pollen grains are carried by wind to pollen chamber of the ovule. A pollination drop oozes out from the micropylar end on which pollens get stucked (Fig. 6.21). The three celled microspores are very light in weight and now reach to the pollen chambers of ovule.

iii. **Male Gametophyte Development (After Pollination)**: After a period of four monthsinside the pollen chamber the generative cell divides into a sterile (stalk cell) and a spermatogenous (body) cell. The exine breaks up and the intine comes out in the form of a pollen tube. The latter penetrates the nucellar tissue and acts as sperm carrier. The stalk cell does not divide any further. The body cell also enlarges in size. Now the prothallial cell pushes into the stalk cell and presses it against the cell. The body cell divides in the plane of the long axis of the tubes to form two sperm mother cells each having a single nucleus, a small amount of cytoplasm and develop a blepheroplast. Each sperm mother cell later on develops into a sperm. The sperms are liberated in the pollen tube by the breaking of the sperm mother cell. The whole process is shown in Fig. 6.22.

iv. Mature Sperm- A mature sperm or spermatozoid of *Cycas* contains 5-6 turns of spiral bands with thousands of cilia (Fig 6.22 I) and are clearly visible to the naked eye.

B.Female gametophyte

i. Female Gametophyte Development: Development of female gametophyteis shown in Fig. 6.20 E-G.Megaspore is the first stage of female gametophyte and is haploid in nature.The development of the female gametophyte occurs within the nucellus. Megaspore has thick outer wall called exospore and thin inner wall, endospore.The functional megaspore increases in size and divides by free nuclear divisions, thus produces a large number of nuclei.Now a vacuole appears in the centre. It pushes the free nuclei and cytoplasm of the megaspore towards its periphery.The wall formation takes place from periphery to the centre. Thus the whole gametophytictissue becomes cellular and each cell contains a single nucleus.This cellular haploid tissue is now called as female prothallus or endosperm.

ii. **Development of Archegonium**: An archegonium developsfrom a single superficial initial lying towards the micropylar end of the endosperm (Fig 6.23A).Archegonial initial gets enlarge and can be easily differentiated from the surrounding cells of the endosperm. It divides periclinally to form an outer primary neck cell and an inner central cell. The primary neck cell divides to form two neck cells. These cells form the neck of the archegonium. The central cell enlarges in size and form the venter.The nucleus of venter divides to form a ventral canal nucleus and an egg nucleus. The venter is surrounded by nutritive jacket of cells which is called as archegonial jacket (Fig. 6.23 A-C).**The number of archegonia in *Cycas* ranges from 2-8.**

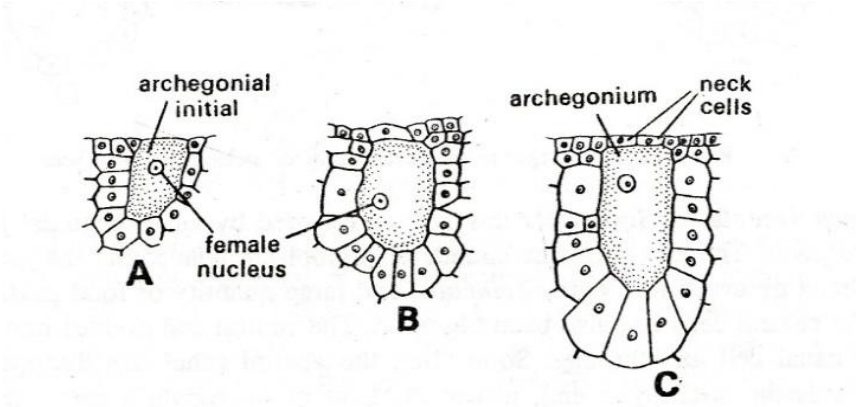


Fig.6. 23.A-C.Stages in development of archegonium

C. Fertilization

The pollen tubes containing sperms and the tube nucleus grow downward penetrating the tissue of the pollen chamber. In the end the pollen tube bursts and discharges its contents into the archegonial chamber. One of the sperm enters the archegonium through

Siphonogamy is a condition in plants in which pollen tubes are developed for the transfer of the male gametes to the eggs *e.g.* seed plants. While in lower plants and some gymnosperms the male gametes (antherozoids)swim in a film of water or transferred by wind to the female gametes (archegonium), this condition is called as Zoidogamy.

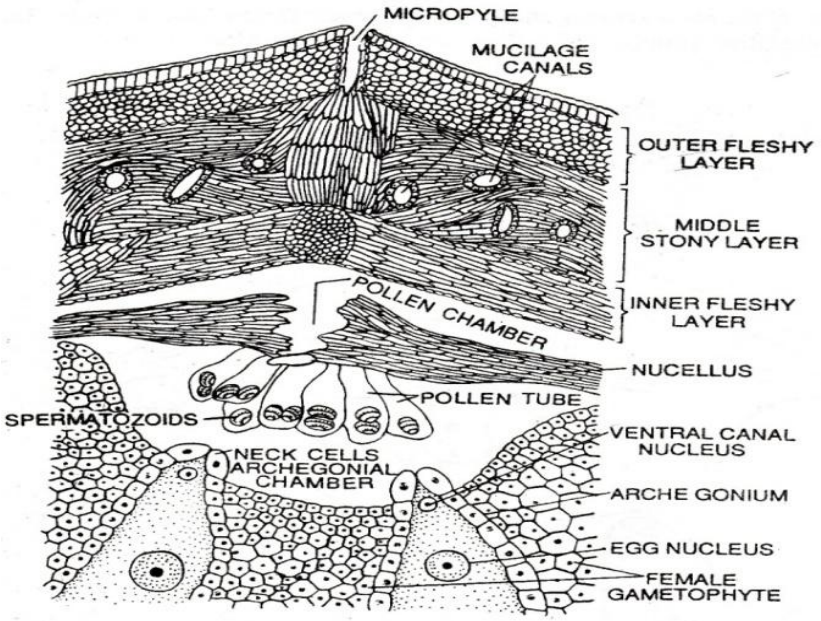


Fig. 6.24.V.S. of mature ovule

its neck and reaches upto the egg. In this process the cilia and the cytoplasmic membrane of sperm are stripped off and the fusion takes place between the female nucleus and the naked male nucleus.

Thus, the fertilization in *Cycas* takes place with the help of motile ciliated sperms (Fig. 6.24), a phenomenon known as **zoidogamy**. This phenomenon was first reported by Ikeno (1896).Zoidogamy of *Cycas* is accompanied by the pollen tube formation, a phenomenon now called **siphonogamy**. The pollen tube acts a sperm carrier.

D. Embryogeny

Development of Zygote: The fertilized egg or oospore or zygote is the first cell of sporophyte. The zygote contains dense cytoplasm and a large nucleus. The nucleus moves towards the base and starts dividing by repeated free nuclear divisions to form hundreds of nuclei (Fig. 6.25). They lie scattered throughout the cytoplasm. A vacuole appears in the center. The wall formation starts from the base and progresses towards the upper side to form a small mass of cells. **This embryonal mass of cells represents the pro-embryo (**Fig. 6.25**).** It has three regions (Fig 6.26).

Haustorial zone: This is the upper part of the pro-embryo.It absorbs the food material for the developing embryo.

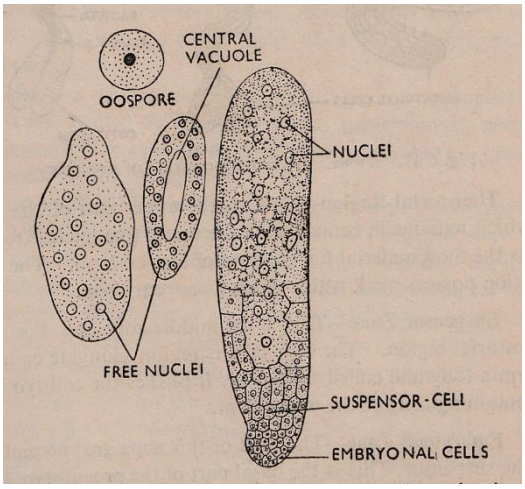


Fig.6.25. Cycas, Development of oospore (sporophyte)

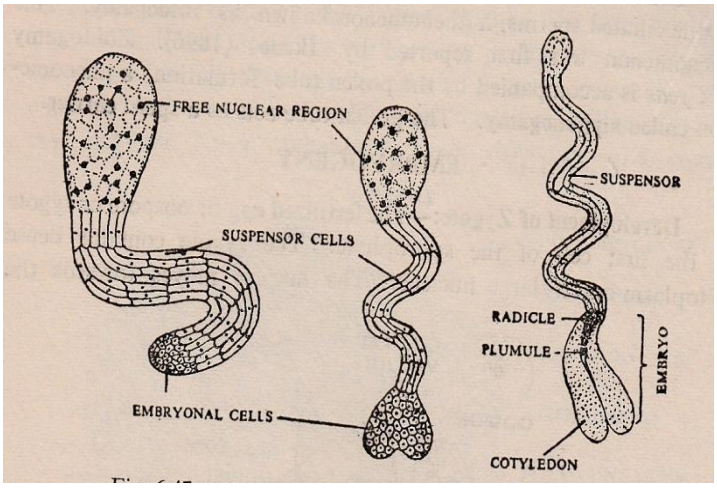


Fig. 6.26 Cycas, Showing development of proembryo

***Suspensor zone*-** This is the middle zone and lies next to the haustorial region. The cells of this region elongate enormously and form a long coiled suspensor. It pushes the embryo into the food containing cells of the endosperm.

***Embryonal zone*-** This is the basal part of the proembryo, which give rises to proper embryo. The embryo takes about one year for its complete development. It consists of suspensor, radical, two unequal cotyledons and plumule. The mature embryo is straight and the hypocotyls are very small. Now, ovule has converted into seed, which has three layered seed coat(outer, middle and inner).

E. Structure of seed

The mature*Cycas* seed (Fig 6.27A) is fleshy and red orange or brownin colour.The seed consists of testa, nucellus, endosperm and straight embryo.

Thus mature seed of *Cycas*, is representation of three generations:

a. The old parent sporophytic generation (2n) is represented by integument(testa),
b. The gametophytic generation(n) is represented by the endosperm and,

c. The new sporophytic generation (2n) is represented by the embryo.

3. Germination of seed

The seed starts to germinate without undergoing a period of rest. The germination of *Cycas* seed is **epigeal***i.e.*the cotyledons do not come out of seed(Fig6.27 C-D) but they absorb the food material from the endosperm for germinating seedlings.

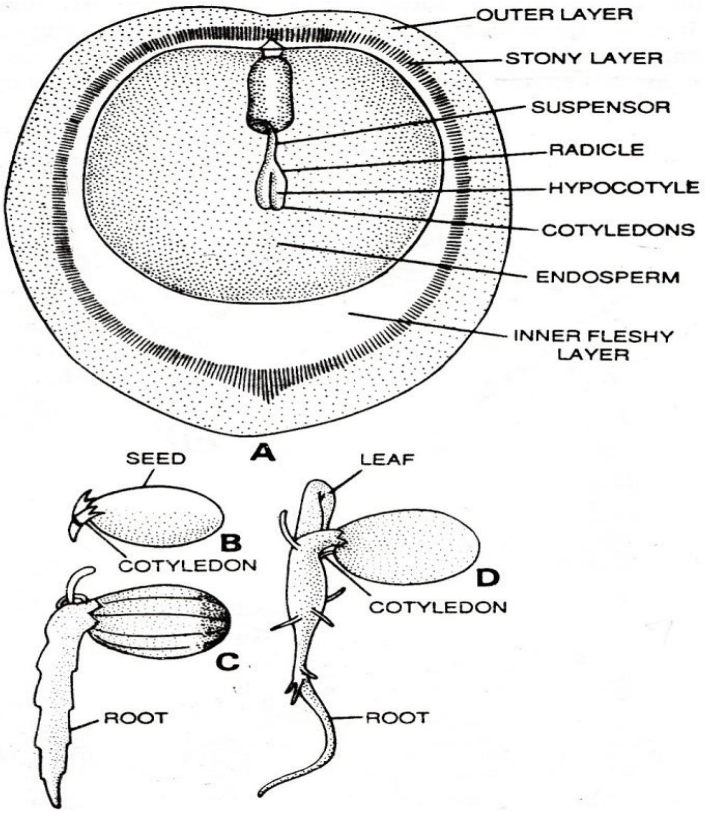


Fig. 6.27.Cycas, A. L.S. of seed, B-D. Succesive stages in seed germination

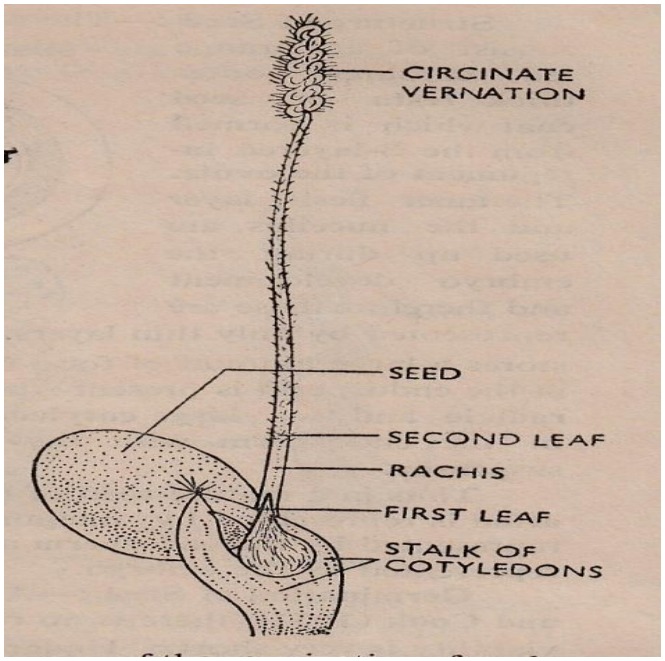


Fig. 6.28.Cycas, Germinated seed with two leaves

The plumule comes out and forms first, a few scaly leaves and then a foliage leaf. The young foliage leaves show cercinate vernation (Fig. 6.28). The first crown of leaves is formed after several years. The diagrammatic representation of life- history of *Cycas*has been given in previous chapter in Fig.5.8 while graphical representation is shown in Fig. 6.29.

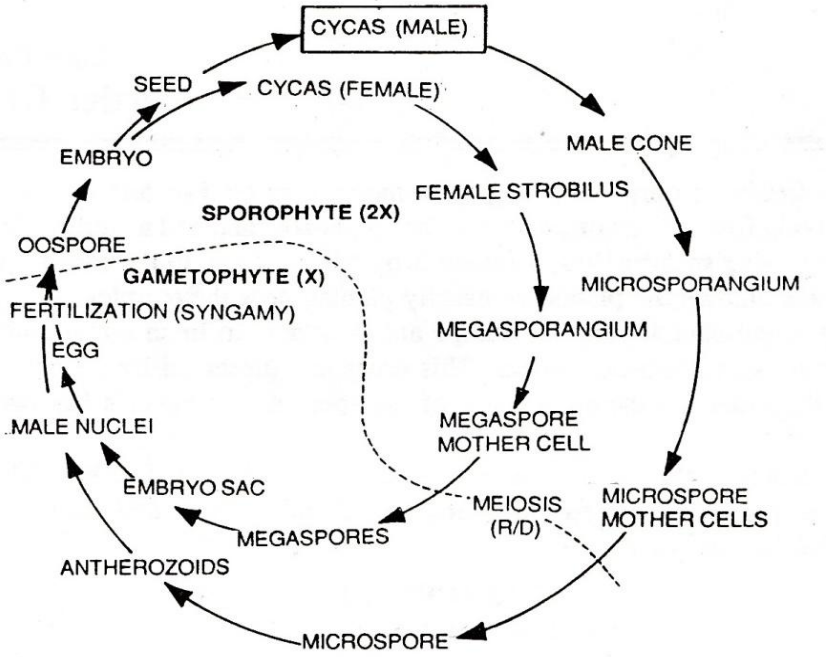


Fig.6.29. Graphical life cyle of Cycas

6.3.3 Economic Importance of *Cycas* and its Affinities

Now, after describing the systematic position, geographical distribution, structure and life-history of *Cycas*, let you know the economic importance and affinities of this plant with other gymnosperms and ferns.

***Cycas* is economically important as below-**

1. The pith of *Cycasrevoluta* yields "sago". It is a starch rich food and largely cultivated in Japan.
2. Cooked seeds of *Cycasrumphii* are eaten by Andamanes tribes.
3. Tender fleshy shoot of *C. pectinata* are eaten by hill tribeof Assam.
4. Young shoots of *C. circinalis* are also edible.
5. The leaves of *C. circinalis* are used in making mats in south India.
6. *C. rumphii* yields a kind of gum.
7. In Indonesia, Malaya and Assam the young succulent leaves of *Cycas*spp. are cooked as vegetable.
8. Leaves of *Cycas* are popularly used for decoration.

The structure of the *Cycas* leaflet is such that the leaves of *Cycas* are strong and leathery. As they keep their freshness and green colour for a long time, after being cut off from the plant.Thus they are popular for decoration.

Affinities of *Cycas*

Resemblances with other gymnosperms: *Cycas*shows resemblances with other gymnosperms in having following characters:

1. Cycas is xerophytic and possesses conjoint, collateral and open vascular bundles.
2. Xylem lacks vessels and phloem lacks companion cells.
3. Female gametophyte is reduced and completely dependent on the sporophyte.
4. Pollen tube develops inside pollen chamber.
5. Archegonia are without neck canal cells and the neck is reduced.

Resemblance with Filicinae (ferns): They show following resemblances-

1. Stem when young is underground and subterranean.
2. Leaf-bases are like tree ferns.
3. Young leaves exhibit circinate vernation.
4. Sporophylls are leaf-like.
5. Microsporangia are aggregated to form the sori on the lower surface of microsporophylls.
6. Development of the microsporangium is eusporangiate type.
7. Sperms are multiflagellate and motile and need a film of water for fertilization.

6.4- SUMMARY

In this unit you have studied the structure and life-history of *Cycas*and also learnt in detail the distribution of *Cycas*in India, it'sstructure and life history, economic importance and affinities with ferns and other gymnosperms. So, letus sum up it:

1. *Cycas* is commonly called as "sago palm".
2. It is found wild or cultivated in the tropical and sub-tropical regions of the world.
3. The plant is slow growing, long lived and evergreen.
4. The stem is thick, woody and usually unbranched. Young stem is tuberous(found under the soil surface) while mature stem is columnar, erect and stout.
5. Two types of leaves are present in *Cycas i.e.* green(assimilatory foliage leaves) and scaly leaves (cataphylls).
6. Foliage leaves are produced at stem apex in large number and are pinnately compound.
7. Leaflets of young leaf show circinate vernation.
8. Two types of roots are found, *i.e.* tap root and coralloid roots. The former are normal roots while the later are green, dichotomously branched,negatively geotrophic and look like corals.
9. The internal structure of the coralloid roots is similar to that of normal roots but they differ with normal roots in having poorly developed secondary tissue or none.
10. The cortex is differentiated into three distinct zones*i.e.* outer cortex, middle cortex (algal zone) and inner cortex.
11. The algal zone is usually one celled wide, made up of loosely connected thin walled cells and dominated by certain cynophycean algae which perform the function of nitrogen fixation.
12. The tap root is similar to a dicot root in internal features.

13. Stem anatomy of *Cycas* shows manoxylic wood which is formed by the activity of polyxylic vascular rings.
14. Starch in the parenchymatous cells of the cortex is the source of "sago".
15. There are no vessels in xylem and companion cells in phloem tissue.
16. An interesting feature of *Cycas* is girdling of stem by the formation of leaf traces. Two out of the four, are direct traces while remaining two are girdle traces.
17. Anatomy of rachis shows that vascular bundles are arranged in the shape of inverted Greek letter Omega(Ω) or horse shoe.
18. The vascular bundles show differences in their structures at the base, middle and apex of the rachis.
19. In a vertical section the leaflet is differentiated into swollen mid rib portion and two lateral wings.
20. The presence of transfusion tissue in leaflet of *Cycas* is an interesting feature.
21. *Cycas* reproduces vegetatively bymeans of bulbils.
22. *Cycas* plant is heterosporous and strictly dioecious*i.e.* male and female sex organs are born on separate plants.
23. Sexual reproduction is oogamous type.
24. The male sex organs are born on male plants(male cones bearing microsporophylls) while female sex organs are produced on female plants(a loose collection of megasporophylls).
25. The male cone or strobilus is a large, conical or ovoid, compact, solitary and shortly stalked structure which is normally terminal in position.
26. Several microsporophylls are spirally arranged on cone axis to unite and form a cone.
27. Microsporophylls bear numerous microsporangia on their lower surface which in turn consists of thousands of microspores.
28. True female cone is absent in *Cycas*. A number of loosely arranged megasporophylls are present at the apex of female plant.
29. Each megasporophyll is a flat body consisting of an upper dissected or pinnate leaf portion, middle ovule bearing portion and proximal petiole.
30. The middle part is wider than petiole and bears two pinnate rows of ovules.
31. The ovules are green when young but at maturity they are fleshy and bright orange or red coloured. The ovule of *Cycas*is the largest ovule in the plant kingdom.
32. Microspore is the first cell of male gametophyte and is shed at three celled stage *i.e.*prothallial cell, generative cell and tube cell.
33. In *Cycas*pollination is anaemophilous
34. The functional megaspore or the embryo sac cell is the first cell of the female gametophyte. It is haploid in nature.
35. An archegonium develops from the micropylar end of the female gametophyte.
36. A mature archegonium of *Cycas* consists of two neck cells and an egg.
37. Fertilization is siphonogamous.
38. The fertilized egg or oospore is the first cell of sporophyte.
39. After divisions of zygote,proembryo is formed which has three distinct regions. The mature seeds of *Cycas* are fleshy and red or orange coloured.
40. The germination of *Cycas* seed is epigeal.

41. *Cycas* shows resemblance with ferns in having underground and subterranean stem, circinate vernation, sporophylls leaf-like, *etc*.
42. With gymnosperms it shows resemblance in xerophytic habit, devoid of vessels and companion cells, pollen tube development inside pollen chamberand archegonia without neck canal cells.

6.5- GLOSSARY

Archegonium : The structure that produces the female gamete or egg.
Bordered pit : A pit in which the margin projects over the thin closing membrane, as in coniferous wood.
Bulbil : A mode of vegetative reproduction.
Casparian strip/band: A strip encircling radial walls of endodermis cells.
Ciliate : Fringed with hairs.
Cone : A group of sporophylls arranged compactly on a central axis.
Conifer : Cone-bearing plants, such as pines (*Pinus*).
Crown : The uppermost portion of a tree.
Dichotomous : Divided into two approximately equal branches resulting from the division of a growing point.
Dioecious : Having the male and female reproductive structures on separate plants
Exine : Outer layer of a spore wall.
Frond : The whole leaf of a fern or cycad, including the lamina and petiole.
Manoxylic : Having secondary wood of a loose texture with discontinuous xylem and a large proportion of included parenchyma.
Megasporophyll: A specialised leaf upon which (or in the axil of which) one or more megasporangia are borne.
Monoecious : Having the male and female reproductive parts in separate organs but on the same plant.
Oospore :The zyogte or fertilized egg cell.
Ovule : The structure in flowering plants and gymnosperms which when fertilized develops into a seed.
Rachis : A midrib of the lamina.
Rhomboidal : Diamond-shaped or almost so.
Sarcotesta : The fleshy outer layer of the seed coat in Cycads.
Sorus : A cluster of sporangia.
Sphaeraphides: Globular clusters of minute crystals in vegetable cells.
Sporangium : A structure within which spores are formed.
Sporophyll : A specialised leaf-like organ that bears one or more sporangia.
Stout : With armature that is relatively thick and sturdy; not breaking easily.
Strobilus : A cone-like body, consisting of sporophylls borne close together on the axis.
Tetrad : A group of four.
Tracheid : An elongated closed cell of wood having secondary thickening and conducting water.
Vascular bundle: The primary fluid-conducting system of a plant.

Vernation **:** The arrangement of the unexpanded fronds in a bud.

6.6- SELF ASSESSMENT QUESTIONS

6.6.1 Very short answer type

1. Name the algae found in the coralloid roots of *Cycas.*
2. In rachis of *Cycas* the vascular bundles are arranged in which fashion?
3. Centripetal and centrifugal xylem is present in which parts of *Cycas* plant?
4. The wood of *Cycas* is of what type?
5. The ovule of *Cycas* is of what type?
6. Name the plant in which a pollination drop is oozes out from the micropylar end.
7. At what cell stage pollination takes place in *Cycas*?

6.6.2 Objective type Questions:

1. Which is known as Sago palm?

(a) *Cycas* (b) *Pinus*
(c) *Gnetum* (d) *Ginkgo*

2. A blue green alga lives in;

(a) *Riccia* thallus (b) *Marchantia* thallus
(c) *Cycas* roots (d) *Pinus* roots

3. Spermatozoids large enough to be seen by naked eyes are produced in;

(a) *Cycas revolute* (b) *Pinus roxburghii*
(c) *Gnetum ula* (d) *Ginkgo biloba*

4. Anatomical features of the *Cycas* leaflet indicate that *Cycas* is a;

(a) Xerophytes (b) Mesophyte
(c) Hydrophyte (d) Parasite

5. What could be the best function attributed to the transfusion tissue seen in *Cycas* leaflets?

(a) Mechanical (b) Photosynthetic
(c) Conduction (d) Storage

6. Which of the following is not the characterstic feature of *Cycas*?

(a) Circinate type of foliage leaves (b) Presence of arm parenchyma
(c) Presence of motile sperm (d) Absence of vessels in the xylem

7. In *Cycas*;

(a) Male cone (strobilus) and megasporophylls occur on separate plants
(b) Male cone and megasporophyll occur on the same plant
(c) The same cone contain both microsporangia and ovules
(d) The same sporophyll bears microsporangia and ovules

8. Which of the following is the living fossil?
(a) *Pinus* (b) *Cycas*
(c) *Ephedra* (d) None of the above

9. In *Cycas* male cone lacks;
(a) Microspore (b) Microsporophylls
(c) Microsporangium (d) Nucellus

10. The tracheids of *Cycas* are:
(a) With uniseriate bordered pits (b) With biseriate bordered pits
(c) With multiseriate bordered pits (d) Without bordered pits

11. The coralloid roots are found in;
(a) *Cycas* (b) *Pinus*
(c) *Gnetum* (d) *Ephedra*

12. The pollination in *Cycas* takes place through;
(a) Wind (b) Water
(c) Insects (d) None of the above

13. *Cycas* is;
(a) Monoecious (b) Dioecious
(c) Hermaphrodite (d) None of the above

14. The wood of *Cycas* consist of:
(a) Tracheids only (b) Vessels only
(c) Equal number of tracheids and vessels (d) More of tracheids and less of vessels

15. *Cycas* differs from *Pteris* in having;
(a) Tracheids (b) Motile sperms
(c) Pollen tubes (d) Archegonia

16. In *Cycas* pollen grains are shed at the;
(a) 4-celled stage (b) 3-celled stage
(c) 2-celled stage (d) 5-celled stage

17. *Cycas* ovule is;
(a) Anatropous (b) Orthotropous
(c) Hemiantropous (d) Circinatropores

18. Sperms of *Cycas* are;
(a) Very large and have numerous spirally arranged cilia
(b) Very small and have no flagella
(c) Large and non-ciliate

(d) Small and non motile

6.6.3 Fill up the blanks:

1. *Cycas revolute* is commonly known as . . . . . .
2. *Cycas* is known as . . . . . because it's all related genera are fossils.
3. Sago starch is obtained from . . . . . .of *Cycas*.
4. *Cycas* have . . . . . .types of roots.
5. Coralloid roots are found in. . . . . .
6. The ovule of *Cycas* is. . . . . .
7. Young leaves of *Cycas* show. . . . . .
8. The leaves of *Cycas*show. . . . . .character.
9. During the vegetative propagation in *Cycas*, a bulbil from male plant will develop into. . . . . plant only.
10. Manoxylic wood is the characteristic feature of. . . . . .
11. Leaf margins of *Cycasrevoluta* are. . . . . .
12. Leaf margins of *Cycascircinalis* are. . . . . .

6.6.4True/ False:

1. Polyembryonyis seen in *Cycas*.
2. *Cycas* pollen grain shed at 5 celled stage.
3. *Cyacs* wood consists of tracheids only.
4. The endosperm of *Cycas* is triploid.
5. Leaf margins of *Cycascircinalis* are revolute.

6.6.1 Answer key: 1.*Anabaena* and*Nostoc*, 2. Inverted omega, 3.Rachis and leaflet, 4. Manoxylic, 5.Orthotropous, 6. *Cycas* (ovule), 7. Three celled stage.

6.6.2 Answer key: 1.a, 2.c, 3.a, 4.a, 5.c 6.d, 7.a, 8.b, 9.d, 10.c, 11.a, 12.a, 13.b, 14.a,15.c 16.b, 17.b, 18.a

6.6.3 Answer key: 1. Sago-palm, 2. Living fossil, 3. Stem, 4.Two, 5.*Cycas*, 6. Orthotropous, 7. Circinate vernation, 8. Xerophytic, 9. Male, 10.*Cycas*, 11.Revolute, 12.Entire.

6.6.4 Answer key: 1. False, 2. False, 3. True, 4. False, 5. False.

6.7- REFERENCES

- Brandis, D. (1907*), Indian Trees*, Archibald Constable & Co., London.
- Brongniart, A. (1829), Recherches sur'1 organisation des tiges des Cycadees. *Ann. Sci, Nat. Bot. Ser*. I, Vol.16, pp.389-402.
- Chamberlain, C.I. (1935), *Gymnosperms-Structure and Evolution*, Chicago.
- Eichler, A.w. (1889), Cycadaceae In:Engler, A. AndPrantt, K. Die*NaturlichenPflanenfamilien*II, 1: 6-26.
- Frank, A.B. (1864), EinBritragzurkenntris der Getassbundel, *Bot. Zeit*, Vol. 22, pp.149.
- Fritsch, F.E. (1945), *TheStructure and Reproduction of the Algae* vol. 2, Cambridge.

- Ikeno, S. (1896), Das spermatozoid von *Cycasrevoluta*, Bot. Mag. Tokyo, Vol. 10, pp.367-368.
- Life, A.C. (1901), Thetuberlike rootlet of *Cycasrevoluta*. Bot. Gaz, Vol.31, pp.265-271.
- Pant. D.D. (1973), *Cycas and Cycadales*, Central Book Depot, Allahabad.
- Schuster, J. 1932. Cycadaceae in *Engler, A. Das Planzenreich*, 4, I. Leipzig.
- Seward. A.C. (1933), *Plant Life Cycle ThourghAges*, Cambridge.
- Spratt, E.R. (1911), The root nodules of the Cycadaceae. *Ann. Bot*., Vol. 25, pp.369-380.
- Von Mohl, M. (1871).Bot. Zeit. Vol. 29, pp.17-23.
- Winter, G. (1933).Beitr. Biol. *Pflanz.,* Vol. 23,pp.295-335.
- Worsdell, W.C. (1906), The structure and origin of the Cycadaceae, *Ann. Bot*. Vol. 20, pp.129-155.

6.8-SUGGESTED READINGS

- Botany for Degree Students -Gymnosperms: P.C. Vashishta, A.K. Sinha and A. Kumar (1976).
- College Botany. Vol. 2 : H.C. Gangulee and A.K. Kar (Reprint 1999).
- Gymnosperms- Structure& Evolution: C.J. Chamberlain (1935).
- Gymnosperms : P.C. Vashishta (1976).
- Gymnosperms of India and Adjacent Countries: K.C Sahni (1990).
- Gymnosperms: S.P BhatnagarandAlok. Moitra (1997).
- Gymnosperms: A Treatise :O.P. Sharma (1980).
- Indian Gymnosperms in Time and Space: C.G. K. Ramanujan (1979).
- Living Indian Gymnosperms : M.B. Raizada and K.C. Sahani, (1960).
- A Text Book of Botany : V. Singh, P.C. Pande and D.K. Jain (2008).
- The Moropology of Gymmosperms: K.R. Sporne (1991).
- http://plantnet.rbgsyd.nsw.gov.au/PlantNet/cycad/(accessed in March, 2015).
- http://biology.clc.uc.edu/courses/bio106/gymnospr.htm(accessed in March, 2015).
- http://www.biologyreference.com/Gr-Hi/Gymnosperms.html#ixzz3VIBvPMJk (accessed in March, 2015).
- http://www.conifers.org (accessed in March, 2015).

6.9-TERMINAL QUESTIONS

6.9.1 Long Answer Type:

1. Discuss briefly the systematic position, external morphology and economic importance of *Cycas* plant.
2. Write a brief account of stem of *Cycas*.
3. Give an illustrated account of the internal structure of young and old stems of *Cycas.*
4. How you will distinguish between normal root and coralloid root of *Cycas*?
5. Give a well illustrated account of the anatomy of the leaf of *Cycas* and comment upon the features of special interest found there in.

6. Give an account of anatomy of the leaflet of *Cycas* and explain the function of various tissues found therein?
7. Why *Cycas* is called sago palm? Give the distribution of this genus in India and describe the structure of vascular bundle of its rachis.
8. Give an account of female gametophyte of *Cycas?*
9. With the help of labelled diagrams show the development of male and female gametophytes of *Cycas*.
10. Give the graphical representation of the life cycle of *Cycas*?
11. Give an illustrated account of the reproduction in *Cycas*?

6.9.2 Short Answer Type:

1. Give diagram to illustrate the structure of ovule in *Cycas*. Why in most gardens of your locality the plants of *Cycas*don't bear seeds?
2. Describe the peculiarities in the structure and reproduction of *Cycas* which would indicates its origin from fern like ancestors.
3. Discuss the primitive and advanced features of *Cycas*.
4. Write short notes on
   a) Transfusion tissue.
   b) *Cycas*as a living fossil
   c) Economic importance of *Cycas.*
5. Answer the following-
   a) List the characters common to the *Cycas* and ferns.
   b) Why all *Cycas* plants donot produce seeds?
   c) Are the coralloid roots of *Cycas* useful for aeration or nitrification?
   d) Mention two common characters shared by all gymnosperms.

Q.6. Describe secondary growth in *Cycas* stem.

6.9.3 Diagrammatic type:

1. External morphology of a Cycad andConifer plant.
2. Draw the well labelled diagrams of following:
   i. T.S. of *Cycas* coralloid root and normal root.
   ii. T.S. of *Cycas* rachis and leaflet.
   iii. Male strobilus andmegasporophyll of *Cycas*.
   iv. L.S. of ovule of *Cycas*.
3. With the help of labelled diagram show the:
   i. Development of male gametophyte in *Cycas*.
   ii. Development of female gametophyte in *Cycas*.
   iii. Development of pro-embryo in *Cycas*.

UNIT-7 STRUCTURE AND LIFE HISTORY OF *PINUS*

7.1 OBJECTIVES

This unit describes structure and Life History of*Pinus.* After reading this unit you will be able to:

- Describe systematic position, habit, habitat and general features of *Pinus*
- Explain reproduction in*Pinus*
- Discuss life cycle in *Pinus*

7.2 INTRODUCTION

All of the pines are woody plants. The mugo pine (*Pinus mugo*), native to the Alps of Europe, is one of the smallest pines. At maturity, it is really more of a bush than a tree, and is often planted in gardens of Europe and North America. Many other pines which are native to North America are large trees which can grow 197-262 ft (60-80 m) or more in height.

The leaves of all pines are needle-like and arise from the stem in bundles, called fascicles. Each fascicle is often associated with a fascicle sheath, a special tissue at its base. Most species have two to five needles per fascicle, but some species have as few as one and others have as many as eight needles per fascicle. The needles of pines are arranged in a spiral about the stem. Each year, as the branch of a pine tree grows, it produces a whorl of new leaves, called a candle. The needles of pines last about two years and most species are evergreen, meaning they have some needles at all times. Since pines have needles throughout the year, they have the potential to photosynthesize whenever conditions are suitable.

The needles of pines, like those of other conifers, are well-adapted for growth in dry environments. In particular, the outer surface of pine needles has a thick waxy layer, called a cuticle, which reduces evaporative water loss. Like the leaves of all higher plants, pine needles have special microscopic pores on their surface, called stomata, which are important for exchange of water vapor, carbon dioxide, and oxygen. The stomata are usually arranged in rows on the underside of the needles, where they appear as white lines. At the microscopic level, the stomata are beneath the surface cells, so they are often called "sunken stomata." This stomata adaptation reduces evaporative water loss.

The pines are vascular plants, in that their trunks and stems have specialized cells, xylem and phloem, for the transport of water and food. The xylem of pines consists mainly of tracheids, elongated cells with thick walls and tapered ends. The phloem of pines consists mainly of sieve cells, elongated cells with relatively unspecialized sieve areas at the ends. Sieve cells are characteristic of gymnosperms and free-sporing plants, whereas sieve tube elements are characteristic of the more evolutionarily advanced flowering plants.

All species of pines are monoecious, in that male and female reproductive structures occur on the same plant. Once a pine tree reaches a certain stage of maturity, it forms male and female reproductive structures, termed strobili (singular: strobilus). The strobili of pines are unisexual, in that they contain either male or female reproductive organs, but not both. The

male strobili are typically about 0.4-0.8 in (1-2 cm) in diameter and form on the lower part of the tree. The female strobili are much larger and form on the upper part of the tree.

7.3 *PINUS*

Systematic Position

Division: Gymnospermae
Class: Coniferopsida
Order: Coniferales
Family: Pinaceae
Genus: *Pinus*

Distribution and habitat

The genus *Pinus* is widely distributed in the Northern hemisphere. There are about 75 species of this genus. About six species have been recorded from different parts of the country. The blue pine, *Pinuswalichiana* is largely found in North-West Himalayan region at 1,800 metres to 7000 metres elevation. The chir pine *P. roxburghii* occurs from Afghanistan to Bhutan in the outer range of Himalayas. This species is also commonly found in the Indian plains. The chilgoza pine *Pinusgerardiana* is found in the inner arid valley of the Himalayas at 1,800 m. to 3,000 m. elevation.

The Khasi pine, *Pinus insularis* is distributed in the Khasi, Naga hills and Manipur region at elevations-of 750 m to 1950 m. Recently a Chinese species *Pinusarmandi* has also been recorded from the north-east hills of Assam. The merkus pine, *Pinusmerkusii* is found in the hills of Burma150 m to 172 m elevations. In addition to these species several exotic pines have been introduced in India, e.g., *P. montana, P. laricio, P. sylvestris,* etc.

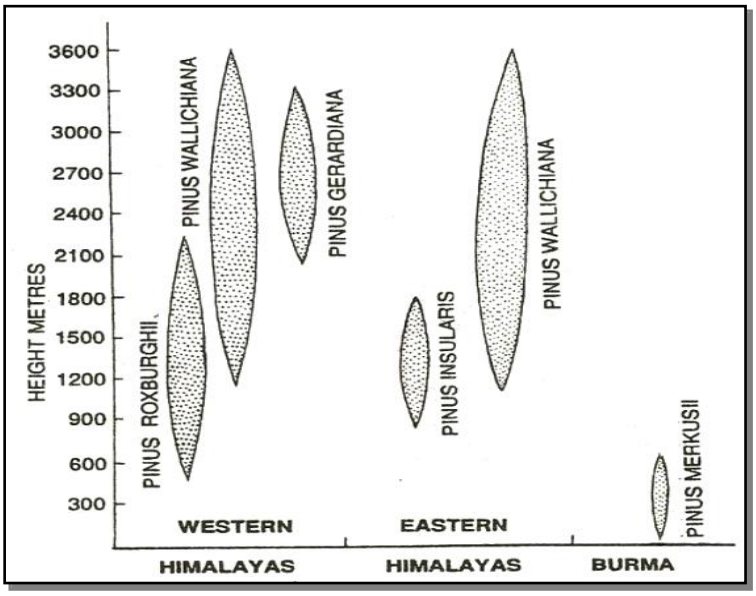


Fig. 7.1. *Pinus:* Distribution of the different species in the Himalaya and Burma

7.3.1 *Pinus:* structure

External Features

The full-grown plant of *Pinus* is a large tree giving rise to a series of widespread branches. In most of pine trees a whorl of branches are produced each year. Sometimes, in young and vigorous trees two such whorls may be produced in one year. The whorls are formed in the axils of scale leaves every year. The main shaft is cylindrical and covered with a rough scaly bark. The branching is confined to the upper part of the stem, giving a pyramid like appearance to the plant. The branches are dimorphic, the two forms being characterized as long shoots and dwarf shoots. These shoots are also known shoots of unlimited growth and shoots of limited growth respectively. There are two kinds of leaves, the scale leaves and the

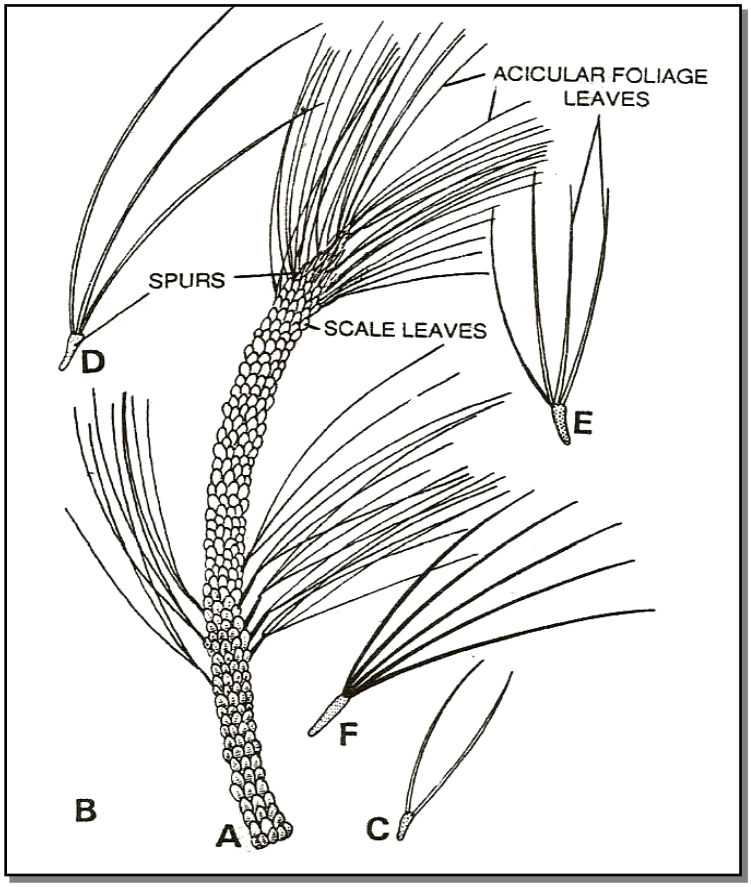


Fig.7.2. *Pinus:* External Features, A. shoot of unlimited growth, B. spur of *P. Monophylla, C.* spur of *P. Sylvestris*, D. spur of *P. Roxburghii,* E.Quadrifoliar spur, F. pentafoliar spur of *P. Wallichiana*

green acicular foliage leaves which are commonly termed as needles. The dwarf shoots or shoots of limited growth bear the foliage leaves whereas the long shoots or shoots of unlimited growth bear the scale leaves on them. The dwarf shoots with their cluster of green leaves are known as spurs. The number of needles in each spur varies from species to species. Each spur of *Pinus monophylla* is unifoliate; the spurs of *P. sylvestris* and *P. pinaster* are bifoliate, the spurs of *P. roxburghii, P. gerardiana* and *P. insularis* are trifoliate while the spurs of *P. wallichiana* are pentafoliate. The pine trees possess tap root. The tap root is elongated and possesses strong lateral-roots. The flowers are monoecious, i.e., male and

female strobili (cones) are borne on the same plant. The male flowers are catkin-like (cones) but erect in position. They are found in axils-of membranous bracts which are spirally arranged on the axis. The young female cones are solitary, paired or whorled at the apex of the current year's shoot and consist of a central woody axis on which the two sets of scales are arranged in spiral way. The female cones are usually found on the shoots which do not bear male cones and take the place of shoots of unlimited growth.

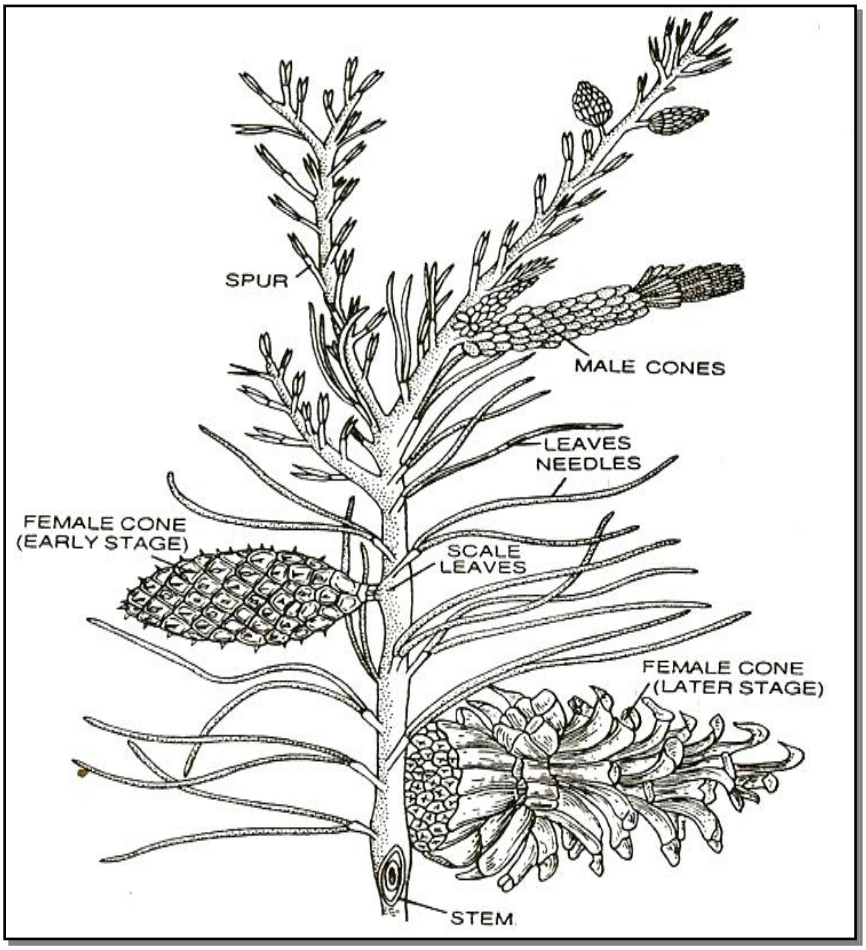


Fig.7.3. *Pinus:* Twig showing male and female cones, spurs, scale leaves and foliage leaves

Internal Features

Root

The internal structure of root resembles to that of a dicotyledonous root. In a transverse section the root shows a piliferous layer bearing unicellular root hairs. The root hairs are found in the young roots and root tips. In young roots there is a fungal growth of ectophyticmycorrhiza. With the appearance of this fungus the root hairs of the root disappear. Just beneath the piliferous layer there lies a broad cortex which consists of 4-5 layers of thin walled parenchymateous cells. The inner most layer of the cortex is a single layered endodermis consisting of brown suberized cells containing tannin in them. Just below the endodermis there is a multilayeredpericycle containing tannin and starch grains. Lateral roots are developed from the second layer of the pericycle. The outermost layer of the pericycle

helps in the formation of the digestive sac which enables the lateral roots to penetrate through cortex to the outside.

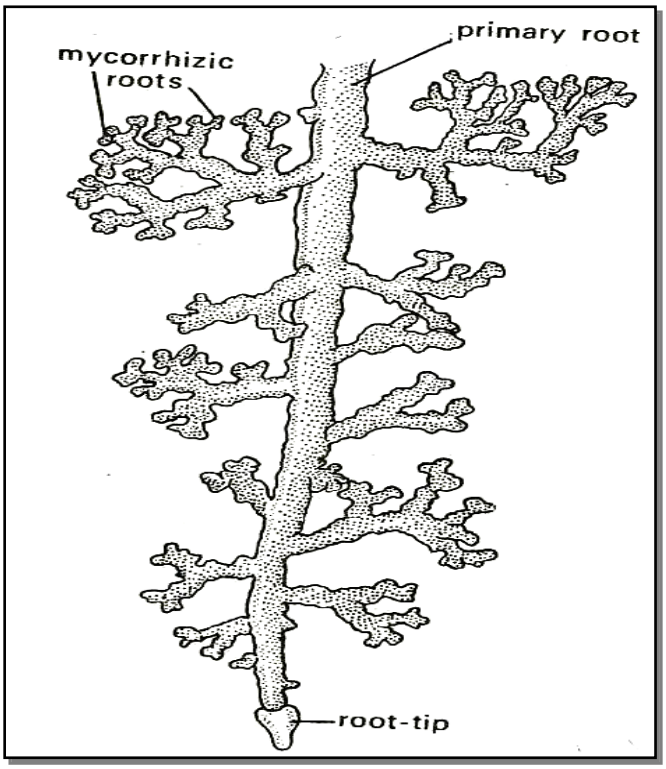


Fig.7.4. *Pinus:* The primary tap root bearing mycorrhizic roots

In the centre of the stele there are two six Y-shaped xylem bundles, and an equal number of phloem bundles alternating with them. The xylem has no true vessels and consists of tracheids. The phloem consists of sieve tubes and phloem parenchyma. Companion cells are altogether absent. In between the arms of a Y-shaped xylem bundle there lies a resin canal. In the centre there is small pith.

The secondary growth takes place as in dicotyledonous roots. A cambial strip develops from parenchymatous cells in between the phloem and metaxylem. This cambium cuts secondary xylem towards the inner side and the secondary phloem towards the outside. Simultaneously a layer of the pericycle functions as a cork cambium and cuts off a layer of cork cells towards the outside. A thick layer of cork develops which separates the cortex from the stele and because of this barrier of cork the cortex does not get food and dies.

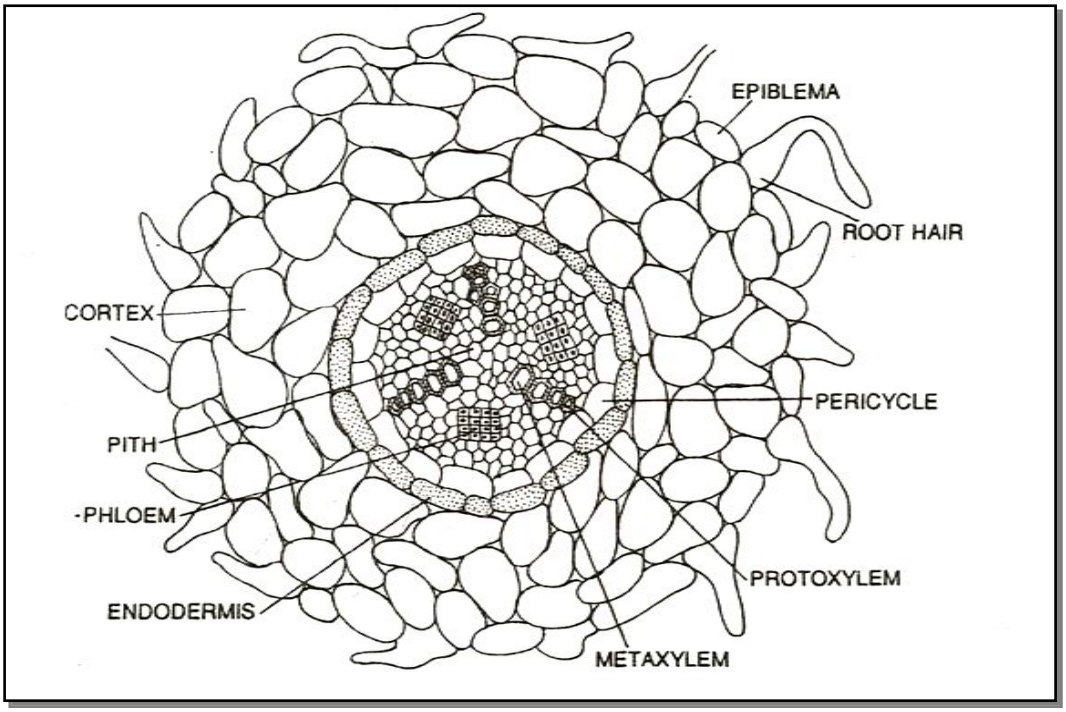


Fig.7.5. *Pinus:* T.S. of young root

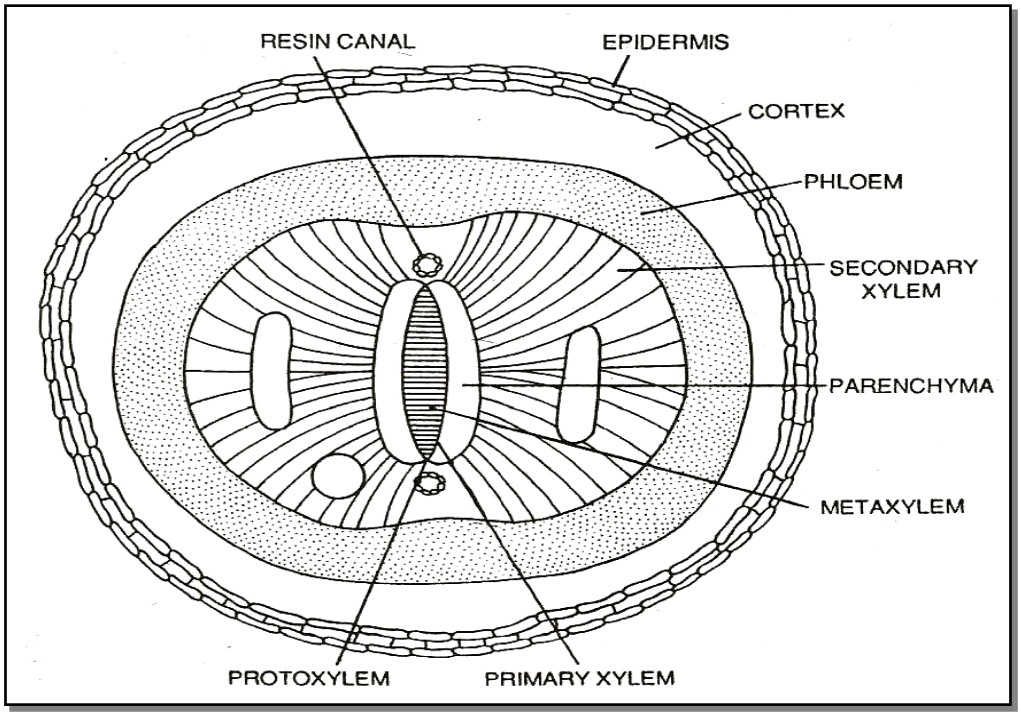


Fig.7.6. *Pinus:* T.S of root

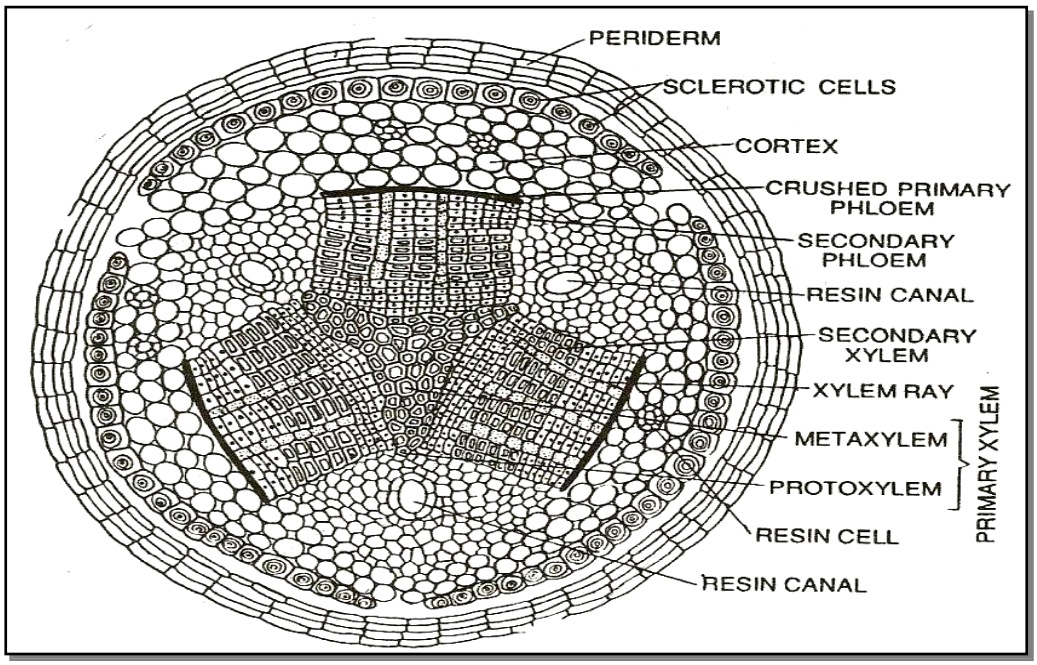


Fig. 7.7. *Pinus:* T.S of an old triarch root with secondary growth

Stem

The internal structure of the stem of *Pinus* resembles to that of a dicotyledonous stem, though on the whole it displays the simpler structure. The young stem is somewhat wavy in outline. It is surrounded by a single-layered cuticularized epidermis. Just beneath the epidermis there is multilayered hypodermis consisting of lignified sclerenchymatous cells. The hypodermis constitutes the outer region of the cortex. Underneath the hypodermis there lies the inner cortex consisting of thin walled parenchymatous cells containing chloroplasts and resin canals. Each resin canal is surrounded by a layer of glandular epithelial cells. The innermost layer of the cortex may be considered as endodermis but it is not at all clear. The pericycle is also inconspicuous. It is parenchymatous.

The vascular bundles are conjoint, collateral and open forming a ring in the transverse section. The primary bundles are separated from each other by narrow medullary rays. The phloem consists of sieve tubes and phloem parenchyma. The sieve tubes are elongated and possess sieve plates on the radial walls. The companion cells are altogether absent. The xylem consists of tracheids. The protoxylem consists of annular and spiral tracheids.

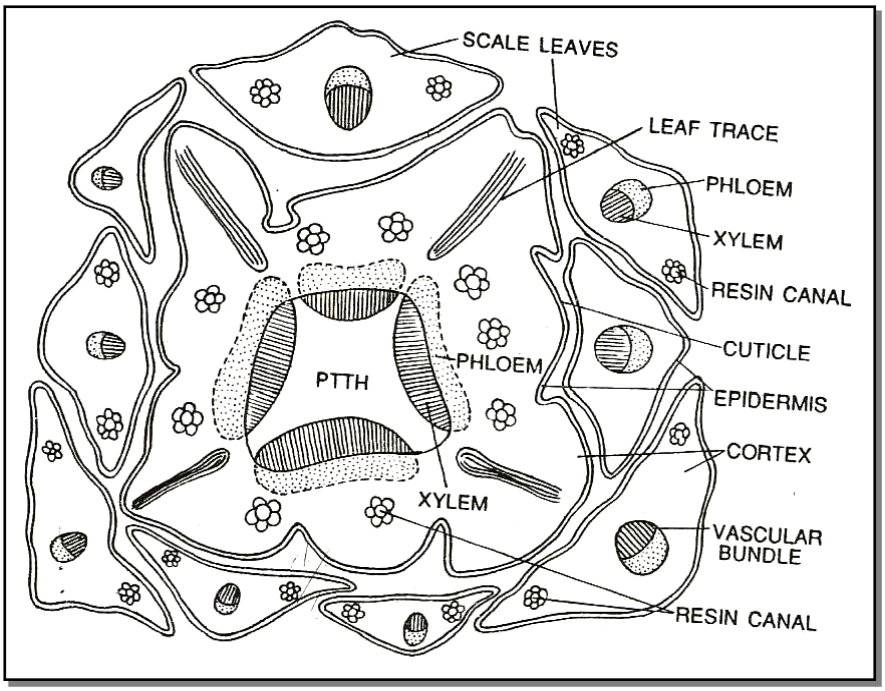


Fig.7.8. *Pinus:* T.S of a young stem

Secondary growth

The secondary growth in the stem of *Pinus* takes place exactly in the same way as in dicotyledonous stems. A complete ring of vascular cambium develops. It cuts the secondary xylem towards the inner side and secondary phloem towards the outside. After the secondary growth the primary xylem may be seen outside the pith region while the primary phloem is completely obliterated.

Medullary rays

At many places the secondary xylem and secondary phloem zones are traversed by secondary medullary rays. These vascular rays also develop from the cambial to replace the original primary rays. These rays are usually uniseriate. Each ray is composed of rectangular cells with thick walls and numerous simple pits. The cells contain cytoplasm, a nucleus and many starch grains. The upper and lower margins of the medullary rays are constituted of one or two rows of marginal ray-tracheids which run horizontally and resemble short tracheids of the xylem from which they have been derived. In the cambium and phloem zones instead of marginal ray-tracheids, large thin walled cells develop which extend upwards and downwards in between the cells of vascular tissue. In the secondary phloem the rays consist partly of starch containing cells and partly of albuminous cells. The medullary rays vary in their size.

The medullary rays are only two cells high and one cell wide. Usually they are only one cell broad and less than a dozen cells in height.

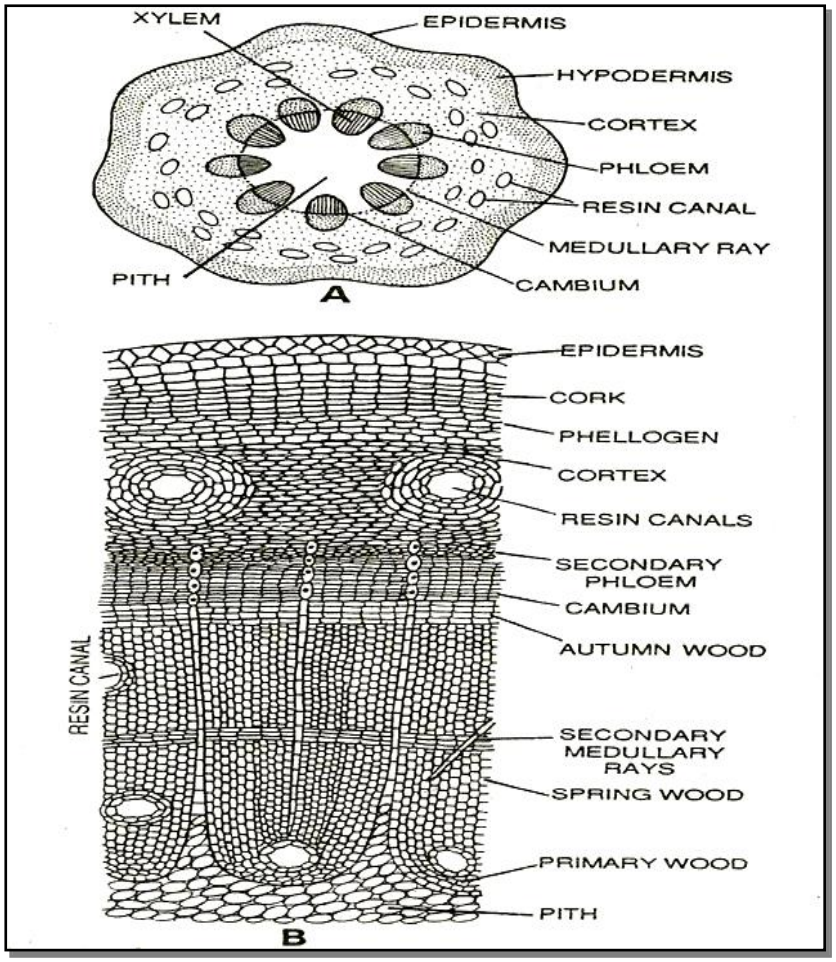


Fig. 7.9. *Pinus:* Anatomy of the stem. A. T.S of young stem, B. T.S of three year old stem

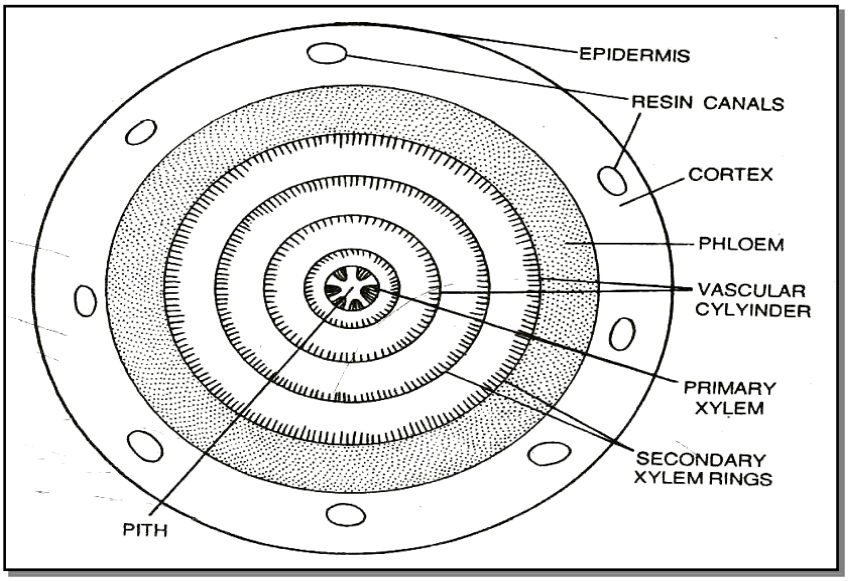


Fig. 7.10. *Pinus:* Anatomy of the stem. T.S of stem showing secondary growth

The secondary wood or metaxylem consists of tracheids with typical bordered pits. The tracheids are about 4 mm. long and pointed at both ends. The bordered pits are found on the radial walls and in certain species of *Pinus* the bordered pits are also found on tangential walls but fewer in number. The protoxylem consists of annular and spiral tracheids. The resin canals are present both in primary and secondary wood. Each resin canal is surrounded by the epithelial cells. The secondary phloem consists of sieve tubes and phloem parenchyma. The sieve tubes are elongated and possess the sieve plates on the radial walls. The companion cells are altogether absent.

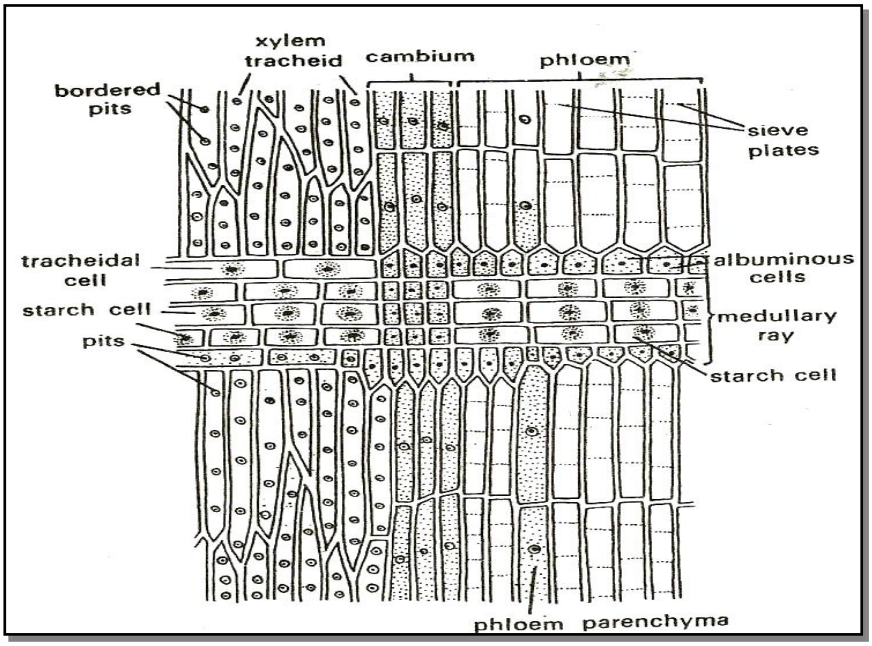


Fig.7.11. *Pinus:* Anatomy of the stem, T.L.S of secondary wood and phloem and structure of secondary medullary ray

As seen in transverse section the secondary growth is not uniform throughout. It shows annual rings. Each annual ring represents the growth for one year. The cambium ceases its activity in the winter season which is renewed in the following spring season. The wood formed in spring differs from that formed in autumn. In autumn there is less supply of food material therefore, the tracheids formed in autumn are quite small in size while in spring there is abundant supply of food material and the larger tracheids are formed. By counting the number annual rings one can estimate the age of the tree. The walls of autumn tracheids are much thicker than those of spring tracheids. In the *Pinus* stem the wood is dense and massive and known as pycnoxylic wood. The cork cambium or phellogen (meristematic layer) originates in the outer cortical region the surface. This meristematic layer cuts off additional cortical cells (phelloderm) towards the inner side and forming cork towards the outside. This cork constitutes the bark which is impervious to water and protects the stem and other delicate tissues from excessive evaporation and injury.

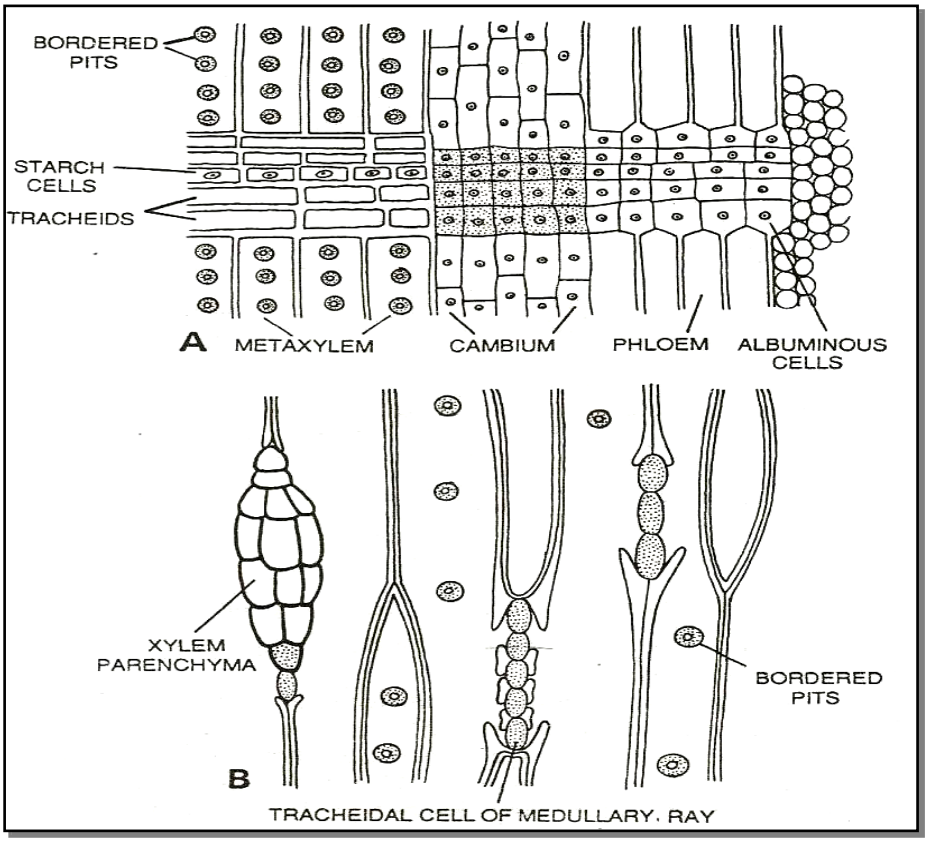


Fig.7.12. *Pinus:* Medullary ray, A. radial longitudinal section of old stem, B. a part of tangential longitudinal section showing the medullary rays and xylem parenchyma

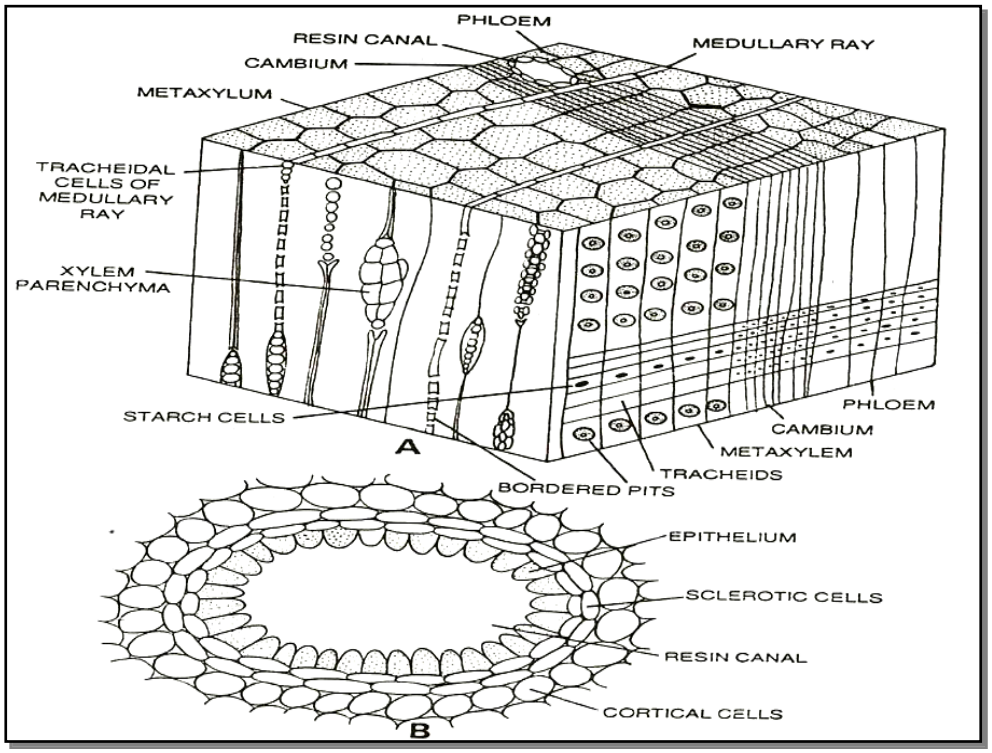


Fig.7.13. *Pinus:* A. three dimensional diagram showing spring and autumn wood, the medullary rays in T.L.S and R.L.S, B. T.S of schizogenous resin canal in the cortical region

In *Pinus*, the resin canals are found in the cortical region opposite each primary vascular bundle. The resin canals form an interconnected system throughout the xylem, phloem and cortex. Each canal is bounded by a layer of glandular secreting epithelial cells, which secretes turpentine. The turpentine acts as an antiseptic in healing the wounds caused by fungi or bacteria. The turpentine is oxidized to solid resin when exposed to air. This solid resin covers the wound until new bark is replaced. Sometimes, the epithelial cells become large and known as tyloses which block the resin canals.

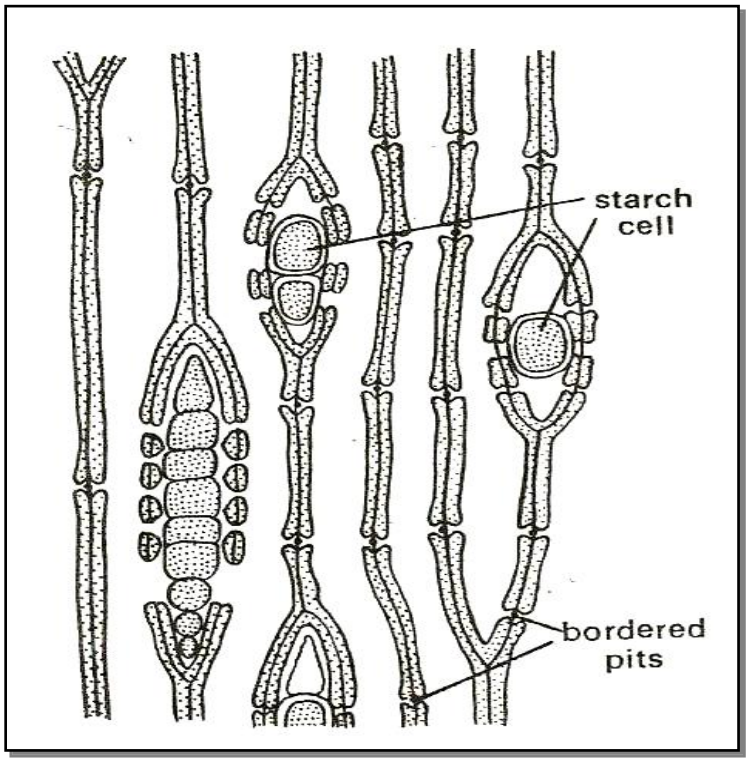


Fig.7.14.*Pinus:* R.L.S of secondary wood showing the medullary rays

The Leaf

The leaf of *Pinus* is xeromorphic. The whole anatomy of the leaf makes adaptable to withstand the low temperature and scarcity of water supply.

The outline of the needle (foliage leaf) in a transverse section depends on the number of the needles in the dwarf shoot (spur). In *P. monophylla* the spur bears a single needle and, therefore, outline of the needle is circular. In *P. sylvestris* each spur consists of two needles aid the outline of each needle is semi-circular. In *Pinus roxburghii* and *P. wallichiana* each spur consists of three needles and, therefore, the two flat faces of each needle are towards the inner side and the curved face towards the outside. In these species the outline of the needle is somewhat triangular.

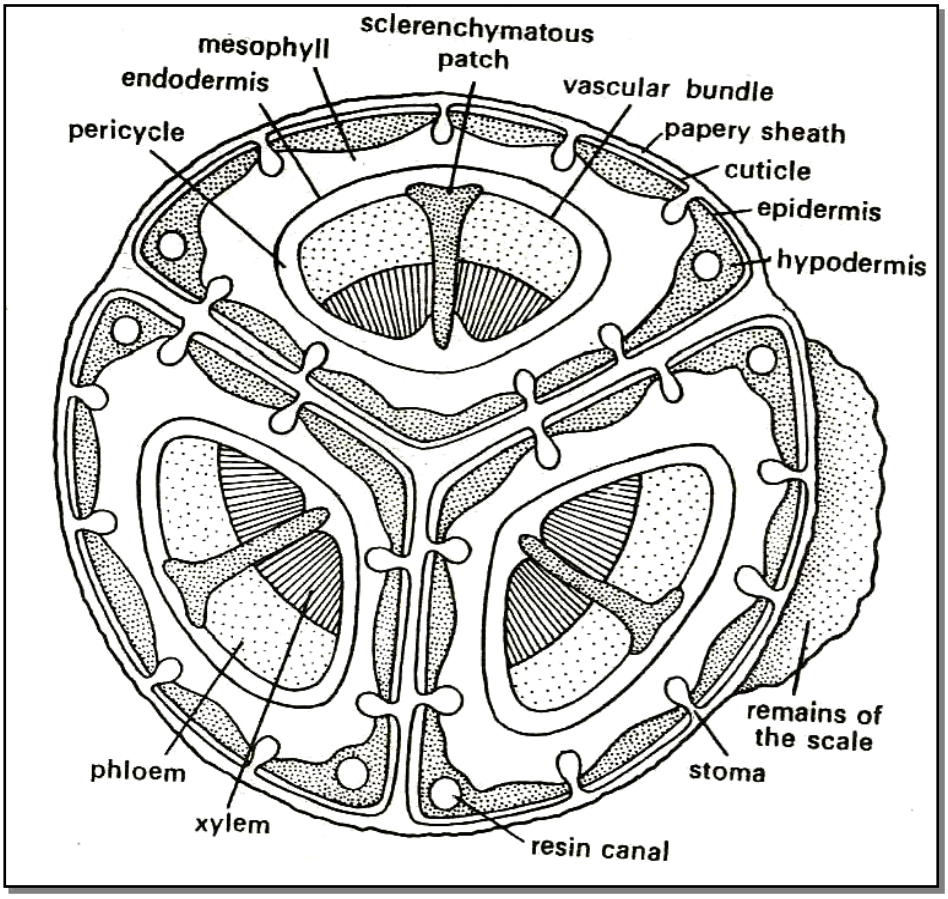


Fig.7.15. *Pinus:* T.S of spur of P. roxburghii showing three needles

The outermost layer is the epidermis which consists of extremely thick-walled and cuticularized cells. A number of depressions arc found over the epidermis. The stomata arc developed all over the epidermis in these depressions. The guard cells are sunken in depressions below the level of the epidermis. Just beneath the epidermis there is a hypodermis which is composed of one or two layers of sclercnchymatous cells. The hypodermis is several layered at the corners. The hypodermis is interrupted by air-spaces beneath each stoma. The parenchymatous mesophyll is not differentiated into palisade and spongy tissues. It consists of thin-walled cells containing a large number of chloroplasts and starch grains.

These thin-walled cells have peg-like infoldings of cellulose projecting into their cavities. The presence of these infoldings is probably connected with the development of the air spaces in the leaf. Beneath the hypodermis there are number of resin passages in the mesophyll tissue. The structure of resin canal is the same as that of the stem. In the centre of the leaf there is a conspicuous endodermis encircling a many layered pericycle. Within the pericycle there are two vascular bundles. The xylem of the bundle being directed to the inner side and phloem to outside. The two bundles run parallel and unbranched from base to the apex of the leaf. These two vascular bundles arise from a single leaf trace.

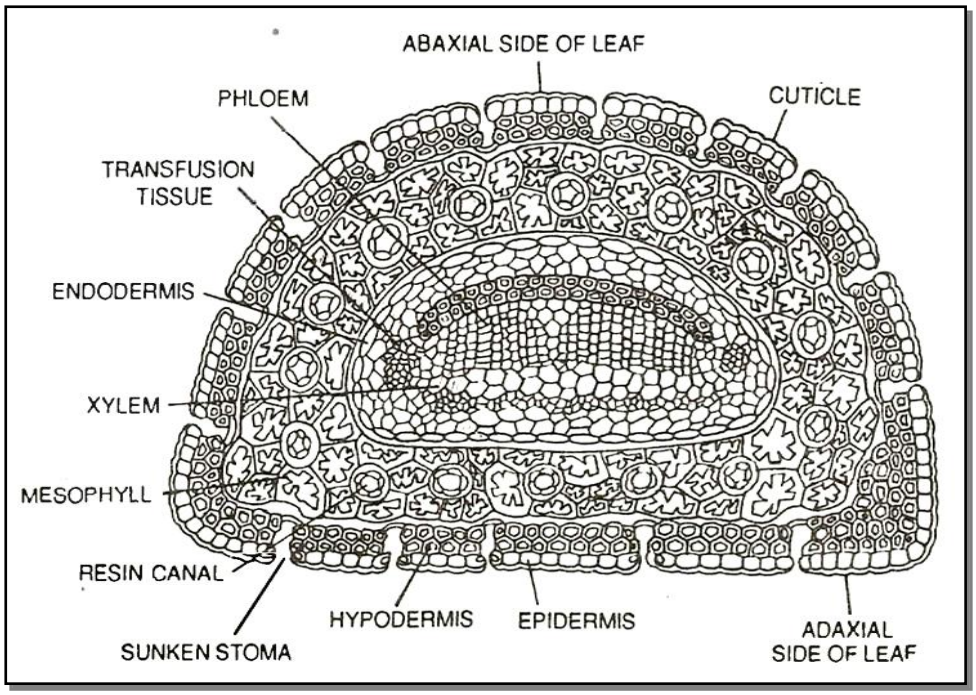


Fig.7.16. *Pinus:* T.S of needle (structure)

The pericycle consists of different types of cells. Firstly, they are parenchymatous cells rich in proteins and known as albuminous cells. These cells are found above the phloem of vascular bundles. The remaining tissue within the sheath is the transfusion tissue which consists of two kinds of parechymatous cells viz., the cells without protoplasm and pitted. They are tracheidal cells which serve to conduct water from the xylem to the mesophyll and they are thought to represent in function an extension of the tracheidal system. According to Worsdell, these cells have been derived from the centripetal xylem of the ancestral mesarch bundle; the cells with protoplasm are not pitted. These cells are intermediate in between the mesophyll and the phloem in the transfer of food. In addition to transfusion tissue, many fibres are also found in the pericycle near the bundles.

On the whole the leaf shows many xerophytic characteristics. The leaves are acicular in form. In the transverse section the leaf shows thick cuticle, the sunken stomata, sclerenchymatous hypodermis, the simple vascular system and the peculiar transfusion tissue.

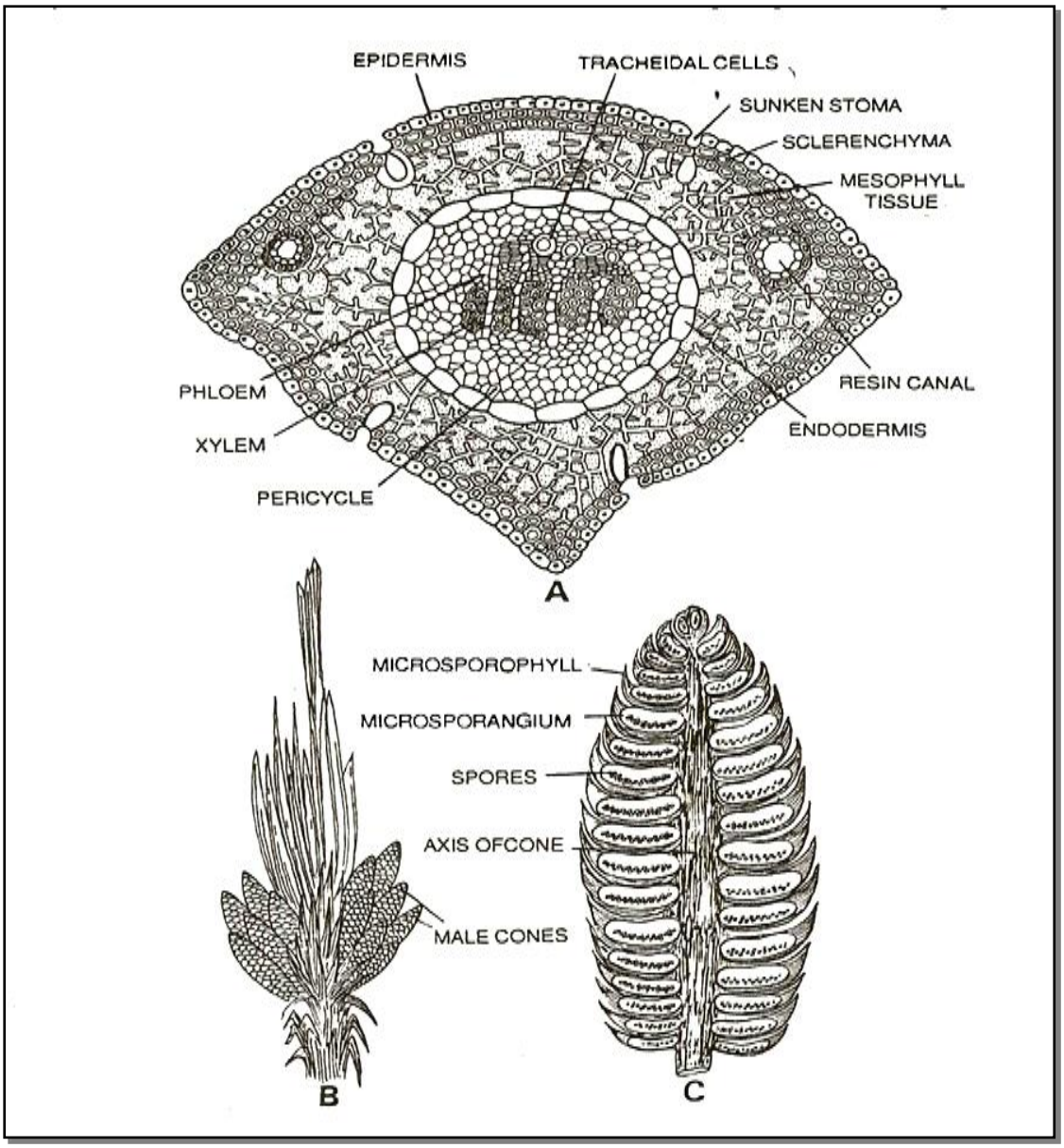


Fig.7.17. *Pinus:* T.S of needle, *P. roxburghii,* B. shoot of unlimited growth with male cones, C. longitudinal section of male cone showing microsporophylls and microsporangia

7.3.2 *Pinus:* life history

The reproduction takes place by means of spores developed in sporangia situated on the sporophylls. The strobili or cones of *Pinus* are monosporangiate, i.e., the two kinds (male and female cones) occur on the same plant. The plants are monoecious. In some of the species bisporangiate strobili are occasionally produced, they have been reported in *P. Roxburghii* by Rao (1931), in *P. montana* by Stell (1918) and in *P.maritima* by Goebel.

Male Cones

The male cones of *P.wallichiana* reach maturity and shedding of pollen takes place earliest at low elevations and in hot dry weather.

The male cone is produced in the axil of a scale leaf at the base of the current year's young shoot and thus replaces a shoot of limited growth. The cones of *P.wallichiana* are about 7 mm. to 1 cm. long immediately before their ripening. They lengthen to 1-2 cm and fall soon after ripening. At the base of the cone there is an involucre consisting of a number of small imbricate scales. The cone bears 60 to 100 spirally arranged specialized leaves known as microsporophylls. Each microsporophyll bears two microsporangia or pollen sacs on its underside. The development of the microsporangium is of eusporangiate type. The sporangial wall consists of four layers. It takes place either by a single cell or by a layer of hypodermal cells. In *P. wallichiana* the wall of microsporangium consists of the epidermis, two middle layers and a glandular tapetum. Within young sporangium there is a peripheral tapetum and a central archesporial tissue which forms a number of microspore mother cells. The microspore mother cells represent the last stage of sporophyte generation. Each microspore mother cell divides meiotically producing four haploid (n) microspores. The microspores or pollen grains separate from each other and absorb their nourishment from the disintegrating tapetal cells.

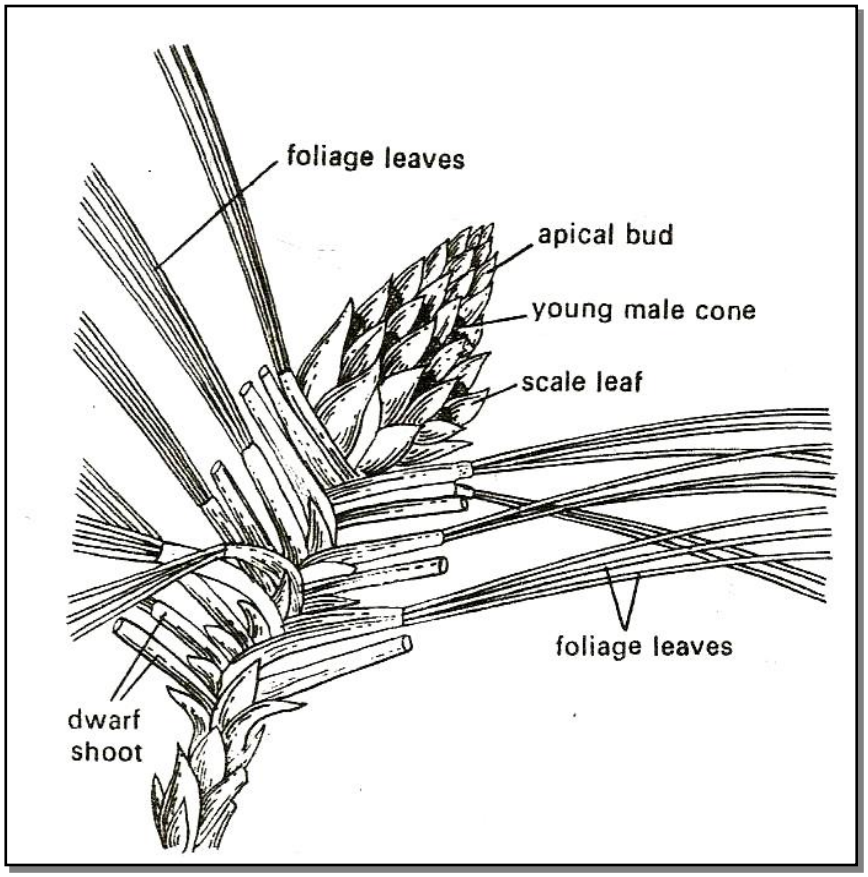


Fig.7.18. *Pinus:* cluster of very young male cones

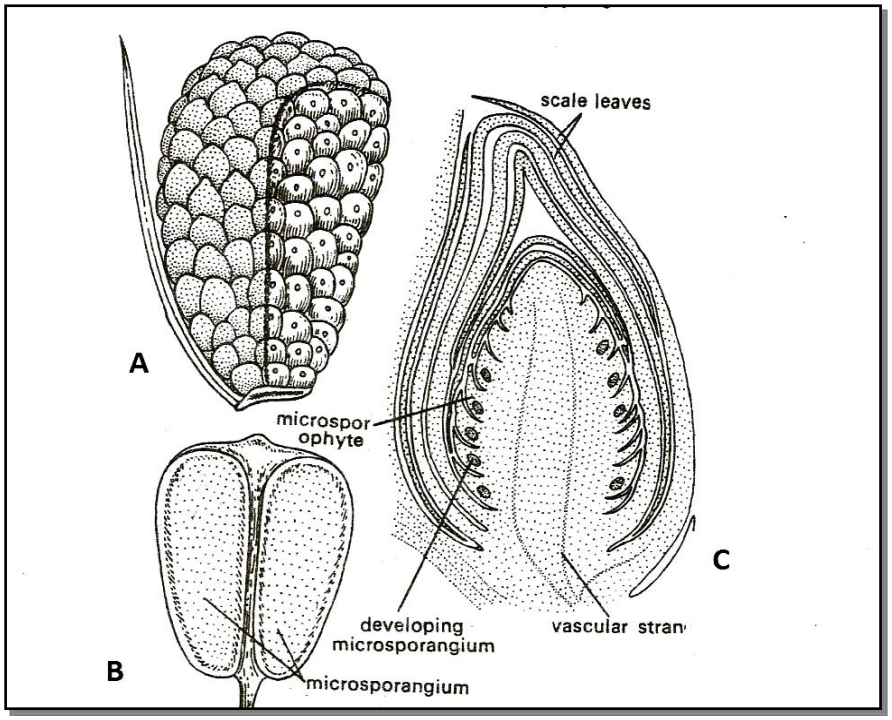


Fig.7.19. *Pinus:* A. fully developed male cone, B. microsporophyll bearing two undehisced sporangia, C. V.S of very young male cone showing developing sporangia

The Microspore

The microspore is surrounded by a three layered wall. The exine is heavily cuticularized and is found only on one side of the microspore. It does not completely cover the mature spore. The exointine or the middle layer covers the rest of the spore. The exointine is projected out-ward into two large balloon like air sacs or wings which make the spore much more buoyant and aid in its dispersal by wind. The intinc or inner layer of the spore is very thin. On the maturation the spores germinate *in situ, i.e.,* within the microsporangium. Firstly, the nucleus of microspore divides into two and simultaneously a wall develops in between these two daughter nuclei forming a very small flattened prothallial and a large tube cell. At this stage the microsporangia burst by longitudinal slits and the microspores are shed. The shedding of the pollen grains of *P.wallichiana* takes place in hot dry weather from end of April to the beginning of June in our country.

The Female Cone

The female cones develop laterally in the axil of scale leaves. They are formed in clusters in place of long shoots, i.e., shoots of unlimited growth. They are produced on the different branches from those of the male cones. There may be one to four on each long shoot.

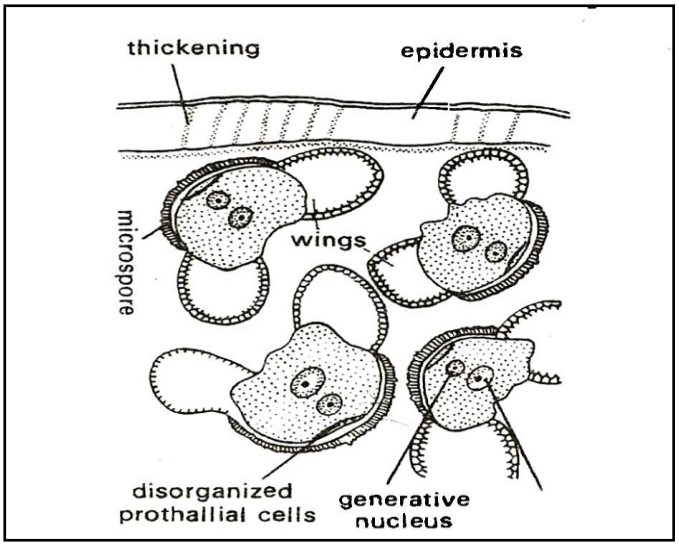


Fig.7.20. *Pinus:* A. part mature micro sporangium with winged microspores

The female cones are initiated in January and visible in February at the ends of youngest female shoots. In *P.wallichiana* the young female cones are pollinated from the end of April to the beginning of June. The young female cones of *P.wallichiana*, at the time of pollination are 10-13 mm. long and 3.8 mm. in diameter, young cones are dark reddish purple in colour. Each cone consists of central axis bearing spirally arranged scales. At the base of the cone certain sterile scales are also found. Each fertile consists of two structures viz., bract scales or cover scales which are arranged spirally and developed directly from the cone axis, and the ovuliferous scale which develops on the upper surface of the bract scale. The bract scale is leathery while the ovuliferous scale is woody in structure. Each ovuliferous scale bears two ovules on its upper surface. The bract scales are connected under the ovuliferous scales and, therefore, they are not visible from outside.

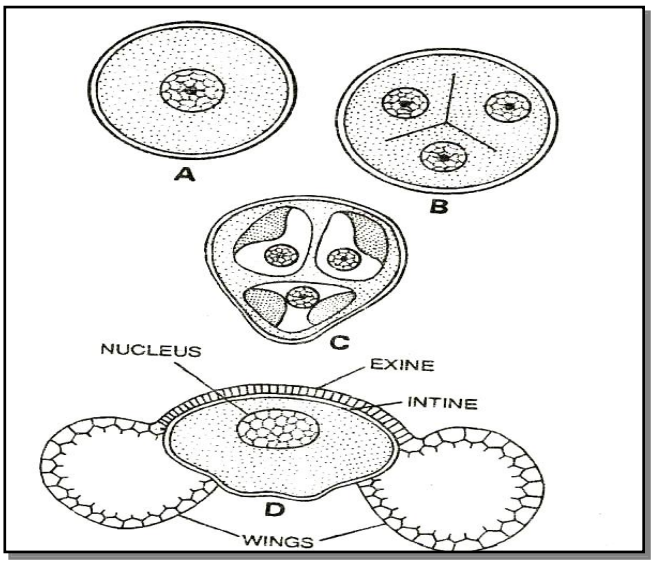


Fig.7.21. *Pinus:* formation of microspores. A. microspore mother cell, B. microspore mother cell dividing meiotically, C. microspore tetrad, D. A microspore or pollen grain

The ovulate strobilus of *Pinaceae* has long been a morphological puzzle. The question arises whether structure of ovulate strobilus is simple or compound. There is much confusion about the double structure of the strobilus. The views of the various workers are as follows:

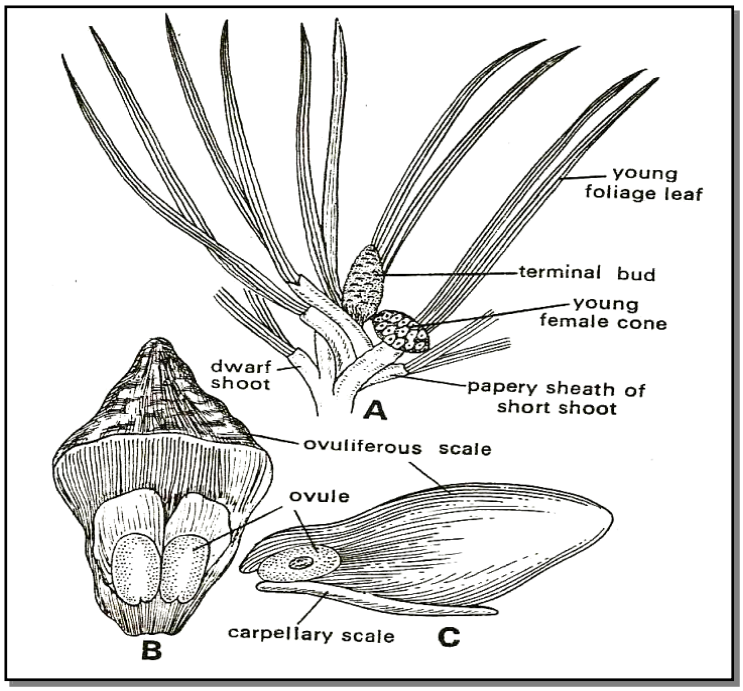


Fig.7.22.*Pinus:* long shoot bearing dwarf shoots with two needles, apical bud and female young cone, B. megasporophyll bearing two seeds, C. sectional view of megasporophyll showing ovule

Robert Brown regarded the ovuliferous scale as an open carpel. Alexander Braun (1853) stated that the ovuliferous scale represents the first two leaves of an axillary shoot which are fused by their upper margins. This view was accepted by many botanists of the time. According to Sachs and Eichler, the ovuliferous scale is an outgrowth of the bract scale comparable to a ligule or placenta. Kubart and Bessey regarded the ovuliferous scale as a combined outgrowth of the ovules themselves and call an aril or an enlargement of the chalaza of the ovules. According to Delpino the ovuliferous scale develops from two lateral lobes of the bract scale which have been turned inwards and fused together. Hirmer states that the ovuliferous scale and the bract scale are both parts of one structure which has forked vertically in the *Cheirostrobus.* Florin, however, regards the cone as a compound structure. He regards the cone as inflorescence and the ovuliferous scales as short shoots.

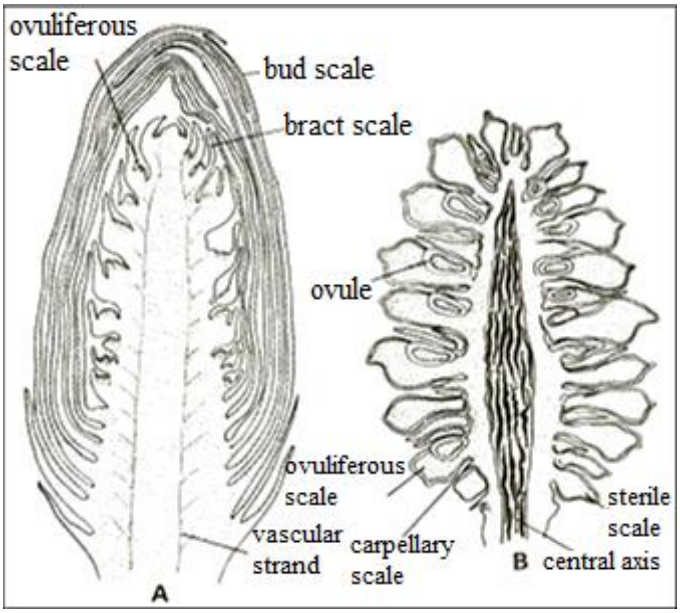


Fig. 7.23. ***Pinus,*** **L.S. of young female cone of** ***P. wallichiana*** **showing well developed bract scales and developing ovuliferous scales, B. mature female cone of** ***P. roxburghii***

The Ovule

The two ovules are found side by side on the upper surface of the ovuliferous scale. Each ovule consists of a group of the cells forming a tissue, the nucellus. The ovule is surrounded by a two-lipped covering known as integument. The integument develops up around the ovule. It starts from the abaxial or outer end of the nucellus and grows inwards toward the base of the ovuliferous scale. The integument completely surrounds the nucellus except at the inner and where a wide aperture lies, known as micropyle. The integument is fused to the nucellus except for a short distance near the micropyle. At the apex of the young nucellus& single deep seated hypodermal cell is found. It is known as archesporial cell. The archesporial cell divides formimg a tapetal cell and a megaspore mother cell. The megaspore mother cell divides meiotically producing a linear tetrad of four haploid megaspores. The three upper megaspores of the linear tetrad degenerate leaving the lowermost functional megaspore of embryo sac. As regards the development the sporogeneous tissue is small and hypodermal. The hypodermal cells cut off the tapetum which forms a more or less nutritive layer around the megaspore. This is described as spongy tissue, which is formed by tapetum surrounding the megaspore mother cell. At this stage the pollination takes place. The development of the embryo-sac takes place after pollination.

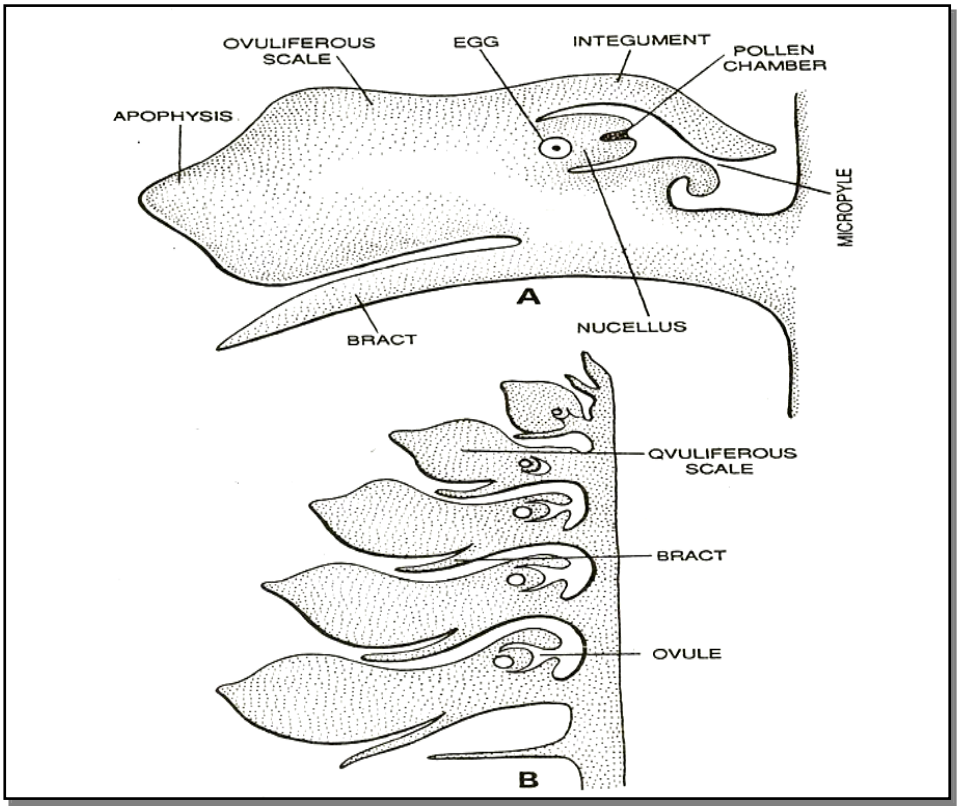


Fig.7.24. ***Pinus,*** **female cone, A. single ovuliferous scale showing ovule in longitudinal view, B. longitudinal section of female cone showing bract and ovuliferous scale**

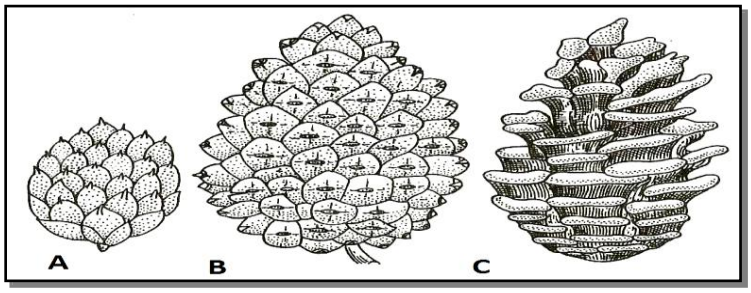


Fig.7.25. ***Pinus spp.*** **female cones, A. first year, B. second year, C. third year**

Pollination

In *Pinus* the pollination is effected by the wind. The balloon-like wings of the pollen grains aid them to reach the ovule. Usually the pollination occurs towards the of May when the pollen grains arc liberated in large quantities from the microsporangia of male flowers. The pollen grains fall on the scales of the female cone. At this time, the edges of the bract scales become incurved separating the ovuliferous scales, which allow the pollen grain to reach to the ovules. Prior to the pollination the scales remain tightly closed around the cone axis and soon after pollination the scales close again and remain in the same condition the ripening of the seeds. At the time of the pollination the yellow clouds of the micros may be seen in the

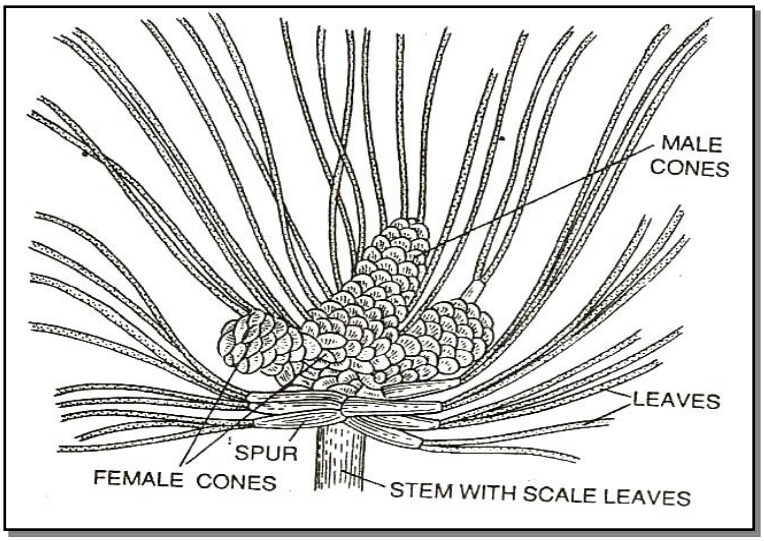


Fig. 7.26. *Pinus spp.* Long shoot with male and female cones

atmosphere. Most of the pollen grains go waste. As the ovuliferous scales are separated from each other, the nucellus secretes a mucilaginous fluid. The pollen become entangled in this mucilaginous fluid. As the pollination is over, this drop of mucilaginous fluid dries up, drawing the pollen grains through the micropyle to the apex of the nucellus where they germinate. After pollination the scales close, the young cones increase some in size and begin to become hard.

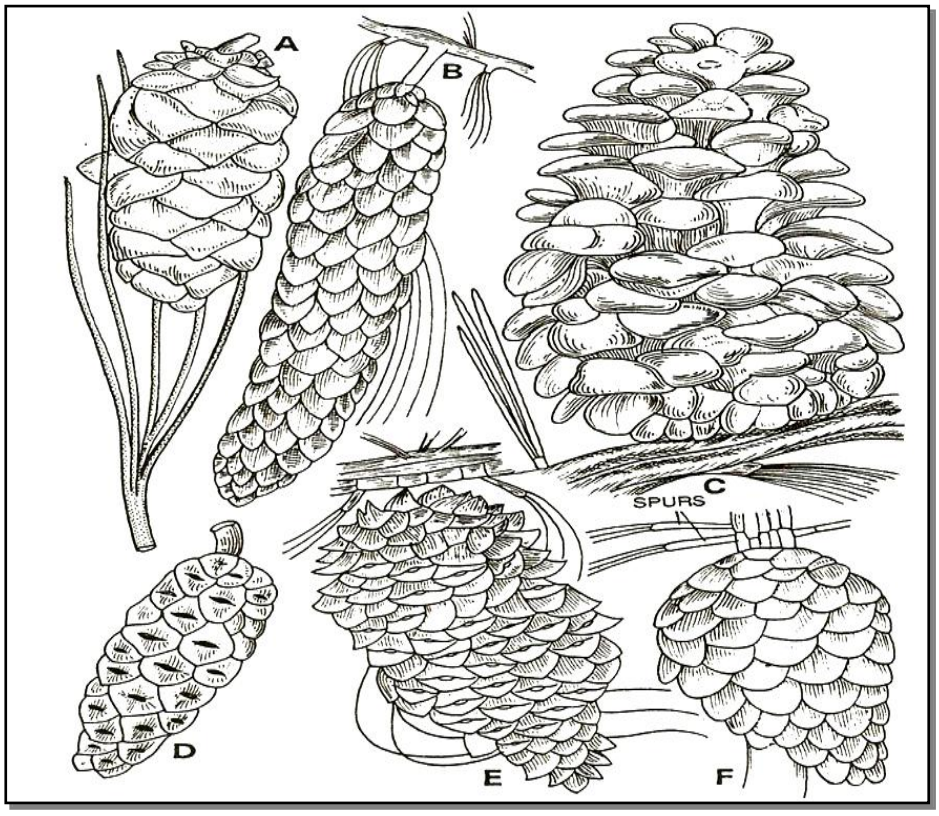


Fig.7.27. *Pinus spp.* Female cones of different species, A. *Pinusarmandi*, B.*Pinuswallichiana*, C.*Pinusgerardiana*, D. *Pinusmerkusii*, E.*Pinusroxburghii*, F.*Pinusinsularis*

The Male Gametophyte and its Development

At the time of pollination the first nuclear division has already occurred in the pollen grain. The first prothallial cell and the tube cell have also been formed at this stage. The further development of the male gametophyte takes place when it germinates on the nucellus. The tube cell divides forming a small second prothallial cell and a large tube cell. The first and second prothallial cells soon become flattened and disintegrate. The remaining nucleus divides third time producing a large rounded cell, the antheridial cell on top of the degenerating prothallial cells. The nucleus which remains in the tube cell of the pollen grain is known as tube nucleus. On making the contact with the apex of the nucleus the exo-intine of the microspore or pollen grain breaks between the wings, and the intine grows out in the form of the pollen tune. The tube nucleus passes in the pollen tube. The pollen tube

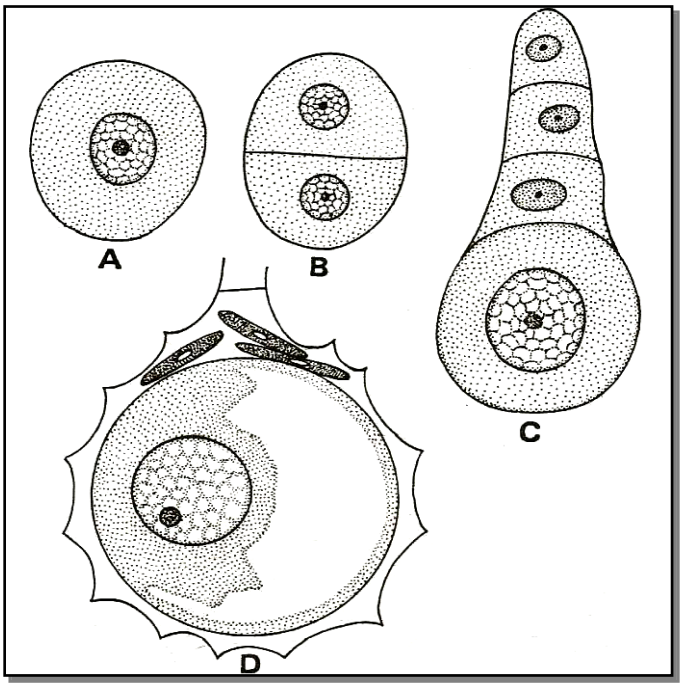


Fig. 7.28. *Pinus spp.* Megasporogenesis, A. megaspore mother cell, B-D. Successive stages in the formation of single megaspore

penetrates the nucellar tissue and grows slowly throughout the following summer. Now the scales of the female cone become thickened and thus the female cone becomes completely closed. The developing pollen rests there throughout the winter. In the next April, the antheridial cell divides into two cells, forming the body cell and stalk cell. The stalk cell does not divide further. The body cell divides into two unequal cells with less cytoplasm and large nuclei. These cells are known as male cells

The Female Gametophyte and its Development

During the period between pollination and fertilization many changes take place in the ovule and the cone as a whole. The female cone increases in size and becomes green. This increase in size of the cone takes place due to the enormous growth of the axis and of the ovuliferous scales. The megaspore is formed when the surrounding nucellus is in earlier stages of development. Both the megaspore and nucellus continue to grow simultaneously. The nucleus within the megaspore enlarges and begins to divide. Free nuclear division takes place

and from 256 to more than two thousand nuclei are formed within the germinating megaspore. After free nuclear division a large vacuole appears in the centre and all nuclei now come to lie near periphery. After this peripheral disposition of the nuclei the wall

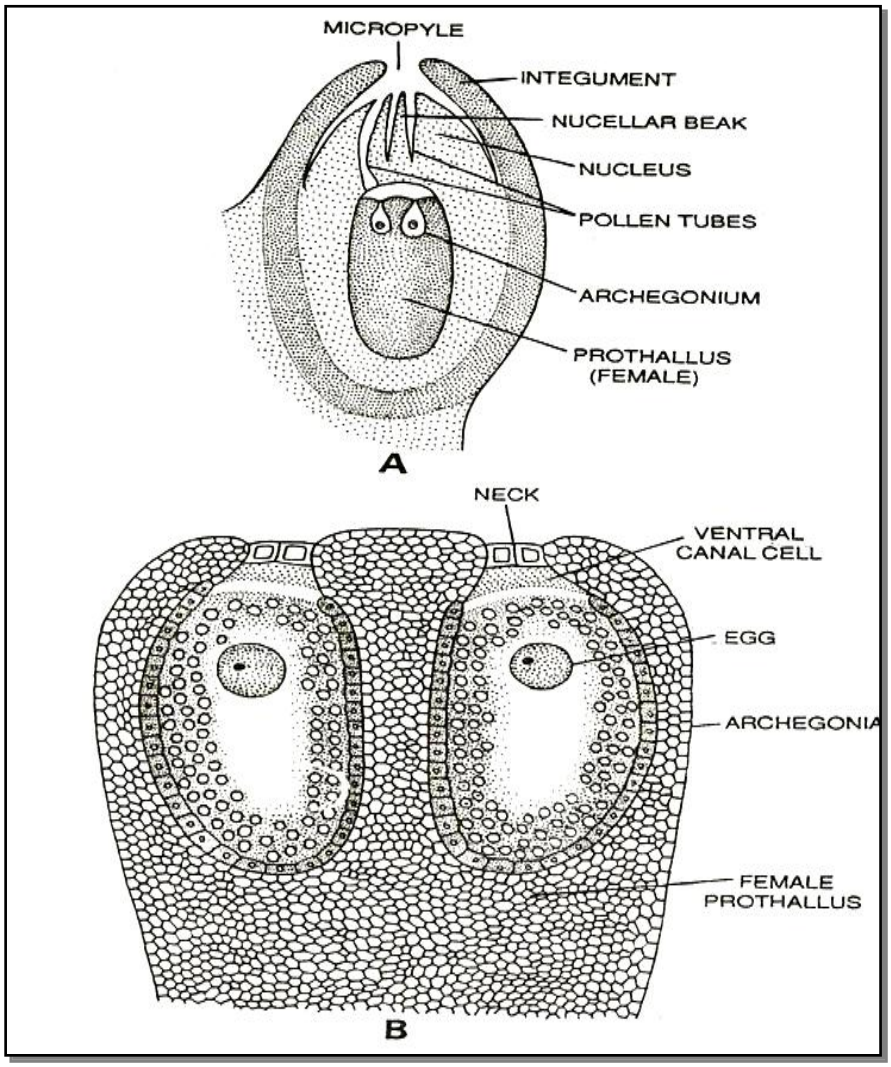


Fig.7.29. *Pinus spp.* A. longitudinal section of mature ovule showing pollen tubes and process of fertilization, B. female gametophyte, C. prothallus with two archegonia

formation starts. During all this time the megaspore gradually increases in size and its membrane that of the ovule becomes thicker. The wall formation takes place by the formation of perpendicular walls from the periphery and gradually proceeds towards the centre. As the cell formation proceeds towards the centre, in the beginning the cells remain open, and towards the inner side in the megaspore the walls are laid down. In *P.walllchiana,* during the first year the functional megaspore undergoes only a few free nuclear divisions, and in the next year the free nuclear division continues and cell formation begins in the following May.

Thereafter the embryo sac or megaspore is cut into a number of radial spaces in the form of long tubes, containing several nuclei described as alveoli. These alveoli project towards the

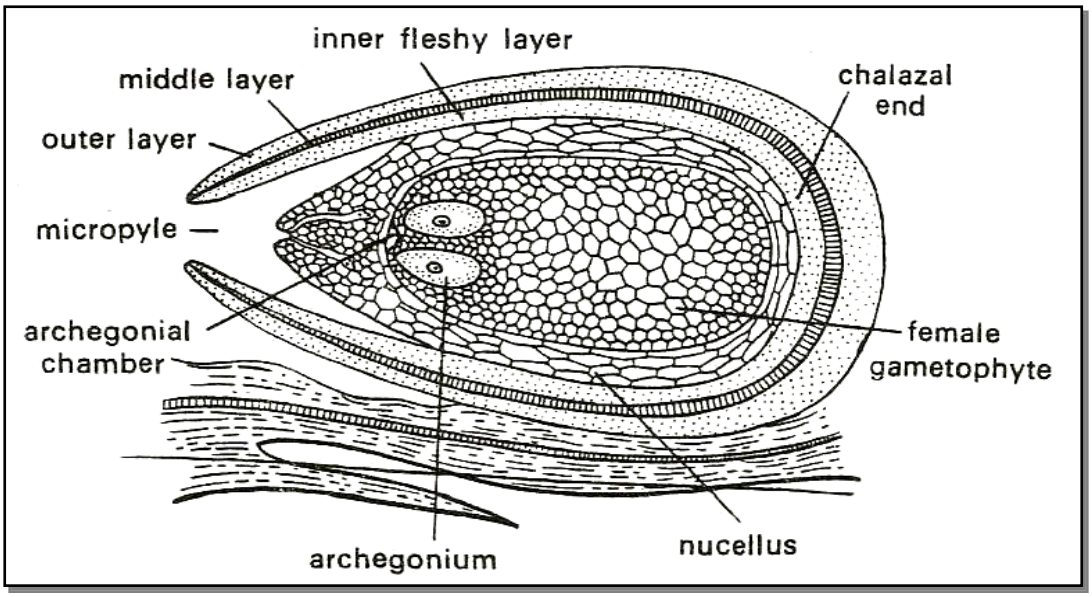


Fig.7.30. *Pinus sroxburghii.*L.S.of mature ovule showing archegonia

centre of the germinating megaspore. They are open on the inner side in the beginning but later on they become closed and new cross walls are laid down in these tubes. They form the endosperm or female prothallus (female gametophyte) within the megaspore.

In early stages of the development of megaspore, it is surrounded by a layer of cells formed by tapetum this layer forms the endosperm jacket. The nutritive matter is gradually passed on from the surrounding nucellus to the developing endosperm (female prothallus). The nucellus gradually decreases in size.

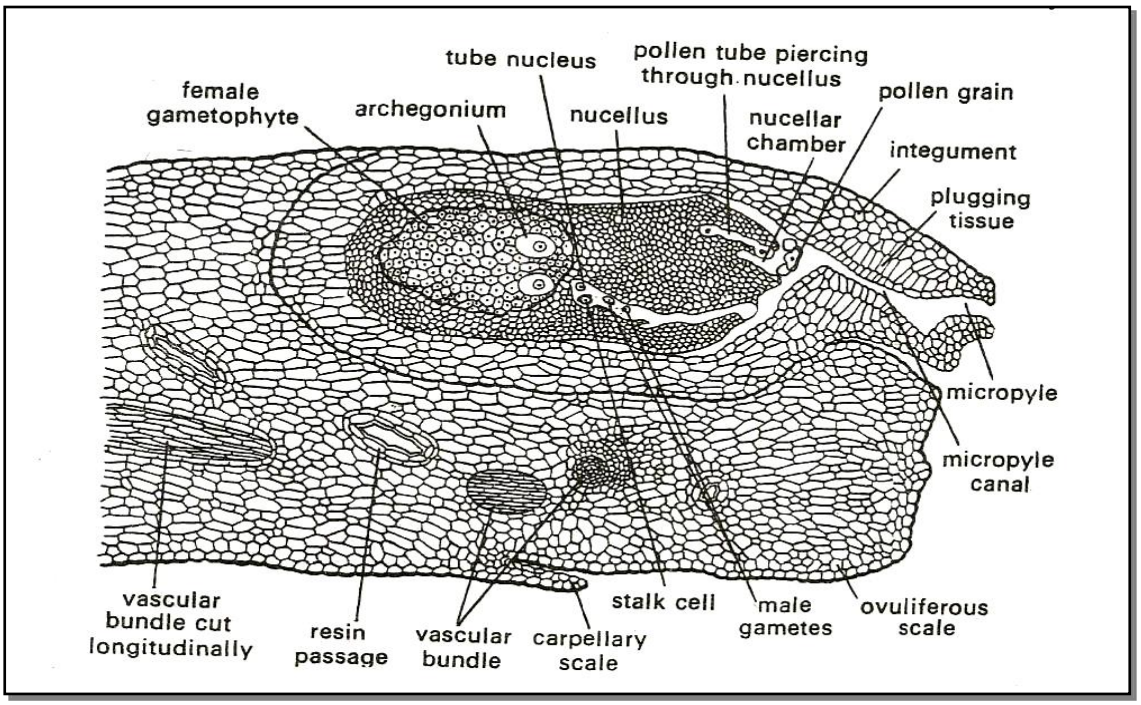


Fig.7.31. *Pinus roxburghii.* L.S. of mature ovule (cellular)

In *Pinus* the formation of archegonia starts at an early stage of the formation of endosperm or prothallus (female gametophyte). In *Pinus* the archegonia are quite separate from each other. At the micropylar end of the ovule the archegonia are produced from superficial cells of female prothallus. In many species of *Pinus* the numbers of archegonia ranges from one to five but usually two or three archegonia are found. Each archegonium is quite simple in structure and consists of a short neck and a large venter. As regards the development of the archegonium the archegonial initial divides producing two cells-the primary neck cell and the central cell. The primary neck cell divides thrice successively producing eight cells which constitute neck. Usually the neck consists of eight cells arranged in two tiers of four cells each.

The central cell divides to produce an oosphere (egg) and the ventral canal cells. The cells surrounding the archegonium form a jacket layer which supplies food to the developing egg. The cells of the female prothallus surrounding the archegonium grow more vigorously than the neck cells so that an archegonial chamber is resulted.

Fertilization

In the month of April of the second year the pollen tube completes its resting period and again becomes active and the two unequal male cells are formed from the body cell. The pollen tube elongates until it reaches the neck of an archegonium. The end of the pollen tube enters the neck and bursts discharging the stalk cell, tube nucleus and the two unequal male cells. The larger nucleus enters the egg and fuses with the female nucleus, thus effecting the fertilization. The other nuclei, however, die and disappear. With the result of fertilization, a thick-walled, diploid (2n) oospore is formed. The fertilization is completed by the end of June.

Development of the Embryo

In *Pinus,* the free nuclear division of the fertilized egg takes place in the early embryogeny and the number of nuclei formed is very low as compared that of *Cycas.* The oospore is also smaller than that of *Cycas.*

In *Pinus*, the fertilized diploid nucleus of the oospore divides twice to form four nuclei which lie side by side at the bottom of the egg. Thereafter a third nuclear division takes place forming the eight nuclei which are arranged in two tiers of four each.

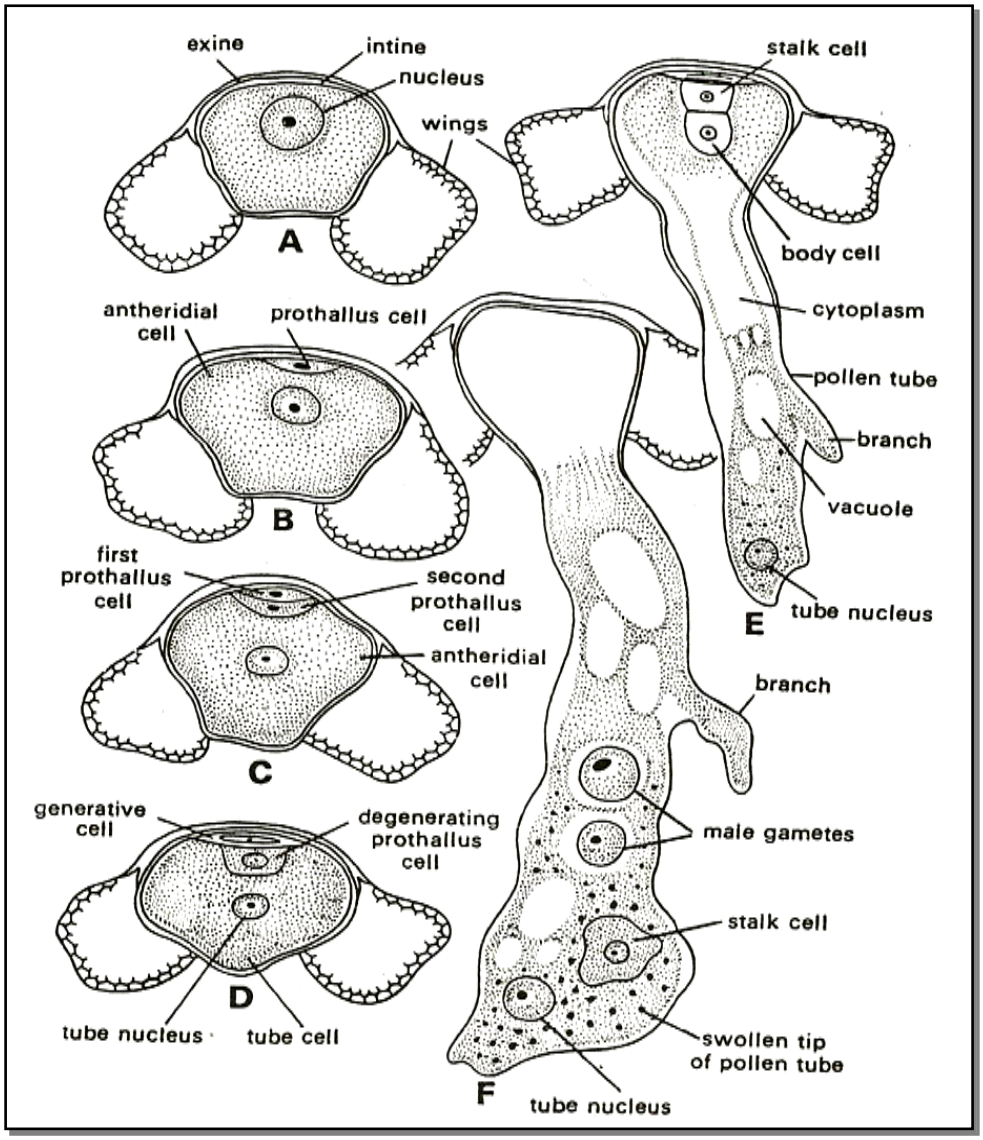


Fig. 7.32. *Pinu s*spp. Development of male gametophyte, A. pollen grain, B-D.successive stages in the development, E. Pollen tube with nucleus, F. two unequal male gametes, stalk nucleus, tube nucleus within pollen tube.

The cell walls are laid down across the four basal nuclei, and this way four small cells have been produced at the lower end of the oospore. The upper free nuclei are separated only by imperfect walls and they do not take any part in the formation of the embryo. The cells again divide and this way, three tiers of four cells each have been formed. Once the lower most nuclei divide and four tiers of 4 cells each have been formed. This structure consists of sixteen cells, four tiers of four cells each, is known as proembryo. The cells of the uppermost tier remain open towards the cavity of egg. This tier of four cells is known as open tier. The second tier of four cells constitutes the rosette tier. The cells of this tier are functionless. The third tier consists of elongated cells is known as suspensor tier. The cells of suspensor tier form the elongated suspensors. The fourth and the lowermost tier of the four cells is known

as embryonal tier. The cells of this tier give rise to the embryo proper. It is seen in some cases (Buchholz) that rosette cells are also meristematic and give rise to secondary embryos.

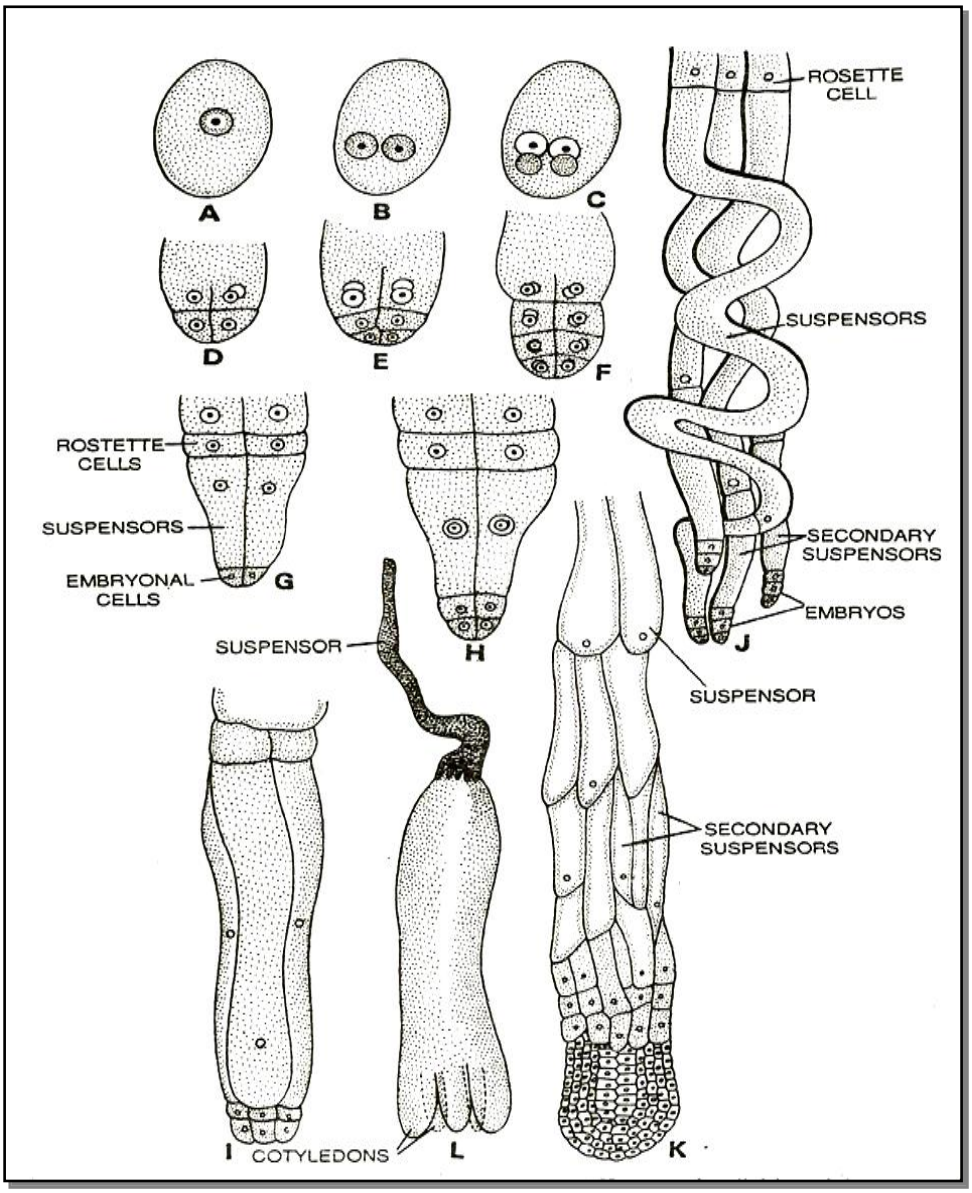


Fig.7.33. *Pinus* spp. Development of embryo, A. oospore B-H.successive division of the oospore, J. formation of secondary suspensors and embryos , K. formation of single embryo, L. Formation of cotyledons

The suspensors elongate very greatly and thrust down the embryonal cells into the tissue of the female prothallus.

There is a peculiar feature of embryogeny in *Pinus* that the four embryonal cells generally become separated from each other and give rise to four independent embryos. Each of such embryos develops secondary suspensor cells. When more than one embryo is formed from single fertilized egg is called cleavage polyembrony. Ultimately only one of these embryos survives and becomes mature. In *Pinus,* the cleavage polyembryony can be recognized both

by counting the number of embryos produced from each zygote and tracing each embryo back to single-celled suspensor (Buchholz, 1926).

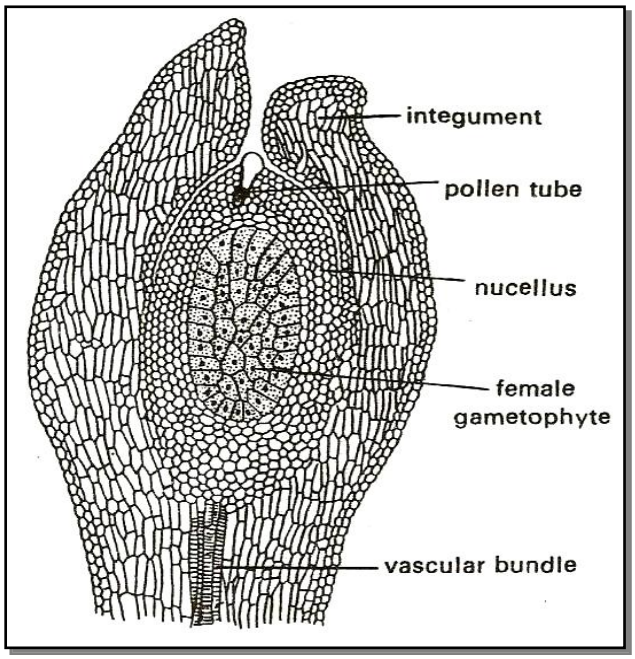


Fig.7.34. *Pinus roxburghii,* V.S ovule with young cellular female gametophyte

Structure of Embryo

The mature embryo consists of a short axis with the radicle towards the micropylar end and a small plumule downwards. The plumule is surrounded by a number of tiny leaves or cotyledons. The cotyledons may be ten or so in number. The suspensor remains attached as a small thin coil to the tip of the radicle which forms a thick cap over it. The mature embryo is embedded in the endosperm which is laden with food material. The nucellar tissue is altogether crushed and disorganized because of the expansion of endosperm and embryo, however, the remaining thin layer of nucellus is known as perisperm.

The Seed

The seed contains the following structure:

1. Embryo: It contains a straight mature embryo.

2. Endosperm: The endosperm is laden with food material. The embryo remains embedded in the endosperm and absorbs its nutrition from it.

3. Perisperm: A thin layer of crushed nucelluspersists which is known as perisperm.

4. Testa: The integument of the ovule becomes the seed coat or testa. The testa is hard and stony as it develops from the middle stony layer of the integument.

5. Wing: The seed has a thin membranous wing which is derived from the surface of the ovuliferous scale. The wing helps in the dispersal of the seed.

Dispersal of Seeds

In the third year when the female cone reaches maturity the cone becomes dry, brown and woody. Each ovuliferous scale bears two mature seeds placed side by side on its upper surface. When the seeds are mature the axis of cone elongates and the scales are separated

from each other leaving spaces among them. The seeds are liberated and they are blown away by the wind. The wings of the seeds aid in their dispersal.

Germination of Seed

The pine seeds may germinate immediately after they fall on moist soil. The seeds may also remain dormant for some time in unfavourable conditions. In favourable conditions the seed absorbs water and the seed coat splits up. On splitting the seed coat the radicle grows downward in the soil and plumule upwards towards the light. The green cotyledons carry up the remaining part of the seed and the tips of the cotyledons absorb the remainder of the endosperm. The radicle goes downwards and forms the primary tap root while the plumule which passes upwards produces a shoot of unlimited growth which bears delicate acicular green leaves. These leaves are spirally arranged on the shoot. The germination of pine seed is epigeal as the cotyledons come upwards above the soil.

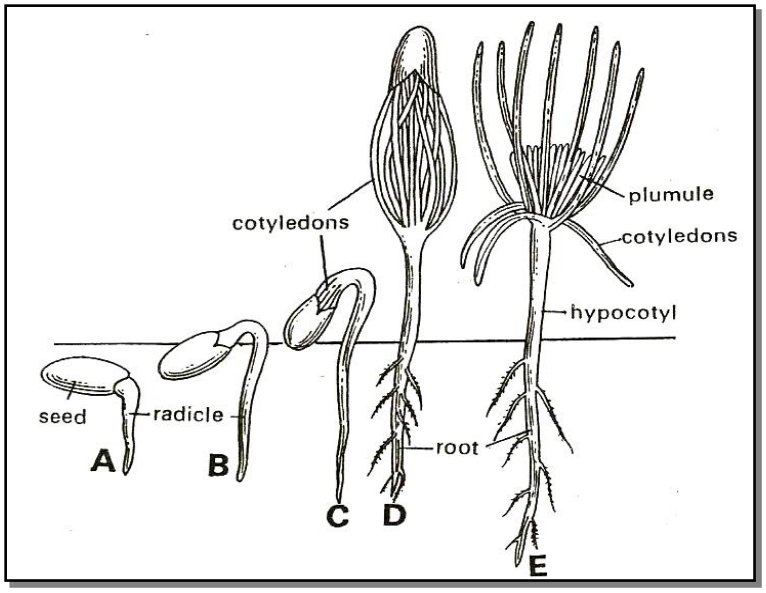


Fig.7.35. *Pinus roxburghii,* A-E stages in the development of seed

This condition of juvenile leaves prevails until the seedling is 3 or 4 inch high and thereafter first foliar spurs (dwarf shoots) develop in the axils of these leaves. The juvenile condition is a primitive feature of *Pinus*. The later formed juvenile leaves of the seedling become smaller and smaller and pass on into the scale leaves of the stem.

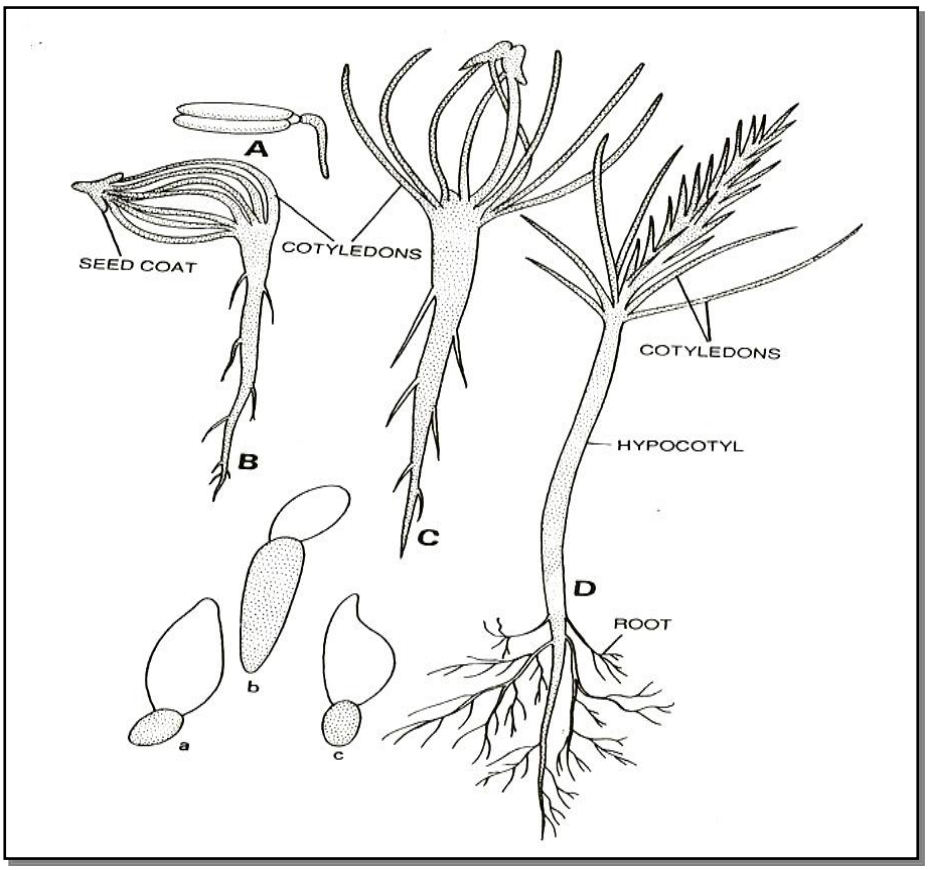


Fig.7.36. *Pinus* spp. Seed and its germination.A-D successive stages in the formation of seeding. (a) seed of *P. roxburghii* (b) seed of *P.gerardiana* (c) seed of *P. Wallichiana*

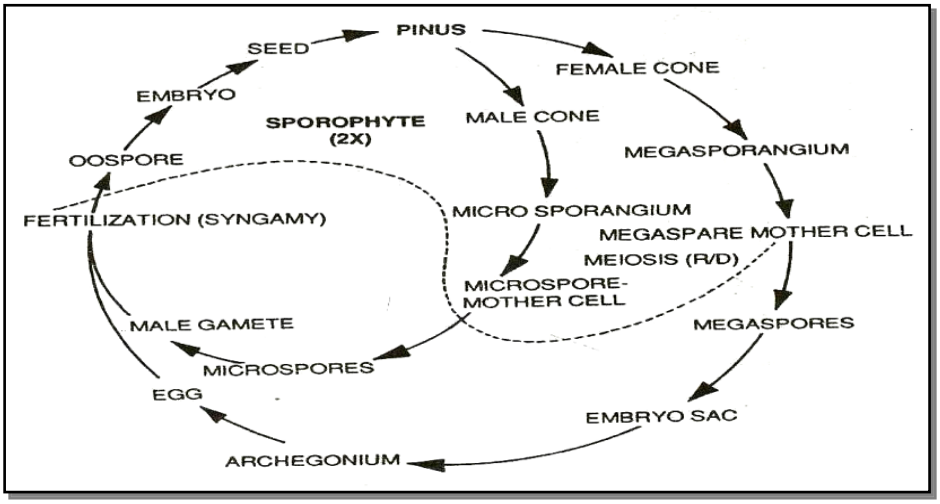


Fig.7.37. *Pinus* spp. Graphic life cycle

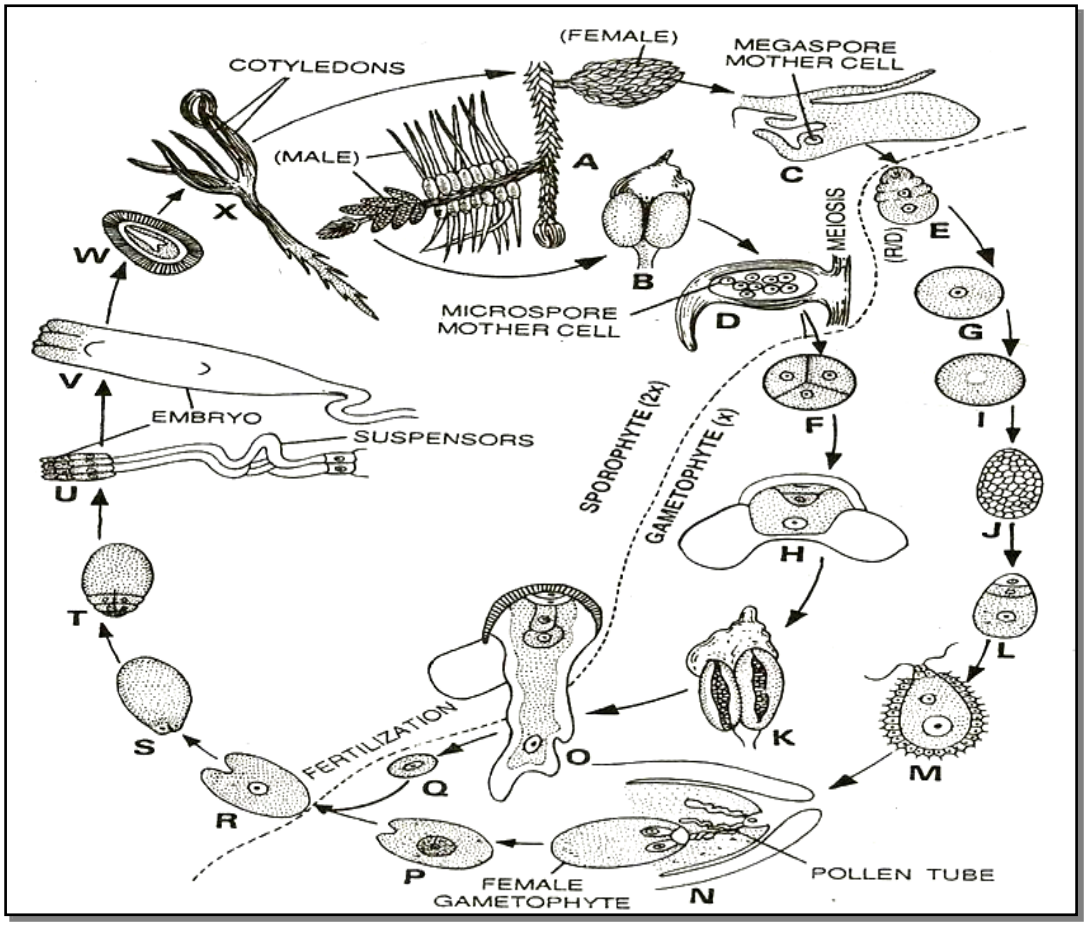


Fig.7.38. *Pinus* spp. Diagrammatic Life cycle. A. twig with male and female cone, B. microsporophyll with microsporangia, C. ovuliferous scale with ovule, D. microspaorangium with microspore mother cell, E. megaspore linear tetrad, F. micropore tetrad, G.megaspore, I-J. formation of female prothallus, K. dehiscence of microspores, L-M. Development of sporangium, N. mature ovule and fertilization, O. male gametophyte, P. egg, Q. male gamete, R. oospore, S-V, successive stages in the development of embryo, W. seed, X. Seedling

7.4 SUMMARY

The genus *Pinus* is widely distributed in the Northern hemisphere. There are about 75 species of this genus. About six species have been recorded from different parts of the country. The blue pine, *Pinuswalichiana* is largely found in North-West Himalayan region at 1,800 metres to 7000 metres elevation. The chir pine *P. roxburghii* occurs from Afghanistan to Bhutan in the outer range of Himalayas. This species is also commonly found in the Indian plains. The chilgoza pine *Pinusgerardiana* is found in the inner arid valley of the Himalayas at 1,800 m. to 3,000 m. elevation.

The Khasi pine, *Pinus insularis* is distributed in the Khasi, Naga hills and Manipur region at elevations-of 750 m to 1950 m. Recently a Chinese species *Pinusarmandi* has also been recorded from the north-east hills of Assam. The merkus pine, *Pinusmerkusii* is found in the

hills of Burma150 m to 172 m elevations. In addition to these species several exotic pines have been introduced in India, e.g., *P. montana, P. laricio, P. sylvestris,* etc.

Several species of *Pinus* yield wood which is used for building material, furniture, poles, match boxes and other such articles. The wood of *P. wallichiana* (Kail) and *P. roxburghii* (Chir) yield good timber. The wood is also used as fuel because it catces fire quite easily because of the presence of resin. The old female cones are also used for decoration pieces.

The pine trees yield large amount of resin which is used to manufacture turpentine and turpentine are used to make paints, varnishes and medicines.

The seeds of *P. gerardiana* are edible and known as 'chilgoza'. The seeds of *P. roxburghii* are also edible. Many species of *Pinus* make cheap sources of cellulose which is used for various purposes. In India *P. gerardiana* provides edible seeds, 'chilgoza'; *P. roxburghii* and *P. wallichiana* yield timber, *P. insularis* yield resin and turpentine.

7.5 GLOSSARY

Acute – Tapering to a pointed apex with more or less straight sides, the sides coming together at an angle of less than 90º.

Alternate – Positioned singly at different heights on the stem; one leaf occurring at each node.

Angiosperm – Plants that bear their seeds enclosed in an ovary; the flowering plants.

Anther – The pollen-producing portion of the stamen, typically borne at the tip of a stalk or filament.

Apex – The portion of a plant structure (such as a leaf, bud, stem, etc.) farthest from its point of attachment or uppermost; the tip.

Appressed – Pressed upwardly, close or flat against the bearing structure, thus more or less parallel to it.

Bark – The outermost layer of a woody stem, usually with one or more corky layers that prevent water loss and protect the inner living tissues from mechanical damage.

Bark plate – A more or less flat section of bark, often separated by furrows or grooves, as in bark of mature loblolly pine (*Pinustaeda*).

Base – The portion of a plant structure (such as a leaf, bud, stem, etc.) nearest the point of attachment or lowermost; the bottom.

Bisexual – Having functional reproductive structures of both sexes (i.e. male and female) in the same flower or cone.

Blade – The flat, expanded portion of a leaf, petal, sepal, etc

Bract – A modified, usually reduced leaf, often occurring at the base of a flower or cone; in some conifers, such as firs (*Abies*), bracts are interspersed between the cone scales

Branchlet – An ultimate branch, i.e. one located at the end of a system of branches; a small branch

Broad-leaved – With leaves that are not needle-like or scale-like, but having relatively broad, flat surfaces, as in most deciduous trees such as maples (*Acer*) and hickories (*Carya*)

Bud – An immature shoot, either vegetative, floral (or cone producing), or both, and often covered by protective scales

Clustered – Leaves grouped closely together at the point of attachment and tending to diverge from one another, as the leaves on short shoots in gingko (*Gingko biloba*) or the needles on short shoots in larches (*Larix*)

Compound – Divided into two or more equivalent parts, as a leaf that consists of multiple, distinct leaflets; not simple

Cone – The reproductive structure in conifers comprised of scales and/or other types of modified leaves densely arranged on a central stalk; female, or seed cones, bear ovules on the surface of their scales; male cones produce pollen

Cone scale – The structure in seed cones, derived from a modified leaf, that bears an ovule on its surface. Cone scales are typically flattened, dry and woody, as the scales of pine (*Pinus*) cones. However, they may be soft and fleshy, as in junipers (*Juniperus*), or leathery as in eastern arborvitae (*Thujaoccidentalis*)

Conifer – Cone-bearing plants, such as pines (*Pinus*)

Corolla – The collective term for all of the petals of a flower; the inner perianth whorl

Deciduous – Falling at the end of one growing season, as the leaves of non-evergreen trees; not evergreen

Decurrent – With the leaf base extending downward along the stem

Dentate – Toothed along the margin, with pointed teeth that are directed outward rather than forward

Dioecious – Having functionally unisexual (i.e. separate male and female) flowers or cones, which are borne on different plants within the species; thus some plants are male and others are female

Entire – With relatively smooth margins that lack teeth, spines or other projections (the margins may be lobed); with a continuous margin

Evergreen – Bearing green leaves through the winter and into the next growing season; persisting two or more growing seasons; not deciduous

Glabrous – Lacking plant hairs (trichomes)

Gland – A distinct structure that produces and secretes a substance such as oil or nectar, or resembles those that do

Glaucous – Covered with a whitish or bluish waxy coating (bloom) that can sometimes be rubbed off

Globose – Circular in cross section and in outline when viewed from any angle; like a globe or sphere

Gymnosperm – A seed plant that produces seeds which are not enclosed inside an ovary, as the conifers.

Internode – The portion of a stem between two nodes, i.e. the part where leaves and/or branches do not arise

Involute – With margins rolled inward, toward the upper side

Keel – A longitudinal ridge, more or less triangular in cross section, like the keel of a boat.

Leaf – A lateral outgrowth of a stem, usually green and photosynthetic, and often consisting of a stalk (petiole) and an expanded portion (blade); leaves may also be needle-like or scale-like in form.

Leaflet – One of the separate, leaf-like segments of a compound leaf

Leathery – Moderately thick, tough and pliable

Linear – Long and narrow, with the sides more or less straight and parallel.

Lobe – A more or less major protrusion or segment of a leaf or leaflet delimited by concavities (sinuses) in the leaf margin.

Long shoot – A typically formed stem or branch, without compressed internodes.

Margin – The edge, as in the edge of a leaf blade.

Midrib – A main or primary vein running lengthwise down the center of a leaf or leaf-like structure; a continuation of the leaf stalk (petiole); the midvein

Monoecious – Having functionally unisexual (i.e. separate male and female) flowers or cones, which are borne on the same plant; each plant thus possessing both male and female reproductive structures

Nearly sessile – With a very short, somewhat indistinct stalk.

Nearly symmetric – Not fully symmetric, but divisible into nearly equal halves along one or more planes.

Needle – A leaf that is long and thin (more or less needle-shaped) and usually evergreen; it may be flattened as in hemlocks (*Tsuga*) or more rounded as in pines (*Pinus*).

Needle-like – With leaves that are more or less needle-shaped, and usually evergreen; they may be flattened as in hemlocks (*Tsuga*) or more rounded as in pines (*Pinus*)

Node – The portion of a stem where leaves and/or branches arise; often recognizable by the presence of one or more buds.

Obtuse – More or less blunt at the apex, with the sides coming together at an angle of greater than 90º.

Opposite – Positioned in pairs along the stem, the members of each pair at the same level across from one another; two leaves occurring at each node.

Oval – Elliptic in cross section.

Ovary – The lower portion of a pistil where ovules are borne; often distinguishable from the rest of the pistil by its larger circumference.

Ovoid – Rounded in cross section, broadest near a bluntly rounded base and convexly tapering to a narrower rounded tip; egg-shaped.

Ovule – The structure in flowering plants and gymnosperms which when fertilized develops into a seed.

Palmate – With three or more leaflets, lobes or other structures arising from a common point and diverging from one another; arranged or structured in a hand-like pattern.

Perennial – Normally living more than two years, with no definite limit to its life span

Perianth – The collective term for the outer sterile parts of a flower, comprising the calyx (sepals) and the corolla (petals) when both whorls are present.

Petal – A unit or segment of the inner floral envelope or corolla of a flower; often colored and more or less showy.

Petiole – The stalk of a leaf

Pinnate – With several leaflets, lobes or other structures positioned along and on either side of a central axis; arranged or structured in a feather-like pattern

Pistil – The female or ovule-bearing organ of a flower, typically composed of an ovary, style and stigma.

Plane – With midrib and margin all in one plane, or nearly so; flat

Plated – Bark with relatively large, more or less flat plates, as in mature loblolly pine (*Pinustaeda*) or mature white oak (*Quercusalba*).

Pollen – The small, often powdery, grains which contain the male reproductive cells of flowering plants and gymnosperms.

Pollen cone – A male or pollen-producing cone; typically smaller and of shorter duration than seed cones.

Prickle – A small, sharp structure developed from outgrowth of the surface of bark or epidermis.

Pubescent – Bearing plant hairs (trichomes).

Reflexed – Bent backward or downward.

Resin pocket – A small indentation in the surface of the bark of some conifer species where resin or pitch accumulates; a pitch pocket.

Resinous – Bearing resin and often, therefore, sticky.

Revolute – With margins rolled backward, toward the underside.

Root – The portions of a plant that are anatomically distinct from the shoot and that lack nodes and internodes; roots serve for anchorage, absorption and/or storage, and usually grow below ground.

Scale (1) – Small, flattened structures that are usually thin, dry and membranous in texture.

Scale (2) – Small, often triangular shaped, leaves that are appressed to the branchlets as in juniper (*Juniperus*).

Scale-like – With small, typically triangular-shaped leaves that are often appressed to the branchlets, as in juniper (*Juniperus*).

Seed – A mature or ripened ovule.

Seed cone – A female or ovule-producing cone; typically larger and persisting longer than pollen cones.

Sepal – A unit or segment of the outermost floral envelope or calyx of a flower; usually green and leaf-like.

Serotinous – Having cones that remain closed long after the seeds are ripe.

Serrate – Toothed along the margin, the sharp teeth pointing forward; sawtoothed.

Sessile – Without a stalk, positioned directly against the bearing structure.

Shoot (1) – The portions of a plant that are anatomically distinct from the root and differentiated into nodes, where leaves and branches originate, and the spaces in between (internodes); shoots consist of stems, leaves and any other structures borne from the stem.

Shoot (2) – A young stem or branch.

Short shoot – A stumpy, slow growing, lateral branch with very short internodes, often bearing flowers; a dwarf shoot.

Shrub – A relatively short, woody, perennial plant, usually without a single stem or trunk, and often with many crowded branches.

Simple – Undivided, as a leaf blade that is not separated into distinct leaflets; not compound.

Sinus – The space or recess between two divisions or lobes of an organ such as a leaf or petal.

Smooth – Bark having a more or less continuous, even surface, with relatively few fissures or protrusions, as in American beech (*Fagusgrandifolia*).

Solitary – Occurring singly and not borne in a cluster or group.

Spine – A woody, sharp-pointed, modified leaf or leaf part.

Spiral – Arranged along the stem in such a way that a line connecting the points of attachment would form a spiral; a form of alternate arrangement.

Spreading – Extending outward horizontally or upward at an angle between 90º to 45º relative to the bearing structure.

Stalk – A supporting axis or column that bears a structure at its apex and is usually narrower than the structure being borne, as the stalk of a flower or leaf.

Stalked – With a stalk

Stamen – The male reproductive organ in a flower that produces and releases pollen, composed of an anther usually borne on a stalk (filament)

Stem – The axis of a shoot, bearing leaves, bracts and/or flowers, and usually growing above ground, but sometimes specialized and growing underground or on the surface of the ground; stems are differentiated into regions called nodes, where leaves and branches originate, and internodes.

Sterigma – A persistent leaf base that remains on the twig after the leaf falls, appearing as peg-like projection

Stigma – The pollen-receptive region at the tip of a pistil

Stomate – A microscopic pore on the surface of a leaf, stem or other surface, that controls moisture loss and exchange of gases

Stout – With armature that is relatively thick and sturdy; not breaking easily

Style – The more or less elongated portion of a pistil between the ovary and the stigma

Symmetric – Divisible into essentially equal halves along one or more planes

Synoecious – With all flowers or cones bisexual, i.e. bearing functional reproductive structures of both sexes

Thorn – A woody, sharp-pointed, modified stem

Three-sided – More or less triangular-shaped in cross section

Tree – A relatively tall, woody, perennial plant usually with a single stem (trunk) that bears branches.

Trichome – Any type of plant hair (except for root hairs)

Trunk – The aboveground, relatively stout, main stem of a tree; the bole

Twig – The relatively small end portion of a woody branchlet; a small branchlet.

Two-sided – More or less flat in cross section, with an upper and lower surface

Two-ranked – Arising from the bearing axis in two rows, usually on opposite sides

Unarmed – Without a hook, prickle or other sharply pointed structure on the end of the cone scale

Unisexual – Having functional reproductive structures of only one sex in the flower or cone

Vegetative – Of, or relating to, the non-reproductive parts of a plant.

Weak – With armature that is slender and tends to break easily

Whorled – With three or more leaves positioned on the stem at the same level; three or more leaves occurring at each node

Woody (1) – With an aboveground shoot composed of relatively hard tissue that persists from one growing season to the next.

Woody (2) – Of or resembling wood, and thus relatively hard and dry.

7.6 SELF ASSESSMENT QUESTIONS

7.6.1. Tick the right answer:

1. The female cone in conifers is equated to an inflorescence by:
(i) Florin (ii) Brown
(iii) Brawn (iv) Khan

2. The armed parenchyma of *Pinus* helps in:
(i) Photosynthesis (ii) Support and strength
(iii) Checking excess respiration (iv) Mechanical strength

3. The green leaves in *Pinus* are:
(i) Caducous (ii) Deciduous
(iii) Persistent (iv) Both Caducous andDeciduous

4. In *Pinus* stem resin canals are present:
(i) Below the ridges (ii) Below the furrows
(iii) In cortex, primary and secondary xylem (iv) Between the pith and the epidermis

5. Transfusion tissue in *Pinus* is present in:
(i) Root only (ii) Stem only
(iii) Leaf only (iv) Stem and leaf

7.6.2. Fill in the blanks:

1. Development of several embryos from a single zygote of *Pinus* is called _____
2. The ovule bearing structure in the megasporophyll of *Pinus* is called_____
3. The persistent remnants of the nucellus in *Pinus* is called _____
4. Each ovuliferous scale of *Pinus* has _____ovules
5. In *Pinus* the time required between pollination and fertilization is _____ months

Answer Keys:

7.6.1: 1. (ii), 2.(iii), 3. (iv), 4. (iii), 5. (iv)
7.6.2: 1. Polyembryony, 2.Ovuliferous scale, 3. Perisperm, 4.Two, 5.12

7.7 REFERENCES

- Champion, H. G. and Seth, S. K. 1968.*A revised survey of forest types of India*. Manager of Publications, Government of India, Delhi.
- Chonker, U. P. S. and Bisth, N.S. 1961.Gymnosperm flora of Nainital and adjacent regions.*Proceedings of Indian Science Congress*.
- Dar, A.R. and Dar, G.H. 2006.Taxonomic appraisal of conifers of Kashmir Himalaya.Pakistan*Journal of Biological Sciences.*

- Duthie, J. F. 1906. *Catalogue of plants of Kumaun and of the adjacent portions of Garhwal and Tibet based on the collections of Strachey and Winterbottom during the year 1846-1849, on the catalogue originally prepared in 1852 by Sir Richard Strachey.*Lovell Reeve & Co., Limited, London.
- Gupta, R. K. 1968. *Flora Nainitalensis*. Navyug Publication, New Delhi.
- Hooker, J. D. 1888. *Flora of British India*. Ashford, L. Reeve & Co. Ltd. The Oast House.
- Kanjilal, U.1928. *Forest Flora of the Chakrata, Dedradun and Saharanpur Forest Divisions, United Provinces* (Revised edition by B.L.Gupta).
- Osmaston, A. E. 1927. *A Forest Flora for Kumaun*. Superintendent Government Press, United Provinces, Allahabad.
- Pande, P.C. 1991. Gymnospermous flora of Almora district of KumaunHimalaya.*Vegetos.*
- Pande, P.C. and Joshi, P. 2005. Gymnospermous flora of Kumaun Himalaya: A census. *Journal of Economic and Taxonomic Botany.*
- Pandey, B. and Pande, P.C. 1999. Ethnobotanical studies on gymnospermic plants of Kumaun Himalaya. *Journal of Economic and Taxonomic Botany*.
- Raizada, M. B. and Sahni, K.C. 1958. Living Indian Gymnosperms.Part I. Indian *For.Rec. (N. S.)Bot.*
- Rana, T.S., BhaskarDatt and Rao, R.R.. 2003. *Flora of Tons Valley, Garhwal Himalaya (Uttaranchal).*Bishen Singh Mahendra Pal Singh, Dehradun.
- Sahni, K.C. 1990. *Gymnosperms of India and Adjacent Countries.*Bishen Singh Mahendra Pal Singh, Dehradun.
- Singh, K. P. and Mudgal, V. 1997.*Gymnosperms in Floristic diversity and conservation strategies in India. In: Cryptogams and Gymnosperms*, ed., Mudgal,V. and Hajra, P. K., Botanical Survey of India, Howrah.
- Singh, K.K. and Prakash, A. 2002.*Flora Rajaji National Park, Uttaranchal*.Bishen Singh Mahendra Pal Singh, Dehradun.
- Tewari, Lalit M., Kumar, Sanjay and Kanchan, Upreti. 2010. Assessment of Gymnosperms diversity of Uttarakhand. In Tewari et al. (eds.) *Biodiversity Potentials of the Himalaya,* GyanodayaPrakashan, Nainital
- Uniyal, B.P., Sharma, J.R. Choudhery, U. and Singh, D.K. 2007.*Flowering Plants of Uttarakhand*(A Checklist).Bishen Singh Mahendra Pal Singh, Dehradun.
- Uniyal, S. K. and Awasthi, A. 2000).Gymnosperms of Uttar Pradesh; an enumeration.*Indian Journal. Forestry*

7.8 SUGGESTED READINGS

- Bhatnagar, S.P. and A. Mitra. 1996. *Gymnosperm, New Age International* Pvt. Ltd. N. Delhi.
- Chamberlian, C.J. 1955. *Gymnosperms: Structure and Evolution.* Chicago.
- *College Botany*. S Chand and Company, New Delhi, Pandey

- *Botany for Degree Students: Gymnosperms.* S. Chand Publications, Meerut
- *Gymnosperms*. Pragati Publications, Meerut. Sharma
- Sporne, K.R. 1965. *The Morphology of Gymnosperms*.Hutchinson Co. Ltd., London.

7.9 TERMINAL QUESTIONS

Q.1. Write a note on the distribution of *Pinus* in India.

Q.2. With the help of the suitable diagram describe the anatomy of *Pinus* stem. Also comment upon the important characters of the wood.

Q.3. Describe the development of female gametophyte of *Pinus*. How does it differ from that of angiosperm.

Q.4. Describe the post fertilization changes occurring in the ovule of *Pinus*

Q. 5. Give an illustrated account of the internal structure of the *Pinus* needle and point out its xeromorphic features.

UNIT-8 STRUCTURE AND LIFE HISTORY OF *EPHEDRA*

8.1 OBJECTIVES

After reading this unit students will be able to:

- Describe systematic position, habit, habitat and general features of *Ephedra*
- Explain reproduction in *Ephedra*
- Discuss life cycle in *Ephedra*

8.2 INTRODUCTION

The order *Ephedrales* includes a monotypic family *Ephedraceae*, represented by *Ephedra*. It is one of the highly evolved groups of gymnosperms. The plants are mostly small trees or perennial herbs or shrubs. They usually grow in xerophytic habitats. The leaves are minute and scaly. Resin canals are absent and the medullary rays are multiseriate. The plants are dioecious and bear compound strobili (also known as flowers).

At one time, *Ephedra* was included along with *Gnetum* and *Welwitschia* in the family Gnetaceae of the order Gnetales. However, due to the heterogeneous nature of the family, the order Gnetales was divided into three families, each comprising one genus. Florin (1934) and Eames (1952) pleaded for the establishment of three distinct orders: *Ephedra*les, Welwitschiales and Gnetales, with a monogeneric family in each. Pant (1957) placed *Gnetum* and *Welwitschia* together in Chlamydospermophyta and treated *Ephedra* under Coniferophyta.

There are about 42 species of *Ephedra*, widely distributed in both Eastern and Western hemispheres. These species are equally divided between the New and Old World, occurring in the temperate and sub-tropical regions. Eight species of *Ephedra* are known from India; of these, seven (*E. pachyclada, E. intermedia, E. saxatilis, E. gerardiana, E. nebrodensis, E. major* and *E. regeliana*) are confined to the north-west Himalayan region and only one (*E. foliata*) occurs in the plains of Rajasthan and Punjab.

Ephedra is the source of a drug, ephedrine, obtained from species like *E. equisetina, E. gerardiana, E. major, E. sinica, E. intermedia* and *E. nebrodensis.*

The importance of this group is because of its forming a connected link between gymnosperms and angiosperms. They possess extraordinary morphology and diverse habit. They are gymnosperm like in that their ovules are naked and borne on cones, whereas angiosperm like in that their ovules and microsporangia are borne on somewhat flower like fertile shoot. The ovules are, however, enclosed within coverings additional to the true integument, which are sometimes considered to be the equivalent of ovary walls. Another angiosperm like character the presence of vessels in the xylem.

A common character of the group is the prolongation of the apex of the integument into long narrow tube with a flattened orifice, by means of which the pollen is collected. They are so advanced in structure that in several respects they resemble the angiosperms. However, is no direct relationship, and it has been established that the Gnetales were not the ancestors the angiosperms. They are a parallel line of evolution.

Three genera, *i.e.*, *Gnetum, Welwitschia* and *Ephedra,* were long considered to form a single family Gnetaceae of the order Gnetales, but on the basis of morphological evidences order has been divided into three families, i.e., Gnetaceae, Welwitschiaceae and Ephedraceae. The three orders have been established known as Ephedrales, Welwitschiales and Gnetales. Whatever the system of classification may be, there are three genera, *Ephedra, Welwitschia* and *Gnetum*. The genus *Ephedra* consists of shrubby plants with minute leaves. There are about 35 distributed in the New and the Old Worlds. The species have mostly a restricted range distribution. The genus *Welwitschia,* comprises the remarkable living plants. There is only one species, *W. mirabilis,* particularly confined to the desert region of South West Africa. The stem resembles enormous woody carrot, the top of which is concave and may reach 4 feet in diameter. It is entirely buried in the sand and bears only two long strap-shaped leaves, which persist throughout life. The genus *Gnetum* includes trees, shrubs or woody climbers. The climbers are predominating. There are about 4 species distributed in the tropical regions of the world, especially West Africa the Amazon region. They are invariably the jungle plants.

8.3 EPHEDRA

Systematic Position

Class - Gnetopsida
Order - Gnetales
Family - Gnetaceae
Genus - *Ephedra*

Distribution and habitat

The family is represented by a single genus called *Ephedra.* It is represented by forty species that are widely distributed throughout the globe and are mostly xerophytic shrubs or woody climbers and lianes. One species grows into a small tree e.g., *E. triandra* Tul. *E. gerardiana* is a perennial herb. *E. foliata* is a scrambling shrub that may attain a height of up to 6 metres. It climbs up the neighbouring trees or even walls. In the absence of a support it spreads along the ground. Other Indian species, e.g., *E. intermedia, E. saxatilis, E. regeliana* are shrubs. Usually the plants are low straggling shrubs reaching the height of one metre or so. The green, long jointed, slender branches bear minute leaves. The scaly leaves are opposite and connate in a two-toothed sheath. The whole aspect of the plant is xeromorphic. True foliage leaves are generally lacking and the whole habit is suggestive of a shrubby ***Equisetum.*** The leaves also occur in threes and rarely in fours.

Distribution

Ephedra is widespread and sporadic in distribution in arid regions of tropics and sub-tropics of northern and southern hemi-spheres. About eighteen species occur in the old world (France, Canary islands, around the Medi-terranean east to Persia, India and China), and about 22 in the New World with 10-12 in North America and 7-9 in South America (Bolivia to Patagonia). The North American species are most abundant in California, Arizona, and

New Mexico, with ranges extending north and south into Mexico, and 3-4 species occurring as far east as Texas.

In India the genus is represented by *E.foliata, E. gerardiana , E. Intermedia, E. Nebrodensis, E. regeliana* and *E. Saxatilis. E foliata* is a scrambling shrub found in the drier parts of Rajasthan, Panjab and Haryana. *E. gerardiana* grows at Chakrata (Himalayas, Uttarakhand.) in the crevices of rocks as a perennial herb. It also grows in Baluchistan. It grows up to an altitude of 7,000-16,000 feet above sea level and extends from the drier regions of temperate and alpine Himalayas, from Kashmir to Sikkim, Frequently met with in Pangi, Labaul, Spiti, Chni and Kilba-Kailash ranges of Kanawar, Shali-hills (north of Simla), Kashmir and Ladakh. *E. intermedia* occurs along Pangi hills, Kanawar and to a lesser extent in Kashmir, Kulu and Jaunsar. *E. nebrodensis* grows in Kashmir, Lahaul and Spiti. *E. saxatilis* also grows in the drier ranges of the Himalayas especially in the Lahaul and Spiti valleys.

8.3.1 *Ephedra:* structure

External features

The stem is green, hard, ribbed, glabrous and much branched. It is distinctly jointed, slender and has long internodes. The branches are also green and photo-synthetic. They remain green for several seasons. The leaves are deciduous, opposite or whorled, more or less connate basally and usually reduced to membranous sheaths. In the case of whorled phyllotaxy each node bears 3 or 4 leaves. Each leaf is inervated by two unbranched veins that run parallel to each other. The scale leaves bear a bud each in their axils. These axillary bud grow into branches. The internodes grow by means of a basal or an intercalary meristem that is present at the base of each node. Sometimes this basal or intercalary meristem becomes non-functional and hard and forms an abscission zone. This usually happens at the close of the growing season and results in the fall of the branches. The plants are usually dioecious and only rarely monoecious. *E. campylopoda* has pendulous branches and is commonly grown in hanging baskets. In *E. gerardiana* one to several short thick stems arise from the ground and branch profusely above so as to give a characteristic hemispherical look to the plants. The roots are long, branched and deep feeders. They are tap roots that grow pretty deep into the soil. There is no report of a mycorrhiza.

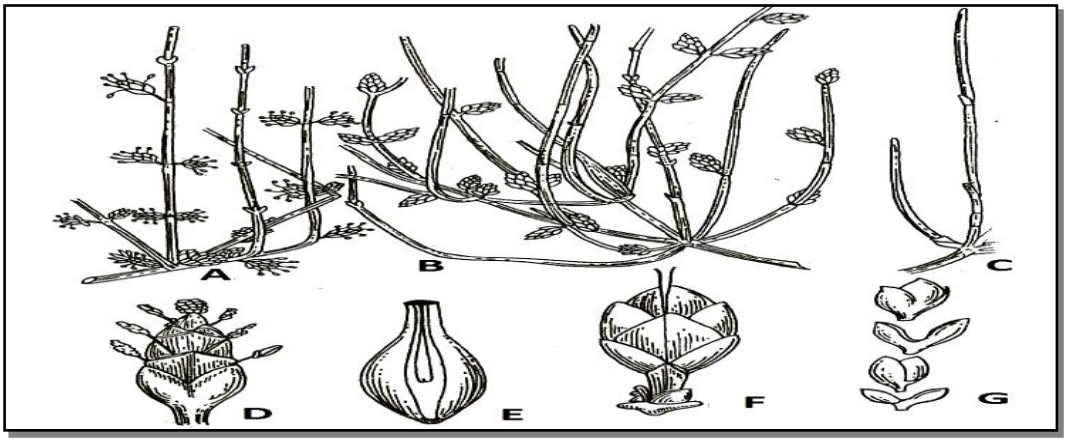


Fig. 8.1. *Ephedra.* A. male branches, B. female branches, C. sterile branches, D. staminate strobilus, E. L.S. of seed, F. ovulate strobilus, G. bracts of female strobilus

Stem

The stem is green, profusely branched, jointed and is differentiated into distinct nodes and internodes. The branches develop into the leaf axils at the nodes. The number of branches is equal to the number of leaves present at the node. The internodes grow by a meristematic zone present at its base. The meristem dries up at the end of each growing season causing brittleness and shedding of branches. New axillary branches develop in the next season. The young stem is tender but its older parts become woody as the result of secondary growth. Due to jointed nature of stems and whorled branches, *Ephedra* is commonly known as jointed fir. Superficially it resembles with the aerial shoot of the *Equistem.*

Root

It is long tap root in xerophytic species, but in larger forms it is replaced by adventitious roots.

Leaves

The leaves are inconspicuous, very minute, scaly and sessile. They are arranged in pairs or whorls at the nodes. The leaves at the node are fused at the base to form a sheath. Each leaf has two unbranched parallel veins. Since the leaves do not have the capacity of food synthesis, the function of photosynthesis is carried by green stem.

Internal structure

Stem: The transverse section of the stem reveals a circular outline with ridges and furrows. The internal structure clearly portrays its xerophytic nature and consists of all the tissue systems.

Epidermis: It is made up of a single layer of parenchymatous cells that appear nearly rectangular. The outer walls of epidermal cells are covered with a thick cuticle. The continuity of the epidermis is interrupted by the stomata that are sunken in circular pits and are located only in the furrows. Each stoma has two guard cells and a substomatal cavity. The subsidiary cells are not distinct. The stomata development is haplocheilic.

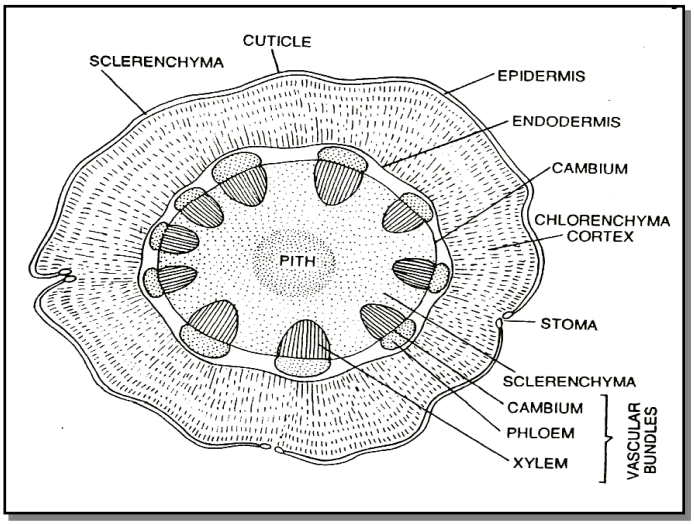


Fig. 8.2 *Ephedra*- Transverse sections of young stem showing primary structure

Hypodermis: It consists of patches of sclerencymatous cells located below the ridges. These cells are elongated and have thick lignified walls. They give mechanical strength to the stem.

Cortex: It is distinguishable into two zones. The outer chlorenchymatous cortex that consists of elongated palisade-like cells full of chloroplasts. These are loosely arranged and enclose lot of inter-cellular spaces. It is also called the photosynthetic zone. Next to it is the parenchymatous cortex which is made up of oval or elliptical thin-walled cells that also possess chloroplasts. They also enclose small intercellular spaces. The chlorenchymatous cortex makes up the deficiency of leaves that are mostly scale-like.

Endodermis: It is the last layer of the cortex and is quite distinct in young stem. Pericycle is not clearly defined.

Vascular Region : It consists of an interrupted ring of conjoint, collateral, endarch and open vascular bundles. The cambium consists of a single layer of meristematic cells. There are 8-12 vascular bundles in the internode. Each pair of small bundles supplies a leaf at the upper node. Just above the node one bundle produces as smaller one by tangential division towards the next larger one so that the paired alternation is re-established and the two leaf traces extend the entire length of the next internode. Just below the level of departure of the traces to the leaves there is a complete girdle of primary vascular tissue that inter- connects all boundles of the rings. Branch traces are also two in number and are given off by adjacent large bundles immediately above the point of departure of leaf traces. In some species there is an alternation of three small and two large bundles. The nodes are two-trace and unilacunar type.

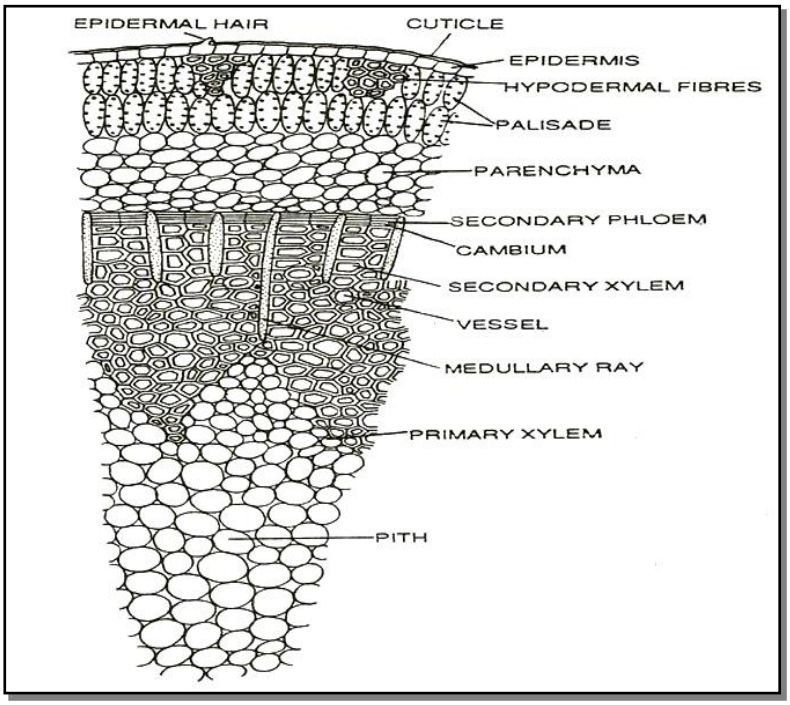


Fig. 8.3. ***Ephedra.*** **T.S of stem showing broad cortex with photosynthetic tissue. Vessels are found in the secondary xylem**

The xylem consists of tracheids, vessels and xylem parenchyma. The vessels originate from the pitted tracheids. Certain groups of pits on long and sloping walls near the ends of tracheids are larger in diameter, loose their pit closing membranes, and make up the foraminate perforation plates characteristic of the vessel members of *Ephedra.* The plates show a uniseriate arrangement of pores in early formed elements, but in later formed ones most pores are two ranked *(E. major)* or irregularly grouped *(E. califomica).* The vessels have bordered pitted thickening. The tracheids may be annular spiral or have uniseriate or irregularly arranged bordered pits on their radial walls.

The phloem consists of sieve cells, phloem parenchyma and albuminous cells. The albuminous cells are associated with the sieve cells and look like companion cells of the angiosperms. They are however, different in origin and derived from a different cell and not from the same mother cell.

Pith: It occupies the centre of the stem and consists of parenchymatous cells that enclose small inter cellular spaces. In older branches the cells become thick-walled in the nodal region. This is the intercalary meristem whose cells become thick-walled and help in abscision of the branches. It is also termed as the peridermal diaphragm. The medullary rays between the vascular bundles are narrow.

Secondary Growth in the Stem

It is affected by means of vascular cambium present between the primary phloem and primary xylem. The cambium forms a complete ring and starts dividing horizontally to cut off secondary phloem towards the outside and secondary xylem towards the inside. The amount of secondary xylem produced is more than the secondary phloem. The cambium is persistent and keeps pace with the growing cylinder by the anti-clinal division of its cells. It has the usual two types of cells, the ray initials and fusiform initials, the former giving rise to the phloem and xylem rays, whereas the latter giving rise to the secondary vascular elements. The activity of the cambium varies with the season and hence there are distinct annual rings. The secondary wood is markedly ring porous.

The secondary xylem consists of vessels, tracheids and scanty amount of xylem parenchyma. Xylem fibres are absent. The vessels in *Ephedra* originate from the long tracheid like cells by the loss of closing membranes from a series of circular bordered pits located near the ends of such elongated cells. Such a step leads to the creation of a foraminate perforation plate. Transitional conditions leading to such a state are noticeable in *E. califomica* and *E. major.* In the latter case end walls with both perforations and circular bordered pits occur. This illustrates that the perforations originated by the loss of closing membranes of the circular bordered pits. There are clear transitional forms between tracheids and vessel members. These perforation plates may be arranged in a uniseriate manner or biseriate manner or may be even irregular in arrangement. In the angiosperms, on the other hand, the vessels originate from tracheid-like cells with transversely elongated or scalariform bordered pits located at their tapering end walls. These elongated pits lose their closing membranes. Later elaboration results in the development of well defined scalariform perforation plates on the end walls. Elimination of the bars between these scalariform plates leads to the establishment of a

simple oval or circular perforation plate. The spring wood abounds in vessels and is ringporous, whereas the autumn wood has only a few vessels and more tracheids. The vessels and tracheids have bordered pits that may have uniseriate arrangement or may be irregularly scattered. Spiral, annular or reticulate tracheids occur in the protoxylem elements of the primary xylem. The nodes especially have reticulate thickenings on the tracheids. Some cells with crystals of calcium oxalate are also present in the secondary xylem. There is no distinction into hard wood and soft wood. Most of the branches fall down after 3 or 4 yeas, due to abscission.

The secondary phloem is a typical of the gymnosperms in general and exhibits some angiospermic characters. The conducting phloem which lies just outside the cambial zone contains parenchymatous rays, sieve cells and axial parenchyma including albuminous cells. The albuminous cells in *Ephedra* are found in the axial system and are the product of fusiform initials that also give rise to other vascular elements like sieve cells and phloem parenchyma. These albuminous cells are found along with the sieve cells and may be of the same length as the sieve cell or half its length. These cells cannot be regarded as companion cells because they do not occur in the same radial rows as the sieve cells. Their origin may also be from different cells. They form a conspicuous element of the axial system and exist in radial files or may be scattered in the conducting phloem. They result from the transverse or oblique division of a fusiform phloem mother cell and have one slightly inclined end wall and the other end wall is tapering. They have denser cytoplasmic contents and have connections with small sieve areas of an adjoining sieve cell. They also contain besides the nucleus an ovoid slime body. The sieve cells and sieve elements resemble each other: (i) in possessing an ovoid proteid body; (ii) dispersing slime; (iii) general shape; (iv) a similar position arrangement in the tissue.

The sieve cells in *Ephedra* may have blunt or tapering ends and have their walls with no second-ary or nacreous walls. Each sieve area has pores that are generally aggregated into groups. These sieve areas do not occur between sieve cells and albuminous cells. The mature sieve elements have several nacrotic-appearing nuclei that are generally flattened and are found around the periphery of the parietal cytoplasmic layer. Sometimes these nuclei are rounded and occur in the centre of the cell. Slime body is present in the young sieve element but it is lost in the mature elements which contain a P-protein. The P-protein may appear in the form of a parietal cylinder, thread-like strands, as a slime plug or in the form of amorphose globules.

The radial system of the conducting phloem consists of secondary medullary rays that are mainly parenchymatous and multiseriate and are usually bordered by short fusiform cells. Uniseriate and biseriate rays are also present, but mainly in stems with a year or two of secondary growth. Multiseriate condition results as secondary growth continues for more years. In mature stem only multiseriate rays are found. Thick-walled sclereids are also met with in the rays. These selereids are living and store starch.

The xylem rays are also uniseriate or biseriate in the beginning and become multiseriate later. That part of the phloem in which the sieve elements have stopped functioning is called the non conducting phloem. In *Ephedra* this type of phloem forms a small zone external to the

functional region. Some cells of this phloem change into cork cambium or phellogen whereas others become sclerenchymatous.

The annual periderm arises within the non-conducting phloem at about the same time that the vascular cambium is reactivated in spring. The cork cambium arises from the living parenchyma cells of the non-functionary phloem and cuts off suberised cells towards the outer side. Fusiform parenchyma cells lying internal to the new periderm develop into fibre sclereids. These cells possess crystal sand in the region of the middle lamella.

The pith becomes narrow in the stems that have undergone secondary growth and may ultimately disappear in very old stems, its place being taken by the secondary xylem.The secondary growth in the root is normal.

Root

The root has the usual structure and consists of epiblema, cortex, endodermis, pericycle and a diarch vascular region. There are no resin canals. Mucilage canals are, however, present here and there in the cortex.

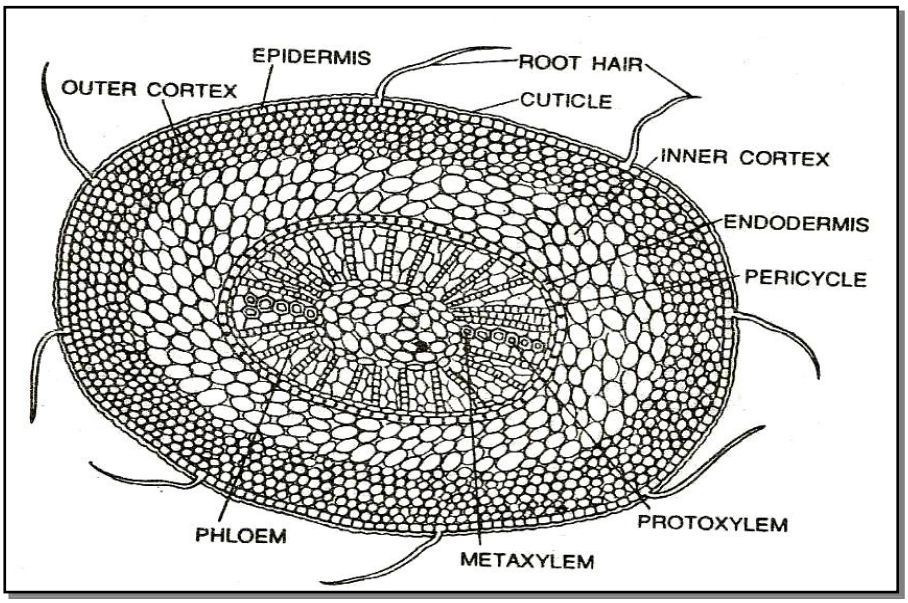


Fig. 8.4. *Ephedra.* Transverse section of young root

Leaf

All the species of *Ephedra* have reduced and membranous scale leaves. A transverse section of the leaf reveals an almost oval outline. There is a thick cuticle that covers the single layered epidermis of parenchymatous and slightly radially elongated cells. A single stoma was observed in the section. It is sunken. Next to the epidermis is the palisade tissue made up of two or more layers of oval cells that are full of chloroplasts. The centre of the leaf is occupied by parenchy-matous tissue. The palisade and the central tissue enclose small air spaces. Two vascular bundles are present in the central parenchyma.

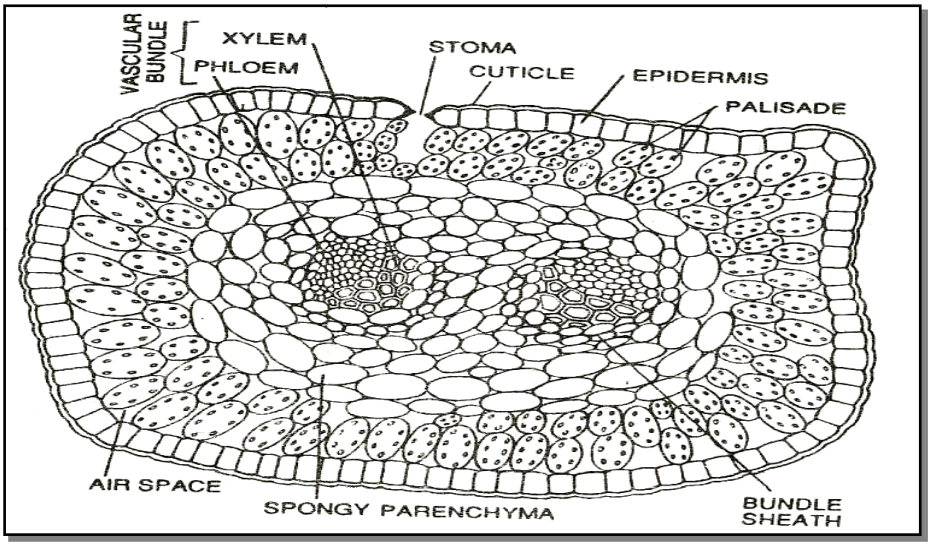


Fig. 8.5. *Ephedra.* Vertical section of a leaf

8.3.2 *Ephedra:* Life history

All the species of *Ephedra* are dioecious and bear male and female reproductive organs on different plants. These plants do not show any difference in their vegetative organisation and can be recognised only when reproductive structures appear. Usually the angiosperm-centred terminology is used to interpret reproductive structures in *Ephedra* and other Gnetales. The terms inflorescence, flower, perianth, stamen and another are commonly used. This type of terminology creates confusion while describing a plant that has gymnospermous morphology.

Microsporangiate or Male Strobilus

The microsporangiate strobilus of *Ephedra* is regarded as a compound structure. These strobili arise in clusters from the nodes of branches. Each strobilus arises in the axil of a scale leaf. Their number at the node depends upon the number of scale leaves. Each strobilus consists of a central axis that bears two to eight pairs of decussately arranged simple, broad and cupped bracts. The basal one or two pairs of these bracts are sterile, whereas the upper ones bear each a solitary male shoot or microsporangiate shoot in their axils. This shoot is continued into a short axis or the micro sporangiophore and bears at its base a pair of fused bracts. The micro sporangiophore bears terminally 8-12 microsporangia that are sessile and dehisce terminally. These fused basal bracts are also called bracteoles or perianth parts. The male flower is also called a simple strobilus. A compound male strobilus, therefore, consists of many such simple strobili. There are slight variations regarding the number of male flowers or simple strobili arising in the axil of each bract of the compound strobilus.

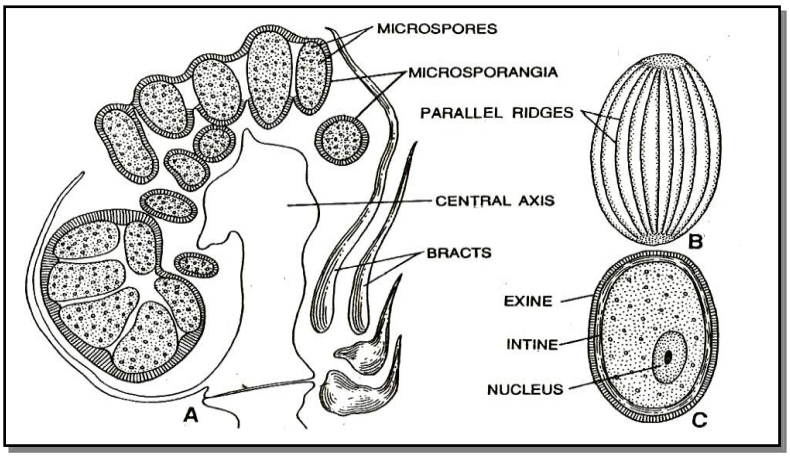


Fig. 8.6. ***Ephedra.*** **A. longitudinal section of male strobilus, B. pollen grain showing parallel ridges on its exine, C. pollen grain in sectional view**

In *E. gerardiana* and *E. foliata* simple strobilus arises in the axil of a bract, but in this case there is a slight external expression of a fusion of two sporangiophores to form one. The male shoot is single but according to Eames (1952) it bears two fused bracteoles and two sporangiophores that become ontogenetically fused (the signs of fusion only slightly clear externally). In *E. antisyphilitia* the single sporangiophore shows no external signs of fusion. In *E. intermedia* and *E. distachya* two or more sporangiophores arise separately in the axil of the two fused bracteoles. The vascular supply to the cone consists of two pairs of vascular bundles at the base of cone axis in *E. gerardiana*. Later the bundles of each pair split into five so that there are 10 vascular bundles in all. Further splitting of bundles occurs in two bundles lying laterally to the middle bundle of each side so as to form a total of fourteen bundles. Four of these supply the bract scales subtending the male flowers. Of the rest 19 bundles three enter the sporangiophore. They unite into an arc shaped vascular bundle at the base of the sporangiophore. The perianth is not supplied any vascular trace. At the tip of the sporangiophore, each sporangium is supplied by its own vein ending, which is a terminus of a dichotomous truss.

Microsporangium

The sporangiophore arises as small protuberance in the axil of the fertile bract of the male strobilus. The protuberance shows a clear distinction into tunica and corpus in the earlier stages of development but later due to periclinal divisions in the tunica this distinction becomes obscure. The two perianth lobes arise growing for some time. Each lobe represents a sporangium. A hypodermal group of archesporial cells becomes apparent in each lobe and consists of larger cells with distinct nuclei and denser contents. After a little period of growth each archesporial group of cells in each sporangium becomes divided into two groups by the appearance of a band of sterile cells. This indicates that a single sporangium becomes two chambered. Now each group of archesporial cells divides by periclinal walls to form an outer layer of primary wall cells and an inner layer of primary sporogenous cells. The primary sporogenous layer undergoes two periclinal divisions to form a middle wall layer and an inner tapetal layer. The primary wall layer functions directly as the outer wall of sporangium.

These three wall layers (including the tapetum) undergo anticlinal divisions to complete the sporangial wall and to keep pace with the growing sporoangiophore. The sporogenous cells undergo divisions in all planes to form a group of sporogenous cell that divide further to form a large number of microspore mother cells. During these stages of development the middle wall layer becomes crushed. Its cells become flattened. The tapetal cells enlarge and develop dense cytoplasmic contents. They become bi or tetra nucleate. They degenerate after the meiosis of mother cells is complete. The microspore mother cells divide meiotically to form tetrahedral tetrads of haploid microspores. The dehiscence of the microsporangium is terminal i.e., a slit appears at the apex of each sporangium.

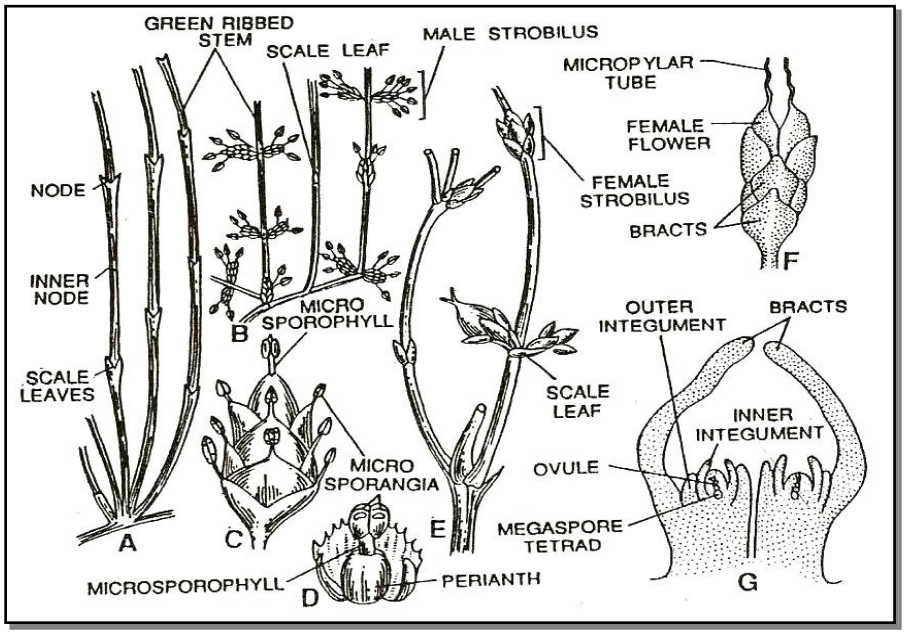


Fig. 8.7. ***Ephedra.*** **A. plant with sterile branches, B. branches with male strobilus, C. male strobilus, D. male flower, E. branches with female strobili, F. female strobilus, G. female flower showing ovules and megaspore tetrads**

Megasporangiate Strobilus or Female Cone

The female cones appear in April in *E. gerardiana* and the seeds mature in September. They usually arise in pairs at each node, in the axil of scale leaves. Sometimes three or four strobili may be borne at each node. Rarely a single strobilus may terminate the main axis.

The female cone appears to be an elliptical structure with a pointed apex. It seems to retain the same compound strobilar organisation as the male strobilus and consists of a short axes to which are attached three or four pairs of decussate bracts. The lower bracts are sterile whereas the upper two bear an ovule in their axils (one bract bears one ovule). Each ovule terminates a short stalk. The lower bracts are sterile whereas the upper two bear an ovule in their axils (one bract bears one ovule). Each ovule terminates a short stalk. The stalk and the terminal ovule are also termed as a female flower.

In E. *gerardiana* each female cone is supplied by four vascular strands that enter its base and then bifurcate into eight vascular strands that appear to be arranged in two groups of four each. In each group there are two small median strands that fuse with each other and enter the

first pair of sterile bracts. The fused small bundles again merge with the four bundles of the cone axis so that once again there are four bundles in the cone axis (four bract traces are also seen). They are arranged in a ring. A little above, these bundles again bifurcate into two groups of four bundles each. These are arranged at right angles to the previous bifurcation. In this case again the small median pairs fuse and enter the decussate bracts. Like this the third and the fourth pairs of bracts are supplied. At the end there are six bundles left in the cone axis because after supplying the last pair of bracts the medial bundles do not merge with larger bundles of the cone axis. These six bundles supply the ovules, i.e., three enter each ovule.

Megasporangium

A young ovule has a nucellus made up of parenchymatous cells that show a hypodermal archespo-rial cell in *E. foliata*. The nucleus is surrounded by a two-layered envelope. These are usually des-ignated as outer and inner integuments. The inner integument grows at its tip into a long cylindrical tube (micropyle) that project through the apical opening of the outer integument. This cylindrical tube is called the micropylar tube. The inner integument is fused with the nucellus at its base and a little distance above, but is quite free above. The arhesporial cell divides periclinally to cut off several outer cells and an inner cell. The former constitute the parietal cells, whereas the latter is called the megaspore mother cell and is pushed quite deep into the nucellar tissue by the growth of parietal cells. Divisions of the parietal cells and epidermal cells of the nucellus make up most of its bulk. The megaspore mother cell undergoes meiosis to form a linear tetrad of 4 haploid megaspores. 'T' -shaped tetrads have been noticed in *E. Foliara.* In *E. distachya* wall formation is delayed between the four megaspores so that a false tetrasporic sac is indicated. Usually the lowest or the chalazal megaspore is functional and develops into a cellular female gametophyte that has a broader micropylar end and a narrow and pointed chalazal end *(E. foliata and E. gerardiana).* One to three archegonia develop at the micropylar end of the gametophyte. A distinct plate of colourless and thin-walled cells is present at the chalazal end of the ovule. This is called the hypostase. Below this plate xylem tracheids with spiral and pitted thickenings are present. In *E. intermedia* the archesporial cell directly functions as the megaspore mother cell.

Singh and Maheshwari (1962) report that in *E. gerardiana* the nucellar cells in the micropylar region become bi nucleate and their cytoplasmic contents stain deeply. They also report the development of small papillate outgrowths from the outer integument. These outgrowths are directed towards the inner integument. These outgrowths grow more and become thick-walled as the ovule matures. They close the space between the two integuments and may also help in sealing of the micropyle by pressing in the micropylar tube, after the pollination has been affected.

The ovules vary in shape and vascularisation. In *E. gerardiana* three bundles enter each ovule and after contributing a few tracheids to the nucellar base innervate the outer envelope or integument. The inner integument is supplied by two bundles that end at its base or extend up to the level of separation from the nucellus. According to Eames (1952) the vascular supply to the outer integument indicates that it represents another pair of fused bracts. He does not regard it to be an integument because it is innervated by an anterior and a posterior vascular system.

Gametophytes

The male and the female gametophytes develop from the microspores and the megaspores, respectively. The spores are, therefore, the pioneer structures of the gametophyte generation.

Microspore and the Microgametophyte

The microspore in *E. foliata* is elongate with longer diameter 72 µ and shorter diameter 23 µ. The exine is 1.4 µ thick with plicate surface and is provided with parallel ridges (12 in number) along the longer axis of the grain. In *E. gerardiana* there are seven ridges and the microspores measure 57 x 25 µ and in *E. saxatilis* 48 x 28 µ. The pollen grains are wingless and inaperturate. They are usually ovoid in form. The nucleus is first centrally located and later moves to one end. The microspore is yellow in colour. The microspores start germinating within the microsporangium. The microspore nucleus (that has moved to one end) divides to form a small lenticular male prothallus cell and a larger cell. The nucleus of the latter divides again to form a second male prothallus cell marked off from the large antheridial cell by a cleavage of cytoplasm. The two male prothallus cells start degenerating. The nucleus of the antheridial cell divides into a small generative cell and a tube cell. The generative cell is not surrounded by a definite wall but is marked off by a distinct cytoplasmic sheath. It divides by a periclinal wall into a stalk cell (sterile cell) and a body cell

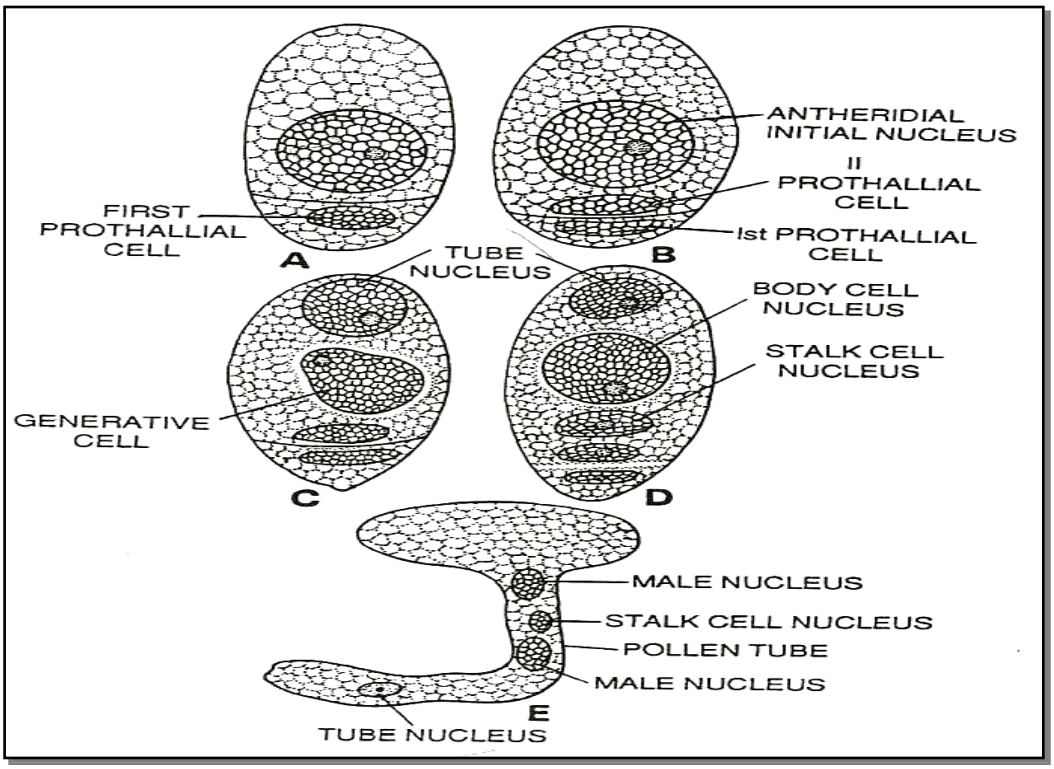


Fig. 8.8. *Ephedra.* Development of male gametophyte. A-D. successive stages in the germination of pollen grain, E. pollen grain with the pollen tube having male nuclei 1 and 2

(spermatogenous cell). At this 5-celled stage the semi germinated microspores are released through an apical slit in the microsporangium and are carried by wind to the micropyles of ovules. Further development takes place on the nucellus of the ovule and consists in the

development of the pollen tube and formation of two unequal male gametes by the division of the body nucleus. Previous literature regarding the development of male gametophyte in *Ephedra* reveals a number of variations, which have been reported in different species of the genus by different authors. Maheshwari (1935) reported that in *E. foliata* the second prothallial cell is actually a prothallial nucleus because it is not surrounded by a cell wall. Mehra (1938) observed that a wall is present around the second prothallial cell as soon as it is formed but it breaks down as soon as it is formed. Mehra (1938, 1947) observed ilistinct male prothallus cells in *E. gerardiana* and *E. saxatilis*. Singh and Mahesbwari (1962) also confirm this observation by Mehra in *E. gerardiana*. Similarly there is a controversy as to whether there is a stalk cell or a stalk nucleus. Berridge (1909) reported the presence of a stalk cell in *E. distachya*; but in *E. saxatilis* Mehra (1947) reported that it is a stalk cell in the beginning but gradually the separating wall disappears and only the nucleus is left behind. In *E. gerardiana* also Mehra (1938) observed a stalk nucleus, but Singh and Maheshwari(1962) observed a distinct stalk cell. Mehra (1947) reported diploid pollen grains in *E. saxatilis, E. intermedia, E. altissima and E. foliata*. These are formed by incomplete partitioning of the mother cell after four free nuclei are formed in it. One cell contains two nuclei that fuse to form a diploid one.

Megagametophyte or the Female gametophyte

The chalazal megaspore is usu-ally functional. It enlarges and its nucleus divides into two. These nuclei move towards the opposite poles and are separated by a large central vacuole. Later four, eight and sixteen free nuclei are formed. These are arranged in a peripheral layer around the central vacuole. The free nuclear divisions are not strictly simultaneous. Singh and Maheshwari (1962) reported that in *E. gerardiana* some nuclei are in metaphase and others in anaphase and telophase. Later the central vacuole disappears and the free nuclei are evenly distributed throughout. In *E. foliata* and *E. gerardiana* the mature gametophyte is almost obovate with a broad micropylar end and a pointed or tapering chalazal end . In *E. trifurca* Land (1904) counted 256 free nuclei whereas Maheshwari (1935) counted 500 free nuclei in *E. foliata*. Singh and Maheshwari (1962) could not determine the exact number of the free nuclei in *E. gerardiana.* Wall formation is centripetal and makes the female gametophyte a cellular tissue with a broad micropylar end and a narrow chalazal end. The cells in the chalazal end undergo active divisions. The cells in the micropylar region are elongated, large and parenchymatous and have scanty cytoplasm whereas those in the chalazal region are comparatively small and almost polygonal. *(E. Gerardiana).*Archegonia develops in the micropylar region whereas the chalazal region acts as the food storage zone. In *E. trifurca* one or two archegonia develop, whereas in *E. foliata* there are three and in *E. gerardiana* the number may be three or four.

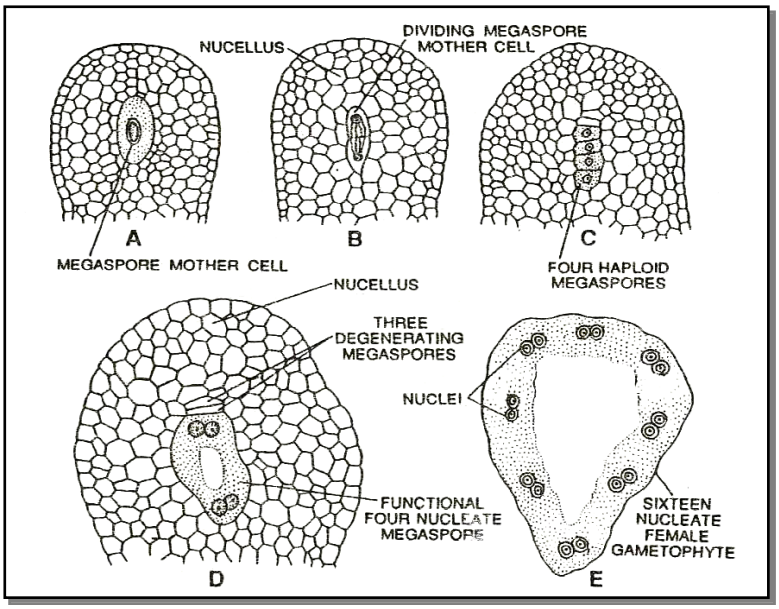


Fig. 8.9. ***Ephedra.*** **A-E. Early stages in the development of female gametophyte**

Archegonium

The archegonia develop froom superficial cells called archegonial initials. Each archegonial initial divides by a transverse wall to form an outer primary neck cell or neck initial and an inner central cell. The neck cell undergoes a number of divisions to form a long and massive neck of about thirty to forty cells. It encloses no neck canal. The neck of archegonium in *Ephedra* is the longest in the gymnosperms. The cells of the neck usually merge with the surrounding gametophytic cells and are hence not very distinct. The central cell enlarges in size and assumes an elliptical appearance with pointed or narrow chalazal end. Its nucleus divides into a ventral canal nucleus and an egg nucleus. The latter moves to the centre of the archegonium. The ventral canal nucleus degenerates. The cells adjacent to the central cell divide transversely to form a distinct jacket layer, which may become two to three layered thick. Singh and Maheshwari (1962) observed that in some cases all the four archegonia in *E. gerardiana* get surrounded by a common jacket, usually every archegonium has its own jacket.

Pollination

The pollen is released in the five-celled stage and is carried by wind to the aperture of the micropylar tube. The pollen lands on a pollination drop and is pulled through the micropyle and into the lysigenously formed pollen chamber and directly on to the female gametophyte. Further germination is resumed after a few hours and consists in the formation of a short pollen tube that grows out through the rupture exine. The body cell divides into two unequal male gametes, the prothale cells degenerate completely. The tube nucleus and the stalk nucleus persist. The male gametes and these nuclei move into the short pollen tube.

Fertilization

The pollen tube along with its four nuclei (2 male nuclei plus tube and stalk nuclei) grows through the archegonial neck and discharges its contents into the cytoplasm of the egg. Its tip swells and bursts. The larger male nucleus migrates toward the female nucleus. The latter is surrounded by a dense cytoplasmic sheath. The male nucleus moves through this sheath and fuses with the female nucleus to form a fusion nucleus. The fusion nucleus along with its surrounding cytoplasm is termed as oospore or the zygote.

Khan (1940, 1941) and Mulay (1941) observed the fusion of second male gamete with the ventral canal nucleus in *E. foliata*. The fusion nucleus formed in this way does not develop into embryo.

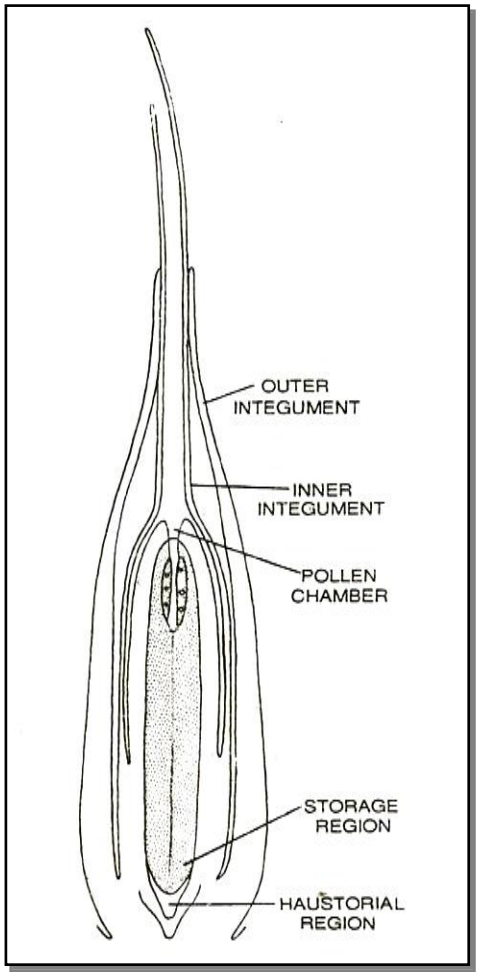


Fig. 8.10. *Ephedra.* L.S of ovule Showing nucellus with deep pollen chamber, inner and outer integuments and female gametophyte with archegonia

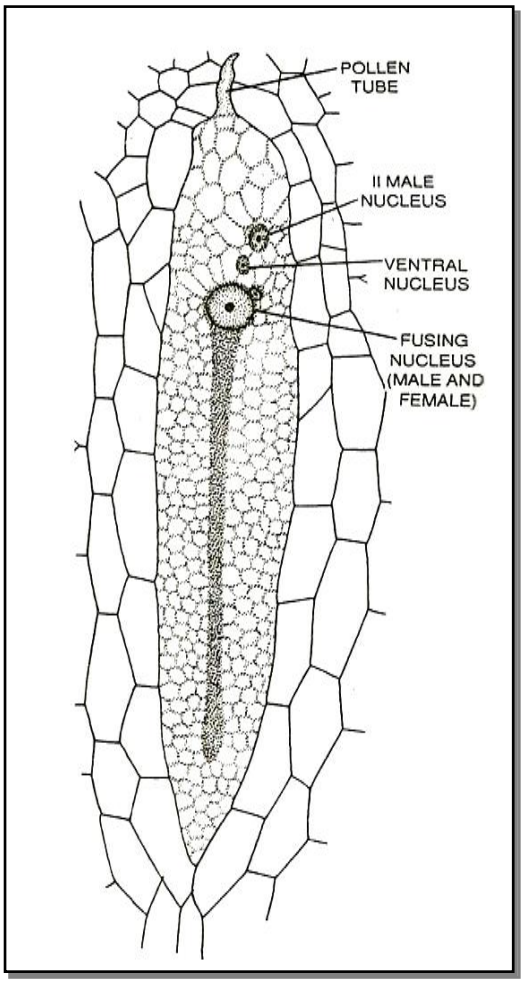


Fig. 8.11. *Ephedra.* Fertilization, pollen tube forces its way between the neck cells, the neck cells, thereafter male and female nuclei fuse together

Embryology

The zygote nucleus divides into eight free nuclei in *E. trifurca* and *E. Foliate.* These eight nuclei are of unequal size in *E. trifurca*. These unequal are unevenly distributed in the cytoplasm of the archegonium. They do not move to the base of the archegonium. Johansen (1950) observed that in *E. trifurca* three to five of these nuclei become individually enclosed

in somewhat irregular walls. These become somewhat globular cells at a later stage. In *E. foliata,* six out of these eight become enclosed within walls and form six globular cells that are all potential embryos.In *Ephedra* this process of polyemryony is unique among the gymnosperms. These proembryos develop further individually and form embryos. Only one of them is able to grow to maturity. Each proembryo grows into a tubular structure called the suspensor tube. The nucleus of the proembryo divides into two. Both these nuclei move into the tube. The tube elongates considerably and pierces the archegonial venter and enters the gametophyte tissue. A wall separates two daughter nuclei, one of which moves backwards into the micropylar end of the tube whereas the other moves towards the chalazal narrow end of the tube. The former disintegrates. The tube grows more, carrying the lower cell deep into the female prothallus tissue. This lower uninucleate cell is called the embryonal cell. It divides into a proximal suspensor cell and a distal embryo cell. The suspensor cell divides longitudinally into two longer cells. The embryo cell divides by two obliquely intersecting longitudinal walls thus cutting off an apical cell. Further cell division results in the formation of a massive apical region. The apical cell ultimately loses its identity. Cells in the proximal part of this apical massive region elongate to form secondary suspensors. At this stage the suspensor tube collapses and loses its identity. The distal cells grow into embryo proper that has two cotyledons. The root is distinguished close to the secondary suspensor cells.

In *E. foliata* the embryonal cell divides transversely into a terminal and a sub terminal cell. The terminal cell divides vertically into two cells so that there are three cells in all (including the sub terminal cell). These cells divide further to give rise to a massive apical part whose proximal cells develop into secondary suspensors, whereas distal cells grow into embryo proper that has two cotyledons. In *E.foliata* about 18-19 embryos were observed by Khan (1943) but only one reaches maturity.

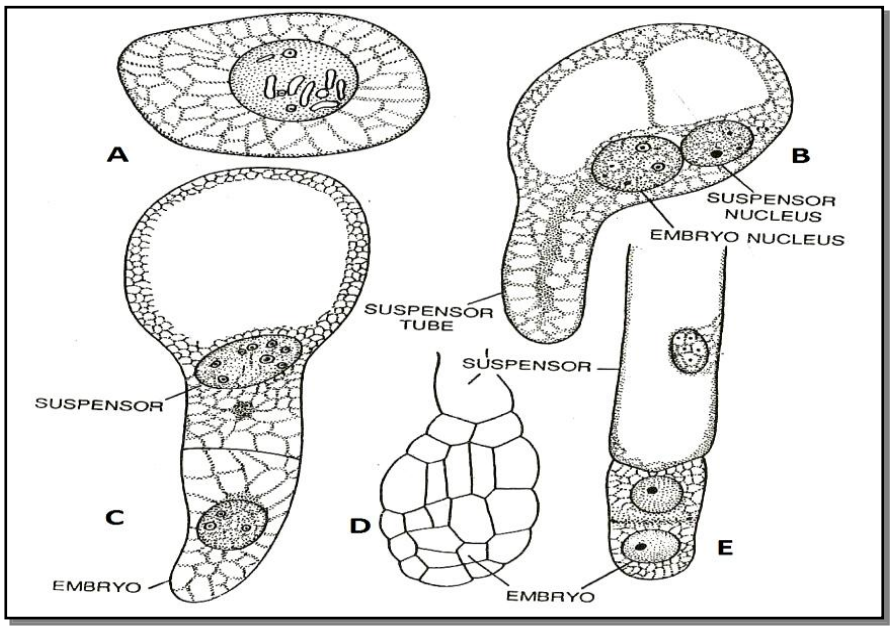


Fig. 8.12. ***Ephedra.*** **Development of embryo. A. one of the proembryos prior to develop suspensor tube, B. pro embryo with suspensor tube and two free nuclei, C. later stage with suspensor, D. division of embryo initial cell, E. later stage of embryo**

Seed

The seed is enclosed within an outer fleshy envelop formed by the two subtending bracts of the megasporangiate strobilus. Next to it are the two seed coats developed from the two integuments of the ovule. These enclose the food laden female gametophyte that contains embedded in it the dicotyledonous embryo. The cotyledons are large. The seed is, therefore, protected by three envelopes.

The nucellus persists as a nucellar cap at the micropylar end of the seed. The micropylar tube withers.

The germination of the seed is epigeal and the cotyledons grow large and green and are traversed by two parallel veins. These veins are fused at the base of the cotyledon. The cotyledons persist during the earlier stages of development, but wither away at a later stage. The seed undergoes no resting period and germinates immediately on falling on the ground. In *E. trifurca* the seed may even germinate within the parent strobilus. In the young seedlings one of the two exarch poles of xylem of the root enters each cotyledon after bifurcating. The two exarch traces of each cotyledon twist around nearly 180 degrees in their longitudinal course to become endarch. Such a twisting within cotyledons or hypocotyl is characteristic of angiosperms also.

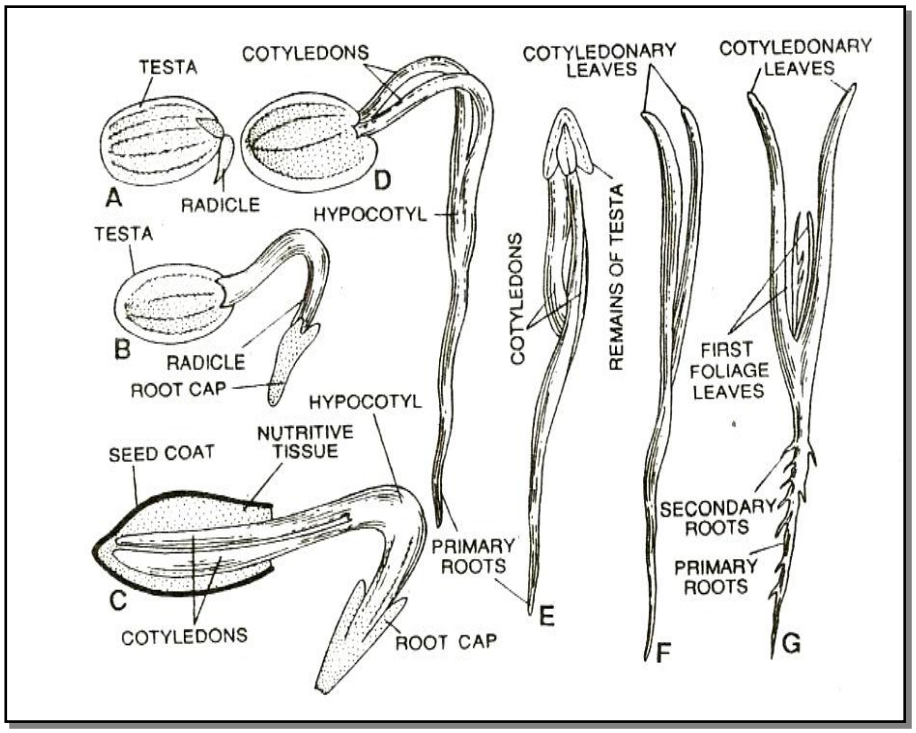


Fig. 8.13. ***Ephedra.*** **A-G. Stages of seed development**

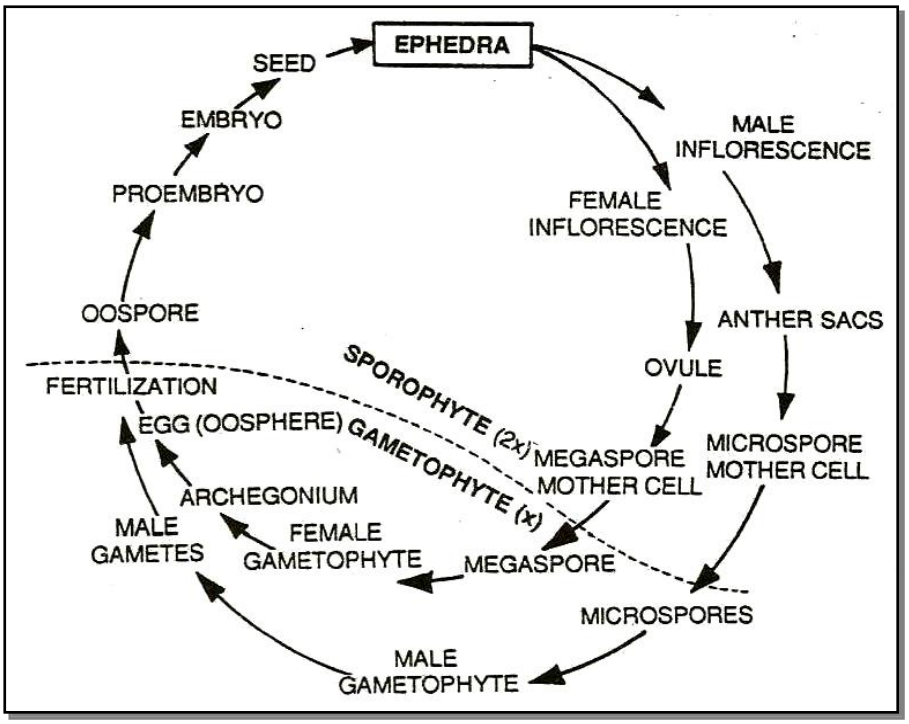


Fig. 8.14. Graphic life cycle of *Ephedra*

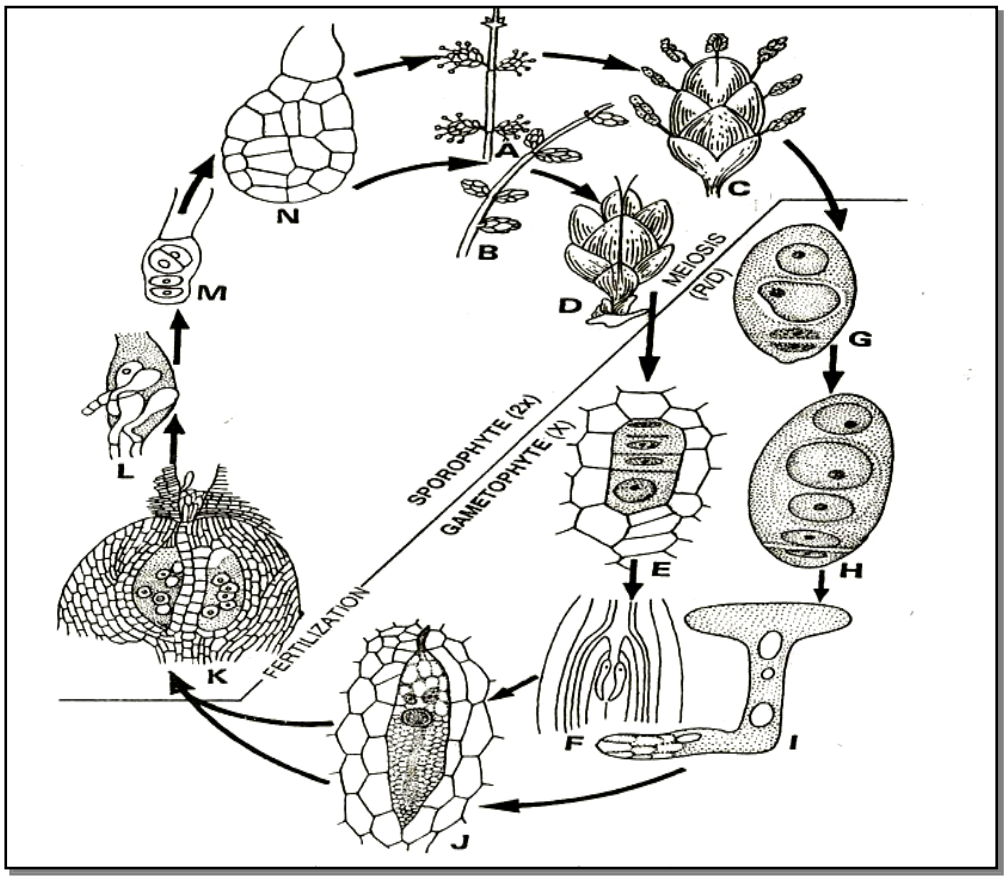


Fig. 8. 15. *Ephedra* life cycle. A. male or staminate branch, B. female or ovulate branch, C. staminate strobilus, D. ovulate strobilus, E. megaspore formation, F. ovule, G-I. formation of male gametes, J-K. fertilization, L-N. development of embryo

8.4 SUMMARY

The order *Ephedrales* includes a monotypic family *Ephedraceae,* represented by *Ephedra*. It is one of the highly evolved groups of gymnosperms. The plants are mostly small trees or perennial herbs or shrubs. They usually grow in xerophytic habitats. The leaves are minute and scaly. Resin canals are absent and the medullary rays are multiseriate. The plants are dioecious and bear compound strobili (also known as flowers).

At one time, *Ephedra* was included along with *Gnetum* and *Welwitschia* in the family Gnetaceae of the order Gnetales. However, due to the heterogeneous nature of the family, the order Gnetales was divided into three families, each comprising one genus. Florin (1934) and Eames (1952) pleaded for the establishment of three distinct orders: *Ephedra*les, Welwitschiales and Gnetales, with a monogeneric family in each. Pant (1957) placed *Gnetum* and *Welwitschia* together in Chlamydospermophyta and treated *Ephedra* under Coniferophyta.

There are about 42 species of *Ephedra*, widely distributed in both Eastern and Western hemispheres. These species are equally divided between the New and Old World, occurring in the temperate and sub-tropical regions. Eight species of *Ephedra* are known from India; of these, seven (*E. pachyclada, E. intermedia, E. saxatilis, E. gerardiana, E. nebrodensis, E. major* and *E. regeliana*) are confined to the north-west Himalayan region and only one (*E. foliata*) occurs in the plains of Rajasthan and Punjab.

Ephedra is the source of a drug, ephedrine, obtained from species like *E. equisetina, E. gerardiana, E. major, E. sinica, E. intermedia* and *E. nebrodensis.*

The importance of this group is because of its forming a connected link between gymnosperms and angiosperms. They possess extraordinary morphology and diverse habit. They are gymnosperm-like in that their ovules are naked and borne on cones, whereas angiosperm like in that their ovules and microsporangia are borne on somewhat flower-like fertile shoot. The ovules are, however, enclosed within coverings additional to the true integument, which are sometimes considered to be the equivalent of ovary walls. Another angiosperm like character the presence of vessels in the xylem.

A common character of the group is the prolongation of the apex of the integument into long narrow tube with a flattened orifice, by means of which the pollen is collected. They are so advanced in structure that in several respects they resemble the angiosperms. However, is no direct relationship, and it has been established that the Gnetales were not the ancestors the angiosperms. They are a parallel line of evolution.

Three genera, *i.e.*, *Gnetum, Welwitschia* and *Ephedra,* were long considered to form a single family Gnetaceae of the order Gnetales, but on the basis of morphological evidences order has been divided into three families, i.e., Gnetaceae, Welwitschiaceae and *Ephedra*ceae. The three orders have been established known as *Ephedra*les, Welwitschiales and Gnetales.

Whatever the system of classification may be, there are three genera, *Ephedra, welwitschia* and *Gnetum*. The genus *Ephedra* consists of shrubby plants with minute leaves. There are about 35 distributed in the New and the Old Worlds. The species have mostly a restricted range distribution. The genus *Welwitschia,* comprises the remarkable living plants. There is only one species, *W. mirabilis*, particularly confined to the desert region of South West Africa. The stem resembles enormous woody carrot, the top of which is concave and may reach 4 feet in diameter. It is entirely buried in the sand and bears only two long strap-shaped leaves, which persist throughout life. The genus *Gnetum* includes trees, shrubs or woody climbers. The climbers are predominating. There are about 4 species distributed in the tropical regions of the world, especially West Africa the Amazon region. They are invariably the jungle plants.

Their vegetative appearance is entirely angiospermic, and their large net-veined leaves cannot be distinguished from those of dicotyledons.

8.5 GLOSSARY

Acicular Leaf: Needle-like, long and slender; *e.g*., *Pinus.*
Apophysis: Exposed outer surface of either an ovuliferous scale or megasporophyll as seen when the cone is closed.
Aril: An outgrowth from the stem forming a fleshy covering of the seed; e.g., *Taxus, Torreya*; or only rudimentary at base of the fleshy seed; *e.g*., *Cephalotaxus.*
Awl-shaped Leaf: Subulate; narrow, flat, stiff, sharp-pointed, usually less than 1/2 in. long; *e.g*., *Juniperus.*
Bract: Modified leaf subtending the ovuliferous scale; may be distinct or fused to the scale.
Cone (strobilus): Aggregation of sporangia-bearing structures at tip of the stem (either sporophylls or scales in the Gymnosperms)
Epimatium: Fleshy covering of the seed and more or less fused with the integument; arising from the chalazal end of the ovule like an additional integument; e.g., *Podocarpus.*
Fascicle Sheath: Closely imbricated bud scales at the base of the fascicle of needles; e.g., *Pinus.*
Fascicle: Cluster of needles borne on a minute determinate short shoot in the axil of a primary leaf (bract); e.g., *Pinus.*
Linear Leaf: Narrow, flattened, triangular, or quadrangular leaf usually 1/2-2 in. long; e.g., *Taxus, Picea.*
Long Shoot: Elongated internodes, rapid annual growth.
Megasporophyll: Modified leaf bearing o w les; e.g., *Zamia.*
Microsporophyll: Modified leaf bearing microsporangia or pollen sacs.
Multinodal Shoot: Spring shoot developing from the terminal winter bud and producing 2 or more whorls of branches; the cones are partly lateral in the middle of the shoot; e.g., *Pinus echinata.*
Needle: Acicular; slender, elongated leaf, usually over 2 in long; e.g., *Pinus*.
Ovuliferous Scale: Highly modified lateral branch in the axil of a leaf (bract), and bearing ovules. May be flat or peltate, woody or fleshy; e.g., Pinaceae.

Peg (sterigmata): Lateral stem projection to which leaf is attached and persistent after leaf dehiscence; i.e., abscission layer between peg and leaf. Leaf may be sessile; e.g., *Picea*; or petiolate; e.g., *Tsuga*, on the peg.
Receptaculum: A fleshy structure below the seed formed from the bases of bracts and the swollen receptacle or cone axis; e.g.,*Acmopyle*, and some *Podocarpus* spp.
Scale Leaf: Small, usually appressed and imbricate; e.g., *Juniperus, Thuja.*
Short Shoot: Very short or inconspicuous internodes and growth very slow if at all.
Umbo: Projection, with or without spine or prickle, on the apophysis of the cone scale
Uninodal Shoot: Spring shoot developing from the terminal winter bud and producing only one internode with one whorl of branches at the end; the cones are subterminal at the end of the shoot; e.g., *Pinus resinosa.*

8.6 SELF ASSESSMENT QUESTIONS

8.6.1. Multiple Choice Questions:

1. Which of the following statements in not true about the stem of *Ephedra*:
(i) Stomata is sunken (ii) Vascular bundles are collateral and closed
(iii) Pith is parenchymateous (iv) None of the above

2. *Ephedra* is:
(i) Monoecious
(ii) Dioecious
(iii) Usually monoecious occasionally dioecious
(iv) Usually dioecious occasionally monoecious

3. How many cells are present in the male gametophyte of *Ephedra* at the time of pollination
(i) 3 (ii) 4
(iii) 5 (iv) 7

4. Leaves of *Ephedra are:*
(i) Below the ridges (ii) Below the furrows
(iii) Minute and scaly (iv) Between the pith and the epidermis

5. Nodal diaphragm is made up of:
(i) Parenchyma (ii) Sclerenchyma
(iii) Collenchyma (iv) Highly lignified cells

8.6.2. Fill in the blanks

1. The species of *Ephedra* which commonly occurs in the plains of Punjab and Rajasthan is _____
2. The drug obtained from *Ephedra* _____is and it is used in the treatment of _____
3. The ovules of *Ephedra* are _____ and _____
4. The type of polyembryony present in *Ephedra* is _____

5. _____ present in *Ephedra* stem differ from those of angiosperms

Answers key:

8.6.1: 1. (iii), 2.(iv), 3. (iii), 4. (iii), 5. (iv)

8.6.2: 1. *E. foliata*, 2. Ephidrine, respiratory diseases, 3. Orthotropous, unitegmic 4. Embryosac polyembryony, 5.Vessels.

8.7 REFERENCES

- Bhatnagar S.P. and Mohitra A 1996 *Gymnosperms*. New Age Publishers, New Delhi
- Bhatnagar, A.M. 2004. *Gymnosperms*, New Age International (P) Limited, Publishers, New Delhi.
- Bhatnagar, S.P. and Moitra, A. 1996, *Gymnosperms*, New Age International Limited, New Delhi.
- Chamberlain, C.U. 1966. *Gymnosperms*, Dover Publications Inc. New York, USA.
- Raven, P.H., Johnson, G.B., Losos, J.B. and Singer, S.R. 2005 *Biology.* Tata MC Graw Hill.
- Richardson, D.H.S. 1981 The *Biology of Mosses*. John Wiley and Sons, New York.
- Sambamurty 2008 *A Textbook of Bryophytes, Pteridophytes, Gymnosperms and Paleobotany*.
- Sharma, O.P. 2002, *Gymnosperms*, Pragati Prakashan, Merrut.
- Singh, G. 1999, *Plant Systematics, Theory and Practice*, Oxford and IBH Pvt. Ltd., New Delhi.
- Sporne, K.R. 1965. *The Morphology of Gymnosperms*, Hutchinson & Co. (Publishers) Ltd., London.

8.8 SUGGESTED READINGS

- Bhatnagar, A.M. 2004. *Gymnosperms*, New Age International (P) Limited, Publishers, New Delhi.
- Bhatnagar, S.P. and Moitra, A. 1996, *Gymnosperms*, New Age International Limited, New Delhi.
- Chamberlain, C.U. 1966. *Gymnosperms*, Dover Publications Inc. New York, USA.
- Davis, P.H. and Heywood, V.H. 1963, *Principles of Angiosperm Taxonomy*, Oliver and Boyd, London.
- Gifford, E.M. and Foster, A.S. 1988, *Morphology and Evolution of Vascular Plants*, W.H. Freeman & Company, New York.
- Jones, S.B., Jr. and Luchsinger, A.E. 1986, *Plant Systematics* (2nd Ed.) McGraw –Hill Book Co., New York.
- Pant, D.D. 1973. *Cyas & Cyadales*, Central Book Dept Allahabad, UP
- Radford, A.E. 1986, *Fundamentals of Plant Systematics*, Harper and Row, New York.
- Sharma, O.P. 2002, *Gymnosperms*, Pragati Prakashan, Merrut.
- Singh, G. 1999, *Plant Systematics, Theory and Practice*, Oxford and IBH Pvt. Ltd., New Delhi.

- Sporne, K.R. 1965. *The Morphology of Gymnosperms*, Hutchinson & Co. (Publishers) Ltd., London.

8.9 TERMINAL QUESTIONS

1. Describe the anatomy of *Ephedra* stem and comment upon the features of special interest.
2 Describe the structure and development of male reproductive structure of *Ephedra.*
3 Describe briefly on the geographic distribution of Ephedra and enumerate the salient features of its life cycle.
4. Describe the structure and development of archegonium of *Ephedra*
5. Describe the structure of male and female cone of *Ephedra*

BLOCK 3: ELEMENTARY PALAEOBOTANY

UNIT-9 GEOLOGICAL TIME SCALE

9.1 OBJECTIVES

After reading this unit students will be able:

- to explain the geologic time scale and how it was elucidated.
- to understand the concept of geologic time scales including eons, eras, epochs, and periods.
- to describe the evolution of life in the context of the geologic and fossil records.
- to learn how the time scale was created and how its major subdivisions fit together to tell the story of Earth's history
- to explain the evidences for evolution including fossils.
- to explain how conditions on earth are currently changing and based on their kno wledge of the above be able to hypothesize about current and future extinctions.

9.2 INTRODUCTION

The study of fossils across geological time, how they were formed, and the evolutionary relationships between taxa (phylogeny) are some of the most important functions of the science of paleontology. Such a preserved specimen is called a "fossil" if it is older than some minimum age, most often the arbitrary date of 10,000 years. The word fossil was derived from the Latin word fodere, means “to dig”. The observation that certain fossils were associated with certain rock strata led early geologists to recognize a geological timescale in the 19th century. The development of radiometric dating techniques in the early 20th century allowed geologists to determine the numerical or *"absolute" age* of the various strata and thereby the included fossils.

The **geological time scale** (**GTS**) is a system of chronological measurement that relates stratigraphy to time, and is used by geologists, paleontologists, and other Earth scientists to describe the timing and relationships between events that have occurred throughout Earth’s history. The first serious attempts to formulate a geological time scale that could be applied anywhere on Earth were made in the late 18th century. The most influential of those early attempts divided the rocks of Earth’s crust into four types: Primary, Secondary, Tertiary, and Quaternary. Each type of rock, according to the theory, formed during a specific period in Earth history.

Geologists and paleontologists constructed the geologic table based on the relative positions of different strata and fossils, and estimated the time scales based on studying rates of various kinds of weathering, erosion, sedimentation, and lithification. Until the discovery of radioactivity in 1896 and the development of its geological applications through radiometric dating during the first half of the 20th century which allowed for more precise absolute dating of rocks, the ages of various rock strata and the age of Earth were the subject of considerable debate. The first geologic time scale that included absolute dates was published in 1913 by the British geologist Arthur Holmes. He greatly furthered the newly created discipline of geochronology and published the world-renowned book *The Age of the Earth* in which he estimated Earth’s age to be at least 1.6 billion years.

Evidence from radiometric dating indicates that Earth is about 4.54 billion years old. The geology or *deep time* of Earth's past has been organized into various units according to events which took place in each period. Different spans of time on the Geological Time Scale are usually delimited by changes in the composition of strata which correspond to them, indicating major geological or paleontological events, such as mass extinctions.

On the basis of time the geological time history of the earth has been divided into many categories named differently by the workers. The largest defined unit of time is the **supereon**, composed of **eons**. Eons are divided into **eras**, which are in turn divided into **periods**, **epochs** and **ages**. Geologic units from the same time but different parts of the world often look different and contain different fossils, so the same period was historically given different names in different locales.

9.3 OBJECTIVES OF PALAEOBOTANICAL STUDY

As per Prof. Birbal Sahni, renowned scientist from India said that, "Palaeobotany is the common ground between Botany and Geology and is in fact the botany of the rocks." Palaeobotany deals with study of plant relics found in sedimentary rocks. It is the integration of plant and earth sciences in the pursuit of palaeobotanical researches and the primary aim and objectives of its study are botanical and geological:

1. To develop palaeobotany in all its botanical and geological aspects by studying external and internal features of fossil plants.
2. To constantly update botanical data for interaction with allied disciplines.
3. To co-ordinate with other palaeobotanical and geological research centres and justify diversification of early life, vegetational dynamics, exploration of fossil fuels, geographical distribution of plants, climatic modeling and conservation of forests.
4. To disseminate palaeobotanical and palaeogeological knowledge in universities, educational institutions and other organisations.
5. To calculate the age of different types of rocks

9.4 GEOLOGICAL TIME SCALE

The geologic time scale is an essential tool for understanding the history of Earth and the evolution of life. In this lesson, explore the principal eons, eras, periods, and epochs that help us track major events in geologic history. How do we know when the dinosaurs died out? How do we know when birds first appeared on Earth or when humans evolved? What about the beginning of life itself? How was our planet formed and populated by living things over time?

To answer these questions, geologists use a special timeline called the **Geologic Time Scale**. It's a record of the earth's geologic history as scientists have come to understand it by studying the layers in rock. The geologic time scale is broken up into larger and smaller subdivisions, which help us, get a better sense of how historical events fit together.

The largest defined unit of time is the supereon, composed of eons. The first shows the entire time from the formation of the Earth to the present, but this compresses the most recent eon. Therefore, the second scale shows the most recent eon with an expanded scale. The second scale compresses the most recent era, so the most recent era is expanded in the third scale. Since the Quaternary is a very short period with short epochs, it is further expanded in the fourth scale.

Age: An age is a unit of geological time which is distinguished by some feature (like an Ice Age). An age is shorter than epoch, usually lasting from a few million years to about a hundred million years.

Epoch: An epoch is a division of a geologic period; it is the smallest division of geologic time, lasting several million years.

Period: Period is the basic unit of geological time in which a single type of rock system is formed, lasting tens of millions of years.

Era: Two or more geological periods comprise an era, which is hundreds of millions of years in duration.

Eon: Two or more geological eras form an Eon, which is the largest division of geologic time, lasting many hundreds of millions of years.

Geologic units from the same time but different parts of the world often look different and contain different fossils, so the same period was historically given different names in different locales. A key aspect of the work of the International Commission on Stratigraphy is to reconcile this conflicting terminology and define universal horizons that can be used around the world.The term "Anthropocene" is used informally by popular culture and a growing number of scientists to describe the current epoch in which we are living. In which humans have had an enormous impact on the environment--polluting its oceans, killing its species, etc. It has evolved to describe an "epoch" starting sometime in the past and on the whole defined by our carbon emissions and our plastic that is left in the ground.

The following table summarizes the major events and characteristics of the periods of time making up the geologic time scale. This time scale is based on the International Commission on Stratigraphy. This table is arranged with the most recent geologic periods at the top, and the most ancient at the bottom. The content of the table is based on the current official geologic time scale of the International Commission on Stratigraphy, with the epoch names altered to the early/late format from lower/upper as recommended by the ICS:

EON	ERA	PERIOD	EPOCH	PIVOTAL EVENT
Phanerozoic "Visible Life" Organisms with	Cenozoic Era"The Age of Mammals" (65 mya	Quaternary Period "The Age of Man" (1.8 mya to today)	Holocene (11,000 mya to today)	Human civilization, Increase of herbaceous plants and evolution of monocots.
			Pleistocene The Last Ice Age	The first humans (*Homo sapiens*) evolve. Mammoths, mastodons, saber-toothed cats,

skeletons or hard shells. (540 mya through today)	through today)		(1.8-.011 mya)	giant ground sloths, and other Pleistocene mega fauna. A mass extinction of large mammals and many birds happened about 10,000 years ago, probably caused by the end of the last ice age. Increase in the number of herbs and grasses.
		Tertiary Period (65 to 1.8 mya)	Pliocene (5-1.8 mya)	First hominid (australopithecines) Modern forms of whales.
			Miocene (24-5 mya)	More mammals, including the horses, dogs and bears. Modern birds. South American monkeys, apes in southern Europe, Ramapithecus. Land or terrestrial plants evolved
			Oligocene (38-24 mya)	Starts with a minor extinction (36 mya). Many new mammals (pigs, deer, cats, rhinos, tapirs appear). Grasses common.
			Eocene (54-38 mya)	Mammals abound. Rodents appear. Primitive whales appear.
			Paleocene (65-54 mya)	First large mammals and primitive primates.
	Mesozoic Era "The Age of Reptiles"	Cretaceous Period (146 to 65 mya)	Upper (98-65 mya)	High tectonic and volcanic activity. Primitive marsupials develop. Continents have a modern-day look. Minor extinction 82 mya. Ended with large extinction (the K-T extinction) of dinosaurs, pterosaurs, ammonites, about 50 percent of marine invertebrate species, etc.
			Lower (146-98 mya)	The heyday of the dinosaurs. The first crocodilians and feathered dinosaurs appear. The earliest-

				known butterflies appear (about 130 million years ago) as well as the earliest-known snakes, ants, and bees. Minor extinctions at 144 and 120 mya. Beginning of evolution of dicots .
		Jurassic Period (208 to 146 mya)		Many dinosaurs, including the giant Sauropods. The first birds appear (*Archaeopteryx*). The first flowering plants evolve. Many ferns, cycads, gingkos, conifers, ammonites and pterosaurs were minor extinctions at 190 and 160 mya. Evolutiom of Gymnosperms was at peak
		Triassic Period (248 to 208 mya)		The first dinosaurs, mammals, and crocodyloformes appear. Mollusks are the dominant invertebrate. Many reptiles, for example, turtles, ichthyosaurs. True flies appear. Triassic period ends with a minor extinction 213 mya (35% of all animal families die out, including labyrinthodont amphibians and all marine reptiles except ichthyosaurs). This allowed the dinosaurs to expand into many niches. Forests of conifers, cycads and other Gymnosperms dominated.
		Permian Period "The Age of Amphibians" (280 to 248 mya)		"The Age of Amphibians" - Amphibians and reptiles dominant. Gymnosperms dominant plant life. The continents merge into a single super-continent, Pangaea. Phytoplankton and plants

				oxygenate the Earth's atmosphere to close to modern levels. The first stoneflies, true bugs, beetle, and caddis flies, The Permian ended with largest mass extinction. Trilobites go extinct, as do 50% of all animal families, 95% of all marine species, and many trees, perhaps caused by glaciation or volcanism.
	Paleozoic Era (540 to 248 mya)	Permian Period "The Age of Amphibians" (280 to 248 mya)		"The Age of Amphibians" - Amphibians and reptiles dominant. Gymnosperms dominant plant life. The continents merge into a single super-continent, Pangaea. Phytoplankton and plants oxygenate the Earth's atmosphere to close to modern levels. The first stoneflies, true bugs, beetle, and caddis flies, The Permian ended with largest mass extinction. Trilobites go extinct, as do 50% of all animal families, 95% of all marine species, and many trees, perhaps caused by glaciation or volcanism.
		Carboniferous Wide-spread coal swamps, foraminiferans, corals, bryozoans, brachiopods, blastoids, seed ferns, lycopsids, and other plants. Amphibians become more common. (360 to 280 mya)		Pennsylvanian Period (325 to 280 mya) First reptiles. Many ferns. The first mayflies and cockroaches appear.Origin of first seed plants.
				Mississipian Period (325 to 280 mya)

				First winged insects.
		Devonian Period "The Age of Fishes" (408 to 360 mya)		Fish and land plants become abundant and diverse. First tetrapods appear toward the end of the period. First amphibians appear. First sharks, bony fish, and ammonoids. Many coral reefs, brachiopods, crinoids. New insects, like springtails, appeared. Mass extinction (345 mya) wiped out 30% of all animal families) probably due to glaciation or meteorite impact.
		Silurian Period (438 to 408 mya0		The first jawed fishes and uniramians (like insects, centipedes and millipedes) appeared during the Silurian (over 400 mya). First vascular plants (plants with water-conducting tissue as compared with non-vascular plants like mosses) appear on land (*Cooksonia i*s the first known). High seas worldwide. Brachiopods, crinoids, corals.
		Ordovician Period (505 to 438 mya)		Primitive plants appear on land. First corals. Primitive fishes, seaweed and fungi. Graptolites, bryozoans, gastropods, bivalves, and echinoids. High sea levels at first, global cooling and glaciation, and much volcanism. North America under shallow seas. Ends in huge extinction, due to glaciation.Plats reached freshwater and marine plants were abundant.
		Cambrian Period		"Age of Trilobites" -

		"The Age of Trilobites" (540 to 500 mya)		The Cambrian Explosion of life occurs; all existent phyla develop. Many marine invertebrates (marine animals with mineralized shells: shell-fish, echinoderms, trilobites, brachiopods, mollusks, primitive graptolites). First vertebrates. Earliest primitive fish. Mild climate. The supercontinent Rodinia began to break into smaller continents (no correspondence to modern-day land masses). Mass extinction of trilobites and nautiloids at end of Cambrian (50% of all animal families went extinct), probably due to glaciation.Multicellular filamentous algae evoved in oceans.
Proterozoic Eon (2.5 billion years ago to 540 mya)	-	Vendian/Ediacaran Period (600 to 540 Million Years Ago)		Vendian biota (Ediacaran fauna) multi-celled animals appear, including sponges. A mass extinction occurred. The continents had merged into a single supercontinent called Rodinia.Single celled bacteria and blue green algae evolved in sea.
		-		First multicellular life: colonial algae and soft-bodied invertebrates appear. Oxygen build-up in the Mid-Proterozoic.
Archaeozoic Eon (Archean) (3.9 to 2.5 billion years ago)	-	-		"Ancient Life" - The first life forms evolve - one celled organisms. Blue-green algae, archaeans, and bacteria appear in the sea. This begins to free oxygen into the atmosphere.

Hadean Eon (4.6 to 3.9 billion years ago)	-	-	"Rockless Eon" - The solidifying of the Earth's continental and oceanic crusts.

Study of Strata

People have been studying earth and rock formations for a very long time. In the 19th century, geologists took a closer look at the layers that they saw in sedimentary rocks. They noticed that the rock tended to lie in horizontal sections that had different colors, textures, and fossils inside. The top rock layer might have been limestone containing lots of snail fossils. The next layer may have been chunky conglomerate rock, while the next was a layer of shale and fish fossils. Geologists called these layers of different rock type's **strata**. They studied rock strata all around the world in order to figure out major events in geologic history. Over time, geologists and other scientists put all that information together to make the geologic time scale.

Timeline Divisions

Before we learn the parts of the geologic time scale, let's first talk about how we measure time in our own daily lives. For instance, how do you measure the time it takes to get ready for work or school? Do you measure it in minutes, hours, seconds, days? Chances are you probably measure in minutes. Minutes are fine for measuring daily chores, like driving to an appointment, fixing dinner, or doing the laundry. But what if you're talking about a bigger chore, like training for a marathon? You probably plan out your preparation on the scale of days, hours, weeks, and months. We measure our age in terms of years. We measure generations in terms of decades. And when we look at human history, we talk about it in terms of hundreds and thousands of years.

Obviously, it doesn't make sense to talk about everything on the same time scale. That's why we've broken up our time. Years are made up of months, months are made up of weeks, and weeks are made up of days, and so on. Geologists use the very same strategy to talk about the history of the earth. They break up geologic time into larger and smaller chunks, so that major events are easier to talk about. Okay, now let's go ahead and check out the major divisions of the geologic time scale.

The first principal subdivision is called the eon. An eon, the largest division of the geologic time scale, spans hundreds to thousands of millions of years. Geologists generally agree that there are two major eons: the Precambrian eon and the Phanerozoic eon. The Precambrian goes from the formation of the earth to the time when multicellular organisms first appeared i.e. from 4500 million years ago to 543 million years ago.

The fossil record of the Proterozoic Era shows that life was very primitive, consisting of photosynthetic bacteria, primitive marine plants, and single-celled animals. The Phanerozoic Eon consists of the Paleozoic, Mesozoic, and Cenozoic Eras. The Paleozoic Era marks the formation and movement of a supercontinent geologists call Pangaea, from 543 million through 248 million years ago. All continents presently on the surface of the Earth had their

origins within this single land mass. During the six periods of the Paleozoic, life developed rapidly from marine plants and invertebrates, to fish and spore-bearing plants, to amphibians.

At the beginning of the Paleozoic, Pangaea was located closer to the South Pole and covered by glaciers, but by the end of the era, it had migrated to the equator, where its glaciers melted, resulting in global climate change. The end of the Paleozoic was a time of mass extinction amongst Earth's life forms. The Mesozoic Era marks the development of life forms of increasing complexity, including reptiles, dinosaurs, small mammals, birds, conifers, cycads, and flowering plants, from 248 million through 65 million years ago.

During the first period of the Mesozoic, the Triassic Period, the rocks now within Petrified Forest National Park and the greater Painted Desert region were deposited. During the Jurassic and Cretaceous Periods, dinosaurs developed into giants, dominating the animal world. The end of the Mesozoic Era is marked by a mass extinction of the dinosaurs, leaving only their fossilized remains to tell their story. We are currently in the Cenozoic Era, dating from 65 million years ago through today. This era includes the development of large mammals and of human beings. It also includes several periods of continental glaciations, or ice ages, that played a role in the formation of geological features visible on Earth today.

Scientists start the search for fossil evidence of plants with indirect evidence for their presence, the evidence of photosynthesis in the geological record. The evidence for photosynthesis in the rock record is varied, but primary evidence comes from around 3000 mya, in rock records and fossil evidence of cyanobacteria, photosynthesizingprokaryotic organisms. Cyanobacteria use water as a reducing agent, producing atmospheric oxygen as a byproduct, and they thereby profoundly changed the early reducingatmosphere of the earth to one in which modern aerobic organisms eventually evolved.This oxygen liberated by cyanobacteria then oxidized dissolved iron in the oceans; the iron precipitated out of the sea water, and fell to the ocean floor to form sedimentary layers of oxidized iron called Banded Iron Formations (BIFs). These BIFs are part of the geological record of evidence for the evolutionary history of plants by identifying when photosynthesis originated. This also provides deep time constraints upon when enough oxygen could have been available in the atmosphere to produce the ultraviolet blocking stratospheric ozone layer. The oxygen concentration in the ancient atmosphere subsequently rose, acting as a poison for anaerobic organisms, and resulting in a highly oxidizing atmosphere, and opening up niches on land for occupation by aerobic organisms.

Evidence for cyanobacteria also comes from the presence of stromatolites in the fossil record deep into the Precambrian. Stromatolites are layered structures thought to have been formed by the trapping, binding, and cementation of sedimentary grains by microbial biofilms, such as those produced by cyanobacteria. The direct evidence for cyanobacteria is less certain than the evidence for their presence as primary producers of atmospheric oxygen. Modern stromatolites containing cyanobacteria can be found on the west coast of Australia.

Chloroplasts in eukaryotic plants evolved from an endosymbiotic relationship between cyanobacteria and other prokaryotic organisms producing the lineage that eventually led to photosynthesizing eukaryotic organisms in marine and freshwater environments. These

earliest photosynthesizing single-celled autotrophs later led to organisms such asCharophyta, a group of freshwater green algae.

Geological Timeline

Era/Period/Epoch			**Time (Myr ago)**
Archaeozoic (Archean) era			5000-1500
Proterozoic era			1500-545
Paleozoic era	Cambrian period		545-505
	Ordovician period		505-438
	Silurian period		438-410
	Devonian period		410-355
	Carboniferous (Mississippian/Pennsylvanian) period		355-290
	Permian period		290-250
Mesozoic era	Triassic period		250-205
	Jurassic period		205-135
	Cretaceous period		135-65
Cenozoic era "Recent Life"	Devonian period Carboniferous (Mississippian/Pennsylvanian) period Permian period	Paleocene epoch	65-55
		Eocene epoch	55-38
		Oligocene epoch	38-26
		Miocene epoch	26-6
		Pliocene epoch	6-1.8
	Quaternary period	Pleistocene epoch	1.8-0.01
		(Lower Paleolithic)	0.50-0.25
		(Middle Paleolithic)	0.25-0.06

		(Upper Paleolithic)	0.06-0.01
		Holocene epoch	0.01-0

Paleozoic flora

(i) Cambrian flora

Early plants were small, unicellular or filamentous, composed mostly of soft body tissues, with simple branching. The identification of plant tissues in Cambrian strata is an uncertain area in the evolutionary history of plants because of the small and soft-bodied nature of these plants. It is also difficult in a fossil of this age to distinguish among various similar appearing groups with simple branching patterns, and not all of these groups are plants. One exception to the uncertainty of fossils from this age is the group of calcareous green algae, Dasycladales found in the fossil record since the middle Cambrian. These algae do not belong to the lineage that is ancestral to the land plants. Other major groups of green algae had been established by this time, but there were no land plants with vascular tissues until the mid-Silurian.

(ii) Ordovician flora

The evidence of plant evolution changes dramatically in the Ordovician with the first extensive appearance of spores in the fossil record (Cambrian spores have been found, also). The first terrestrial plants were probably in the form of tiny plants resembling liverwortswhen, around the Middle Ordovician, evidence for the beginning of the terrestrialization of the land is found in the form of tetrads of spores with resistant polymers in their outer walls. These early plants did not have conducting tissues, severely limiting their size. They were, in effect, tied to wet terrestrial environment by their inability to conduct water, like extant liverworts, hornworts, and mosses, although they reproduced with spores, important dispersal units that have hard protective outer coatings, allowing for their preservation in the fossil record, in addition to protecting the future offspring against the desiccating environment of life on land. With spores, plants on land could have sent out large numbers of spores that could grow into an adult plant when sufficient environmental moisture was present.

(iii) Silurian flora

The first fossil records of vascular plants, i.e., land plants with vascular tissues, appeared in the Silurian period. The earliest known representatives of this group (mostly from the northern hemisphere) are placed in the genus *Cooksonia*. They had very simple branching patterns, with the branches terminated by flattened sporangia. By the end of the Silurian much more complex vascular plants, the zosterophylls, had diversified and primitive lycopods, such as *Baragwanathia* (originally discovered in Silurian deposits in Victoria, Australia), had become widespread.

(iv) Devonian flora

By the Devonian Period, life was well underway in its colonization of the land. The bacterial and algal mats were joined early in the period by primitive plants that created the first recognizable soils and harbored some arthropods like mites, scorpions and myriapods. Early Devonian plants did not have roots or leaves like the plants most common today, and many had no vascular tissue at all. They probably spread largely by vegetative growth, and did not grow much more than a few centimeters tall.

By the Late Devonian, forests of large, primitive plants existed: lycophytes, sphenophytes, ferns, and progymnosperms had evolved. Most of these plants have true roots and leaves, and many were quite tall. The tree-like *Archaeopteris*, ancestral to the gymnosperms, and the giant cladoxylopsid trees had true wood. These are the oldest known trees of the world's first forests. *Prototaxites* was the fruiting body of an enormous fungus that stood more than 8 meters tall. By the end of the Devonian, the first seed-forming plants had appeared. This rapid appearance of so many plant groups and growth forms has been called the "Devonian Explosion". The primitive arthropods co-evolved with this diversified terrestrial vegetation structure. The evolving co-dependence of insects and seed-plants that characterizes a recognizably modern world had its genesis in the late Devonian. The development of soils and plant root systems probably led to changes in the speed and pattern of erosion and sediment deposition.

The 'greening' of the continents acted as a carbon dioxide sink, and atmospheric levels of this greenhouse gas may have dropped. This may have cooled the climate and led to a massive extinction event.

(v) Carboniferous flora

Early Carboniferous land plants were very similar to those of the preceding Latest Devonian, but new groups also appeared at this time. The main Early Carboniferous plants were the Equisetales (Horse-tails), Sphenophyllales (scrambling plants), Lycopodiales (Club mosses), Lepidodendrales (scale trees), Filicales (Ferns), Medullosales (previously included in the "seed ferns", an artificial assemblage of a number of early gymnosperm groups) and the Cordaitales. These continued to dominate throughout the period, but during late Carboniferous, several other groups, Cycadophyta (cycads), the Callistophytales (another group of "seed ferns"), and the Voltziales (related to and sometimes included under the conifers), appeared.

The fronds of some Carboniferous ferns are almost identical with those of living species. Probably many species were epiphytic. Fossil ferns and "seed ferns"include *Pecopteris*, *Cyclopteris*, *Neuropteris*, *Alethopteris* and, *Sphenopteris*, *Megaphyton* and *Caulopteris* were tree ferns.

The Equisetales included the common giant form *Calamites*, with a trunk diameter of 30 to 60 cm and a height of up to 20 meters. *Sphenophyllum* was a slender climbing plant with whorls of leaves, which was probably related both to the calamites and the lycopods.

Cordaites, a tall plant (6 to over 30 meters) with strap-like leaves, was related to the cycads and conifers; the catkin-like inflorescence, which bore yew-like berries, is called *Cardiocarpus*. These plants were thought to live in swamps and mangroves. True

coniferous trees (*Walchia*, of the order Voltziales) appear later in the Carboniferous, and preferred higher drier ground.

(vi) Permian flora

The Permian began with the Carboniferous flora still flourishing. About the middle of the Permian there was a major transition in vegetation. The swamp-loving lycopod trees of the Carboniferous, such as *Lepidodendron* and *Sigillaria*, were replaced by the more advanced conifers, which were better adapted to the changing climatic conditions. Lycopods and swamp forests still dominated the South China continent because it was an isolated continent and it sat near or at the equator. The Permian saw the radiation of many important conifer groups, including the ancestors of many present-day families. The ginkgos and cycads also appeared during this period. Rich forests were present in many areas, with a diverse mix of plant groups. The gigantopterids thrived during this time; some of these may have been part of the ancestral flowering plant lineage, though flowers evolved only considerably later.

Mesozoic flora

(i) Triassic flora

On land, the holdover plants included the lycophytes, the dominantcycads, ginkgophyta(represented in modern times by *Ginkgo biloba*) and glossopterids. The spermatophytes, or seed plants came to dominate the terrestrial flora: in the northern hemisphere, conifers flourished .*Dicroidium* (a seed fern) was the dominant southern hemisphere tree during the Early Triassic period.

(ii) Jurassic flora

The arid, continental conditions characteristic of the Triassic steadily eased during the Jurassic period, especially at higher latitudes the warm, humid climate allowed lush jungles to cover much of the landscape. Conifers dominated the flora, as during the Triassic they were the most diverse group and constituted the majority of large trees. Extant conifer families that flourished during the Jurassic included the Araucariaceae, Cephalotaxaceae, Pinaceae,Podocarpaceae,Taxaceae andTaxodiaceae.

The extinct Mesozoic conifer family Cheirolepidiaceae dominated low latitude vegetation, as did the shrubby Bennettitales. Cycads were also common, as were ginkgos and tree ferns in the forest. Smaller ferns were probably the dominant undergrowth. Caytoniaceous seed ferns were another group of important plants during this time and are thought to have been shrub to small-tree sized. Ginkgo-like plants were particularly common in the mid- to high northern latitudes.

(iii) Cretaceous flora

Flowering plants, also known as angiosperms, spread during this period, although they did not become predominant until near the end of the period (Campanian age). Their evolution was aided by the appearance of bees, in fact angiosperms and insects are a good example of coevolution. The first representatives of many modern trees, including figs, planes and magnolias, appeared in the Cretaceous. At the same time, some earlier Mesozoic gymnosperms, like Conifers continued to thrive, although other taxa like Bennettitales died out before the end of the period.

(iv) Cenozoic flora

The Cenozoic is just as much the age of savannas, or the age of co-dependent flowering plants and insects. At 35 mya, grasses evolved from among the angiosperms. About ten thousand years ago, humans in the Fertile Crescent of the Middle East develop agriculture. Plant domestication begins with cultivation of Neolithic founder crops. This process of food production, coupled later with the domestication of animals caused a massive increase in human population that has continued to the present. At the same time, Sahara is green with rivers, lakes, cattle, crocodiles and monsoons. At 8 ka, Common bread wheat (*Triticumaestivum*) originates in southwest Asia due to hybridization of emmer wheat with a goat-grass, *Aegilopstauschii*. At 6.5 ka, two rice species are domesticated: Asian rice, *Oryza sativa*, and African rice *Oryzaglaberrima*.

Mass Extinction

Life on Earth has suffered occasional mass extinctions at least since 542 mya. Although they were disasters at the time, mass extinctions have sometimes accelerated the evolution of life on Earth. When dominance of particular ecological niches passes from one group of organisms to another, it is rarely because the new dominant group is "superior" to the old and usually because an extinction event eliminates the old dominant group and makes way for the new one.

The fossil record appears to show that the gaps between mass extinctions are becoming longer and the average and background rates of extinction are decreasing. Both of these phenomena could be explained in one or more ways.

The oceans may have become more hospitable to life over the last 500 mya and less vulnerable to mass extinctions: dissolved oxygen became more widespread and penetrated to greater depths; the development of life on land reduced the run-off of nutrients and hence the risk of eutrophication and anoxic events and marine ecosystems became more diversified so that food chains were less likely to be disrupted.

Reasonably complete fossils are very rare, most extinct organisms are represented only by partial fossils, and complete fossils are rarest in the oldest rocks. So paleontologists have mistakenly assigned parts of the same organism to different genera, which were often defined solely to accommodate these finds—the story of *Anomalocaris* is an example of this. The risk of this mistake is higher for older fossils because these are often unlike parts of any living organism. Many of the "superfluous" genera are represented by fragments which are not found again and the "superfluous" genera appear to become extinct very quickly.

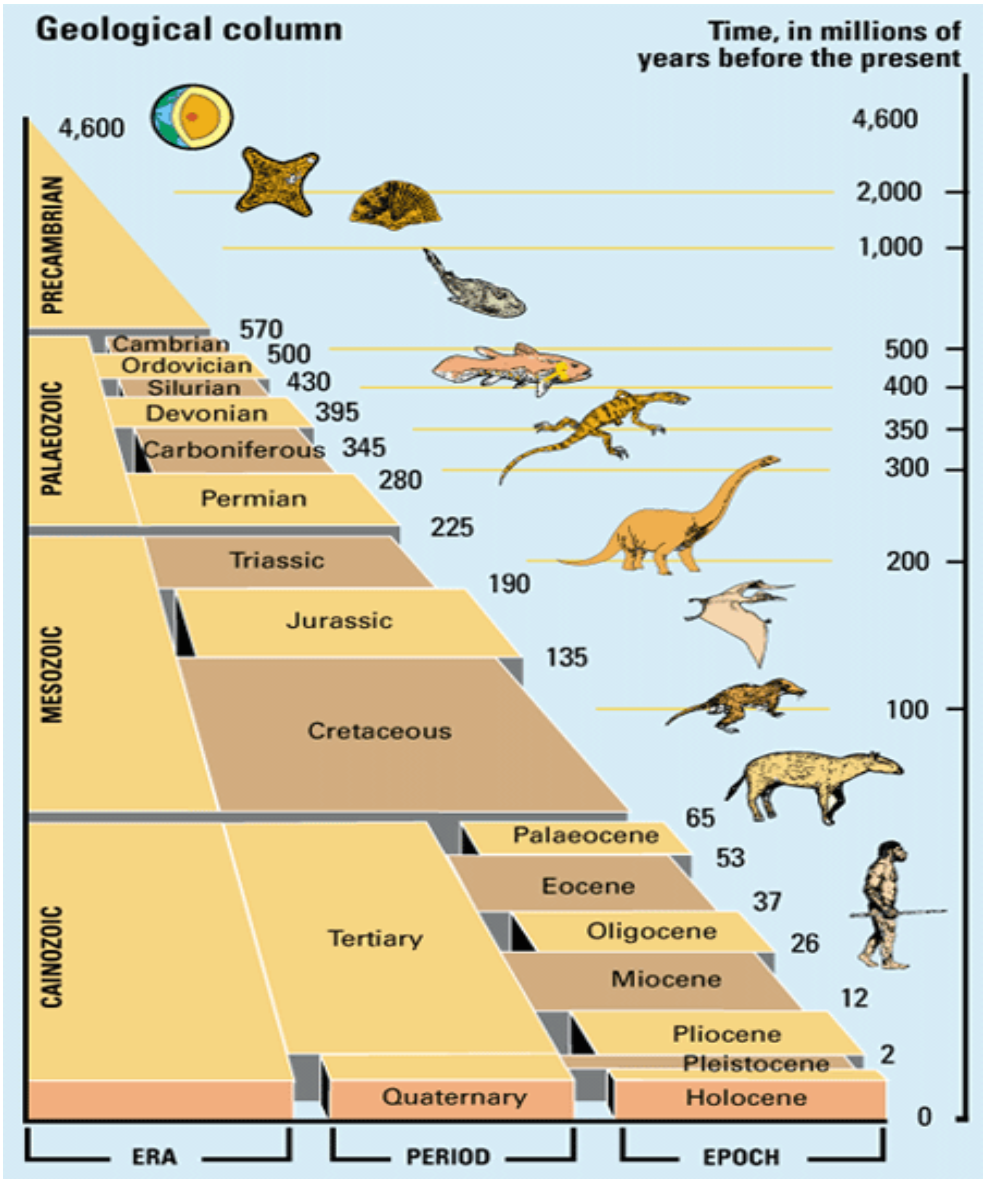


Fig. 9.1.Geological time table

9.5 SUMMARY

Thousands and millions of years are used on a geological time scale. Geologic time is the chronology of the Earth's formation, changes, development, and existence. The Earth is 4.6 billion years old. These events are measured on a geological time scale. Scientists do not measure geologic time on a clock or calendar. They use a linear timeline based on the age of rocks and their corresponding fossils, as well as the change in life that occurred over millions of years. The Geologic Timeline on the next page shows an accepted timeline for the Earth based on current science. The timeline is subject to change as new discoveries are made. Precambrian Time, Phanerozoic Eon, Paleozoic Era, Mesozoic Era, Cenozoic Era marks the origin of the Earth at about 4,500 million (4.5 billion) through 543 million years ago. The oldest rocks and fossils found on Earth to date are within Precambrian Time.

9.6 GLOSSARY

Belemnite: A Mesozoic to early Tertiary cephalopodmollusc with an internal cone-, bullet-, or cigar-shaped shell.

Cambrian: The earliest period of the Paleozoic era, spanning the time between 544 and 505 million years ago.

Carboniferous: A period of time in the Paleozoic era that includes the Mississippian and Pennsylvaniansub-periods and extended from 360 to 286 million years ago.

Cenozoic: ("new animal life") the current of the three Phanerozoiceras in the geological timescale. It began 65.5 million years ago. The era when the modern continents formed, mammals and birds filled the ecological niches vacated by dinosaurs, and modern taxa of plants and invertebrates evolved.

Cretaceous: The final period of the Mesozoic era, spanning the time between 145 and 65 million years ago. The name is derived from the Latin word for chalk ("creta") and was first applied to extensive deposits of this age that form white cliffs along the English Channel between Great Britain and France

Crustacean: Large group of mostly marine arthropods (although there are also some freshwater types and even a few terrestrial ones). Include shrimps, lobsters, crabs, barnacles, krill, ostracods, and terrestrial slaters and pillbugs. Morphologically distinct from other arthropods (hence given their own subphylum), but according to molecular phylogeny closely related to insects.

Cynodont: mostly Triassicmammal-like reptiles, from which true mammals evolved.

Devonian: A period of the Paleozoic era, spanning the time between 410 and 360 million years ago. First clubmosses, horsetails and ferns appear, as do the first seed-bearing plants (progymnosperms), first trees (the progymnosperm*Archaeopteris*), and first (wingless) insects.

Eocene: An epoch of the early Tertiary period, spanning the time between 55.5 and 33.7 million years ago. It was a period of global greenhouse climate and lush forests, in which small to large archaic mammals, large reptiles, and giant flightless birds all flourished.

Fossil: mineralized or otherwise preserved remains or traces (such as footprints) or impressions of animals, plants, and other organisms. Evidence of past life on earth and can include the preserved hard and soft parts of plants and animals, tracks and burrows, whole organisms preserved intact in amber or tar, and fossilized dung.

Holocene: An epoch of the Quaternary period, spanning the time from the end of the Pleistocene (10,000 years ago) to the present. The most recent period of geologic history, which extends from 10,000 years ago to the present. It is named after the Greek words ***holos***, entire and ***kainos***, new.

Jurassic: The middle period of the Mesozoic era, spanning the time between 213 and 145 million years ago. It is named after the Jura Mountains between France and Switzerland, where rocks of this age were first studied. Gymnosperms (especially conifers, Bennettitales and cycads) and ferns common.Many types of dinosaurs, such as sauropods, carnosaurs, and stegosaurs. Mammals common but small.

Mesozoic: The second of the three Phanerozoiceras of the geological timescale, between the Paleozoic and the Cenozoic, and lasting from 251 to 65.5 million ago. More or less equivalent (especially in the popular imagination) to the "age of reptiles "Dinosaurs, pterosaurs, marine reptiles, ammonites, gymnosperms, and primitive mammals and birds all flourished. The word Mesozoic is from Greek and means "middle life."

Miocene: Aepoch of the late Tertiary period, spanning the time between 23.8 and 5.3 million years ago. Modern mammal and bird families become recognizable.

Mississippian: A sub period of the Paleozoic era, spanning the time between 360 and 325 million years ago. It is named after the Mississippi River valley, which contains good exposures of rocks of this age. The term is used by American geologists as a period ranking of geological time, but not European ones, who refer instead to the "Lower Carboniferous". Large primitive trees, first land vertebrates, and amphibious sea-scorpions live amid coal-forming coastal swamps.

Oligocene: An epoch of the early Tertiary period, spanning the time between 33.7 and 23.8 million years ago. Warm but cooling climate, moving towards Icehouse; Rapid evolution and diversification of fauna, especially mammals.

Ordovician: The second earliest period of the Paleozoic era, spanning the time between 505 and 440 million years ago. It is named after a Celtic tribe called the Ordovices.

Paleocene: Earliest epoch of the Tertiary period, spanning the time between 65 and 55.5 million years ago. Modern plants appear; mammals diversify into a number of primitive lineages following the extinction of the dinosaurs. First large mammals (up to bear or small hippo size). Alpine orogeny in Europe and Asia begins. Indian Subcontinent collides with Asia 55 Ma, Himalayan Orogeny starts between 52 and 48 Ma.

Paleogene: A sub period of the Tertiary period of the Cenozoic era, Includes the Paleocene, Eocene, and Oligocene epochs. A move to have the Paleogene and Neogene replace the Tertiary was not successful, and they now seem to have become sub periods.

Paleozoic: the first and longest of the three Phanerozoiceras of the geological timescale, , lasting from 542 to 251 million years ago. Characterised by the emergence and dominance of multicellular life in the Cambrian explosion, and the succession of invertebrates, fish, and early land plants, amphibians and reptiles.Includes six periods: the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian. The word Paleozoic is from Greek and means "ancient animal life."

Pangea, **Pangaea**: meaning "all the earth", is a supercontinent that existed during the Permian and Triassic, and included most of the Earth's continental crust. During this time, terrestrial faunas were often quite uniform, as there were few geographic barriers, although there were distinct vegetation zones (biomes). Beginning in the Jurassic, Pangea divided into Laurasia in the north and Gondwana in the south.

Pennsylvanian: A sub-period of the Carboniferous period of the Paleozoic era, spanning the time between 325 and 286 million years ago. It is named after the state of Pennsylvania where rocks of this age are widespread. Winged insects radiate suddenly; some (esp. Protodonata and Palaeodictyoptera) are quite large. Amphibians common and diverse. First reptiles and coal forests (scale trees, ferns, club trees, giant horsetails, *Cordaites*, etc.). Highest-ever atmospheric oxygen levels.Goniatites,

brachiopod, bryozoa, bivalves, and corals plentiful in the seas and oceans. Testate forams proliferate. Uralian orogeny in Europe and Asia.

Period: A unit or division of geological time, usually lasting several tens of millions of years, and hence intermediate in duration between era and epoch. By convention, each period is divided into two or more epochs. In terms of geological strata, rather than time, the word "system" is traditionally used, although this now seems to be falling out of favour, and only found in older books. (MAK)

Permian: The final period of the Paleozoic era, spanning the time between 286 and 248 million years ago. It is named after the province of Perm, Russia, where rocks of this age were first studied. Landmasses unite into supercontinent Pangaea, creating the Appalachians. End of Permo-Carboniferous glaciation.

Phanerozoic: The most recent, and current, of the four eons of the geological timescale, the time of diverse and complex life, complex ecosystems, and an oxygen-rich atmosphere

Pleistocene: An epoch of the Quaternary period, spanning the time between 1.8 million years ago and the beginning of the Holocene at 8,000 years ago.

Pliocene: Final epoch of the Tertiary period, spanning the time between 5.3 and 1.8 million years ago.

Precambrian: Older term, now rarely used, to refer to the expanse of geological time prior to the Cambrian period. Because the Cambrian was when animal fossils first appear, it, and the following periods to the present, was called the Phanerozoic.

Proterozoic: The most recent, and current, of the four eons of the geological timescale, during which occurred the oxygen crisis, snowball earth, the rise of Eukarya, and the origin of multicellular life.

Quaternary: The second period of the Cenozoic era (following the Tertiary), spanning the time between 1.8 million years ago and the present (in terms of duration, this is the shortest period, equivalent to a standard age). It contains two epochs: the Pleistocene and the Holocene.

Silurian: A period of the Paleozoic, spanning the time between 440 and 410 million years ago. First Vascular plants (the rhyniophytes and their relatives), first millipedes and arthropleurids on land.

Tertiary: The first period of the Cenozoic era (after the Mesozoic era and before the Quaternary period), spanning the time between 65 and 1.8 million years ago. This was the Age of Mammals proper, before the rise of man.

Triassic: The earliest period of the Mesozoic era, spanning the time between 248 and 213 million years ago. The name Triassic refers to the threefold division of rocks of this age in Germany.

9.7 SELF-ASSESSMENT QUESTION

9.7.1-Objective type questions:

1. _____is the division of Earth's history based on life forms which lived during that period.

a. Seafloor spreading **b.** Geologic Time Scale **c.** Prehistoric dinosaurs

2. _____ are the longest subdivision of GTS.
a. Eons **b.** Eras **c.** Periods

3. _____ is change of animals over time.
a. Natural selection **b.** Organic evolution **c.** Periodic table

4. _____ is a group of organisms which have the ability to reproduce with members of their group.
a. Period **b.** Epoch **c.** Species

5. What is the longest part of Earth's history.
a. Precambrian Time **b.** Paleozoic Era **c.** Mesozoic Era **d.** Cenozoic Era

6. During which era did Pangaea break up?
a. Precambrian Time **b.** Paleozoic Era **c.** Mesozoic Era

7. The era of middle life; a time of many changes on Earth.
a. Paleozoic **b.** Mesozoic **c.** Cenozoic

8. During which era were the first land plants formed.
a. Precambrian **b.** Paleozoic **c.** Mesozoic

9. Dinosaurs and birds are said to have evolved during the Mesozoic era.
a. True **b.** False

10. End of this era was believed to be caused by a comet or asteroid colliding with Earth, causing a huge cloud of dust and smoke to rise into the atmosphere, blocking out the sun.
a. Paleozoic Era **b.** Mesozoic Era **c.** Cenozoic Era

11. The movie "Jurassic Park" got its title from which era?
a. Paleozoic Era **b.** Mesozoic Era **c.** Cenozoic Era

12. _____ are blue green algae thought to be one of the earliest forms of life on Earth. It contains chlorophyll and photosynthesized meaning it was a plant. We give thanks to their existence.
a. Mesozoic Era **b.** Cyanobacteria **c.** Epochs

13. Which geologic event occurred during the Mesozoic era?
a. Pangaea formed **b.** The Rocky Mountains formed **c.** The Pleistocene Ice Age began

14. The Geologic time scale is subdivided into 4 groups. List them beginning with the largest.
a. Eons, periods, epochs, eras **b.** Eras, eon, periods, epochs
c. Epochs, periods, eras, eons **d.** Eons, eras, periods, epochs

15. List the 4 time periods (eras) beginning with the most recent one.
a. Precambrian Time, Mesozoic, Cenozoic, Paleozoic
b. Paleozoic, Mesozoic, Precambrian, Cenozoic
c. Precambrian Time, Paleozoic, Mesozoic, Cenozoic

9.7.1-Answer Key:

1. (b), 2. (a), 3. (b), 4. (c), 5. (b), 6. (c), 7. (b), 8. (b), 9. (a), 10.(b), 11.(b), 12.(b), 13.(a) 14.(d), 15 (c)

9.8 REFERENCES

- *"Age of the Earth".U.S. Geological Survey. 1997. Archived from the original on 23 December 2005*. Retrieved 2006-01-10.
- *Cox, Simon J. D.; Richard, Stephen M. (2005). "A formal model for the geologic time scale and global stratotype section and point, compatible with geospatial information transfer standards". Geosphere (The Geological Society of America)* ***1*** *(3): 119–137.*
- *Dalrymple, G. Brent (2001). "The age of the Earth in the twentieth century: a problem (mostly) solved". Special Publications, Geological Society of London* ***190*** *(1): 205–221.*
- *International Commission on Stratigraphy."ChronostratigraphicUnits*."International Stratigraphic Guide.Accessed 14 December 2009.
- Felix M. Gradstein, James G. Ogg, Alan G. Smith (Editors); *A Geologic Time Scale 2004*, Cambridge University Press, 2005, (ISBN 0-521-78673-8)
- *Rudwick, M. J. S. (1985). TheMeaning of Fossils: Episodes in the History of Palaeontology. University of Chicago Press.p. 24.ISBN 0-226-73103-0.*
- Rudwick, Martin *Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform* (2008) pp. 539–545
- *Simon J. D. Cox, Stephen M. Richard. "A geologic timescale ontology and service"*.Retrieved2014-08-03.
- *Sivin, Nathan (1995). Science in Ancient China: Researches and Reflections. Brookfield, Vermont: Ashgate Publishing Variorum series. III, 23–24.*

9.9 SUGGESTED READING

- Bruce L. Stinchcomb, *2013Paleozoic Fossil Plants* Paperback – Import, 28 Oct 2013 by Schiffer Publishing Ltd (28 October 2013).
- Cleal, C.J. & Thomas, B.A. (2010), "Botanical nomenclature and plant fossils", *Taxon* 59: 261–268
- Kathleen Connors Gareth, 2012 *Plant Fossils (Fossilized*!) Paperback – Import,by Stevens Publishing (1 August 2012)
- Rohdendorf, B. B. (Boris B.); Davis, Donald R. (Donald Robert),*1991Fundamentals of paleontology*Washington, D.C. : Smithsonian Institution Libraries and National Science.
- Sepkoski, D.2011, *Rereading the Fossil Record*, University of Chicago Press.
- Smith, A. B., 1994, *Systematics and the Fossil Record*, Blackwell Science.

- Simpson, G. G., 1953, *Major Features of Evolution*, Columbia University Press.
- Thomas N. Taylor, Edith L. Taylor, and Michael Krings. 2008. Paleobotany: *The Biology and Evolution of Fossil Plants*, 2nd edition. Academic Press (an imprint of Elsevier): Burlington, MA; New York, NY; San Diego, CA, USA, London, UK. 1252 pages. ISBN 978-0-12-373972-8.
- Valentine, J. W. 1973, *Evolutionary Paleoecology of the Marine Biosphere*, Prentice Hall, Inc.
- Vermeij, G., 1987, *Evolution and Escalation: An Ecological History of Life*, Princeton University Press.
- Wilson N. Stewart and Gar W. Rothwell. 2010. *Paleobotany and the Evolution of Plants*, Second edition. Cambridge University Press, Cambridge, UK. ISBN 978-0-521-38294-6.
- Zittel, Karl Alfred von, 1839-1904; *Text-book of paleontology*, PublisherLondon, Macmillan and Co. Pages 308.

9.10 TERMINAL QUESTIONS

9.10.1: Long answer questions:

1. Define geological time scale and give its dimensions.
2. What are the major periods of geological time scale and their pivotal events?
3. Describe the life in different eras.
4. Briefly define the evolution of plants with the help of geological time scale.

9.10.2: Short answer type questions:

1. Define chronology of geological time scale.
2. What are the objectives of palaeobotany?
3. Has the Earth always looked the way it does now?
4. How do we know about the Earth's past geology?
5. What is the geologic timescale based on?
6. Why do scientists constantly refine the geologic timescale?
7. What do you understand by eon?
8. What is an epoch?
9. Define period for geological time scale.
10. What do you understand by age?
11. Define the objectives of palaeobotanical studies.

UNIT-10 TYPES OF PLANT FOSSILS

10.1 OBJECTIVES

After reading this unit we are able to know about -

- Introduction to Paleobotany
- How fossils are formed and process of fossilization
- Importance of fossil study
- Different types of fossils and their characters
- Techniques to study the fossils
- What is the importance of fossil?

10.2 INTRODUCTION

Paleobotany, also spelled as **palaeobotany** (from the Greek words *paleon* = old and "botany", study of plants), is the branch of paleontology or paleobiology dealing with the recovery and identification of plant remains from geological contexts, and their use for the biological reconstruction of past environments (paleogeography), and both the evolutionary history of plants, with a bearing upon the evolution of life in general. So the study of fossils of plant life of the geologic past is called paleobotany. Paleobotany tells us the story of preserved vestiges of the plant life of the past. In simplified language paleobotany may be defined as a branch of botany which deals with the study of such plants which are living in past but extinct now. Paleobotany includes the study of terrestrial plant fossils, as well as the study of prehistoric marine photoautotrophs, such as photosynthetic algae, seaweeds or kelp.

The study of fossils is as much about relationships as it is about the study of specific plants and animals. When researchers look at a layer of rock, they look at all the fossils contained there, determining which species lived at the same time. By looking at neighboring rock layers, researchers can eventually determine how life has developed over the billions of years of the Earth's history. All these discoveries add up to create the fossil record -- the total collection of all the known fossils on Earth. These relationships can give scientists a lot of clues about how life has changed over time. When animals, plants and other organisms die, they typically decay completely. But sometimes, when the conditions are just right, they're preserved as fossils. Freezing, drying and encasement, such as in tar or resin, can create whole-body fossils that preserve bodily tissues. These fossils represent the organisms as they were when living, but these types of fossils are very rare. Most organisms become fossils when they're changed through various other means.

The heat and pressure from being buried in sediment can sometimes cause the tissues of organisms including plant leaves and the soft body parts of fish, reptiles and marine invertebrates to release hydrogen and oxygen, leaving behind a residue of carbon.This process which is called carbonization or distillation yields a detailed carbon impression of the dead organism in sedimentary rock. Only a small percentage of the plants that ever lived left a record of their existence, surviving as fossils: mineralized wood, flowers in amber, leaf imprints in coal, or other indicators of life in an earlier era. Paleobotanists document this fossil record and use it to interpret the past evolution of plants.

As a branch of botany, paleobotany is of importance primarily because the record of fossil plants helps scientists understand the long process of plant evolution. Especially since the 1940's, fossil evidence has helped to explain the origin of major classes of organisms, such as algae and fungi.

Fossilization

The formation of a fossil is an exceptional event, one that requires a special combination of favorable environmental conditions. In the most common fossilization process, the plant becomes covered by soft sediment that then hardens to form a sedimentary rock. This type of rock forms gradually, over long periods of time, as particles produced by erosion are compacted on the bottom of the body of water. The large-scale process by which plant parts become impregnated with minerals produces what has traditionally been called petrified wood. The modern term for this process is permineralization. Soluble carbonates, silicates, and other compounds infiltrate plant cells and the spaces between them.

Eventually, the mineral deposits may completely replace the naturally occurring organic matter, preserving the details of the plant's microscopic architecture. Being trapped in a sedimentary rock does not automatically guarantee that the organism will be preserved. The environment must be an anaerobic one—that is, one in which oxygen is excluded—thus preventing the decay that would otherwise result. The process may be interrupted by the action of waves or other erosive forces which re-expose the developing fossil before the process of fossilization is completed. Even after the process is completed, the well-preserved specimen may become distorted or altered in appearance because of the combined effects of time, pressure, and high temperatures that convert sedimentary rocks into metamorphic rocks.

As one would expect, the harder cells and tissues of plants are more likely to be preserved as fossils than are softer ones. For example, the thick-walled cells of wood and bark (called xylem) are more often preserved than are those of the pith (center of a stem) or cortex (found in stems and roots beneath the bark or outer covering). Other cells that are often fossilized are pollen grains and spores, both of which have outer shells that are highly resistant to decay.

Limestone and dolomite are among the most common types of rocks that form in such away that they trap plants and form fossils. Coal, a combustible sedimentary rock, is formed in much the same way as other rocks but is distinctive because the sediment involved is of plant, rather than mineral, origin. Within this matrix of plant-derived material is often embedded a variety of plant parts.

Preservation methods for fossils vary. Plants are fragile and often cook so that the carbon only remains. Animal bones and hard shelled animals are harder, and often have minerals leaching into them replacing the original bone. Sometimes volcanic ash layers cover the plants or animals and preserve them. The most common method of fossilization is called permineralization or petrification. After an organism's soft tissues decay in sediment, the hard parts particularly the bones are left behind. Water seeps into the remains, and minerals dissolved in the water seep into the spaces within the remains, where they form crystals.

These crystallized minerals cause the remains to harden along with the encasing sedimentary rock.

In another fossilization process, called replacement, the minerals in groundwater replace the minerals that make up the bodily remains after the water completely dissolves the original hard parts of the organism. Fossils also form from molds and casts. If an organism completely dissolves in sedimentary rock, it can leave an impression of its exterior in the rock, called an external mold. If that mold gets filled with other minerals, it becomes a cast.An internal mold forms when sediments or minerals fill the internal cavity, such as a shell or skull, of an organism, and the remains dissolve.

Organic Remnants

In recent years, researchers have discovered that some fossils aren't just made of minerals. Fossil analyses have shown, for instance, that some retain organic material dated to the Cretaceous, a period that lasted from 65.5 million to 145.5 million years ago, and the Jurassic period, which lasted from 145.5 million to 199.6 million years ago. Tests suggest that these organic materials belong to dinosaurs because they match certain proteins from birds, which evolved from dinosaurs.

It's unclear how the organic material is preserved, but iron might help the proteins become cross-linked and unrecognizable, or unavailable to the bacteria that would otherwise consume them. Another idea is "microbial masonry, It's possible that the bacteria that initially chomped through the tissue are secreting minerals as a waste product that then hermetically [airtight] seal a little bit of what remains behind," almost like a stone mason sealing off a structure.

Moreover, sandstone rock made of sand-size grains of minerals, sediments or inorganic material seems to be the best type of environment for preserving organic material in fossils.

The study of dead remains of the organism or their imprints preserved in the geological rocks is called fossil. Fossils are used to study organisms present in the past. Word Fossil is derived from a Latin word fodere meaning “to dig”. In fact fossils are impressions or cast of the organelles (organism) living sometime back but now extinct, on. They are present in rocks. Now they are required to be dug out. Normally the plant dies and it degeneration startsimmediately. This degeneration remains continue till the entire body is broken into chemical compounds. Thus no evidences of its former remain in existence. But sometimes under certain circumstances the degeneration of plant body stops. Thus parts of the body remain in visible form. These remains are known as fossils. These fossils are lifeless.

Plant fossils are normally present in rocks composed of sediments deposited in waters. These stratified rocks are super imposed upon one another in series. These rocks are built of sediments. These accumulate in bottoms of seas, lakes, swamps, flooded valleys, subsiding beaches etc. The rock formation is correlated with the geological approach in the subject palaeobotany. In fact fossil are the **makers** of **geologic time.** The study of a botany as well as geology is essential for the study of fossil plants. The classification of fossil plants is very difficult as there are many chances for error.

10.3 TYPES OF PLANT FOSSIL

A plant fossil is any preserved part of a plant that has long since died. Such fossils may be prehistoric impressions that are many millions of years old, or bits of charcoal that are only a few hundred years old. Prehistoric plants are various groups of plants that lived before recorded history (before about 3500 BC).

Fig.10.1. *Ginkgo iteshuttonii*, Leaves preserved as compressions

Plant fossils can be preserved in a variety of ways, each of which can give different types of information about the original parent plant. These modes of preservation are discussed in the general pages on fossils but may be summarized in a palaeobotanical context as follows. Six broad categories of plant fossils are commonly recognized. Although these categories seem well-defined, a given fossil may fall into several categories or may elude them all. *Consequently, these categories should be thought of as broad modes of preservation rather than shoe boxes into which all fossils must go*. When thinking about types of fossils and modes of preservation, it is more important to consider what types of biologically interesting information is or is not present than to fret over strict classifications. With that caveat, the basic types of plant fossils include:

- Compressions -- 2-dimensional, with organic material.
- Impressions -- imprints, 2-dimensional, devoid of organic matter.
- Casts and Molds -- 3-dimensional, may have a surface layer of organic material.
- Permineralization or Petrifaction -- 3-dimensional, tissue infiltrated by minerals allowing internal preservation.
- Compactions -- 3 dimensional, reduced volume, flattened, wholly organic.
- Molecular Fossils -- non-structural, preserves organic compounds.

Each type of plant fossil carries different types of anatomical and biological information. Consequently, to piece together the most complete picture of an ancient plant, paleobotanists hope for the same type of plant or plant part will be preserved in several different styles.

1. Compressions

Compressions are plant parts that have suffered physical deformation such that the three-dimensional plant part is compressed to more-or-less two-dimensions. Compressions retain organic matter, usually more or less coalified. Compressions of leaves, for example, differ from impressions in that some organic substance, often cuticle, is preserved. Peat, lignite, and coal are essentially compressions of thick accumulations of plant debris relatively free of encasing mineral sediment

Compressions are excellent records of external form, especially for planar structures like leaves. They often preserve cuticle that can be recovered by dissolving the mineral matter in hydrofluoric acid (HF) or disaggregating in mild peroxide. The cuticle retains the imprint of epidermal cells, but other than this, cellular information can seldom be recovered from compressions. Consequently, compressions generally preserve plants at the organ, organism, and/or environment level. In addition, because compressions preserve organic material, carbon isotopic studies can be performed on compressions. From these studies, paleobotanists can sometimes recognize the biochemical signature of C3, C4, and CAM photosynthetic physiology in extinct species.

Study the assortment of compressions available. Note color, texture, and type of deformation (usually flattening) experienced by each specimen. Notice distortion in original morphology is introduced by flattening.

Examine samples of coal, noting their weight, texture and surface features (dull vs. shiny). Identify discrete plant parts in the different ranks (essentially grades of metamorphism) of coal. Coal geologists recognize a continuum of degree of metamorphism in coal: peat - lignite - bituminous coal (A-C) - anthracite. Peat is an accumulation of virtually unaltered plant material, while anthracite is nearly pure carbon with little trace of the original plant material. All materials can be burned for fuel, but the energy content per weight increases with degree of metamorphism and the proportion of impurities generally decreases. Study thin sections of coal at the microscope. Can you identify specific plant parts in the thin sections? Study samples of fusain (fossil charcoal).

2. Impressions

Impressions are two-dimensional imprints of plants or their parts found, most commonly, in fine-grained sediment such as silt or clay. Impressions are essentially compressions sans organic material. If the sediment is very fine-grained, impressions may faithfully replicate remarkable details of original external form, regardless of subsequent consolidation of the sediment. Study the specimens of impressions, noting the several categories of plant parts represented. Because of their shape, texture, and abundance, leaves are among the most common organ preserved in impression. Impressions may also occur if, when layers of rock are split apart, the organic material adheres to only one side of the rock. In this case, the side with organic material is the compression, known as the "part", while the corresponding impression known as the "counterpart".

One particularly interesting type of impression forms in "dirty" sand. In this type of sediment, relatively coarse sand grains are mixed with silt and clay. This type of sediment is common in river and flood plain environments so is important for terrestrial plant preservation. When a

leaf falls into this type of sediment and begins to decay, the first organic bonds to break leave charged molecular tails hanging off the leaf surface. This charged tail attracts clay particles with opposite charge that linger within the sediment. The clay migrates to the leaf surface, coating the organic structure. This has two remarkable consequences: First, further decay is retarded because clay is occupying sites of organic reaction. Second, the fine clay allows remarkable detail to be preserved. Because most of the sediment is relatively coarse (sand), the organic material is lost later, but an exquisitely detailed impression is retained in the clay film. This mode of preservation is important in the Dakota Sandstone flora of Cretaceous age. It is also important in the preservation of remarkable animal fossils such as the Jurassic bird *Archaeopteryx* and the strange Cambrian invertebrates of the Burgess Shale.

Impressions, like compressions, record information about external shape and morphology of plant organs. However, because they lack organic material, cuticle and organic carbon cannot be recovered from them. In cases of impressions in very fine-grained sediment, some cellular detail can be recovered by making latex of silicone rubber cast of the impression.

3. Cast and molds

When sediment is deposited into cavities left by the decay of plant parts, a cast results. A mold is essentially a cavity left in the sediment by the decayed plant tissue. Molds are generally unfilled, or may be partially filled with sediment. Casts and molds commonly lack organic matter, but a resistant structure like periderm may be preserved as a compression on the outside of the cast or the inside of a mold. 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 fills in with sediment that subsequently hardens, a cast is formed. Casts of an internal hollow structure like a pith cavity are also common. Pith casts can be confusing because you are looking at the inside of the fossil-what in life would have been empty space. Like compressions and impressions, casts and molds record external (or sometimes internal) organ features well, but provide no cellular or tissue information. Unlike compressions/impressions, molds and casts often are truer records of the original three-dimensional shape of the structure. Casts of ancient trees are among the most impressive plant fossils.

4. Permineralizations or petrifaction

Permineralization occurs when the plant tissues are infiltrated with mineral-rich fluid. Minerals (commonly silica, carbonate, phosphate or pyrite or rarely other minerals) precipitate in cell lumens and intercellular spaces, thus preserving internal structures of plant parts in three dimensions. This type of preservation is known as "structural preservation". Because organic material (commonly cell walls but in some cases finer detail) is preserved, permineralizations can yield detailed information about the internal structure of the once-living plant. When mineral matter actually replaces the cell-wall and other internal structures, the preservation may be called petrifaction.

In petrified specimens, cellular details are lost with the organic material of the cell wall. Silica permineralization (silification) commonly occurs in areas where silica-rich

volcaniclastic sediments are weathering. Silification is also an important preservation mode for Precambrian microbial remains deposited in near-shore marine environments.

Permineralization with calcium carbonate (calcite or dolomite) is particularly common in Carboniferous coal seams, where whole regions of peat were permineralized. Called coal balls (because of their sometimes round or ellipsoidal shape) or widow makers (because of their tendency to drop out of mine roofs onto the heads of unsuspecting miners), these fossils commonly preserve a hodge-podge of plants and plant organs. Permineralization with phosphate is uncommon for land plants, but can be important in some types of marine settings.

5. Compactions

In this type of plant fossil, the plants or their parts get compressed by vertical pressure against one another. Mostly plant rudiments found in peat and coal as compactions. Coal or coal balls are the important sources of plant fossils. Coals are irregular or sub spherical mass of calcium or magnesium carbonates (or some other mineral matter).

In peat, brown coals (lignite), middens and soft sediments, plant remains may retain their external form with only slight volume reduction due to compaction. Such tissues are not mineralized, retain resistant organic material, and may show unidirectional compression (flattening). Internal structure, especially of thick-walled, hard fruits is sometimes well preserved. These fossils may be sectioned by microtome or embedded and treated much like living tissues. Compactions are most common in the youngest plant fossils. Examine specimens of Tertiary fruits and seeds, and thin sections made from them. Pollen and spores are also preserved as compactions. The material making up their outer shells (sporopollenin) is extremely resistant to decay and can remain for hundreds of millions of year practically unaltered in the rock record. However, the pollen and spore shells, once spherical, are flattened by the compressive forces of lithification.

6. Molecular fossils

As more becomes known about the chemistry of modern plants, paleobotanists have begun to examine the fossil record for corresponding chemical data. For example, characteristic breakdown products of chlorophylls and lignin have been found in well preserved fossil leaves. Lipids and their derivatives have also been recovered from sediments. Some carbohydrate break-down products may also survive in sediment. An increase in abundance of these molecules in sediments of mid to Late Cretaceous age is used to document the increasing abundance of flowering plants.

Molecular fossils are recovered and studied using chromatographic techniques, mass spectrometry, and spectrophotometry. The preservation of these chemical products is highly variable, and depends on oxygen levels during deposition, temperatures experienced by the rocks since preservation, and many other physical and chemical factors. Fossil DNA and RNA have also been making headlines in the scientific press. In some exceptional cases, genetic material or proteins have been sufficiently well-preserved to permit their use in the reconstruction of evolutionary relationships, in much the same way as one might sequence living organisms. However, much of this work is controversial due to the difficulty of

preserving and isolating these fragile molecules. Also, contamination by other materials is a common and difficult to recognize problem.

Amber

Coniferous plants exudates resinous substance. It drops on the floor of forests. It accumulates and hardened over ages. Insects, fragments of plants and other animals get preserved in it and become fossilized. It is called ambers.

Coal Balls: Plant organs of spherical shape and petrified are known as coal balls. These are formed by infiltration of calcium carbonate, magnesium carbonate, iron sulphide etc. in buried plant parts. These substances prevent the conversion of plant organs into coal and result in petrifaction. Hence these fossils occur in the form of coal balls. Majority of coal balls occur in localized region and may be congregated in definite bands or in scattered pockets. Coal balls are specifically significant in elucidating palaeobotanical information regarding the plant communities of geological past.

Coal Balls

Many millions of years ago (about 300 million to be more accurate) much of the earth's surface was covered by a swamp forest made up of plants quite different from anything living today. Some of the trees bore conspicuous markings on their bark which resembled fish scales. Another group of plants looked very much like ferns but reproduced by seeds rather than spores. These strange looking plants lived in a continuously mild, moist climate which made conditions for coal formation very favorable. Because of the large amount of coal formed from the remains of these plants, an appropriate name for this geologic time span is the Carboniferous.

Coal balls are limestone nodules which are usually found in the upper layers of the coal seam and which contain petrified plant fragments. Nobody knows for sure just how coal balls were formed, but the presence of limestone strongly suggests an oceanic or marine environment either close by or actually covering the organic litter. Coal miners do not like coal balls because they obviously do not burn and frequently are so hard and in such large masses as to make mining coal very difficult. Consequently coal balls are discarded (Figure 1) along with other mine wastes. However, to a paleobotanist (a person who studies fossil plants), such discarded coal balls are almost like Christmas presents. By studying these fragments we can gain a large amount of information concerning their anatomy and very often their morphology.

Fossil-taxa

Plant fossils almost always represent disarticulated parts of plants; even small herbaceous plants are rarely preserved whole. Those few examples of plant fossils that appear to be the remains of whole plants in fact are incomplete as the internal cellular tissue and fine micromorphological detail is normally lost during fossilization. An added complication is that, as explained above, plant remains can be preserved in a variety of ways, each revealing different features of the original parent plant.

Because of these difficulties, paleobotanists usually assign different taxonomic names to different parts of the plant in different modes of preservation. For instance, in the

subarborescentPalaeozoicsphenophytes, an impression of a leaf might be assigned to the genus *Annularia*, a compression of a cone assigned to *Palaeostachya*, and the stem assigned to either *Calamites* or *Arthroxylon* depending on whether it is preserved as a cast or a petrifaction. All of these fossils may have originated from the same parent plant but they are each given their own taxonomic name. This approach to naming plant fossils originated with the work of Brongniart (1822) and has stood the test of time; although non-palaeobotanist may find it a confusing system, it is generally regarded as the most practical way to overcome the special taphonomic difficulties encountered with plant fossils.

For many years this approach to naming plant fossils was tacitly accepted by Palaeobotanists but not formalized within the *International Rules of Botanical Nomenclature*. Eventually, Thomas (1935) and Jongmans, Halle &Gothan (1935) proposed a set of formal provisions, the essence of which was introduced into the first International Code of Botanical Nomenclature (Lanjouw et al. 1952). These early provisions allowed fossils representing particular parts of plants in a particular state of preservation to be referred to organ-genera.

The situation in the *Vienna Code* (McNeill 2006) was that any plant taxon except Diatoms whose type is a fossil is referred to as a fossil-taxon. Such taxa can refer to a **morphotaxon**, a particular part of a plant preserved in a particular way, as defined in the diagnosis of that taxon. Otherwise, the names of fossil-taxa are subject to essentially the same regulations as control the nomenclature of living plants, notably that the names are fixed to a type specimen, and that competing names are chosen mainly on the basis of chronological priority of first publication. Although the name is always fixed to the type specimen, the circumscription (i.e. range of specimens that may be included within the taxon) is defined by the diagnosis and can be changed by formal emendation. Such emendation could result in an expansion of the range of plant parts and/or preservation states that can be incorporated within the taxon. For instance, a fossil-genus originally based on compressions of ovules could be emended so that it also included the multi-ovulate cupules within which the ovules were originally borne. A complication can arise if, in this case, there was an already named fossil-genus for these cupules. If paleobotanists were confident that the type of the ovule fossil-genus and of the cupule fossil-genus could be included within the newly emended genus, then the two names would compete as to being the correct one for the newly emended genus. However, this only happens if the actual type specimens (and not just specimens that are similar to the types) can be included within the newly revised taxon.

Clues from Fossils

Fossils are our best form of evidence about the history of life on Earth. In addition, fossils can give us clues about past climates, the motions of plates, and other major geological events.

The first clue that fossils can give is whether an environment was **marine** (underwater) or **terrestrial** (on land). Along with the rock characteristics, fossils can indicate whether the water was shallow or deep, and whether the rate of sedimentation was slow or rapid. The amount of wear and fragmentation of a fossil can allow scientists to estimate the amount of wave action or the frequency of storms.Often fossils of marine organisms are found on or

near tall mountains. For example, the Himalayas, the tallest mountains in the world, contain trilobites, brachiopods, and other marine fossils. This indicates that rocks on the seabed have been uplifted to form huge mountains. In the case of the Himalayas, this happened when the Indian Subcontinent began to ram into Asia about 40 million years ago.

Fossils can also reveal clues about past climate. For example, fossils of plants and coal beds have been found in Antarctica. Although Antarctica is frozen today, in the past it must have been much warmer. This happened both because Earth's climate has changed and because Antarctica has not always been located at the South Pole.One of the most fascinating patterns revealed by the fossil record is a number of **mass extinctions**, times when many species died off. Although the mass extinction that killed the dinosaurs is most famous, the largest mass extinction in Earth history occurred at the end of the Permian period, about 250 million years ago. In this catastrophe, it is estimated that over 95% of species on Earth went extinct! The cause of these mass extinctions is not definitely known, but most scientists believe that collisions with comets or asteroids were the cause of at least a few of these disasters.

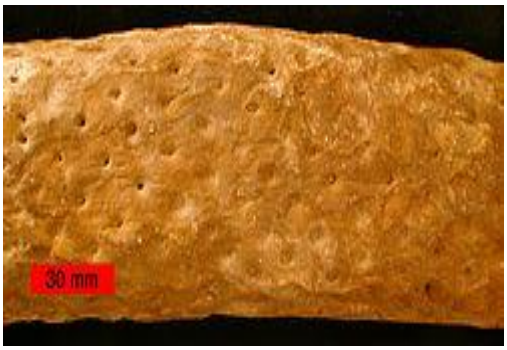


Fig.10.2.*Stigmaria*, a common fossil tree root

Fig.10.3. External mold of *Lepidodendron*

10.4 TECHNIQUES FOR FOSSIL STUDY

Fossil can provide different types of information about the lives of the animals that made them. By measuring **trackways** (series of at least three consecutive tracks), researchers learn about the posture of animals and how they moved. And by analyzing multiple trackways, researchers can find clues about how ancient animals interacted with each other. Paleontologists begin looking for fossil study geologic maps to determine the age of sedimentary rocks exposed on the Earth's surface. It is also important to recognize that some sedimentis more likely to contain fossil tracks than others. Furthermore, certain animals only lived during certain time periods. For example, if a person wants to study pterosaur tracks, they must examine rocks from the Mesozoic Era, which is the only time in Earth history during which pterosaurs lived.

Fossil track analysis

When researchers find fossil tracks, they photograph, measure, and record notes about them. It is important to record as much information as possible about any fossil while it is still in place in the ground (*in situ*) so that information isn't lost. Scientists note the shapes and

orientations of tracks, the positions of the tracks relative to each other, the geological context (age and type of rock), and the exact location of the site. They also take photographs with a size reference (such as a centimeter scale) and often trace the positions of a series of tracks on see-through material such as acetate.

Scientists who study tracks prefer to collect them so they can be stored in a museum and will be available for study by other researchers in the future. But fossil tracks and trackways are made of rock and can be quite heavy! Furthermore, it can be illegal to remove fossil tracks from some sites, or it might be preferable to keep them in place for visitors to observe. Thus it may not always be possible or practical to remove fossil tracks from the ground. In such circumstances, scientists can do some analyses in the field that might otherwise be done in a museum or laboratory. Making molds of tracks out of latex is particularly useful because researchers can use latex molds to make positive casts of the tracks from plaster or other materials. This allows study of the three-dimensional details of tracks when originals cannot be collected. This process must be done carefully, because making replicas can damage the original specimens.

Measuring fossil footprints

Paleontologists measure several different features of fossil footprints. The length and width of a track as well as the lengths of the impressions of digits (fingers or toes) provide basic data on foot morphology (shape and structure). Footprints made with hind feet are called pes tracks, while those made with front feet are called manus tracks. Additional measurements are made of trackways, including step, stride, trackway width, and pace angle. Step is the distance between two consecutive (left and right) tracks. Stride is the distance between two tracks made by the same foot. Trackway width is, as it sounds, the measure of the entire width of the trackway. Pace angle is the angle between two consecutive step lengths.

These measurements offer information regarding the posture and speed of the track-making animal. For example, animals that make tracks with relatively short strides and wide straddles generally have a sprawled posture and carry themselves close to the ground, like lizards and crocodilians. Conversely, animals that make tracks with relatively long strides and narrow straddles usually have an upright posture and walk with their legs held straight under their bodies. Animals that walk with an upright posture include dinosaurs, elephants, and humans.

Other analyses

In addition to recording track measurements, researchers can compare a particular set of fossil tracks with other fossil tracks and with footprints made by extant (living) animals. Distinctive track features are studied as well. Tracks associated with long linear grooves usually show where a track-maker's claws dragged through the sediment as it swam in shallow water. We call these "swim" tracks, and they present evidence that a given site was covered by water that was deep enough to make an animal somewhat buoyant. Other tracks show tail drag marks, indicating that the track-maker let its tail touch the ground. Animal and plant body fossils found at fossil track sites offer additional perspectives about ancient ecosystems. Finally, analyzing tracings of several trackways in an area may offer clues about the track-makers' behaviors, including possible interactions between animals. The challenge

in such cases is figuring out whether all of the trackways at a site were made at about the same time.

The Science of Studying Fossils

The search for fossils begins with geological surveys. Some areas are more likely to yield fossils than others, and researchers normally concentrate their efforts on regions that have good, fossil-bearing rock such as the dolomitic limestone of the Cradle of Humankind and the ancient lake beds of East Africa. But a good measure of luck is also needed sometimes, as was the case in many of the Cradle of Humankind sites, which were first explored by miners. When a potential site is identified, it is surveyed using technology that produces three-dimensional maps and plans of potential fossil-bearing areas. Finds are plotted on virtual maps using a digital Geographical Information System (GIS).

Excavation

The type of excavation method used depends on the type of sediment, or matrix, holding the fossils. Sometime many of the fossils are encased in hard breccia, a matrix consisting of mud or sand and stone fragments cemented together by calcium carbonate. This breccia is excavated using jackhammer drills driven by compressed air. Blocks are then broken away by driving wedges into the holes. Technicians carefully uncover fossils from breccia blocks by removing the surrounding rock using delicate drills, including power tools called airscribes, which use compressed air. Little Foot is being excavated in this way.

Areas of decalcified breccia deposits (i.e. where the lime has been dissolved by ground water) are excavated with picks and shovels and carefully sieved so that even small bones of rodents, insectivores, bats, lizards, frogs and birds can be recovered. Fragmented and crushed fossils can be reconstructed after cleaning.

Jackhammers, crowbars and sledgehammers are used to remove dolomite and layers of calcium carbonate to expose cave breccia when there is no chance of damaging fossils.Blocks of breccia can be removed for preparation in a laboratory. Prior to removal, the position of each block of breccia is recorded in three dimensions, relative to a grid or digital 3D site plan. Technicians carefully remove fossils from the breccia. Fossils can be prepared in a laboratory using small, pointed chisels and lightweight hammers. Fine cleaning of important fossils is done under a microscope with dental picks and airscribes.

Fossilised remains, including microfauna (the bones of small mammals and bats), can be released from hard, calcified breccia by carefully soaking chunks in baths of weak acetic acid. This dissolves the calcium carbonate matrix holding the delicate fossils. Specimens are numbered and catalogued with reference to their position vertically and horizontally in the site. Photography and making drawings of stratigraphic sections are important activities during the excavation.

In the laboratory

After a fossil has been prepared and cleaned, it is studied in the laboratory. There are many ways of examining fossils in detail. Significant fossils can be measured using calipers.

Binocular light microscopes are used to look at surface features of bones. These can show cut marks or carnivore damage. A scanning electron microscope (SEM) is used for detailed, high magnification analysis. Trace element and isotope analysis of soils and fossils provides information about the environment. Isotope analysis of tooth enamel can also indicate the diets of animals that lived millions of years ago.DNA analysis has the potential to add information on the nature of relationships between animals.

Scientific techniques: At the cutting edge

Scientists date fossils using various techniques. Researchers are able to get a rough time-frame for fossils by relating them to the rock layers (stratigraphic sequences) in which they are found. Where fossils are found in association with volcanic ash deposits, as they are at East African sites, their age can be determined using potassium-argon dating. This method is based on the fact that after volcanic rock cools some of the radioactive isotope potassium-40 (K-40) decays to the gas argon-40 (Ar-40), which is then trapped within the rock. By measuring the proportion of K-40 relative to trapped Ar-40 in a sample, the date when the rock cooled can be established. Uranium Series Dating is also based on the decay of radioactive isotopes, in this case by measuring the proportions of uranium to lead or uranium to helium in an ancient sample.

Electron Spin Resonance (ESR) dating

Electron Spin Resonance (ESR) dating is based on natural radioactivity. By measuring the build-up of electrons trapped inside crystals after they were formed, fragments of tooth enamel can be dated.

Cosmogenic dating

Cosmogenic dating is based on the finding that when cosmic rays from outer space reach the Earth they create cosmogenic isotopes. In quartz they produce measurable amounts of the isotopes beryllium-10 and aluminium-26. The relative proportions of these isotopes within buried rocks can be used to establish when they were last exposed to the atmosphere.

Palaeomagnetism

Palaeomagnetism is based on the fact that the Earth's magnetic field "wanders" and has reversed at known periods in the distant past. The alignment of fine iron particles within sediments, relative to the magnetic field prevailing when the sediments were laid down, can be determined and used as a measure of age relative to known periods of reversed polarity.

Radiocarbon dating

Radiocarbon dating is of limited value at the Cradle of Humankind since it cannot be applied reliably to samples that are older than about 50,000 years. This technique is based on the fact that all living organisms have a mixture of stable 12C and radioactive 14C isotopes (absorbed from the atmosphere). After death, organisms do not absorb 14C any longer, and the remaining radioactive isotopes decay at a known constant rate. By measuring the proportion of 14C relative to 12C in an ancient organic sample, it is possible to calculate its age.

X-rays and CT scans

Researchers can study the internal anatomy of fossils without damaging the material by using X-ray analysis (radiography).CT scans (using computed tomography) provide detailed internal images of fossils. For example, CT images revealed that the roots of the wisdom teeth of "MrsPles" were still open at the time of death, indicating that this individual was probably an adolescent.

Cave taphonomy

Taphonomy is the study of processes which relate to the death of organisms, their burial and decay. It is important to understand these to interpret fossil sites correctly.Bones were once parts of living animals. After an animal dies, it naturally decays where it is buried. Taphonomy includes the investigation of things like the age of the individuals which the bones once belonged to, and how weathering has affected them.

Palaeoecology

Palaeoecology is the study of how organisms – including hominids – related with their environment in the past.The proportions of species represented in a fossil assemblage may suggest much about the nature of past environments.

Importance of Fossils

The study of fossil plants has great importance it throw light on phylogeny and evolution of plants. The extinct plants tell us some stages through which existing group have passed during course of their development.Fossil plants give a historical approach to plant kingdom and also are helpful in classification of plants.Fossils plant can be used in the field of descriptive and comparative anatomy. Besides these aspect fossils are also important in the following features:

1. Reconstructing the plants: Because the majority of fossil plants are generally preserved in rocks as disarticulated plant parts. A major aim of paleobotany is to reconstruct the whole plant, that is to say, to put the pieces of the puzzle back together. Once this is accomplished, the research can turn to other areas, such as determining the group of living plants, if any, to which the fossil is most closely related.

2. Evolution of Plant Groups: Paleobotanists are also interested in the origin and subsequent evolution of major groups of plants and their interrelationships. When did plants first inhabit the Earth and what did they look like? When did the first representatives of different groups of plants first arise? A number of paleobotanists study not only the plants themselves, but also the interactions of the plants with other organisms in the environment, especially the symbiotic interrelationships between plants and other organisms.

3. Can we determine from the fossil record if plants possessed certain features that served to attract pollinators, or produced edible seeds, or whether some plants produced certain chemicals that deterred herbivory? The answer to all these questions is YES! There is a multitude of information that can be gleaned from careful examination of the plant fossil

record, and the types of information that we can obtain are constantly increasing as more and more research is done on fossil plants.

4. Form and Function in Fossil Plants: From many plant fossils, it is possible to understand the relationship between form and function in ancient plants, that is, what advantages or limitations are imposed on the growth and development of a plant based on certain biomechanical properties? Studies of this type examine the anatomical and morphological properties of various fossil plants, often using computer simulations to model growth, in an attempt to better understand broad evolutionary patterns of plant growth, as well as changes in growth form through time

5. Biomechanical studies have been especially useful in delimiting adaptations necessary for plants to move onto the land, including upright growth, size limitations, and the nature of the conducting strand, and, once plants became established in terrestrial environments, the influences of gravity and wind on their reproduction, and even aerodynamic features of pollen. Factors such as plant size and form can also be examined over a broad spectrum of plant morphologies and thus offer insights as to why certain plants and plant groups have developed particular anatomical and morphological characteristics.

6. Biostratigraphy and Correlation: Paleobotany has also played a key role in many areas of geology, especially in biostratigraphy—placing rock units in stratigraphic order based on the fossils within them. Pollen grains and spores have been extensively used as index fossils in biostratigraphy and in the correlation of rock units, as have various forms of algal cells and cysts. Pollen and spores, as well as megafossils, are especially useful in correlating terrestrial rocks, as these are generally deposited in limited areas (former lakes, ponds, river systems, etc.), making correlation by lithology (i.e., rock characteristics) very difficult.

7. Paleoecology: It is the study of past environments, is a rapidly changing field that involves the integration and synthesis of both botanical and geological information. In recent years there has been a concerted effort by many paleobotanists to understand the palaeoenvironment of fossil land plants more completely. Paleoecological studies are very important in revealing the diversity of fossil communities inhabiting a geographic area (horizontal variation in floras) at the same time.

8. Determining Paleoclimate from Fossil Plants: Understanding climates of the past has become more and more crucial to appreciating the changes occurring on our warming planet today. Paleobotany is very important in providing baseline data to reconstruct past climates and in calibrating paleoclimate models based on physical parameters.

9. Tree rings and data from fossil tree rings (paleodendrology) represent an important source of paleoclimate information, in some instances with very fine resolution, for example, major atmospheric disturbances. Based on the changes in radial cell diameter within the tree rings and the variation in ring width, it is possible to extrapolate climate information, which is especially useful when coupled with information from megafossils, microfossils, and the sedimentological record of the site.

10. The nearest living relative (NLR) method has been in use since the beginnings of paleobotany, particularly when dealing with late Mesozoic or Cenozoic floras, as these are more likely to have close living relatives. The paleobotanist compares as many fossils as

possible within a flora to their most closely related extant taxa; the more species in a fossil flora that have NLRs, the more precise the paleoclimate estimate, and the more closely related a fossil taxon is to an extant one, the more precise the method.

11. Leaf physiognomy analysis is a powerful technique that has been widely used in paleobotany to reconstruct Cenozoic paleoclimates. It is based only on angiosperms, however, so its applicability before the Cretaceous is uncertain. Physiognomy is the general appearance of a plant, and it has long been known that plant physiognomy, especially leaf physiognomy, can be related to climate. Physiognomy is primarily independent of taxonomy, for example plants with thick water-storing stems and leaves tend to grow in arid regions of the world, even though they may belong to a number of different families of plants.

12. Stomatal Index: The stomatal index (the ratio of the number of stomata to the total number of epidermal cells plus stomata within a given leaf area expressed as percentages) has been widely used in recent years to reconstruct past CO_2 levels, as the stomatal index is inversely proportional to atmospheric CO_2 levels.

10.5 SUMMARY

1. A fossil is any remains of ancient life. Fossils can be body fossils, which are remains of the organism itself or trace fossils, such as burrows, tracks, or other evidence of activity.
2. Preservation as a fossil is a relatively rare process. The chances of becoming a fossil are enhanced by quick burial and the presence of preservable hard parts, such as bones or shells.
3. Fossils form in five ways: preservation of original remains, permineralization, molds and casts, replacement, and compression.
4. Rock formations with exceptional fossils are called very important for scientists to study. They allow us to see information about organisms that we may not otherwise ever know.
5. Index fossils are fossils that are widespread but only existed for a short period of time. Index fossils help scientists to find the relative age of a rock layer and match it up with other rock layers.
6. Living fossils are organisms that haven't changed much in millions of years and are still alive today.
7. Fossils give clues about the history of life on Earth, environments, climate, movement of plates, and other events.

10.6 GLOSSARY

Amber: Fossilized tree sap.

Body fossil: The remains of an ancient organism. Examples include shells, bones, teeth, and leaves.

Cast: A structure that forms when sediments fill a mold and harden, forming a replica of the original structure.

Calcareous: Of, containing, or like calcite (calcium carbonate).

Calcareous nanofossils: Fossil remains of calcareous nanoplankton. *Calcareous Nanoplanktonis* protists that normally produce coccoliths during some phase in their life cycle.

Chalk: soft, earthy, fine-grained white to greyish limestone of marine origin. It is composed almost entirely of by shallow-water accumulations of coccoliths and other microscopic organisms and forms in a sea predominantly free from terrestrial sediment.

Coal swamp: name given to the vast equatorial tropical forests and swamplands of the late Carboniferous, from which most modern black coal comes from (brown coal in contrast is Tertiary in age). Despite the name, coal swamps did not themselves contain any coal.

Coccoliths: Microscopic structures of varying shape and size that are made of calcite, are secreted by calcareous nanoplankton, and are found in marine deposits from the Triassic period to the Recent. Coccoliths range in size from one to thirty-five micrometers in size.

Form taxon: binomial name given to a fossilized plant organ when it is found in isolation, i.e. when the taxonomic affinities of the organ are not known with certainty; for example spore and pollen taxa have their own binomial names, since it is rarely known which fossil genus may have produced them.

Fossil: mineralized or otherwise preserved remains or traces (such as footprints) or impressions of animals, plants, and other organismsorevidences of past life on earth. It can include the preserved hard and soft parts of plants and animals, tracks and burrows, whole organisms preserved intact in amber or tar, and fossilized dung.

Fossil record: the history of life on Earth through geological time, as preserved through fossil remains in sedimentary rock (sometimes referred to poetically in older books as the record of the rocks).

Fossilization: All the processes that involve the burial of a plant or animal in sediment and the eventual preservation of all, part, or a trace of it.

Fossil fuel: A fuel that was formed from the remains of ancient organisms. Examples include coal, oil, and natural gas.

Fossilization: The process of becoming a fossil.

Ichnology: branch of paleontology that deals with traces of organismal behavior, such as burrows and footprints. Thus, burrows, trackways, trails and borings are all examples of biogenic structures, but not casts or molds of dead shells or other bodily remains.

Index fossil: A fossil that identifies and shows the relative age of the rocks in which it is found. Index fossils come from species that were widespread but existed for a relatively brief period of time.

Living fossil: A modern species or genus that has existed on Earth for millions of years without changing very much.

Macrofossil: A fossil that is large enough to be studied without a microscope.

Mass extinction: A period of time when an unusually high number of species became extinct.

Microfossil: A fossil so small that it must be studied with a microscope.

Mold: Fossilized impression of organism preserved in rock. *External molds* are impressions of the outside of a structure, while *internal molds* (also known as *steinkerns*) are impressions of the inside of structure. *Composite molds* are formed when the original material dissolves, and the external and internal mold are pressed together. Both external and internal features are preserved on a composite mold.

Paleoanthropology: the study of fossil hominids, especially human ancestors.

Paleobiogeography: The branch of paleontology that deals with the geographic distribution of plants and animals in past geologic time, especially with regard to ecology, climate, and evolution.

Paleobiology: The study and understanding of fossil organisms from a biological perspective. Whereas paleontology looks at the fossil bone, shell, or leaf for its own sake, paleobiology seeks to understand the organism that produced those remains.

Paleoceanography: The study of oceans in the geologic past includes its physical, chemical, biologic, and geologic aspects.

Palynology: The study of pollen, living and fossil.

Pangaea: meaning "all the earth" is a supercontinent that existed during the Permian and Triassic, and included most of the Earth's continental crust. During this time, terrestrial faunas were often quite uniform, as there were few geographic barriers, although there were distinct vegetation zones (biomes).

Permineralization: A type of fossilization in which minerals are deposited into the pores of the original hard parts of an organism.

Stratigraphy: Branch of geology concerned with the formation, composition, ordering in time, and arrangement in space of sedimentary rocks.

Tethys: during the time of Pangea (Permian and Triassic) this was the sea that separated the northern half (Laurasia) of the supercontinent from the southern (Gondwana).

Trace fossil: fossil not of an organism itself (e.g. shell, bone, mold, carbonised impression) but of the traces and impressions it left behind while alive (footprints, burrows, resting traces, etc. The study of trace fossils is called Ichnology.

10.7 SELF-ASSESSMENT QUESTION

10.7.1 Multiple-Choice Questions:

1. What is unique about a preserved fossil?
   a. Preserved fossils are plants or animals that still have their inner and outer flesh intact.
   b. Preserved fossils are not unique and are very commonly found all over.
   c. Preserved fossils are unique because they are only found at the bottom of the ocean.
   d. None of the above.

2. An animal dies and is buried under a mudslide. After its flesh deteriorates, special conditions allow the bones to be replaced by minerals forming a replica of the bone that was once there. This type of fossil is a_____.
   a. Preserved Fossil b.Mold Fossil
   c. Impression Fossil d.Rocky Fossil

3. A person that studies the forms of life existing in prehistoric times by investigating the fossils of plants, animals, and other organisms is known as _____.
   a. Biologist b. Paleontologist
   c. Teacher d. Science Professor

4. Why doesn't every plant and animal turn into a fossil?
   a. Only animals turn into fossils. Plants do not form fossils.
   b. It is a very complicated process for animals/plants to turn into fossils.
   c. Everything does turn into a fossil, they are just very hard to find.
   d. Many animals/plants are destroyed before they can turn into a fossil.
   e. Both a and c.
   f. Both b and d.

5. What can fossils tell us about past animals and life?
   a. Information about the past environment.
   b. Where animals came from.
   c. What animals from the past looked like
   d. All of the above.

10.7.1 Answer Keys: 1. (c), 2. (b), 3. (b), 4. (f), 5. (d)

10.8 REFERENCES

- Anderson, T.F., M.E. Brownlees, and T.L. Phillips. 1981. A stable isotope study of the origin of permineralized peat zones in the Herrin coal. *Journal of Geology 88*:713-722
- Brady, L.F. 1947. Invertebrate tracks from the Coconino Sandstone of Northern Arizona. *Journal of Paleontology* 21(5):466-472.
- *Brongniart, A. (1822), "Sur la classification et la distribution des végétauxfossiles en général, et surceux des terrains de sediment supérieur en particulier", Mém. Mus. Natl. Hist. Nat. 8: 203–240, 297–348.*
- Cohen, A.D. and W. Spackman. 1980. Phytogenetic organic sediments and sedimentary environments in the Everglades -- Mangrove complex. Part III. The alteration of plant material in peat and the origin of coal macerals. *Palaeontographica 172B*:125-149
- Farlow, J.O., R.E. Chapman, B. Breithaupt, and N. Matthews. 2012. The scientific study of dinosaur footprints. Pp. 713-759 *in* M.K. Brett-Surman, T.R. Holtz, Jr., and J.O. Farlow (eds.), The Complete Dinosaur, second edition.Indiana University Press.
- *Jongmans, W.J.; Halle, T.G. &Gothan, W. (1935), Proposed additions to the International Rules of Botanical Nomenclature adopted by the fifth International Botanical Congress Cambridge1930, Heerlen, OCLC 700752855*
- Karowe, A. and T. Jefferson. 1987. Burial of trees by eruptions of Mt. St. Helens, Washington: implications for the interpretation of fossil forests. *Geology Magazine 124*:191-204.
- Keighley, D.G., and R.K. Pickerill. 1996. Small *Cruziana*, *Rusophycus*, and related ichnotaxa from eastern Canada: The nomenclatural debate and systematic ichnology. *Ichnos* 4(4):261-285.

- *Lanjouw, J.; Baehni, C.; Merrill, E.D.; Rickett, H.W.; Robyns, W.; Sprague, T.A. &Stafleu, F.A. (1952), International Code of Botanical Nomenclature: Adopted by the Seventh International Botanical Congress; Stockholm, July 1950, Regnum Vegetabile 3, Utrecht: International Bureau for Plant Taxonomy of the International Association for Plant Taxonomy, OCLC 220069027*
- Li, R., M.G. Lockley, M. Matsukawa, K. Wang, and M. Liu. 2011. An unusual theropod track assemblage from the Cretaceous of the Zhucheng area, Shandong Province, China. *Cretaceous Research* 32(4):422-432.
- Lockley, M.G., and A.P. Hunt. 1995. Dinosaur Tracks and Other Fossil Footprints of the Western United States. Columbia University Press, New York. 338 pp.
- Lockley, M.G., and C.A. Meyer. 2000. Dinosaur Tracks and Other Fossil Footprints of Europe. Columbia University Press, New York. 360 pp.
- Lockley, M., K. Chin, K. Houck, M. Matsukawa, and R. Kukihara. 2009. New interpretations of *Ignotornis*, the first-reported Mesozoic avian footprints: Implications for the paleoecology and behavior of an enigmatic Cretaceous bird. *Cretaceous Research* 30(4):1041-1061.
- Lomax, D.R., and C.A. Racay. 2012. A long mortichnialtrackway of *Mesolimuluswalchi* from the Upper Jurassic Solnhofen Lithographic Limestone near Wintershot, Germany. *Ichnos* 19(3):175-183.
- McCrea, R.T., M.G. Lockley, and C.A. Meyer. 2001. Global distribution of purported ankylosaur track occurrences. Pp. 413-454 *in* K. Carpenter (ed.), The Armored Dinosaurs. Indiana University Press: Bloomington, Indiana.
- Schopf, J.M. 1975. Modes of fossil preservation. *Review of Paleobotany and Palynology 20*:27-53
- Scott, A.L. and G. Rex. 1985. The formation and significance of Carboniferous coal balls. *Philosophical Transaction of the Royal Society of London 311B*:123-137
- Spicer, R.A. and A. Greer. 1986. Plant taphonomy in fluvial and lacustrine systems. *University of Tennessee Studies in Geology 15*:10-26
- *Thomas, H.H. (1935), "Proposed additions to the International Rules of Botanical Nomenclature suggested by British palæobotanists" (PDF), Journal of Botany 73: 111*

10.9 SUGGESTED READING

- Bruce L. Stinchcomb, 2013Paleozoic Fossil Plants Paperback – Import, 28 Oct 2013 by Schiffer Publishing Ltd (28 October 2013).
- Cleal, C.J. & Thomas, B.A. (2010), "Botanical nomenclature and plant fossils", Taxon 59: 261–268
- Kathleen ConnorsGareth, 2012 Plant Fossils (Fossilized!) Paperback – Import,by Stevens Publishing (1 August 2012)
- Sepkoski, D.2011, *Rereading the Fossil Record*, University of Chicago Press.
- Smith, A. B., 1994, *Systematics and the Fossil Record*, Blackwell Science.
- Simpson, G. G., 1953, *Major Features of Evolution*, Columbia University Press.

- Valentine, J. W. 1973, *Evolutionary Paleoecology of the Marine Biosphere,* Prentice Hall, Inc.
- Vermeij, G., 1987, *Evolution and Escalation: An Ecological History of Life*, Princeton University Press.
- Wilson N. Stewart and Gar W. Rothwell. 2010. Paleobotany and the Evolution of Plants, Second edition. Cambridge University Press, Cambridge, UK. ISBN 978-0-521-38294-6.
- Zittel, Karl Alfred von, 1839-1904; Text-book of paleontology, PublisherLondon, Macmillan and Co. Pages 308.

10.10 TERMINAL QUESTIONS

10.10.1. Long Answer Questions:

1. What do you understand by palaeontology? How would you think that this is an important science?
2. Define different types of fossils.
3. What are the techniques to study the fossils?
4. Discuss in detail about the importance of fossils.
5. Define the science of studying fossils.

10.10.2 Short Answer Questions:

1. What is permineralization?
2. Define compaction fossil.
3. How fossils are important to define climate.
4. Write the conditions required for fossilization.
5. Define radiocarbon dating.
6. What is a paleontologist? What dothey study?
7. At least how old are most fossils?
8. What are trace fossils?
9. What can be learned from trace fossils?
10. What is cave tophonomy?
11. What are resin fossils?
12. How, when and where do fossils form?
13. What conditions are necessary for fossilization to occur?
14. How common or rare is the fossilization of any organism?
15. How are fossils discovered and interpreted by humans?

UNIT – 11 PROCESS OF FOSSILIZATION

11.1 OBJECTIVES

After reading this unit student will be able to:

- Defining process of fossilization. Explain how and under what conditions fossils are created.
- Be aware of the limitations of the fossil record and how those limitations affect our understanding of human evolution.
- Explain the different levels of fossilization.
- Defining factors affecting fossilization
- Describing about the living fossil.
- How fossilization varies in different organisms.

11.2 INTRODUCTION

Throughout human history, people have discovered fossils and wondered about the creatures that lived long ago. In ancient times, fossils inspired legends of monsters and other strange creatures. 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 circulation of elements through biogeochemical cycles indicates that decomposition is indeed efficient, however the presence of organic material in sedimentary rocks (e.g., coal, petroleum, dispersed organic matter, and fossils) shows that some organic matter or its traces escapes these cycles to be preserved in the rock record. The study of palaeobotany relies on this preserved material - fossils - as evidence of past life. In the early history of modern paleontology, fossils were thought of mostly as static parts of the rock record ("sticks in mud"). This fostered description and classification as the main activities of scientific paleontologists. However, a shift in emphasis to thinking of fossils as "once-living organisms" gave paleontology a more biological flair and, more importantly, opened a new world of research questions. One tangible outcome of this philosophical shift is the movement of many academic paleontologists from Geology Departments to Biology Departments.

Fossilization is the process that preserves evidence of life in earth's rock record. Understanding the process of fossilization, and the different means through which it can occur is used by taphonomists, paleontologists, and geologists to understand the lives of past organisms and the ancient environment in which they lived. The fossil record, however, is not a representative sample of past life, because certain organisms, and particular elements of those organisms, are more likely to be preserved than others. In addition certain environments are more suitable for fossilization than others, and some environment will yield no fossil remains through time.

Plants become fossilized in a variety of ways. Each type of preservation carries different information about the once-living organism. Thus, an appreciation of plant fossils requires that one understand the processes of fossilization and how each type of preservation may influence our view of once-living organisms.The study of how organisms or their parts

become fossils is called taphonomy. Taphonomy is literally everything that happens to an organism or part of an organism, as is often the case with plants from the moment that it dies until it is collected and curated for scientific study.

11.3 PROCESS OF FOSSILIZATION

Fossils include **body fossils**, left behind when the soft parts have decayed away, as well as **trace fossils**, such as burrows, tracks, or fossilized waste (faeces). The process of a once living organism becoming a fossil is called **fossilization**. Fossilization is a very rare process: of all the organisms that have lived on earth, only a tiny percentage of them ever become fossils. To see why, imagine an antelope that dies on the land, most of its body is quickly eaten by scavengers, and the remaining flesh is soon eaten by insects and bacteria, leaving behind only scattered bones. As the years go by, the bones are scattered and fragmented into small pieces, eventually turning into dust and returning their nutrients to the soil. It would be rare for any of the antelope's remains to actually be preserved as a fossil.

On the ocean floor, a similar process occurs when clams, oysters, and other shellfish die. The soft parts quickly decay, and the shells are scattered over the sea floor. If the shells are in shallow water, wave action soon grinds them into sand-sized pieces. Even if they are not in shallow water, the shells are attacked by worms, sponges, and other animals.

Fossils are found in different types of rock like sedimentary and volcanic. Fossils are preserved in rocks and especially in sedimentary rocks. Igneous and metamorphic rocks do not contain fossils due to the high temperature and pressure involved in their formation. Igneous rocks form when magma cools, and metamorphic rocks form in the extremely high temperature and pressure under Earth's crust. For animals that lack hard shells or bones, fossilization is even rarer. As a result, the fossil record contains many animals with shells, bones, or other hard parts, and few soft bodied organisms.

There is virtually no fossil record of jellyfish, worms, or slugs. Insects, which are by far the most common land animals, are rarely found as fossils. Because mammal's teeth are much more resistant than other bones, a large portion of the mammal fossil record consists of teeth. This means the fossil record will show many organisms that had shells, bones or other hard parts and will almost always miss the many soft-bodied organisms that lived at the same time. Because most decay and fragmentation occurs at the surface, the main factor that contributes to fossilization is quick burial. Marine animals that die near a river delta may be buried by sediment carried by the river. A storm at sea may shift sediment on the ocean floor, covering and helping to preserve skeletal remains.

On land, burial is rare, so consequently fossils of land animals and plants are less common than marine fossils. Land organisms can be buried by mudslides or ash from a volcanic eruption, or covered by sand in a sandstorm. Skeletons can be covered by mud in lakes, swamps, or bogs as well. Some of the best-preserved skeletons of land animals are found in the La Brea Tar Pits of Los Angeles, California. In spite of the difficulties of preservation, billions of fossils have been discovered, examined, and identified by thousands

of scientists. The fossil record is our best clue to the history of life on Earth, and an important indicator of past climates and geological conditions as well. The fossil record also plays a key role in our lives. Fossil fuels such as coal, gas, and oil formed from the decayed remains of plants and animals that lived millions of years ago.
Fossil record has its limitations and its representation is more important:
(i) The fossil records just present a "snapshot" of life in the past.
(ii) Recognition of this limitation is critical in interpreting the fossil record.
(iii) The Fayum in Egypt has a rich record of early primate evolution ending at about 31 mya, later fossilization conditions may not have been as ideal as in previous millennia.
(iv) The same is true of the human fossil record: the best preservation is in eastern and southern parts of Africa after 4 mya.

There are two major types of fossils - **body fossils** and **trace fossils**. Both are the remains of living organisms. Body fossils reveal the body structure of the organism while trace fossils reveal the activities of these organisms. The process of fossilization is called **taphonomy**. There are three main components. First, there is the death of the organism. Then, there are certain processes that can happen to the organism before it is buried. These processes can include body decay due to natural elements such as wind, water or attack from predators. Finally, there are certain processes that occur after the organism's body is buried. These processes result in the different categories of fossils.

How do fossils form?

There are many ways fossils can be formed including permineralization, recrystallization, replacement and entrapment by amber. Methods of fossilization often involve rapid burial in such a way that predators and erosional effects are eliminated. This allows for preservation of the body parts or trace evidence. Below are some examples.

Permineralization

Permineralization is a major method that involves the hardening of minerals that have entered the small pores and cavities of dead organisms. As hard water (water containing minerals) enters these pores, minerals are deposited and, under high pressures, become solid. Many biological tissues are full of pores and canals. After the soft parts decay, these hard parts are buried and then permeated with flowing groundwater. Calcium carbonate and silica precipitate out of groundwater and fill up the pores. New material comes in but none of the original material is removed. Example: "Petrified wood" completely permineralized with silica.
Natural molds and casts form when the hard parts (such as shells) are buried in sediment leaving behind an impression of its shape. If the interior of the shell were to be filled with sediment that hardened, an internal mold would be created. However, if the shell should dissolve away over the years, it will leave behind a mold of the shell (external mold).

Recrystallization

Some shells are made of unstable minerals (e.g. aragonite) that may revert to calcite after burial Also, shells made out of small calcite crystals may recrystallize into larger crystals

The original shape is preserved and the chemical composition remains the same, but the difference in texture is apparent.

Replacement

The original shell material may be dissolved due to water circulation Original bone or shell material is then replaced without leaving a void, the original mineral is dissolved and another mineral precipitates

Carbonization

Fossils preserved as thin films of carbon on the bedding planes of sandstones and shales preserve the outline and details of the organisms

How is fossilization dependent upon the environment?

The environment plays a crucial role in an organism's ability to fossilize. The best scenario would be in which an organism is buried at the bottom of a lake where it is then covered by a lot of sediment. In this type of environment, the organism is protected from other animals and natural elements that would cause the body's breakdown. It is crucial that the body be in an environment that allows for rapid burial. An area in which there is a high rate of sediment deposition is ideal because of the presence of minerals and the increase of pressure.

The environment can also affect where the fossil is found. For example, river currents can carry a body away from the site of death before it is buried. Drier environment, such as land, are more susceptible to the effects of erosion and so it is more difficult to preserve the organism before it decays.

Levels of preservation

The preservation Plant fossils can take place at a number of levels. Each level contains a different type of information. 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 circulation of elements through biogeochemical cycles indicates that decomposition is, indeed, efficient; however the presence of organic material in sedimentary rocks (e.g., coal, petroleum, dispersed organic matter, and fossils) shows that some organic matter - or its traces - escapes these cycles to be preserved in the rock record. The study of paleobotany relies on this preserved material fossils as evidence of past life. In the early history of modern paleontology, fossils were thought of mostly as static parts of the rock record ("sticks in mud"). Plants become fossilized in a variety of ways. Each type of preservation carries different information about the once living organism.

(i) Cellular Level: Not all organic compounds are equally resistant to chemical degradation and decay. Plant cell walls (composed primarily of the polysaccharide polymer cellulose) are far more likely to escape decomposition than internal membranes and organelles, which are rich in proteins, lipids and sugars. Preservation of cytological details has been reported in fossil plants, but occurrences are rare, and most reports of fossilized nuclei and organelles should be read with caution. Secondary compounds, such as those impregnating or covering cell walls, can also be resistant to decomposition; examples include lignin,

waxes, cutin (which comprises plant cuticle), and sporopollenin, which forms the external shell of spores, pollen, and the resting cysts of some marine algae.

(ii) Tissue Level: Decay-resistant materials are distributed differentially throughout the plant. Consequently, some tissues are more amenable to preservation in the fossil record than others. With respect to vascular tissue, xylem is often preserved, while phloem commonly is not. This is because the cell walls of xylem are impregnated with decay-resistant lignin, while phloem cell walls are cellulosic. Cuticle, composed of the resistant material cutin and various waxes, is more likely to be preserved than actual epidermal cells, however, the shape and distribution of epidermal cells, including guard cells, is faithfully preserved in cuticle. Spores and pollen, because of their resistant spore coats, are the most abundant and ubiquitous structural remains of vascular plants preserved in the rock record. Because they are easily preserved and found in great numbers, pollen and spores (palynomorphs) provide important quantitative data for vegetation reconstruction and a variety of paleoecological questions.

(iii) Organ Level: Plants break apart, both in life and after death, dispersed parts may be transported before settling into the sediment to be buried and become fossils. Assemblages of plant fossils that are preserved close to where their parent-plants originally grew are called autochthonous; assemblages that have been transported are referred to as allochthonous. Whether an assemblage is autochthonous or transported has obvious implications for what sorts of ecological interpretations we can make from it. Therefore, as you study each type of plant fossil preservation, think about whether fossils produced in these ways are autochthonous or not.

Some deposits contain only palynomorphs (e.g., pollen, spores, and a few other do-dads), while others may contain only large chunks of wood, or scattered leaves. Reproductive organs, especially flowers, are relatively rare in the fossil record because they are delicate and full of energy-rich, easily broken-down compounds. Other reproductive structures are sometimes preserved, however, constitute a valuable source of taxonomic and evolutionary information. Fruits and seeds often contain resistant tissues (e.g., sclerenchyma) that yield clues to the reproductive morphology and biology of ancient plants.

When organs are found isolated (not in organic connection), each type of leaf and seed is given it's own binomial name (genus and species name according to the International Code of Botanical Nomenclature), without making any assumption about what belongs to what. To use the example discussed by Oliver and Scott (1904), leaves were described as *Lyginopteris* (genus only for brevity), seeds as *Lagenostoma*, and stems as *Lyginodendron*.

The last syllable of each name gives a hint to the organ typesuch as “dendron" is used for stem, "pteris" is often used for frond-like foliage, "stoma" for seed. However, after Oliver and Scott's recognition of the unique glands on *Lagenostomalomaxi* and species in the other organ form genera, they were able to make the whole-plant link with greater confidence. The whole plant then takes the name of the organ first described, in this case of *Lyginopteris*.

(iv) Organism Level: Not all plants in a given community are equally likely to find their way into the fossil record. Processes of fossilization often favor large or woody plants with resistant tissues over small herbs. Likewise, wind dispersed pollen is much more common in the fossil record than pollen dispersed by animals. Also, plants growing in or near an area of preservation (e.g., riverbank or swamp) are more commonly preserved than their counterparts growing far from water or anoxic sedimentary environments

Plant preservation depends on removing the organic material from the zone of aerobic decomposition. This is most easily accomplished by burying the plant. Consequently, swamps, deltas, lakes, lowland flood plains, and volcanic areas are good spots for fossilization.

Conditions required for plant fossil preservation

Three conditions are required for the preservation of plant fossils:

1. Removing the material from oxygen-rich environment of aerobic decay
2. "Fixing" the organic material to retard anaerobic decay
3. Introducing the fossil to the sedimentary rock record (burial)

Consequently, plant fossils are generally preserved in environments very low in oxygen (e.g., anaerobic sediment) because most decomposers (e.g., fungi, most decomposing bacteria and invertebrates) require oxygen for metabolism. Such sediments are commonly gray, green or black rather than red, a sedimentary signal of oxygen-rich conditions. The "fixing" requirements means that plant material must fall into an environment rich in humic acids or clay minerals, which can retard decay by blocking the chemical sites onto which decomposers fasten their degrading enzymes. Plant material can also be "fixed" by removing degradable organic compounds during the process of charring by wildfire. This is a common and spectacular mode of preservation for flowers. Plant material can then be incorporated into the rock record in areas where sediment is being deposited, which usually, but not always, requires the presence of water. Consequently, streams, flood plains, lakes, swamps, and the ocean are good candidates for fossil-forming systems. Plant fossils are commonly preserved in fine-grained sediment such as sand, silt, or clay, or in association with organic deposits such as peat (coal).

11.4 FACTORS AFFECTING FOSSILIZATION

Taphonomy is the study of what has happened to an organism from the moment of death until it is found as a fossil. Exploring the process of fossilization from a taphonomic perspective allows placement of individual fossils into a wider context. Consequently, researchers reconstruct not only the morphology of organisms, but under the right conditions, their behavior, life history and palaeoenvironment as well.

First, the organism must be deposited in sediment. Between the time of death and burial, biostratinomic processes alter the remains. Before burial, an organic skeleton is normally subject to reorientation, disarticulation, fragmentation and corrosion. Once it is

buried, it undergoes diagenetic processes. Diagenesis is simply any change, chemical or physical, which occurs in an organism after burial. Such changes are necessary for preservation, because organic matter will not survive for long before it is decomposed and even hard parts, as bones, teeth, calcified shells are normally prone to destruction. A typical diagenetic process is mineralization, which can occur with various minerals such as pyrite, phosphates or the various forms of silica.

Fossilization is not a process that only occurred millions of years ago. It has also occurred in the recent past, simply because the same geological processes that happened in the past are also taking place now. This is called the Principle of Uniformitarianism.

There are five general types of fossilization:

1. Carbonized soft tissue
2. Diagenetically mineralized three-dimensional tissue
3. Tissue outlines
4. Carbonized refractory tissue
5. Originally mineralized tissue, i.e., shell and bone.

Carbonization is a process occurring within the sediment in the absence of oxygen. In such conditions, anaerobic bacteria consume hydrogen and oxygen, therefore concentrating carbon. As long as the sediment or rock is kept in anoxic environments, the carbon, which is residual organic tissue, is preserved, but carbonized soft tissue is only preserved as a thin film. The final products of carbonization are coal and hydrocarbons, which can be considered accumulations of very badly preserved fossils.

Permineralization and ***petrification*** are processes leading to the preservation of tissues in three dimensions. They are common, for example, in bones which have a high porosity and are filled with marrow. If bones become buried when an animal dies, ground water can permeate. Carbonate minerals such as calcite, or silica, precipitate out of solution and solidify the organic material, accurately preserving the internal cellular structure. This is the process of permineralization, and has occurred in older fossils.

In permineralization, the cell pores are packed with minerals, while the walls remain highly organic. Replacement happens when minerals replace the organic matter completely. The mineral replacement of shell or bone is also called ***petrification,*** because it turns organic material into stone. When a fossil is petrified, both the cell walls and voids are mineralized. Another example of petrification is silicified wood. Around 20 different minerals have been found to replace fossils. Chalcedony, pyrite and iron oxide are common in replacement.

An organism can leave a ***mold*** behind when it decays, preserving surface details in the surrounding sediment. If the mold later fills with sediment, a replica of the organism is created, called a ***natural cast***. A natural cast does not preserve the internal or cellular structure of the original organism, but only its surface detail. The term cast is also used to indicate three-dimensional copies of a fossil, made out of plaster and resin. These casts are useful for teaching purposes, or when the original fossil is fragile or damaged. However, these laboratory casts are created in a similar way to a natural cast, by using a mold. The

endocranial cast of the Taung child was formed naturally by the accumulation of lime inside the skull, and preserves the sutures of the brain on its surface.

Finally, some hard tissues, as bone or shell, may resist diagenesis and preserve substantially unmodified. This is relatively common for Quaternary fossils, but becomes an exceptionally rare instance for Tertiary or older fossils.

Trace fossils are not remnants of an organism itself, but some record of its behaviour. Tracks, burrows, coprolites (fossil feces), and stone tools are all examples of trace fossils. The study of fossil traces is a special branch of paleontology, called ichnology.

Conditions for preservation

Fossils represent a very small proportion of all the organisms which have ever lived. This is because fossils only form under specific conditions. Decomposition is a requirement for environment to function and so fossilization represents a deviation from this natural process.Destructive agents which aid decomposition include predators and scavengers, transport by wind and water, weathering by changes in temperature, wind, rain chemicals, and decay by microbes, insects and roots. Various agents can be responsible for the preservation of organisms. Commonly, sediments bury the remains and keep them from being disturbed during the process of fossilization. More unusual agents include lava or volcanic ash, and severe cold or aridity. Temperatures below 4°C (39.2ºF) inhibit bacterial activity and thus, decay of organic matter.

Generally, the following circumstances are favorable for fossilization:

1. The organism should be rapidly buried to avoid damage by scavengers or weathering agents like water, wind and fluctuations in temperatures. Thus, fossilization is much more common in marine environments, which are characterized preferentially by sediment deposition rather than erosion. In continental environment, fossils are most common in fluvial sediments, and rare in soils. The remains require little or no disturbance during the fossilization process.
2. The organism should be buried in anaerobic conditions, because oxygen encourages the presence of bacteria which decompose organic material. Examples of continental anaerobic environments include wet areas like swamps and floodplains. However, decay can occur under anoxic conditions, for example by bacterial sulfate reduction.Anoxia also creates reducing conditions, forming reactive ionic species. This encourages mineral precipitation.
3. Containing some hard parts increases the likelihood that an organism will be preserved, but it is not necessary for fossilization. Although multicellular life was already diversifying well before the Cambrian period, an extensive record of pre-Cambrian life forms does not exist. It was only during the Cambrian Explosion of life that many forms began simultaneously covering themselves with a hard exterior. This hard surface developed as protection against predation, but also happened to be conducive to fossilization.

What are the factors affecting fossilization potential?

1) Biological agents

2) Mechanical agents
3) Diagenesis

1) Biological Agents: Predators and scavengers are active in breaking up shells and bones. Burrowing organisms are also active in disturbing, breaking up and consuming carcasses. Bioeroders produce holes and canals in dead shells but Rapid burial reduces biologic destruction.

2) Mechanical Agents: Wind, waves and currents are the factors which affect shape, density and thickness and microstructure of organism and are the most important factors in determining preservation under mechanical factors.

3) Diagenetic processes or Diagenesis: Because of the specific conditions needed for a fossil to be created, organisms that do not live in environment favorable to preservation are likely never to appear in the fossil record. Small, plants and animals are normally too delicate to withstand the ravages of time, as they are living in a high-acidic environment like a tropical forest. Most depositional environment is marine while terrestrial environment tend to be erosional. Thus, a much better fossil record exists for marine organisms than for terrestrial life.
Fossils can be destroyed by a variety of physical, chemical and biological processes. So a lot of changes happen in the fossils to preserve. So the sum total of physical and chemical changes undergone in the fossils and the rocks that contain them. After burial, diagenetic changes (plus metamorphism) can easily destroy shells.

i) Silification
Silica, and especially its most common crystallized form (the mineral quartz), is extremely stable at the Earth's surface, therefore silicified fossils are likely to withstand modification or damage. Silification occurs mainly in plants, while in soft organisms it is very rare. When plant matter is silicified, this is an example of permineralization and not replacement.

ii) Phosphatization
Phosphatization of soft parts has an unsurpassed degree of preservation, with detailed cellular structure. Muscle fibers are most often preserved through phosphate replacement. Normally carbonate ion concentrations are higher than phosphates in both fresh and marine waters, and so carbonate replacement is preferred. For phosphatization to occur, organic content of the water must be high, coupled with a low rate of burial.

iii) Pyritization
Pyritization often happens in conjunction with permineralization and replacement as in silification. It requires an availability of dissolved iron. Soft tissue can be preserved by pyrite in three ways: permineralization, mineral coating or pseudomorphs, and mineral casts or moulds. Although both mineral coating and casts preserve only surface detail, that of coating is far more detailed. Pyritized soft tissue is very rare.

iv) Carbonate preservation

Carbonate preservation is influenced by predation, water chemistry, shell morphology ,mineralogy, and shell dissolution kinetics. Surrounding water must be saturated with carbonates in order to avoid dissolution of carbonate skeletal remains. Ideal conditions for carbonate preservation are normally found in marine shelf sediments, with a high biomass of organisms that could potentially fossilize. In fresh water, concentrations of calcium carbonate vary considerably, and so preservation in these environments is not as predictable. Carbonate preservation in freshwaters may be referred to as a transient state, because even minor changes in water chemistry, temperature, or pressure may be sufficient to destroy all preservation present at that time. Consequently, it may seem astonishing that carbonate preservation occurs at all. There are three mitigating factors: carbonate dissolution occurs much quicker than replacement by other minerals, fine-grained sediments will protect the process from *ex situ* fluctuations, and cementation of the sediment enhances preservation. On the contrary, normal marine waters are constantly supersaturated with respect to calcium carbonate, and the preservation of carbonate shells is a rather common instance.

v) Charcoalification

Charcoalification can preserve tissues burned in wildfires or buried in pyroclastic flows. Internal structure is often detailed. Even though charcoal is soft, it is easily transported because of its lightness, which may explain its survival to present-day.

Living fossil

A **living fossil** is a living species (or clade) of organism that closely resembles species otherwise known only from the fossil record. Normally, to be considered a living fossil, the fossil species must be old, relative to the age of the (living) clade. Living fossils have three main characteristics:

(1) they exhibit notable longevity (2) they demonstrate little morphological divergence from early members of the lineage as well as low morphological diversity within the group and (3) they often also exhibit little taxonomic diversity.

A living fossil is a species or lineage that has undergone exceptionally little change over a long time (i.e., as if the fossil species has always lived). The average species turnover time (the time a species lasts before it is replaced) varies widely among the phyla, but averages about 2–3 million years. So, a living species that was thought to be extinct (e.g., the coelacanth, *Latimeriachalumnae*) could be called a Lazarus taxon. It would also be considered a living fossil if it closely resembles the earliest members of its lineage. Coelacanths disappeared from the fossil record some 80 million years ago (upper Cretaceous) and if it does exhibit exceptionally low evolutionary rates, then it would qualify as both a Lazarus taxon and as a living fossil.

Some living fossils are taxa that were known from fossils before living representatives were discovered. The most famous examples of this are *Ginkgo biloba*, though there are others, such as *Syntexislibocedrii* (the cedar wood wasp). Dinoflagellates include also such examples, which have been first described as fossil taxa (being typified on coccoid, occasionally calcareous cell remnants: dinocysts), but stratigraphically range until today.

Preservation Potential

Preservation potential is primarily determined by the bone itself, rather than by what happens to it. Small bones, bones with high marrow content, cancellous bone, and bones intimately associated with soft tissue (e.g. ribs) have the lowest preservation potential. This can create a biased taphonomic assemblage. For example, an assemblage consisting only of large-boned, savanna animals does not necessarily indicate a savanna environment. Smaller-boned forest animals are much less likely to be preserved, but they could have been present in life.
Taphonomic processes are also important in determining whether an animal will enter the fossil record. The cause of death, in particular, directly impacts upon an animal's chance of fossilization. If an animal is predated upon, at least some of the carcass will be eaten, reducing its chance of being preserved. However, some predators are less destructive than others when it comes to feeding. The fact that some fossils have been found with tooth marks means that it is possible for a predated animal to enter the fossil record. Disease as a cause of death has little impact on the likelihood of fossilization. Dying of old age may mean that the animal's bones have lost minerals with age, but this could be offset that they have grown to a larger size. Larger bones are more likely to withstand destructive agents. Accidental deaths are frequently excellent for preservation. Many or an animal has been trapped in tar pits, soft mud or volcanic lava, all of which ensure rapid burial. Falling into a cave would ensure the skeleton is kept together, and protect it from predation if the cave was inaccessible.

Following the death of an organism, several forces contribute to the dissolution of its remains. Decay, predators, or scavengers will typically rapidly remove the flesh. The hard parts, if they are separable at all, can be dispersed by predators, scavengers, or currents. The individual hard parts are subject to chemical weathering and erosion, as well as to splintering by predators or scavengers, which will crunch up bones for marrow and shells to extract the flesh inside. Also, an animal swallowed whole by a predator, such as a mouse swallowed by a snake, will have not just its flesh but some, and perhaps all, its bones destroyed by the gastric juices of the predator.

11.5 SUMMARY

The fossil record does not represent all of the living things once found on Earth. Therefore, the fossil record can only provide a piece of Earth's history. Plants become fossilized in a variety of ways. Each type of preservation carries different information about the once-living organism. Fossils include body fossils, left behind when the soft parts have decayed away, as well as trace fossils, such as burrows, tracks, or fossilized waste (feces). The process of a once living organism becoming a fossil is called fossilization. There are two major types of fossils - body fossils and trace fossils. Both are the remains of living organisms. The process of fossilization is called taphonomy. Generally organism should be rapidly buried to avoid damage and organism should be buried in anaerobic conditions are the circumstances favorable for fossilization. Every organism has a potential to become fossil known as preservation potential.

11.6 GLOSSARY

Abyssal plain: Large area of extremely flat ocean floor lying near a continent and generally over 4 km in depth.

Acanthodians: Now extinct, earliest group of fish with jaws, ranging from the Silurian to the Permian.

Adaptation: Any heritable characteristic of an organism that improves its ability to survive and reproduce in its environment. Also used to describe the process of genetic change within a population, as influenced by natural selection.Alternatively, some heritable feature of an individual's phenotype that improves its chances of survival and reproduction in the existing environment.

Allopatric speciation: Speciation that occurs when two or more populations of a species are geographically isolated from one another sufficiently that they do not interbreed.

Archaeans: Single-celled creatures that along with eubacteria (true bacteria) make up a category of life called the prokaryotes. While archaeans resemble bacteria and have some genes that are similar to bacterial genes, they also contain other genes that are more like what you'd find in eukaryotes. Furthermore, they have some genes that aren't like any found in any other organism, which is why they have been now distinguished by their own third domain of life.

Biostatigraphy: The branch of geology concerned with the separation and differentiation of rock units by means of the study of the fossils they contain.

Breccia: a rock formed similarly to conglomerate, except that breccia's rock fragments are very sharp and angular. These irregular rock fragments have not been transported by water, wind, or glaciers long enough to be rounded and smoothed as in conglomerate. The cementing agents silica, calcite (CaCO3), and iron oxides are the same as in conglomerate.

Carbonate rock: A rock consisting primarily of a carbonate mineral such as calcite or dolomite, the chief minerals in limestone and dolostone, respectively.

Cladogram: A branching diagram that illustrates hypotheses about the evolutionary relationships among groups of organisms. Cladograms can be considered as a special type of phylogenetic tree that concentrates on the order in which different groups branched off from their common ancestors. A cladogram branches like a family tree, with the most closely related species on adjacent branches.

Conglomerate: A clastic sedimentary rock that forms from the cementing of rounded cobble and pebble sized rock fragments. Conglomerate is formed by river movement or ocean wave action. The cementing agents that fill the spaces to form the solid rock conglomerate are silica, calcite, or iron oxides.

Coprolite: The fossilized waste (dung; fecies) matter of animals.

Craton: A part of the earth's crust that has attained stability and has been little deformed for a prolonged period.

Diagenesis: The physical, chemical or biological alteration of sediments into sedimentary rock at relatively low temperatures and pressures that can result in changes to the rock's original mineralogy and texture. After deposition, sediments are compacted as they are buried beneath successive layers of sediment and cemented by minerals that

precipitate from solution. Grains of sediment, rock fragments and fossils can be replaced by other minerals during diagenesis. Porosity usually decreases during diagenesis, except in rare cases such as dissolution of minerals and dolomitization.

Dolomite: A class of carbonate sedimentary rock, called dolomite or dolomitic limestone. It is uncertain how dolomite beds formed since it does not form on the surface of the Earth in modern times, yet massive layers of dolomite can be found in ancient rocks. It is conjectured this is because it undergoes a significant mineralogical change after deposition. Originally deposited as calcite or aragonite rich limestones, it subsequently undergoes a process called diagenesis where the calcite and/or aragonite is altered to dolomite.

Gondwana: The southern portion of the late Paleozoic supercontinent known as Pangea. It means, literally "Land of the Gonds" (a people of the Indian subcontinent).

Ichnofossils: trace fossils that are seen as preserved tracks or other signs of the behaviors of animals in the substrate. Ichnofossils can provide insights on the behavior of an extinct animal. Very rarely is the animal itself found in direct association with the ichnofossil it created.

Laurasia: The northern portion of the late Paleozoic supercontinent called Pangea.

Lithosphere: the outer skin of the earth, composed of the crust and the uppermost mantle.

Mantle: The zone of the earth below the crust and above the core.

Mineralization: replacement of organic or inorganic matter by minerals such as silica, calcite or iron during the process of fossilization

Monophyletic: A group composed of a collection of organisms, including the most recent common ancestor of all those organisms and all the descendants of that most recent common ancestor. A monophyletic taxon is also called a clade.

Paleobiology: The biological study of fossils.

Paleontologist: A scientist who studies fossils to better understand life in prehistoric times.

Pangea: A supercontinent that existed from about 300 to 200 million years ago, and included most of the continental crust of the Earth.

Plate tectonics: The theory that the surface of the earth is made of a number of plates, which have moved throughout geological time resulting in the present-day positions of the continents. Plate tectonics explains the locations of mountain building as well as earthquakes and volcanoes. The rigid plates consist of continental and oceanic crust together with the upper mantle, which "float" on the semi-molten layer of the mantle beneath them, and move relative to each other across the earth. Six major plates (Eurasian, American, African, Pacific, Indian, and Antarctic) are recognized, together with a number of smaller ones. The plate margins coincide with zones of seismic and volcanic activity.

Silica: A chemical combination of silicon and oxygen. It is a structural component in many organisms, such as diatoms.

Stratigraphic: The study of rock strata, especially of their distribution, deposition, and age.

11.7 SELF-ASSESSMENT QUESTION

11.7.1 Objective Type Questions:

1. The branch of geology concerned with the separation and differentiation of rock units by means of the study of the fossils is known as
(a) Biostatigraphy (b) Taphonomy
(c) Biogeography (d) Paleontology

2. What scientific avenue of investigation gave scientists the best estimate of the age of the earth:
(a) dating fossils (b) archaeological dating
(c) radiometric dating (d) carbon dating

3. Fossils fuels are important sources of energy in
(a) transport (b) homes
(c) industries (d) all of them

4. Buried plants due to constant heat and pressure turn in to
(a) wood (b) coal
(c) fertilizer (d) oil

5. Fossils are most common in which rock types?
(a) sedimentary (b) igneous
(c) metamorphic (d) all of these

6. Which of the following will not make a fossil?
(a) decomposed organic material (b) plant impressions (casts)
(c) animal footprints (d) loose animal bones

7. The northern portion of the late Paleozoic supercontinent known as:
(a) Crust (b) Pangea
(c) Gondwana (d) Core

8. The physical, chemical or biological alteration of sediments into sedimentary rock.
(a) Fossil (b) Diagenesis
(c) Fertilizer (d) Humus

9. The study of what has happened to an organism from the moment of death until it is found as a fossil.
(a) Taphonomy (b) Preservation
(c) Phosphatization (d) None of these

10. *Carbonization* is a process occurring within the sediment in the absence of:
(a) Carbon di oxide (b) oxygen
(c) Nitrogen (d) Phosphorus

11.7.1: Answer Key: 1. (d), 2. (c), 3. (d), 4. (d), 5. (a), 6. (a), 7. (b), 8. (b), 9. (a), 10. (b)

11.8 REFERENCES

- Anderson, T.F., M.E. Brownlees, and T.L. Phillips. 1981. A stable isotope study of the origin of permineralized peat zones in the Herrin coal. *Journal of Geology 88*:713-722
- Brady, L.F. 1947. Invertebrate tracks from the Coconino Sandstone of Northern Arizona. *Journal of Paleontology* 21(5):466-472.
- Cohen, A.D. and W. Spackman. 1980. Phytogenetic organic sediments and sedimentary environments in the Everglades -- Mangrove complex. Part III. The alteration of plant material in peat and the origin of coal macerals. *Palaeontographica 172B*:125-149
- Farlow, J.O., R.E. Chapman, B. Breithaupt, and N. Matthews. 2012. *The scientific study of dinosaur footprints.* Pp. 713-759 *in* M.K. Brett-Surman, T.R. Holtz, Jr., and J.O. Farlow (eds.), The Complete Dinosaur, second edition. Indiana University Press.
- Karowe, A. and T. Jefferson. 1987. *Burial of trees by eruptions of Mt. St. Helens, Washington: implications for the interpretation of fossil forests*. *Geology Magazine 124*:191-204
- Keighley, D.G., and R.K. Pickerill. 1996. Small *Cruziana*, *Rusophycus*, and related ichnotaxa from eastern Canada: The nomenclatural debate and systematic ichnology. *Ichnos* 4(4):261-285.
- Li, R., M.G. Lockley, M. Matsukawa, K. Wang, and M. Liu. 2011. An unusual theropod track assemblage from the Cretaceous of the Zhucheng area, Shandong Province, China. *Cretaceous Research* 32(4):422-432.
- Lockley, M.G., and A.P. Hunt. 1995. *Dinosaur Tracks and Other Fossil Footprints of the Western United States*. Columbia University Press, New York. 338 pp.
- Lockley, M.G., and C.A. Meyer. 2000. Dinosaur Tracks and Other Fossil Footprints of Europe. Columbia University Press, New York. 360 pp.
- Lockley, M., K. Chin, K. Houck, M. Matsukawa, and R. Kukihara. 2009. New interpretations of *Ignotornis*, the first-reported Mesozoic avian footprints: Implications for the paleoecology and behavior of an enigmatic Cretaceous bird. *Cretaceous Research* 30(4):1041-1061.
- Lomax, D.R., and C.A. Racay. 2012. A long mortichnial trackway of *Mesolimuluswalchi* from the Upper Jurassic Solnhofen Lithographic Limestone near Wintershot, Germany. *Ichnos* 19(3):175-183.
- McCrea, R.T., M.G. Lockley, and C.A. Meyer. 2001. *Global distribution of purported ankylosaur track occurrences.* In K. Carpenter (ed.), The Armored Dinosaurs. Indiana University Press: Bloomington, Indiana. Pp. 413-454.
- *Oliver F. W.; Scott D. H. 1904. "On the structure of the Palaeozoic seed LagenostomaLomaxi, with a statement of the evidence upon which it is referred to Lyginodendron". Philosophical Transactions of the Royal Society of London, Series B* ***197****: 193–247.*

- Schopf, J.M. 1975. Modes of fossil preservation. *Review of Paleobotany and Palynology 20*:27-53.
- Scott, A.L. and G. Rex. 1985. The formation and significance of Carboniferous coal balls. *Philosophical Transaction of the Royal Society of London 311B*:123-137.
- Spicer, R.A. and A. Greer. 1986. Plant taphonomy in fluvial and lacustrine systems. *University of Tennessee Studies in Geology 15*:10-26.

11.9 SUGGESTED READING

- Jain P.C. & M.S. Anantharaman, 2014, *Palaeontology Palaeobiology*,Paperback–by Vishal Publishing Co.; 9th (Revised and Enlarged)
- Sepkoski, D.2011, *Rereading the Fossil Record*, University of Chicago Press.
- Smith, A. B., 1994, *Systematics and the Fossil Record*, Blackwell Science.
- Simpson, G. G., 1953, *Major Features of Evolution*, Columbia University Press.
- Singh, V., Pande, P.C. & Jain D.K., 2006,*A Text Book of Botany Diversity of Microbes and Cryptogams*, *Rastog*i Publication, Meerut (U.P.)
- Singh, V., Pande, P.C. & Jain D.K., 2014-15**,** *A Text Book of Botany*, Rastogi Publication, Meerut (U.P.)
- Stanley Raup, 2006, *Principles of Paleontology* Paperback– by CBS Publishers & Distributors; 2nd edition.
- Valentine, J. W. 1973, *Evolutionary Paleoecology of the Marine Biosphere*, Prentice Hall, Inc.
- Vermeij, G., 1987, *Evolution and Escalation: An Ecological History of Life*, Princeton University Press.

11.10 TERMINAL QUESTIONS

11.10.1 Short answer type Questions:

i) What is paleontology?
ii) What do you understand by taphonomy?
iii) What are the 2 types of fossils? Give examples.
iv) Name the types of preservation processes.
v) Define phosphatization.
vi) What are the factors that can affect fossilization?
vii) Does the organism have hard or soft body parts?
viii) Do the surrounding conditions allow for rapid burial and preservation?
ix) Where are fossils found?
x) Define diagenesis.

11.10.2 Long answer type Questions:

i) Briefly describe the agents of confusion that can affect potential fossils and discuss how their effects can be recognized.
ii) What changes happen in the fossils so that it preserves for a long duration?
iii) Define factors affecting fossilization potential.
iv) What are different levels of preservation? Define them in brief.
v) Define living fossils in detail.

UNIT-12 IMPORTANT FOSSILS IN INDIA

12.1 OBJECTIVES

After reading this unit students will be able to understand:

- Historical account of Indian fossil study.
- Important fossil types in India.
- Informations regarding different fossil parks and museum of India.
- Detailed idea of Birbal Shani Institute of Lucknow

12.2 INTRODUCTION

Paleobotany is important in the reconstruction of ancient ecological systems and climate, known as paleoecology and paleoclimatology respectively; and is fundamental to the study of green plant development and evolution. Paleobotany has also become important to the field of archaeology, primarily for the use of phytoliths in relative dating and in paleoethnobotany. Although the history of plants on the earth is billion years old and during this period numerous species originated and extincted as well.

Once the study of the sediments of the rocks and their fossils became firmly established on a scientific basis during the first two decades of the 19th century, the investigation of Indian geology didn't lag far behind that from the European countries. The pioneer of this work in India was largely British army officers, surgeons and missionaries. Their collections were sent to England, where they were described by the foremost specialist and eventually found their way to British Museum. In India, the first fossil plant was recorded in the later part of the eighteenth century, although detailed studies were carried out only in the later half of the nineteenth century, almost entirely at the Geological Survey of India, Calcutta.

Since fossilization requires very unique circumstances, fossils are very rare. As a result, fossils do not necessarily provide a complete representation of the past. The more fossilized remains available for study, the more information can be obtained and a more complete understanding achieved. The incomplete fossil record is due in part to lack of discovery, as only some areas are the focus of excavation and investigation. In addition, local climatic and environmental conditions determine whether fossilization will occur, so that there is differential preservation among different locations. Moreover, the rock sequences are not always complete in all places, so certain periods cannot be investigated. Paleoanthropologists focus much of their research in East and South Africa, because these areas have the most ideal conditions for fossilization and access to the deep layers containing the fossils. While early hominids likely lived throughout the entire continent, it is in the specific regions where paleoanthropologists have had the most success at discovering fossils.

History of the palaeobotany in India can be traced as far as 1828 when *A. Brongniart* first described few fossil plants from here in his Prodrome. Since then to the end of 19th century most of the literature on Indian fossil plants is to be found in the publications of the Geological Survey of India and is based on their collections from all the parts of the country. Professor Birbal Sahni was the first Indian to revitalize study of Indian fossil plants. He was a visionary and saw the potential of palaeobotanical research in India in

understanding plant evolution through the ages and application of this knowledge for human welfare. It was through Prof. Sahni's efforts and zeal that the Institute of Palaeobotany was founded in September 1946 at Lucknow. The study of fossil plants in India in the present century entirely represents his efforts.

One more scientist, who contributed a lot to Indian fossil science was Dr. D.D. Pant. In his honor and as a mark of recognition of his versatile academic status, seven taxa have been named after him so far, viz. *Pantopteris* Chandra & Rigby, (a pteridophyll),*Pantophyllum* Rigby (a noeggera-thiopsid leaf), *Isoetespantie* Goswami & Arya (an extant lycopod), *Hepaticitespantie* Bose & Pal (a fossil bryophyte), *Brachyphyllumpantie* Nautiyal & Srivastava(a fossil conifer) *Glossopteris pantie* Chandra & Surange (a pterido- sperm) and *Birbalsahnia-divyadarshanii* Bajpai & Maheshwar (a male pterido-spermous fructification). On the last named fossil plant, a postal stamp was released by the Government of India in 1997 on the occasion of the Golden Jubilee of Birbal Sahni Institute of Palaeobotany.

The blending of interest in living and fossil plants and combination of facts with interpretative ideas were Pant's main distinctions. His work enables us to peep into the plant world of Gondwana and Pre-Gondwana times through the modern window. On the basis of his important research contributions on the reconstruction of plants of glossopterids, diversity of the floristic elements and reproductive biology, he was recognized as an authority on *Glossopteris* flora. His interpretation of the compressed organs of *Glossopteris* and related genera, including their vegetative parts and fructifications has been vividly confirmed by the subsequent findings of permineralized fossils. He was the first to propose the existence of mycorrhizic gametophytes in RhynieChert by his interpretation of gametophytic and mycorrhizic nature of *Rhynia Gwynne-vaughanii* and strongly advocated it against criticisms throughout his life. However, this work induced others to discover various gametophytes in Rhynie Chert like *Lyonophyton* and *Sciadophyton.*

12.3 IMPORTANT FOSSILS IN INDIA

Indian continent consists of a lot of biodiversity presently and so in the past. So a lot of fossil records are also found in the earth crust of this country. Initiation of palaeobotanical research in India in the true sense, that is the study of fossil plants from a botanical angle to examine their structure and the light they threw on the evolution in plant kingdom goes to the credit of Prof. Birbal Sahni.

Some of the early work on Indian fossils, such as illustrations of the Jurassic and Tertiary fossils of Cutch and South India were contributions to palaentological knowledge of considerable importance in some cases more comprehensive than contemporary work on British fossil. Brongniart described the first *Glossopteris* leaf from India in 1928 and after that a volume of literature has been published on Indian fossil plants. The species described in the majority of works on Indian fossils published prior to the inauguration of *Palaeontologia Indica* in 1861 remained in London.

Indian fossil plants belonging different divisions of plant groups. In India there is as yet no definite record of plant life in the Precambrian. But in the Cambrian some plant life has been recorded. Some algal and fungal remains from Vindhyans are regarded as Cambrian in age. The earliest land vascular plants known from India would be the *Psilophyton* like axes from Spiti. Next record of the vascular plant is from Po series of Spiti, which is of Lower Carboniferous age. Ghosh and Bose reported plant microfossil from the Cambrian formation from Punjab Salt Range now in Pakistan and obtained spores, wood fragments and cuticle.

Paleontologists have found that at least seven types of dinosaurs roamed on these lands, including the mighty T Rex. The latest find has been that of *Rajasaurusnarmdensi*s, a previously unknown dinosaur. This dinosaur has been reconstructed fully and is on display in a museum in Calcutta. A model of this can be also found in the Indroda Fossil and Dinosaur Park in Gandhinagar, Gujarat. Enough fossils have been recovered to suggest that both herbivore and carnivore dinosaurs ambled through the entire Narmada basin. These dinosaurs disappeared from the face of the earth about 65 million years ago. Scientists attribute the extinction to various reasons. But this site is believed to have been destroyed by a meteor, called the Shiva Crater that was discovered beneath the Indian Ocean, west of Mumbai, India.

Some other important fossil types of India are given below:

Glossopteris **-** The tongue-shaped leaf *Glossopteris* represents a unique group of extinct vascular plants (age: Permian, 250-280 million years). During this period India occupied a position south of equator close to South Pole as a part of a very large continent which included South America, Antarctica, Africa and Australia, called Gondwanaland. This vegetation was responsible for the precious coal reserves in peninsular India.

Fig. 12.1. *Glossopteris* sp.

More than 70 fossil species of this genus have been recognized in India alone, with additional species from South America, Australia, Africa, Madagascar and Antarctica. Essentially, *Glossopteris* was restricted to the middle- and high-latitude parts of Gondwana during the Permian and was an important contributor to the vast Permian coal deposits of the Southern Hemisphere continents. *Glossopteris* was a woody, seed-bearing shrub or tree, some apparently reaching 30 metres (98 ft) tall. They had a softwood interior that resembles conifers of the family Araucariaceae. Seeds were borne on one side of variably branched or fused structures, and microsporangia containing pollen were borne in clusters at the tips of

slender filaments. Both the seed- and pollen-bearing organs were partially fused (adnate) to the leaves, or, in some cases, possibly positioned in the axils of leaves.

Pentoxylon- An important discovery of Prof. Birbal Sahni is the extinct plant group named Pentoxylae from Nipania in Dumka district, Rajmahal Hills, Bihar (age 110-114 million years). The Gondwanan seed plant (Pentoxylon), now extinct, was one of the characteristic plants of the Rajmahal fossil flora of India during the Jurassic–Cretaceous period. This plant possessed characters showing affinities with almost all gymnospermous groups, but with unique reproductive structures of its own. A permineralized chert embodying this plant displays amazingly preserved subcellular details, which are rare and unique in fossil condition. Fossilization of organisms and their structural details depends upon a distinctive type of preservational environment. Although most of the hard plant parts get fossilized, cytoplasmic structures and subcellular organelles are seldom preserved and reported in fossil biota.

Williamsonia sewardiana **-** A model of the extinct plant *Williamsonia sewardiana* which thrived in Rajmahal, Bihar about 140 million years ago. This model is based on the reconstruction envisaged by Prof. Birbal Sahni.

Fig. 12.2.*Williamsonia sewardiana sp.*

Williamsonia possessed a sturdy stem and had multiple fern-like leaves. The plant did not live in groups. The stamens of *Williamsonia* curved inward and upward. *Williamsonia* produced flowers up to 4 inches (10 cm) in length. Its stalked seeds would have grown from a central receptacle, and the entire flower of *Williamsonia* would have been surrounded by protective bracts (which are often the only part of the plant to undergo fossilization). The cones of *Williamsonia* were monosporangiate. They were "cup shaped" and could be up to 15 centimetres (5.9 in) in diameter. As many as 25-50 ovules could be present in each cone. The development of the ovules appears to be similar to that of *Cycadeoidea*.

***Birbal sahnia divyadarshanii*–**This is the fossil of an enigmatic flower-like organ of the extinct plant. It features a male reproductive organ of an extinct plant--":Birbal sahnia divyadarshanii named after eminent Indian Palaeobotanists Professor Birbal Sahni and

Professor DivyaDarshan Pant. The fossil was discovered by H.K. Maheshwari and UshaBajpai from Hura Coalfield, Santhal Pargana, Bihar (age 250-280 million years).

The Geological Survey of India (GSI) currently maintains four protected areas bearing rich fossil deposits.

Fig. 12.3.Fibre glass life size model of extinct elephant of Sivalik Hills

1. Shivalik Fossil Park: It is a fossil park, also known as the **Suketi Fossil Park**, with a collection of prehistoric vertebrate fossils and skeletons recovered from the upper and middle Sivalik geological formations of sandstones and clay at Suketi in the Sirmaur district in Himachal Pradesh. The park has a display of the fossil finds and also an open-air exhibition of six extinct mammals formed in life-size models made of fiberglass and resins, in a natural ambiance of the Sivalik Hills environment of the Plio-Pleistocene era (circa 2.5 million years) from where the fossils were unearthed. There is also a museum, within the precincts of the park, where the fossils are curated and exhibited. It is Asia's biggest fossil park. The exhibits in the park are used for generating scientific interest in the public and for facilitating special international studies by visiting research scholars from all over the world, apart from tourism development.

The park is named after the Suketi village where it is located, at the very site where the fossils were found, in the Markanda Valley, at the foot of the Himalayas. It is at a distance of 22 kilometres (14 mi) to the south west of Nahan, the district headquarters of Sirmaur district. The park, extensively forested, is spread out over an area of 1.5 square kilometres (0.58 sq mi) at Suketi.

The Geological Survey of India, in close association with the Government of Himachal Pradesh, took the initiative and established the park on 23 March 1974. The park is also maintained by the Geological Survey of India. The fossils are identified by the Geological Survey of India as vertebrate fossils which resided in the area about 2.5 million years ago, during a period when the region was known for the geological formations of the Shivalik system of hills. It has also been concluded that the Shivalik Hills, which formed about twenty-five million years ago, give proof of the evolution of mankind. The mammalian fossils found in the Shivaliks of this park are one of the world's richest antiquities.

Fig. 12.4.Life size model of the extinct Giant Turtle *Megalochelys atlas*

The fiber glass models on display in an open area in the fossil park are of six extinct animals. These are: Huge land tortoise, gharial, four horned giraffe, sabre-toothed cat, large tusked elephant, and hippopotamus. The Saketi Park has a unique feature, in a miniature form, of the prehistoric biological record of the Upper Sivalik rocks, similar to those which are found in the Patwar Plateau and adjacent hills, also in Mangla dam areas in the region.

The model of the sabre-tooth cat, almost similar to the present day species, is depicted with very long upper canine teeth, used to tear its prey to death, became extinct about a million years ago; at the same time many species of elephants also became extinct. In the hippopotamus model, made to a life-size similar to its present-day counterpart, animal has six incisors with a comparatively larger mouth but with a small brain hole, longer lower jaw and legs like the pig. This species, which existed in very large numbers about 2.5 million years ago, is now extinct. The model of the giant land tortoise, representing a species found in the Shivalik region, is the largest of all tortoises but its present-day counterpart is of much smaller size. Models of the giant-sized elephants are of those which roamed 7 to 1.5 million years ago here, had a smaller cranium (bone portion of the skull), unusually long pair of tusks and huge limbs; these species numbering 15 vanished about 1.5 million years ago. The model of a four-horned giraffe, an ancestor of the present day species, lived in the region 7 to 1.5 million years back; it has an unusually large skull but a comparatively short neck.

2. Mandla Plant Fossils National Park

It is situated in Mandla district of Madhya Pradesh in India. This national park has plants in fossil form that existed in India anywhere between 40 million and 150 million years ago spread over seven villages of Mandla District (Ghuguwa, Umaria, Deorakhurd, Barbaspur, Chanti-hills, Chargaon and DeoriKohani). The Mandla Plant Fossils National Park is an area that spreads over 274,100 square metres. Such fossils are found in three other villages of the district also, but they lie outside the national park.

The BirbalSahni Institute of Palaeobotany, Lucknow, has done some work on the plant fossils of Mandla, though the study is yet in a preliminary stage. In Ghuguwa and Umaria the standing, petrified trunks of trees have been identified as Gymnosperms and Angiosperms-Monocotyledons and palms. There are certain Bryophytes also. There is some question about whether the fossils are from the late Jurassic or the early and mid-Cretaceous age. This is

because when the breakup of the single land mass, Pangaea occurred, it was split by the continental drift into Laurasia and Gondwana somewhere between the Jurassic and Cretaceous ages. India formed a part of Gondwana. Depending on the age in which the split occurred, the fossils are either Jurassic or Cretaceous.

Interspersed with the plant fossils are to be found the fossils of molluscs. One theory is that the area in which the fossils are located, i.e., the Narmada Valley near Mandla, was actually a deep inundation of the sea into peninsular India until the Post- Cambrian Tertiary age, about 40 million years ago. This means that Narmada was a very short river which terminated in the inland sea above Mandla, and that the recession of the sea caused geological disturbances, which created the present rift valley through which the riversNarmada and Tapti flow in their present journey to the Arabian Sea. All this, however, is speculation and conjecture because it is only recently that an interest has developed in the fossils of Mandla and detailed scientific studies are still wanting.

Fig. 12.5.Fossil of a bottle palm at Mandla Plant Fossils National Park

A region as ancient as this tells a great deal about what Madhya Pradesh was like millions of years ago. The absence of dicotyledons suggests that plant evolution was still at an early stage. The whole matter requires much more detailed study. The national park is spread over agricultural fields in seven non-contiguous villages, which makes it difficult to protect the fossils. The fossils look like ordinary rocks and are either removed from the fields unwittingly by agriculturists or are damaged by tourists and those unscrupulous people who think they can make quick money out of their sale. In Chargaon and DeoriKohani villages there has been extensive damage, especially by excavation of embedded molluscs.

To save Fossil National Park, a separate administrative unit for park management is to be set up, the land on which fossils are located should be acquired and fenced and the nearest university, Jabalpur, should be asked to set up a special research unit on the fossils.Parks, as well as numerous fossil displays and models in Indian zoological parks, are part of the Geological Survey's charter program to educate the general public on the Earth's evolutionary history. One of the more comprehensive displays is that of the Natural History Museum of the Nehru Zoological Park, Hyderabad.

3. National Fossil Wood Park, Tiruvakkarai in Tamilnadu: The National Fossil Wood Park, Tiruvakkarai is a geological park located in the Villupuram district in the Indian state of Tamilnadu and is maintained by the Geological Survey of India. The park was established in 1940 and is located 1 km east of Tiruvakkarai village on the road between Tindivanam and Pondicherry.

The park contains petrified wood fossils approximately 20 million years old, scattered throughout the park, which covers about 247 acres (100 ha). The park consists of nine enclaves, but only a small portion of the 247 acres (approx 1 square km) is open to the public.Officials of the GSI believe that, the fossils were formed during massive flooding that occurred millions of years ago.The park hosts about 200 fossilized trees. They range in size from 3 to 15 metres (9.8 to 49.2 ft) meters in length, some of which are up to 5 meters in width. They are strewn and partially buried in the park ground. No branches or leaves remain on the fossilized trunks.Scientists speculate that the trees did not originally grow at the site, but were transported before they had petrified.

4. National Fossil Wood Park, Sathanur, in Tamilnadu: National Fossil Wood Park, Sathanur is located in Perambalur District, in Tamil Nadu. This park is located within Sathanur panchayat and has a fossilized tree trunk, which was discovered in 1940 by renowned geologist Dr. M. S. Krishnan of the Geological Survey of India, who hailed from Tanjore. The petrified tree trunk is believed to be over 120 million years old, and is considered to be evidence for the presence of a sea during the Cretaceous period in this area.

Fig. 12.6. This fossil is of a conifer, measures around 18 meters long and a geological treasure. Similar fossilized tree trunks have been found in nearby Varagur, Anaipadi, Alundalippur, and Saradamangalam,all located within a 10 km radius of Sathanur

This national park is open to public throughout the year. However, September to February is the best period to visit to enjoy the cool weather and to view the thriving tropical agriculture greenery.This national park is frequently visited by geologists and nature lovers throughout the year. Early visitors (1960s to 1980s) caused some damage by collecting samples for their research or in their college or university labs. Now it is well fenced and guarded.

This park is located approximately one kilometer north of Sathanur village. There used to be a sandy, muddy road and reaching the park used to be a very taunting task. This was well

explained by *The Hindu* correspondent Soma Basu in 2005 (Sathanur: a tree that is as old as forever).

Other fossil parks in India include:

- Indroda Dinosaur and Fossil Park, Gujarat
- Ghughua Fossil Park, Madhya Pradesh
- Salkhan Fossils Park, Uttar Pradesh

5. Indroda Dinosaur and Fossil Park

The Indroda Dinosaur and Fossil Park in Ahmedabad in the state of Gujarat, India, has been described as the second largest hatchery of dinosaur eggs in the world.The Park was set up by the Geological Survey of India and is the only dinosaur museum in the country.The Park is run by the Gujarat Ecological and Research Foundation (GEER) and has been called India's *Jurassic Park*, though in fact, the fossils are from the later Cretaceous period, not the Jurassic. Several fossilized dinosaur eggs and skeletal parts have been found here. The fossils which were found in Upper Cretaceous formations in the region date back 66 million years ago. The eggs are of different sizes, some the size of cannon balls. Fossil trackways of these gargantuan animals are also on display in the park.

Fig. 12.7. Fossilized Dinosaur eggs displayed at Indroda Fossil Park

Dinosaurs that are on display include *Tyrannosaurus rex*, *Megalosaurus*, *Titanosaurus*, *Barapasaurus*, *Brachiosaurus*, *Antarctosaurus*, *Stegosaurus* and *Iguanodon*. The park displays life-size models of the dinosaurs along with details of each period in which they existed and characteristics of the animals. The fossils were found in the Songhir Bagh Basin, the Himatnagar basin of Balasinor, south-eastern parts of Kheda, Panchmahal and Vadodara districts of the state.

6. Ghughua Fossil Park

Ghughua Fossil Park is a National Park located in Madhya Pradesh, India (23 7 N, 83 37 E) between Ghughua and Umaria villages, in which plant fossils belonging to 31 genera of 18 families have been identified. The site was founded during the 1970s by Dr. Dharmendra Prasad, a statistical officer of the Mandla district and honorary secretary of the district

archaeology unit. It was declared a National Park in 1983. Numerous plant, leaf, fruit, seed, and shell fossils can be found in this park, some of which dates as far back as 65 million years, the most prominent of which are the palm fossils.A Eucalyptus fossil found at Ghughua is the oldest fossil of its type ever discovered and this find supports its origins from Gondwana. Additional notable discoveries include a dinosaur egg fossil.

7. Salkhan Fossils Park

Salkhan Fossils Park, officially known as **Sonbhadra Fossils Park**, is a fossil park in Uttar Pradesh, India. It is located 12 km from Robertsganj, near Salkhan village on state highway SH5A in Sonbhadra district. The fossils in the park are estimated to be nearly 1400 million years old.The fossils found in the Sonbhadra Fossils Park are algae and stromatolites types of fossils. The park is spread over an area of about 25 hectares in Kaimur Range, adjacent to Kaimur Wildlife Sanctuary. It comes under jurisdiction of the State forest department.

Geologists have been aware of the fossils found in the present-day park area since the 1930s. People who have carried out research in the area include Mr. Auden (1933), Mr. Mathur (1958 and 1965), and Professor S. Kumar (1980–81). On 23 August 2001, the area was featured in an article written by journalist Vijay Shankar Chaturvedi for the Hindi newspaper *Hindustan*. Subsequently, it was formally inaugurated as a fossil park by District Magistrate Bhagawan Shankar on 8 August 2002.

List of Indian and Madagascan dinosaurs

S.No.	Name	Period	Location	Diet
1	*Alwalkeria*	Late Triassic	*India*	Omnivore
2	*Archaeodontosaurus*	Middle Jurassic	*Madagascar*	Herbivore
3	*Barapasaurus*	Early Jurassic	*India*	Herbivore
4	*Brachypodosaurus*	Late Cretaceous	*India*	Herbivore
5	*Bruhathkayosaurus*	Late Cretaceous	*India*	Herbivore
6	*Coeluroides*	Late Cretaceous	*India*	*Carnivore*
7	*Compsosuchus*	Late Cretaceous	*India*	*Carnivore*
8	*Dandakosaurus*	Early Jurassic	*India*	*Carnivore*
9	*Dahalokely*	Late Cretaceous	*Madagascar*	*Carnivore*
10	*Dryptosauroides*	Late Cretaceous	*India*	*Carnivore*
11	*Indosaurus*	Late Cretaceous	*India*	*Carnivore*
12	*Indosuchus*	Late Cretaceous	*India*	*Carnivore*
13	*Isisaurus*	Late Cretaceous	*India*	Herbivore
14	*Jainosaurus*	Late Cretaceous	*India*	Herbivore
15	*Jaklapallisaurus*	Late Triassic	*India*	*Omnivore*

16	*Jubbulpuria*	Late Cretaceous	*India*	*Carnivore*
17	*Kotasaurus*	Early Jurassic	*India*	Herbivore
18	*Laevisuchus*	Late Cretaceous	*India*	*Carnivore*
19	*Lametasaurus*	Late Cretaceous	*India*	*Carnivore*
20	*Lamplughsaura*	Early Jurassic	*India*	Herbivore
21	*Lapparentosaurus*	Middle Jurassic	*Madagascar*	Herbivore
22	*Majungasaurus*	Late Cretaceous	*Madagascar*	*Carnivore*
23	*Masiakasaurus*	Late Cretaceous	*Madagascar*	*Carnivore*
24	*Nambalia*	Late Triassic	*India*	*Omnivore*
25	*Ornithomimoides*	Late Cretaceous	*India*	*Carnivore*
26	*Orthogoniosaurus*	Late Cretaceous	*India*	*Carnivore*
27	*Pradhania*	Early Jurassic	*India*	*Omnivore*
28	*Rahonavis*	Late Cretaceous	*Madagascar*	*Carnivore*
29	*Rahiolisaurus*	Late Cretaceous	*India*	*Carnivore*
30	*Rajasaurus*	Late Cretaceous	*India*	*Carnivore*
31	*Rapetosaurus*	Late Cretaceous	*Madagascar*	Herbivore
32	*Titanosaurus*	Late Cretaceous	*India*	Herbivore
33	*Vahiny*	Late Cretaceous	*Madagascar*	Herbivore

Alwalkeria

Barapasaurus

Isisaurus

Lamplughsaura

Majungasaurus

Masiakasaurus

Rahonavis

Rajasaurusnarmadensis

Rapetosaurus

Fig.12.8. Indian and Madagascan dinosaurs

12.4 BIRBAL SAHANI INSTITUTE OF PALAEOBOTANY

The Birbal Sahani Institute of Palaeobotany (acronym BSIP) is an autonomous institute constituted under the Department of Science and Technology, Government of India. The Institute is located at Lucknow, Uttar Pradesh, India and is a seat of higher learning in the field of plant fossil research.The Institute of Palaeobotany was established in the year 1946, by the Palaeobotanical society formed by a group of botanists led by the renowned Indian botanist, Professor Birbal Sahani. Professor Birbal Sahni was appointed as firsr Director of the Institute who is called as the father of Denrology. The initial office of the Institute was at the Department of Botany, Lucknow University. The then government of the United Provinces gifted a bungalow sitting on 3.50 acres of land to the Institute in 1948, which till today remains its campus.

Savitri Sahani, took over the reins of the Institute on her husband's death in 1949 and the Institute moved into a new purpose-built building in 1953. The Institute, by that time, had already started to be known and, in 1951, UNESCO included it in their Technical Assistance Program. On 9 July 1969, the research activities were alienated from the society and BirbalSahni Institute of Palaeobotany was formed, in honor of the scientist, as an independent autonomous research organization funded by the Government of India.

BSIP works in close coordination with various organizations such as Geological Survey of India, Physical Research Laboratory, Oil and Natural Gas Commission, Oil India Limited, Coal India Limited, Coal Mine Planning and Design Institute, Council of Scientific and Industrial Research Laboratory, Neyveli Lignite Corporation, Mineral Exploration Corporation Limited,Indian Institutes of Technology, Institute Francais de Pondicherry, Botanical Survey of India,Forest Research Institute, Dehradun, Bhabha Atomic Research Center, Laboratories under Department of Science and Technology, Archaeological Survey of India, Wadia Institute of Himalayan Geology, different State Departments of Archaeology and Geology Departments of several Universities. The Institute has signed specific MOUs with Oil and natural Gas Corporation, Geological Survey of India (Coal Wing), Delta Studies Institute,Vishakhapattanam (for delta/basin modeling in relation to paramecia and hydrocarbon exploration) and National Institute of Oceanography, Goa (for Quaternary palaeoclimate of marine and coastal areas).

Objectives

The main objectives of the Institute are set as:

1. To develop palaeobotany in all its botanical and geological aspects.
2. To constantly update data for interaction with allied disciplines.

3. To co-ordinate with other palaeobotanical and geological research centres in the areas of mutual interest, such as diversification of early life, exploration of fossil fuels, vegetational dynamics, climatic modelling, conservation of forests.
4. To disseminate palaeobotanical knowledge in universities, educational institutions and other organisations.

Fig. 12.9. Mammals are the dominant terrestrial vertebrates of the Cenozoic

Fig. 12.10. Drill for dendrochronology sampling and growth ring counting

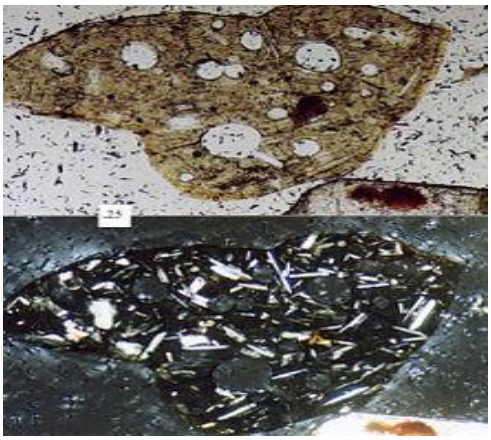


Fig. 12.11. A volcanic sand grain seen under the microscope, with plane-polarized light in the upper picture, and cross polarized light in the lower picture. Scale box is 0.25 mm

Fig. 12.12. Fossil nummulitid foraminiferans showing microspheric and megalospheric individuals; Eocene of the United Arab Emirates; scale in mm

MUSEUM

BSIP nurses a museum, originally housing the fossil collections of Professor Sahni, but now holds later collections made by the scientists over the years. The collection includes holotype specimens, slides and figured specimens.

- Figured specimens : 6679
- Figured slides : 12740
- Slide negatives : 17504

The museum, with its foundation stone, laid by Prof. BirbalSahni, composed of fossils of various geological ages embedded in a marble-cement block, displays the specimens based on their general and geological relevance. The museum also maintains a *Geological Time Clock*.

HERBARIUM

The Herbarium functions with four different sections:

- General collection of dried plants mounted on herbarium sheets
- Xylarium - collection of woods and their thin sections
- Sporothek - collection of pollen and spore slides and polleniferous material
- Carpothek - collection of fruits, seeds

The fossil specimens such as leaves, cuticle, pollen, spores, fruits, seed and wood, numbering 51,472, are preserved according to their variation, local names, uses, distribution , ecology and include contributions from J. F. Duthie, R. R. Stewart, K. N. Kaul, BirbalSahni, O. A. Hoeg and A. L. Takhtajan.

BirbalSahni Institute of Paleobotany (BSIP) will now be able to date fossils as old as a million years. Till now, fossils dating back to 50,000 years can be studied. With seven ultramodern instruments that the institute inaugurated on its 60th foundation day on Saturday, BSIP claims to be the first institute in the country to have the rare combination of all machines for paleobotanical studies under one roof.

"Radio carbon dating has its limitation with a bracket of age. The sample should also have organic carbon in its composition to be assessed with it. Luminescence dating will provide us specific age of sediment samples ranging between 10 years and a million years of even carbon-less minerals," said Dr Chandra Mohan Nautiyal, scientist in charge of the radio carbon lab.

Another instrument, the X-Ray diffraction, procured by BSIP, will help in the identification of a mineral extracted from a particular area. Based on that, details about the climatic conditions of the area can be known since different minerals are found in different climatic conditions. Three of the imaging machines now at BSIP will be able to photograph even the minutest of samples.
"The seven instruments will give us a multipronged approach, addressing samples from various angles. We will be able to know elements and minerals, their size and shape, the nature of minerals (biotic or abiotic), their age and also the type of vegetation (terrestrial, aquatic or desert) present on the earth over a million years ago," explained Dr.Nautiyal.

12.5 SUMMARY

Prof Birbal Sahni was the backbone of Indian Paleontology and he was Graduate from Cambridge University. Under the guidance of Prof. A.C. Seward he did his botanical research. He had a great knowledge of Indian plants and was asked to revise the Lawson's widely used "Text Book of Botany" at that time. Prof. Sahni in between 1918 and 1949 published a large number of papers dealing with nearly every aspect of fossil botany. Besides describing a large quantity of fossil material from India and other countries he contributed important observations on the related paleographical and geological problems, such as Permo-carboniferous life provinces and Wagner's continental drift theory and Himalayan uplift.

Fossiliferous area in India to which Prof. Sahni gave special attention was Rajmahal hills of Bihar and Salt range of Punjab. From here he got important fossil types as *Homoxylonrajmahalense*, *Rajmahaliaparadoxa* and *Williamsoniasewardiana* and Pentoxylae. India has several fossil parks like Shivalik Fossil Park, near Saketi, Himachal Pradesh, Mandla Plant Fossils National Park, near Dindori, Madhya Pradesh, National Fossil Wood Park, Tiruvakkarai, Tamil Nadu and so on.

12.6 GLOSSARY

Agnatha: Name given to what was previously considered a class of jawless fish, including both Paleozoicostracoderms and extant lampreys and hagfish. With the cladisticrevolution, the term has been replaced by more phylogenetically accurate terms such as "basalvertebrate" (MAK)
Ammonite: A coiled, chambered fossil shell of a cephalopodmollusc of the extinct subclass Ammonoidea. Traditionally divided into three types, according to suture: *goniatites*

(Devonian to Permian) have simple lobes, *ceratites* (Triassic) have a saw-toothed pattern, and *ammonites* proper (Jurassic and Cretaceous) are the most complex, have fractal sutures with rounded lobes and saddles.

Bryozoa: Meaning "moss animal", is a phylum of exclusively aquatic and mostly marine colonial organisms. At one time thought to be related to brachiopods because of the common possession of a lophophore, this is now considered the result of convergence.

Calcareous: Rich in calcium carbonate.

Calcareous nanofossils: Fossil remains of *Calcareous Nanoplankton*,protists that normally produce coccoliths during some phase in their life cycle.

Chalk: Soft, earthy, fine-grained white to greyish limestone of marine origin. It is composed almost entirely of by shallow-water accumulations of coccoliths and other microscopic organisms and forms in a sea predominantly free from terrestrial sediment.

Chelicerate: "claw horn bearing". Morphologically distinct arthropodclade characterized by have chelicera (a pair of pre-oral appendages), including arachnids (spiders, mites, etc), horseshoe crabs, scorpions and eurypterids ("sea scorpions").

Coccoliths: Microscopic structures of varying shape and size that are made of calcite, are secreted by calcareous nanoplankton, and are found in marine deposits from the Triassic period to the Recent. Coccoliths range in size from one to thirty-five micrometers in size.

Cynodont: Mostly Triassicmammal-like reptiles, from which true mammals evolved. (MAK)

Fossil record: the history of life on Earth through geological time, as preserved through fossil remains in sedimentary rock (sometimes referred to poetically in older books as the record of the rocks).

Graptolite: "Painted stone", mostly planktonic, Paleozoic, colonial hemichordates with a chitinous skeleton (periderm), commonly preserved as carbon films in black shales, common during the Ordovician, Silurian, and EarlyDevonian, important as index fossils 240 genera are known.

Limestone: The most abundant of the non-elastic sedimentary rocks that is produced from the mineral calcite (calcium carbonate) and sediment. The main source of limestone is the limy ooze formed in the ocean.

Macrofossil: A fossil that is large enough to be studied without a microscope.

Microfossil: A fossil so small that it must be studied with a microscope.

Paleoanthropology: the study of fossil hominids, especially human ancestors.

Paleosol: A fossil soil or soil horizon.

Pterosaur: "Winged lizard" or "winged finger" (pterodactyl); Order of Mesozoic flying archosaurian reptiles characterized by a greatly elongated fourth digit that supported a membranous wing.

12.7 SELF-ASSESSMENT QUESTION

12.7.1-Multiple choice questions:

1. Fossiliferous area in India to which Prof. Sahni gave special attention was

(a) Rajmahal hills of Bihar and Salt range of Punjab (b) Rajasthan desert

(c) Karakoram Hills (d) Shivalik Hills of Northern Himalaya

2. Birbal Sahani Institute of Palaeobotany is situated in?
(a) Delhi (b) Kolkata
(c) Chennai (d) Lucknow

3. Limestone the most abundant of the non-elastic sedimentary rocks comprises:
(a) Sodium carbonate (b) Calcium carbonate
(c) Sulphur (d) Phosphorus

4. Prof Birbal Sahnidid his botanical research under the guidance of?
(a) Prof. A.C. Seward (b) Prof. S.C. Lawson
(c) Charles Darwin (d) Prof. Satner

5. The Birbal Sahani Institute of Palaeobotany was established in the year?
(a) 1942 (b) 1943
(c) 1946 (d) 1948

12.7.1: Answer Keys: 1. (a), 2. (d), 3. (b), 4. (a), 5. (c)

12.8 REFERENCES

- Anderson, T.F., M.E. Brownlees, and T.L. Phillips.(1981). A stable isotope study of the origin of permineralized peat zones in the Herrin coal. *Journal of Geology 88:*713-722.
- Brady, L.F. 1947. Invertebrate tracks from the Coconino Sandstone of Northern Arizona. *Journal of Paleontology* 21(5):466-472.
- *Brongniart, A. (1822), "Sur la classification et la distribution des végétauxfossiles en général, et surceux des terrains de sediment supérieur en particulier", Mém. Mus. Natl. Hist. Nat.8: 203–240, 297–348.*
- Cohen, A.D. and W. Spackman.(1980). Phytogenetic organic sediments and sedimentary environments in the Everglades -- Mangrove complex. Part III. The alteration of plant material in peat and the origin of coal macerals. *Palaeontographica 172B*:125-149
- Current Science, Vol. 81, No. 1, 10 July, 2001
- Farlow, J.O., R.E. Chapman, B. Breithaupt, and N. Matthews.(2012). *The scientific study of dinosaur footprints.*Pp. 713-759 *in* M.K. Brett-Surman, T.R. Holtz, Jr., and J.O. Farlow (eds.), The Complete Dinosaur, second edition.Indiana University Press.
- *Jongmans, W.J.; Halle, T.G. &Gothan, W. (1935), Proposed additions to the International Rules of Botanical Nomenclature adopted by the fifth International Botanical Congress Cambridge1930, Heerlen, OCLC 700752855*
- Karowe, A. and T. Jefferson.(1987). Burial of trees by eruptions of Mt. St. Helens, Washington: implications for the interpretation of fossil forests. *Geology Magazine 124*:191-204.
- Keighley, D.G., and R.K. Pickerill.(1996). Small *Cruziana*, *Rusophycus*, and related ichnotaxa from eastern Canada: The nomenclatural debate and systematic ichnology. *Ichnos* 4(4):261-285.

- *Lanjouw, J.; Baehni, C.; Merrill, E.D.; Rickett, H.W.; Robyns, W.; Sprague, T.A. &Stafleu, F.A. (1952), International Code of Botanical Nomenclature: Adopted by the Seventh International Botanical Congress; Stockholm, July 1950, Regnum Vegetabile 3, Utrecht: International Bureau for Plant Taxonomy of the International Association for Plant Taxonomy, OCLC 220069027*
- Li, R., M.G. Lockley, M. Matsukawa, K. Wang, and M. Liu.(2011). An unusual theropod track assemblage from the Cretaceous of the Zhucheng area, Shandong Province, China. *Cretaceous Research* 32(4):422-432.
- Lockley, M.G., and A.P. Hunt.().1995 *Dinosaur Tracks and Other Fossil Footprints of the Western United States*. Columbia University Press, New York. 338 pp.
- Lockley, M.G., and C.A. Meyer.(2000). *Dinosaur Tracks and Other Fossil Footprints of Europe.* Columbia University Press, New York. 360 pp.
- Lockley, M., K. Chin, K. Houck, M. Matsukawa, and R. Kukihara.(2009). New interpretations of *Ignotornis*, the first-reported Mesozoic avian footprints: Implications for the paleoecology and behavior of an enigmatic Cretaceous bird. *Cretaceous Research* 30(4):1041-1061.
- Lomax, D.R., and C.A. Racay.(2012). A long mortichnialtrackway of *Mesolimuluswalchi* from the Upper Jurassic Solnhofen Lithographic Limestone near Wintershot, Germany.*Ichnos* 19(3):175-183.
- McCrea, R.T., M.G. Lockley, and C.A. Meyer.(2001). *Global distribution of purported ankylosaur track occurrences.in* K. Carpenter (ed.), The Armored Dinosaurs. Indiana University Press: Bloomington, Indiana. Pp. 413-454.
- Schopf, J.M. (1975). Modes of fossil preservation. *Review of Paleobotany and Palynology 20*:27-53
- Scott, A.L. and G. Rex.(1985). The formation and significance of Carboniferous coal balls. *Philosophical Transaction of the Royal Society of London 311B*:123-137
- Spicer, R.A. and A. Greer.(1986). Plant taphonomy in fluvial and lacustrine systems. *University of Tennessee Studies in Geology 15*:10-26
- *Thomas, H.H. (1935), "Proposed additions to the International Rules of Botanical Nomenclature suggested by British palæobotanists" (PDF), Journal of Botany**73**: 111*

12.9 SUGGESTED READING

- Felix M. Gradstein, James G. Ogg, Alan G. Smith (Editors); *A Geologic Time Scale 2004*, Cambridge University Press, 2005, (ISBN 0-521-78673-8).
- Jain P.C. & M.S. Anantharaman, 2014,*PalaeontologyPalaeobiology*,Paperback–by Vishal Publishing Co.; 9th (Revised and Enlarged)
- *Rudwick, M. J. S. 1985. The Meaning of Fossils: Episodes in the History of Palaeontology. University of Chicago Press.p. 24.ISBN 0-226-73103-0.*
- Rudwick, Martin *Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform* 2008. pp. 539–545
- *Simon J. D. Cox, Stephen M. Richard."A geologic timescale ontology and service"*.Retrieved2014-08-03.

- Singh, V., Pande, P.C. & Jain D.K., 2006,***AText Book of Botany Diversity of Microbes and Cryptogams,*** Rastogi Publication, Meerut (U.P.)
- Singh, V., Pande, P.C. & Jain D.K., 2014-15,***A Text Book of Botany,*** Rastogi Publication, Meerut (U.P.)
- Stanley Raup, 2006, *Principles of Paleontology*.Paperback– by CBS Publishers & Distributors; 2nd edition ,1 December 2006.

12.10 TERMINAL QUESTIONS

12.10.1-Short Answer Type Questions:

i) What are the objectives of BirbalSahani Institute of Palaeobotany?
ii) Write in short about the museum of the BirbalSahani Institute.
iii) Comment on fossil records of dinosaurs in India.
iv) What are the herbaria sections in BirbalSahani Institute of Palaeobotany?
v) Give brief idea of Ghughua Fossil Park.

12.10.2-Long Answer Type Questions:

i) Define fossil parks of India in detail.
ii) Give a brief idea about the objectives and functioning of BirbalSahni Institute of Paleobotany.
iii) Define important fossils found from India.
iv) Why Shivalik forest park is famous?
v) Give an idea of fossil history in India?
vi) Explain the contribution of Prof. BirbalSahni in fossil science.
vii) How BirbalSahni Institute of Paleobotany is contributing to science students?