UNIT 2 INTRODUCTION TO CYANOBACTERIA, FUNGI, ALGAE AND LOWER PLANTS

Structure

2.1 INTRODUCTION

In Unit 1 you learnt about the origin of life, diversity of living things, classification of organisms and what are the different groups of organisms that are studied by botanists. The rest of this course on plant diversity is devoted to a study of individual groups, namely, algae, fungi, bryophytes and pteridophytes. The gymnosperms and angiosperms are discussed in Plant Diversity – 2.

In this Unit you are briefly introduced to the characteristics of the different groups, from cyanobacteria to the pteridophytes. Table 1.2 gives a broad outline of classification of organisms into kingdoms and divisions. In this Unit current views on further classification of different groups are summarised. You will note that modern classification schemes are strongly phylogenetic and try to bring out the evolutionary history and relationship among the various taxa in each group.

The purpose of this Unit is to give an overview of the different groups of organisms you will be studying. These groups are: 1) The cyanobacteria which are prokaryotic and along with bacteria, are members of the kingdom Monera. 2) The fungi which are eukaryotic and nonphotosynthetic members of the fungal kingdom. 3) The algae, all of which are eukaryotes, photosynthetic and may be unicellular or multicellular in organisation. All these are members of the kingdom Protista. 4) The bryophytes which are true land plants that produce embryos but do not have highly developed vascular tissues for conduction of food and water, and 5) The pteridophytes which have embryos and well-developed vascular tissues. They include the familiar ferns and a number of allied plants of ancient lineages. The bryophytes and pteridophytes are true members of the plant kingdom.

Objectives

After reading this Unit you will be able to

- describe the characteristics of different groups of organisms,
- contrast the characteristics that are the basis of categorising the organisms in different groups,
- discuss the diversity within each group of organisms,
- explain how biologists classify each group and
- discuss the evolutionary history of each group.

2.2 CYANOBACTERIA

The cyanobacteria are true bacteria (singular, bacterium). They are prokaryotes and do not possess a true nucleus or membrane-bound organelles such as mitochondria or plastids. Like other prokaryotes they have 70S ribosomes. Although there are other bacteria which can photosynthesise, the cynaobacteria are unique in possessing the pigment chlorophyll *a*. This pigment is also present in algae and plants and is responsible for the evolution of oxygen during photosynthesis. The photosynthetic bacteria possess a different kind of pigment, bacteriochlorophyll which does not permit oxygen evolution during bacterial photosynthesis.

The term "cyan" in cyanobacteria refers to the colour, blue. Cyanobacteria possess certain accessory pigments such as phycocyanin and phycoerythrin. The presence of these pigments and chlorophyll *a* together impart characteristic colour to these organisms. It is for this reason that the cyanobacteria are commonly known as blue-green algae. Like true algae they also evolve oxygen during photosynthesis and often occupy habitats where algae occur, in fresh, marine and brackish water bodies and on moist soil surface. However, true algae are eukaryotic and the two are not immediately related.

Since the affinities of the cyanobacteria are with the other bacteria we must briefly examine these organisms for a more complete picture of the position of cyanobacteria in the world of living things. About 4,000 species of bacteria have been described so far. These include about 1,700 species of cyanobacteria. Although small in number of species, bacteria are the most abundant of all organisms. They are also the most ancient. (Not the amoeba, which is a eukaryote of later origin). Bacteria are known in the fossil record as far back as 3.5 billion years ago. Bacteria are morphologically and anatomically the simplest of organisms. Yet, metabolically they are very diverse. Many bacteria are identified not by the morphology of the individuals but by their characteristics in culture.

Bacteria are very small, ranging in size between 1 to few µm. A most unusual discovery was made in 1993 of a bacterium living in the intestinal tracts of a surgeonfish that is 600 µm in length! Bacteria vary in shape. Some are rod-shaped, others spherical and yet others spiral or even comma-shaped. Tiny as they are, bacteria are responsible for activities that strongly affect our lives. Many are agents of serious diseases of human beings, animals and plants. Others ferment food and are thus useful in making varied products such as curd or 'idli' as well as many industrial chemicals. Some are the source of life-saving antibiotics.

Bergey's Manual of Determinative Bacteriology is the standard reference for the classification of bacteria. Since sufficient information is not available to place all bacteria into a hierarchical system of classification, the Bergey's Manual recognises 19 major groups such as the spirochaetes, Gram-positive cocci, gliding bacteria, mycoplasma and actinomycetes. Cyanobacteria is included in one such group. The classification of bacteria is an active area of research. In recent years molecular biologists have analysed the structure of ribosomal RNA (rRNA) and the sequence of rRNA nucleotides in bacteria and other organisms. Such analysis has revealed fundamental differences among two major bacterial groups, the ARCHAEBACTERIA and EUBACTERIA. Differences have also been noted in the chemical composition of the cell membranes of these two bacterial groups and the eukaryotes.

The American scientist Carl Woese considers that the differences between the archaebacteria and the eubacteria are as fundamental as between these groups and the eukaryotes. Thus, life on this planet is considered to comprise of three ancient and primary lineages. The three ancient domains are shown in Fig. 2.1. The cyanobacteria are members of the true bacterial lineage. The archaebacteria include members that live in most unusual environments such as very hot and acidic pools or in waters with extremely high salt contents. Some members of this group live in deep sea vents several kilometres below the ocean surface. The bacteria which produce methane gas are called methanogens.

Cyanobacteria are of great evolutionary interest. According to the endosymbiont theory some ancestral cyanobacterial cells became the plastids of different algal groups. The plastids of red algae resemble the cells of cyanobacteria and both possess chlorophyll *a* and biliproteins. The green algae and plants possess both chlorophylls *a* and *b*. Although most cyanobacteria possess only chlorophyll *a* at least three organisms are known to contain both the chlorophylls. *Prochloron didemni* live as symbionts in the gut walls of sea squirts. *Prochlorothrix hollandica* was recently discovered in lakes in Holland. More recently *Prochlorococcus* was discovered as a free-floating form in open seas. All these organisms possess chlorophylls *a* and *b*, and their cells resemble the chloroplasts of green algae and plants. For this reason, some authors describe them as prochlorophytes and include the three genera in a separate division or class. Some ancestral prochlorophyte was perhaps the endosymbiont that evolved into the green plant chloroplast.

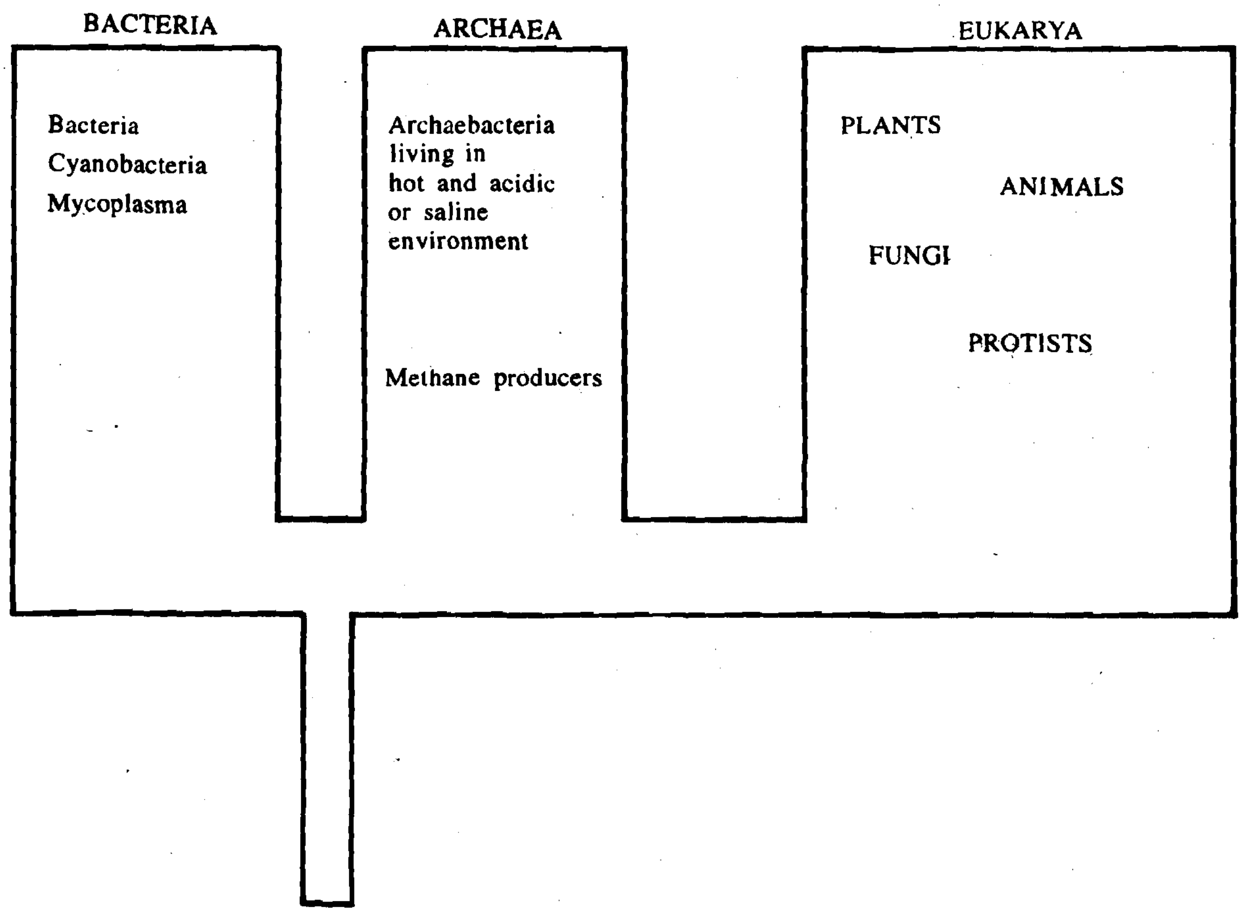

Fig. 2.1 : Three domains of organisms representing ancient and primary lineages.

SAQ 2.1

Indicate whether the following statements are **true** (T) or **false** (F) by pacing the appropriate letters in the space provided.

i) Blue-green algae are closely related to the green algae rather than to the bacteria. ☐

ii) Cyanobacteria possess chlorophyll *a* and evolve oxygen during photosynthesis. ☐

iii) Archaebacteria are prokaryotes and eubacteria are eukaryotes ☐

iv) *Prochloron* is an unusual prokaryote with chlorophylls *a* and *b*. ☐

v) Bacteria are among the simplest of organisms in terms of structural organisation. ☐

2.3 FUNGI

Fungi are a vast assemblage of 95,000 organisms. All of them completely lack photosynthesis. They are heterotrophs that depend upon other living or dead matter for nutrition. As parasites many are serious pathogens on other plants. As saprotrophs they, along with bacteria, degrade dead organisms and release organic chemicals and nutrient elements so they can be recycled. About 13,500 fungal species have a unique association with some algal partners resulting in symbiotic structures known as lichens. The majority of higher plants possess mycorrhizal association where some species of fungi live as symbionts inside or around the roots.

Fungi are eukaryotes. They are an ancient group. Fossil evidence shows that all major fungal groups known today had already evolved by the end of the Paleozoic era, about 280 million years ago. At a time when all living things were grouped under either the animal or the plant kingdom the fungi were thought to be plants. We now place all fungi in the kingdom, Fungi (Myceate). Members of this kingdom lack plastids. They are mostly filamentous in construction. Except in one group their walls contain chitin rather than cellulose. Fungi do not store starch as plants do. The filamentous structures that make up the fungal body are known as mycelia (singular, mycelium). Although the filaments are microscopic, the extensive growth of fungal mycelium can be seen as a fuzzy mass. The reproductive bodies of some fungi such as the mushrooms are made up of well defined aggregates of mycelia. Complex tissues and organs characteristic of the plants are never found among the fungi. Fungi reproduce by spores (before you read on have a good look at the figures of fungi in Unit 7, Block 2).

In spite of the many features that seem to unite the members of the fungal kingdom the fungi are a heterogenous group. Fungi are classified into 7 divisions (Table 1.2). Relationships among these groups are shown in Fig. 2.2. The slime molds (Myxomycota) are not true fungi. They appear to have evolved independently from some protozoan ancestors. In their vegetative phase the slime molds lack a cell wall. The wall-less cells aggregate to form an amoeba-like mass that moves around and engulfs bacteria and other organic matter. Two groups of slime molds are known: the plasmodial slime molds with a multinucleate true plasmodium and the cellular slime molds. The vegetative body of cellular slime molds is a pseudoplasmodium where the aggregating cells retain their cell membranes and individuality. Slime molds produce motile spores.

The oomycetes or water molds differ from other fungi by the possession of cellulose in their cell walls. The fungal body is diploid rather than haploid as in other true fungi. These and other features of reproduction and metabolism suggest that the oomycetes are not related to other fungal groups. They might have evolved from some green or yellow-green algal ancestors after losing their plastids.

The chytrids are simple water molds that live as parasites or saprotrophs. Because they possess motile spores they are often classified with the oomycetes. However, the chytrids have chitin and their filaments are haploid. They are probably distantly related to the bread molds and other true fungi.

The zygomycetes (bread molds), ascomycetes (sac fungi) and basidiomycetes (club fungi) are evolutionarily related as shown in Fig. 2.2. None of them produce motile cells at any stage of their life cycle. The fungal filaments do not have septa (cross walls) in the zygomycetes. The mycelium is septate in the other two groups.

Fungi reproduce asexually and sexually. In sexual reproduction the ascomycetes produce characteristic structures known as asci (singular, ascus). Basidia are the equivalent structures among the basidiomycetes. A fungal species can be assigned to either one of these groups only when they produce an ascus or basidium. A vast number of fungi, about 22,000 species, reproduce only asexually, *or* sexual cycle has not been observed yet. Because their life cycle is imperfectly known and they cannot be assigned with confidence to either one of the groups they are known as **Fungi Imperfecti**. The divisional name Deuteromycota is often used for this group of imperfect fungi. When the sexual life cycle is known the species is automatically assigned to either the ascomycetes or the basidiomycetes.

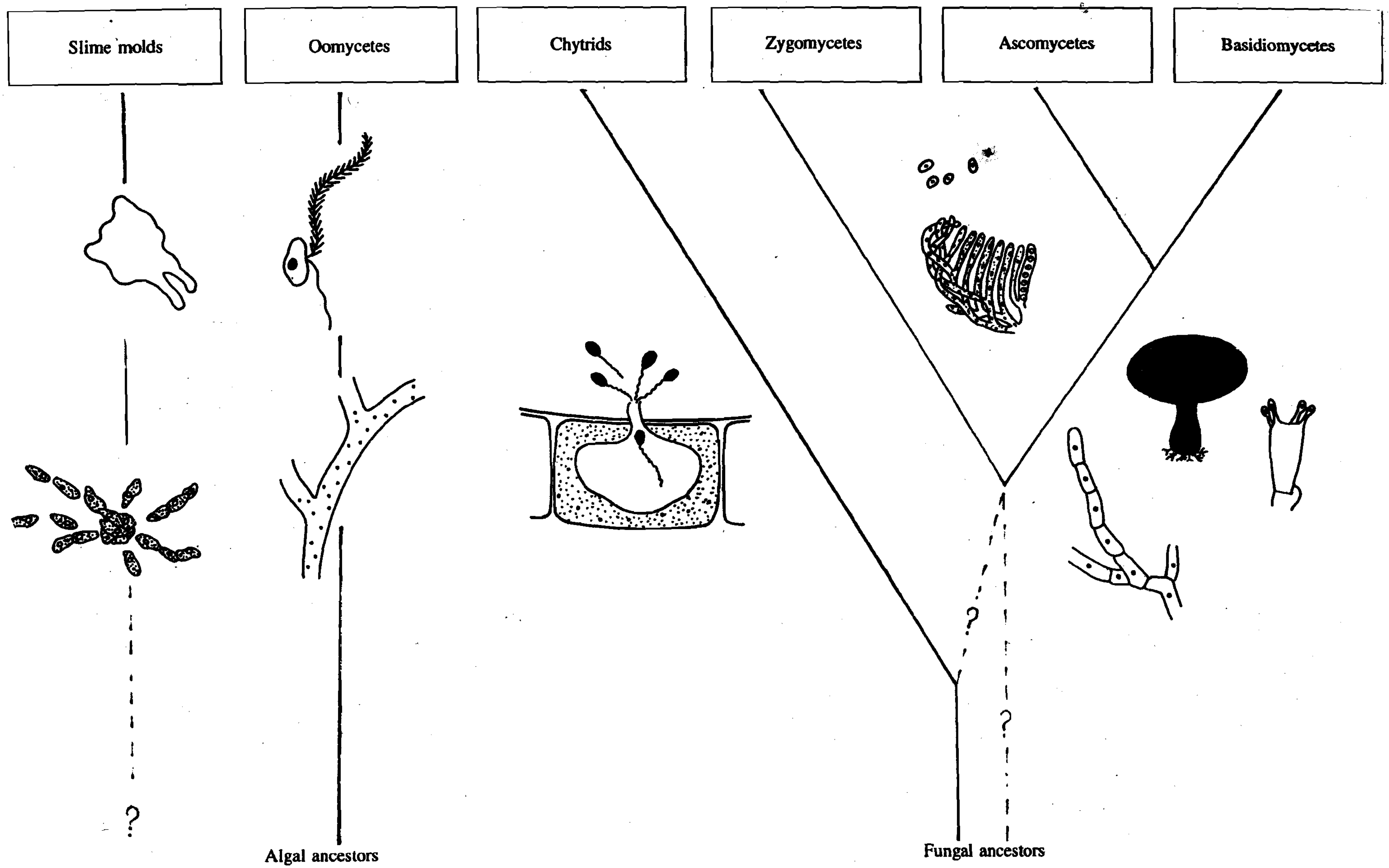

Fig. 2.2 : Relationship among fungal groups.

Lichens are unique organisms consisting of a fungal and an algal partner. Less than 40 algal or cyanobacterial species enter into this association. Yet, there are about 13,500 species of lichens! The characteristic form of each lichen appears to be determined by the fungal component. About 2% of the species have either a basidiomycete or an imperfect fungus as the fungal partner. The remaining 98% of lichens are composed of ascomycete species. The lichens are not considered to be a separate taxonomic category. Rather, they are treated as members of the respective fungal divisions, and the name of a lichen refers to the name of its fungal partner.

In Table 2.2 the fungi are divided into 7 formal divisions. In other classifications only two divisions are recognised, the Myxomycota (slime molds) and Eumycota (true fungi). The latter is divided into subdivisions and classes etc.

SAQ 2.2

Fill in the blanks with suitable sentences.

i) Cell walls of most fungi contain .... rather than cellulose.

ii) Fungi are heterotrophs and obtain their carbon compounds as .... or ....

iii) The association of fungi with roots of plants is known as .... while their association with algae result in organisms known as ....

iv) The .... fungi have cellulose in their walls and might have evolved from algal ancestors.

v) Flagellated cells are completely lacking in ...., ... and ....

2.4 ALGAE

Algae are eukaryotes. Most algae live in marine and fresh water habitats. In the five-kingdom system described in Fig. 1.3 all algae are included in the kingdom Protista. This is clearly an artificial grouping, for some of the green algae are more related to true plants than to other algae. Some algal members such as the unicellular euglenoids and cryptomonads are probably protozoans that acquired plastids through endosymbiosis. Indeed of the 36 genera of euglenoids 25 genera do not possess chloroplasts and live as heterotrophs.

There are about 24,000 species of algae described so far. The algae as a group is autotrophic, synthesising food through photosynthesis. During photosynthesis they evolve oxygen as the plants do. Plants and algae differ in many respects. One major difference between the two groups concerns the way in which reproductive structures are organised. The reproductive structures of algae are not covered by a protective sterile tissue. Instead all cells are converted into spores or gametes. In plants a sterile jacket is present as an essential part of reproductive structures.

How can we classify this vast assemblage of algae? Phycologists (also known as algalogists), use a variety of characters to help delimit the different algal groups. These are summarised below.

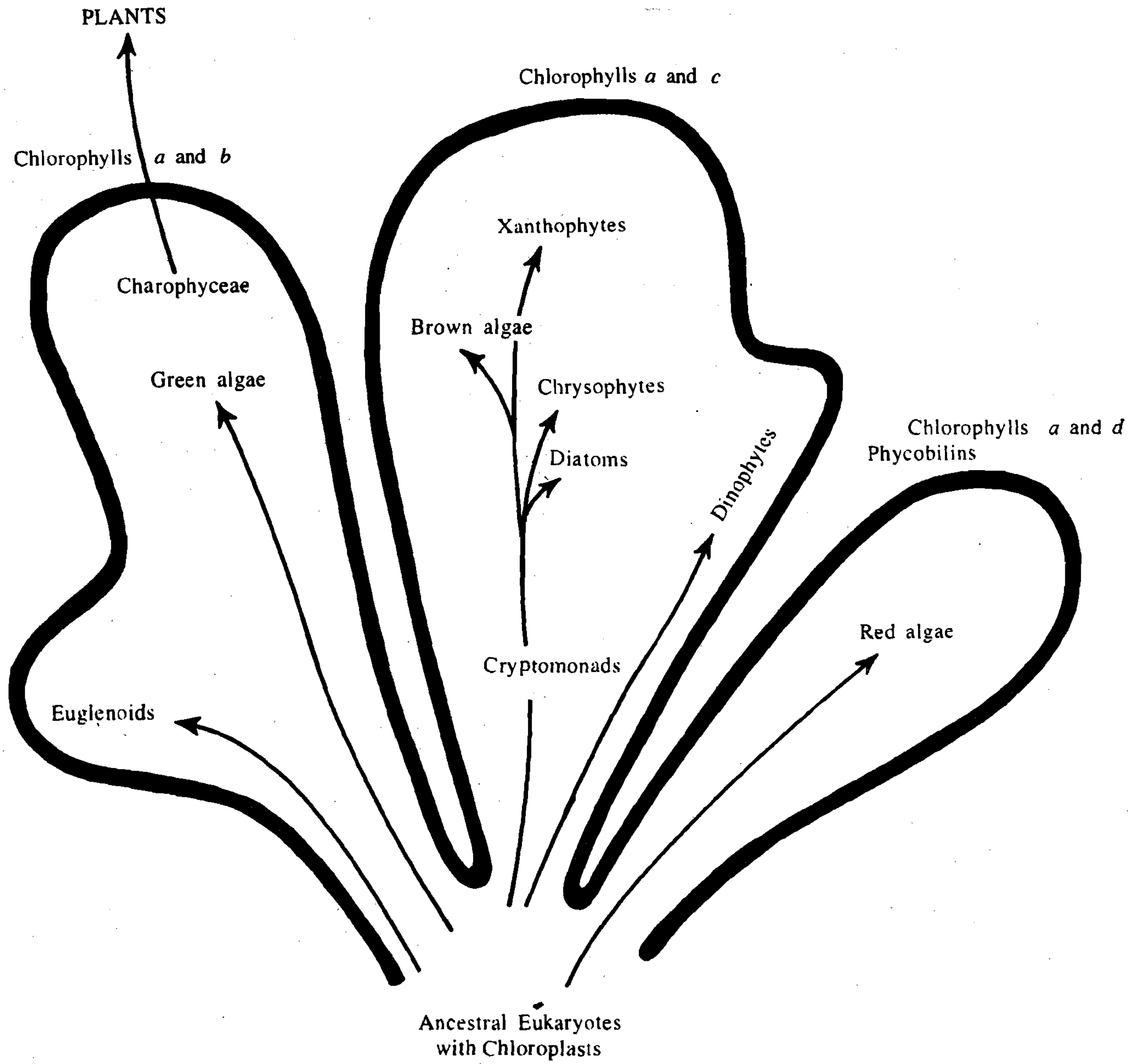

Fig. 2.3 : Relationship among algal groups

Pigments in plastids. The presence of different chlorophyll pigments and photosynthetic accessory pigments (Fig. 2.3).

Food reserves. Different algal groups store food as starch, oils etc.

Cell wall. The cell walls may contain cellulose or other polysaccharides. Some algae have naked cells. Cell walls may be incrusted with silica, calcium carbonate and scaley structures.

Flagella. The number and kinds of flagella as well the location of flagella are helpful. Whiplash flagella have a smooth surface while the tinsel flagella possess fine hairs. Flagella are completely lacking in the red algae (Fig. 2.4).

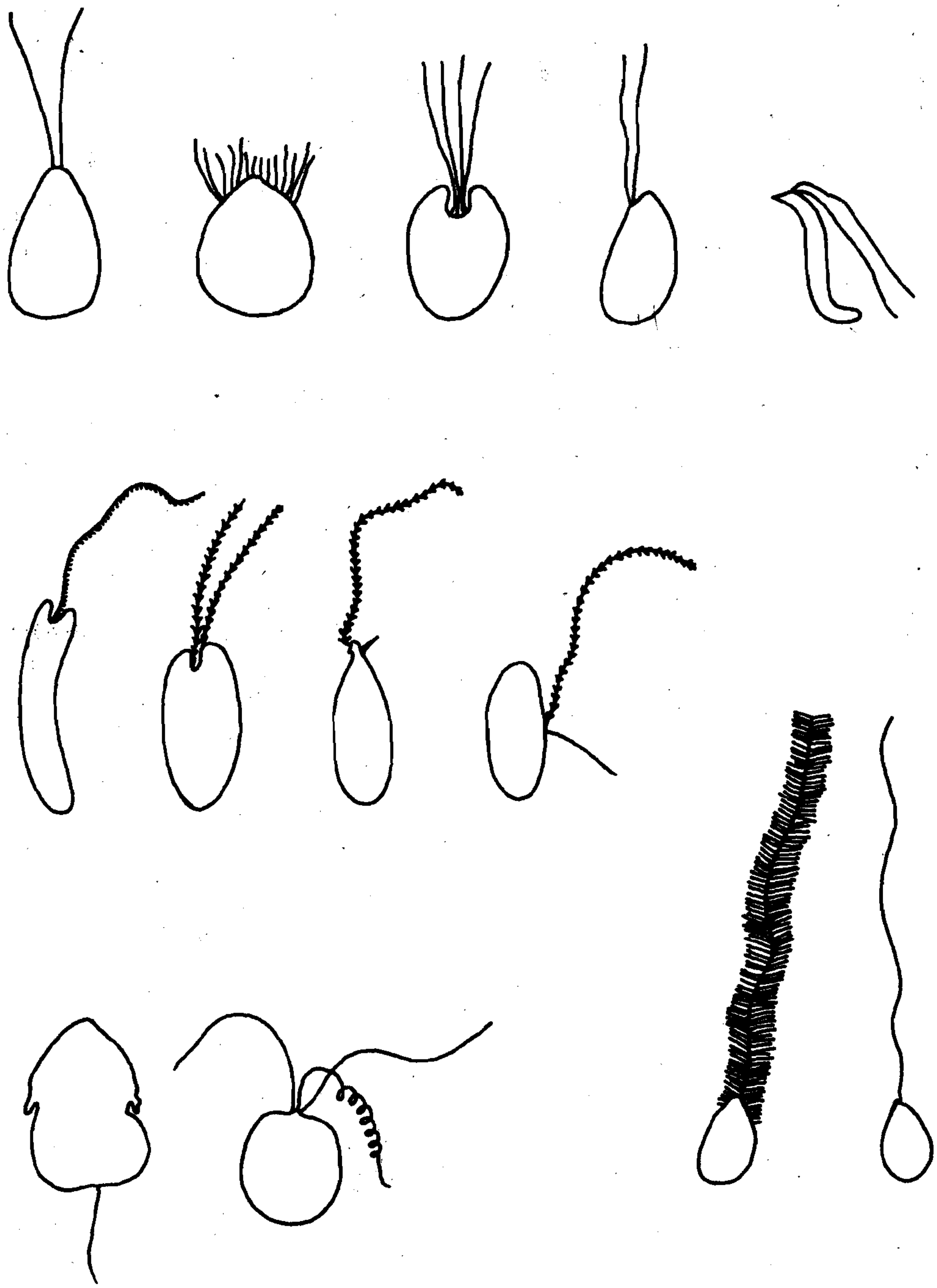

Fig. 2.4 : Structure and arrangement of flagella in different algal groups. Note that a flagellum can be smooth or feathery. Flagella are inserted terminally or laterally and singly or more than one per cell.

Cell division. Four different kinds of cytokinesis are known in algal groups: furrowing, cell division by phycoplast and two kinds of phragmoplasts (Fig. 2.5)

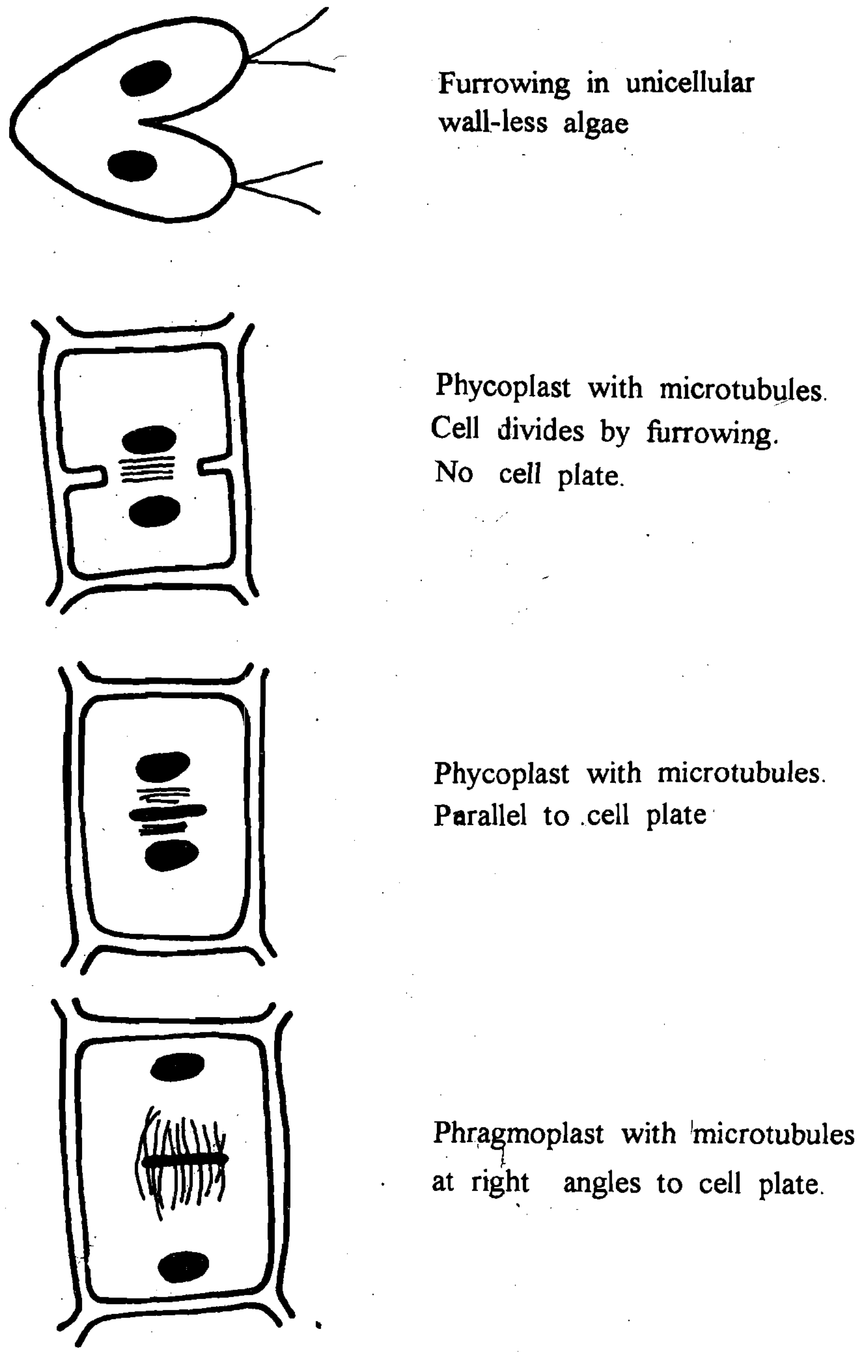

Fig. 2.5 : Cytokinesis in Algae.

Chloroplast organisation. Ultrastructure of chloroplast reveals differences in the organisation of photosynthetic and surrounding membranes (Fig. 2.6).

Morphological organisation. Algal thallus may be unicellular, motile, sessile, colonial, filamentous, branched, coenocytic or multicellular with parenchymatous organisation.

Life cycle. The morphology of the haploid and diploid generations also helps in the recognition of different algal groups. Reproduction in algae is covered in detail in Unit 4 of Block 1-B, Algae.

Figure 2.3 summarises one possible scheme of relationships among the different algal groups. The red algae (Rhodophyta) probably evolved from some ancestral eukaryotes after the symbiotic acquisition of a cyanobacterial cell as the chloroplast. Red algal chloroplasts are remarkably similar to cyanobacterial cells in ultrastructure and chemical

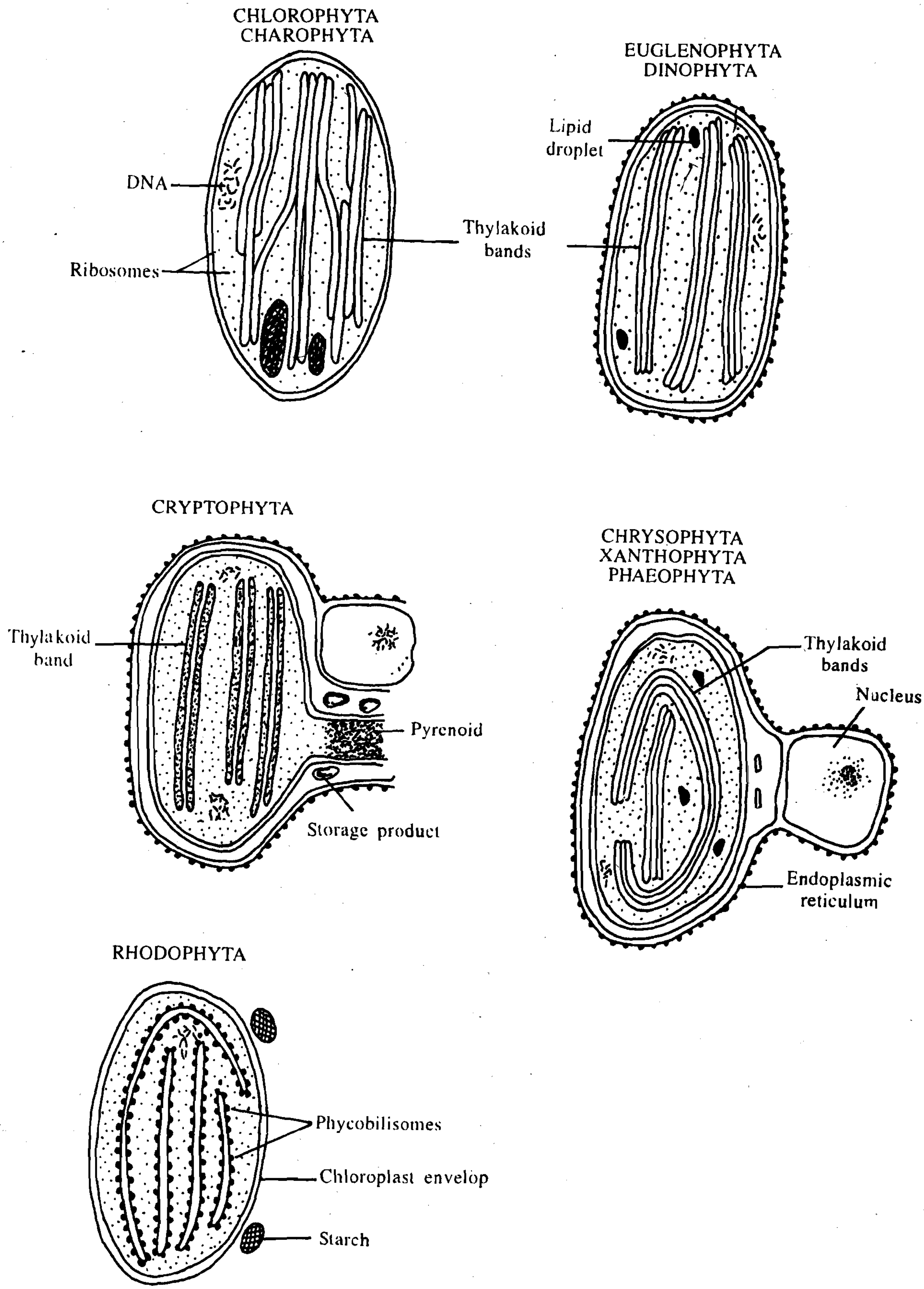

Fig. 2.6 : Ultrastructure of chloroplasts in different algal groups.

composition. As in cyanobacteria, the red algae possess chlorophyll *a* and the biliproteins. In addition the red algae possess chlorophyll *d*.

Several algal groups treated as divisions in Table 1.2 are sometimes collectively known as **chromophytes**. The chromophytes are characterised by the presence of chlorophyll *a* and *c* This group includes the cryptomonads (Cryptophyta), dinoflagellates (Dinophyta), diatoms and golden-brown algae (Chrysophyceae), yellow-green algae (Xanthophyta) and brown algae (Phaeophyta). Unlike the red algae all the chromophytes possess motile cells at some stage of their life cycles. The dinoflagellates do not possess histones that are characteristic of other eukaryotes. The chromosomes remain permanently condensed. These and other features suggest that the *dinoflagellates* might represent an independent line of evolution.

The green algae (Chlorophyceae) and the euglenoids (Euglenophyceae) possess both chlorophyll *a* and *b*. In this respect they resemble higher plants. However, the euglenoids are probably more related to the protozoans. The green algae include an important subgroup, the charophytes, which is considered to be the ancestors of true plants. As discussed earlier the plastids of green algae might have originated from cells similar to *Prochloron* by endosymbiosis. This prokaryote is unusual in possessing both chlorophylls *a* and *b*. Many green algae including charophytes and red algae are known from fossils dated to be 400 million years old.

In Table 1.2 we have grouped algae under 8 different divisions. Some authors recognise only 4 divisions: Chromophyta, Rhodophyta, Euglenophyta and Chlorophyta and include others as classes under Chromophyta. It should be emphasised that while phycologists may study the blue-green algae (cyanobacteria) along with other algal groups the cyanobacteria are true prokaryotes related to the bacteria and are hence members of the kingdom Monera.

SAQ 2.3

Match the words in column A with the most suitable words in column B

	Column A		Column B	
i)	red algae	(a)	dinoflagellates	( )
ii)	diatoms	(b)	chrysophyceae	( )
iii)	green algae	(c)	chlorophylls *a* and *b*	( )
iv)	condensed chromosomes	(d)	chlorophylls *a* and *c*	( )
v)	chromophytes	(e)	chlorophylls *a* and *d*	( )

2.5 BRYOPHYTES

Bryophytes are true plants. Three other groups of organisms are also members of the plant kingdom. These are the pteridophytes, gymnosperms and angiosperms. Together they are also known as **land plants** and **embryophytes**. All members of the above four groups of plants produce a multicellular embryo that is nutritionally dependent upon the maternal tissue and represents the next sporophytic generation. The embryos within the seeds of flowering plants are familiar to you.

The bryophytes differ from the other embryophytes by the absence of specialised vascular tissues characteristic of the pteridophytes, gymnosperms and angiosperms. These more advanced groups possess xylem and phloem. The xylem is composed of dead conductive cells whose cell walls are reinforced by a highly resistant polyphenolic compound, lignin. All land plants other than the bryophytes are also known as vascular plants. Bryophytes are nonvascular land plants. Some members, such as certain mosses, of the bryophytes do possess conductive tissue that transport water but these conductive cells do not possess lignified thickenings characteristic of vascular plants.

Some botanists restrict the term 'land plants' to vascular land plants. However, it is more desirable to include the bryophytes also as land plants. Land plants have recently been defined as photosynthetic organisms customarily living on land and having relations with other plants living on land. Land plants have several adaptations that enable them to survive on a terrestrial habitat. These include protective coverings over the plant body and pores known as stomata. Land plants must obtain water from the soil. To prevent evaporation and desiccation the epidermis of land plants is covered with a highly water impermeable **cuticle**. Spores and pollen are minute reproductive cells released into the air. Their walls too are made up of one of the most resistant organic chemicals known, **sporopollenin**. In order to regulate entry of carbondioxide and exit of water vapour the epidermis is also provided with stomata. A stomatal apparatus consists of two kidney-shaped cells surrounding a pore. Most land plants including many bryophytes possess stomata.

One of the most interesting fields of plant biology is the study of the origin of land plants. Fossil evidence indicates that authentic land plants lived about 400-430 million years ago. During this period known as the Silurian there were small, dichotomously branched plants known as **Cooksonia**. *Cooksonia* was a vascular land plant. Microfossils of spores, cuticles and conductive tubes have been discovered from 450-470 million year old sediments suggesting that land plants might have existed millions of years before the arrival of *Cooksonia*. Bryophytes are not known from such early periods. This may be because the fragile thallus of the bryophytes may not have been well preserved in fossils.

Scientists now believe that land plants might have originated from some fresh water algal members about 470 million years ago. They were probably derived from green algal ancestors of the group related to modern green algae such as the stoneworts (*Chara* and *Nitella*) and **Coleochaete**. These charophycean members share several structural and biochemical similarities with the land plants. The ancestors of land plants might have resembled some modern Coleochaete. The earliest land plants would have been nonvascular embryophytes, not unlike some liverworts. It is likely that two subsequent lines of evolution might have resulted in the bryophyte and vascular land plant groups.

There are about 23,000 species of bryophytes described so far. All these are small green plants, measuring in centimetres, and devoid of roots. They occur in a variety of moist terrestrial habitats. As is true of other land plants they are multicellular and parenchymatous. Life cycle consists of a prominent gametophytic and less prominent sporophytic alternation of generations. Bryophytes include the familiar mosses, the less familiar liverworts and hornworts. Bryologists consider these three groups to be closely related and classify them as three classes under the division Bryophyta.

Division: Bryophyta
Classes: Hepaticopsida (liverworts)
Anthocerotopsida (hornworts)
Bryopsida (mosses)

Some bryologists who consider members of the three classes to be much less related to each other elevate them to divisional levels: 1.Hepatophyta 2. Anthocerotophyta, and 3. Bryophyta. In species abundance the bryophytes are dominated by mosses (14,000) followed by liverworts (8,500) and hornworts (350).

2.6 PTERIDOPHYTES

Pteridophytes are vascular land plants. Unlike the bryophytes they possess typical xylem and phloem tissue characteristic of vascular plants. Like the bryophytes they are also embryophytes. Pteridophytes reproduce by spores but never by seeds. Thus, it is convenient to further classify the vascular plants into non-seed producing pteridophytes (also known as vascular cryptogames) and seed producing gymnosperms and angiosperms. The later two groups will be discussed in the course Plant Diversity – 2.

The pteridophytes include ferns and their allies. In Table 1.2 the fern allies are classified under three divisions: Psilotophyta, Lycopodiophyta and Equisetophyta. There are about 1,000 species of fern allies. They are descendants of very ancient groups of vascular plants and are therefore of great interest to students of plant evolution (Fig. 2.7). About 10,000 species of ferns are included in the division, Pterophyta. We have a rich collection of fossils that represent many extinct members of pteridophytes including major groups that are known only from fossils. In recent years scientists have studied these groups in detail and have established possible evolutionary relationships among the early vascular plants (Fig. 2.11). Although you may not study representatives of all these groups it is essential that we list the major divisions of living and extinct pteridophytes to fully comprehend the diversity and importance of early vascular plants:

Extinct pteridophytes known only from fossil record

Rhyniophyta
Zosterophyllophyta
Trimerophyta

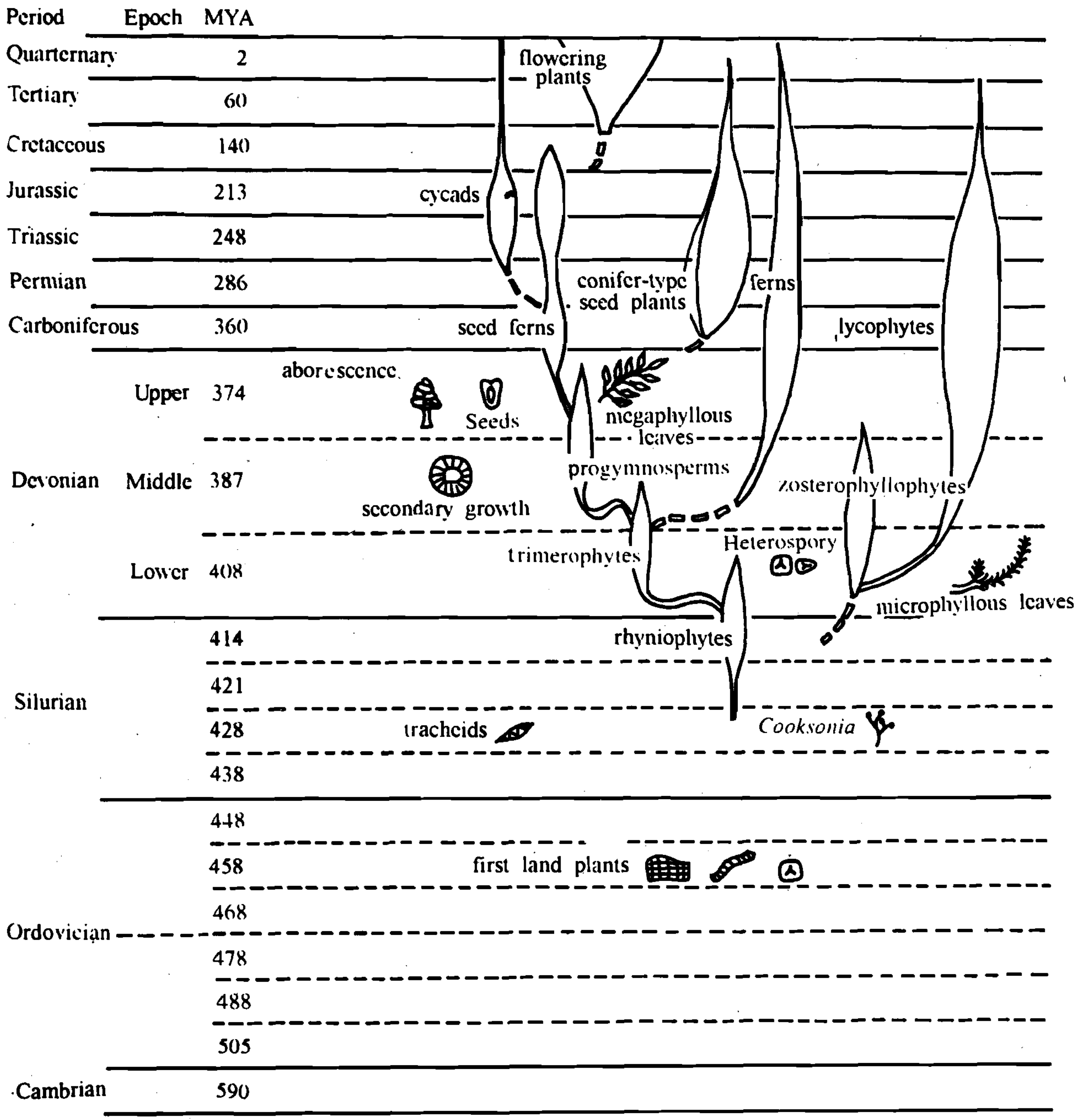

Fig. 2.7: Geological time chart. This chart illustrates the time of appearance of land plants and different groups of vascular plants. Time is given in millions of years ago (MYA). (After Gensel and Andrews)

Living pteridophytes
Psilotophyta
Lycopodiophyta
Equisetophyta
Pterophyta

Some members of the fossil pteridophytes are illustrated in Figs. 2.8 – 2.10. The geological time chart (Fig. 2.7) is an important aid in our understanding of the history of plant life. The chart depicts not only the time when various plant groups evolved or became extinct but also the relationships among the different groups and the abundance of species in each group during the course of its history. You should also refer to Figure 2.11 that presents a simplified version of possible evolutionary relationships among extinct and living land plants.

The earliest group of vascular plants known from about 420 million-year-old sedimentary rocks is the rhyniophytes. The earliest and best known genus of this group is *Cooksonia* (Fig. 2.9).

The genus *Rhynia* evolved soon after. These early vascular plants had adaptations suited to live on land. In addition to cuticle, stomata, sporopollenin and a multicellular body these plants also possessed true xylem tissue consisting of lignified tracheids. The rhyniophytes might have evolved from more primitive vascular plants which in turn might have evolved from some ancestral bryophytes or directly from some ancestral green algae. A number of well preserved fossils from the Rhynie chert indicate that some of them are gametophytes rather than sporophytes (Fig. 2.9). It is likely that plants superficially resembling each other might have represented haploid and diploid generations of the same species.

Another major Devonian vascular plant group was the zosterophyllophytes. It is likely that an offshoot of this group developed into the lycopodiophytes (lycopods). The lycopods were a successful group that dominated the earth's vegetation in the Carboniferous period (Fig. 2.10). Today the lycopods are represented by only about 200 species. About 700 species of *Selaginella* and more than 60 species of *Isoetes* are usually studied along with *Lycopodium*. However, these are more directly related to the rhyniophytes rather than to the zosterophyllophytes.

The trimerophytes also evolved from the rhyniophytes (Fig. 2.11). This is an important group from which three major vascular plant groups evolved — the equisetophytes, ferns and seed plants. The former is now represented by the single genus *Equisetum* with about 15 species. *Calamites* was a giant member of this group that lived during the Carboniferous period (Fig. 2.10).

The division Psilotophyta includes two living genera, *Psilotum* and *Tmesipteris*. Structurally these are the simplest known living vascular plants. Unfortunately nothing is known of their fossil history to relate them to extinct groups. Some pteridologists consider these interesting plants to be highly reduced members of ferns rather than any fern allies.

Fig. 2.8 : A reconstruction of the Devonian landscape, some 400 million years ago showing some of the early vascular plants that lived then. (After Gensel and Andrews)

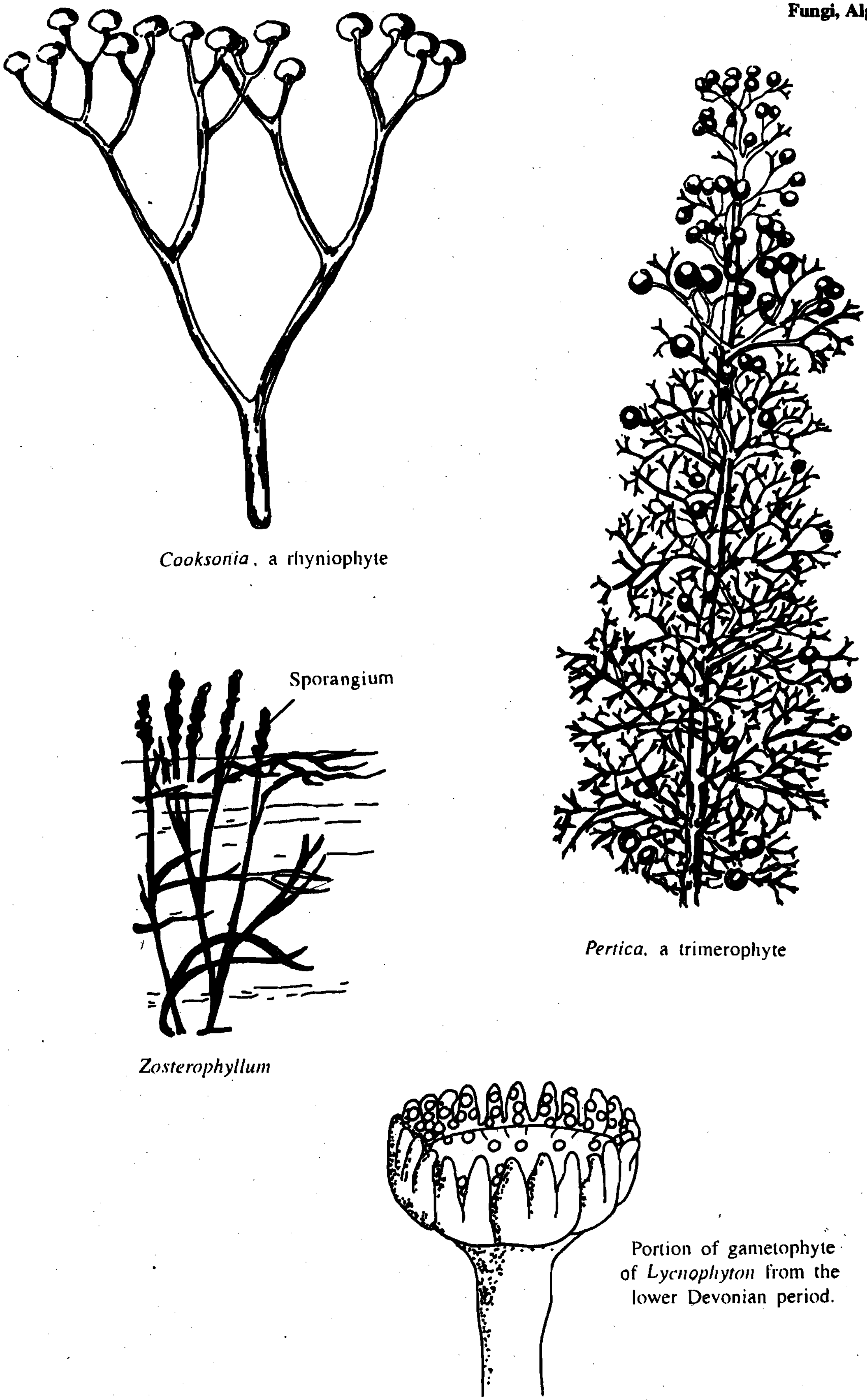

Fig. 2.9 : Reconstruction of three members of early vascular plants representing three important groups of evolutionary interest

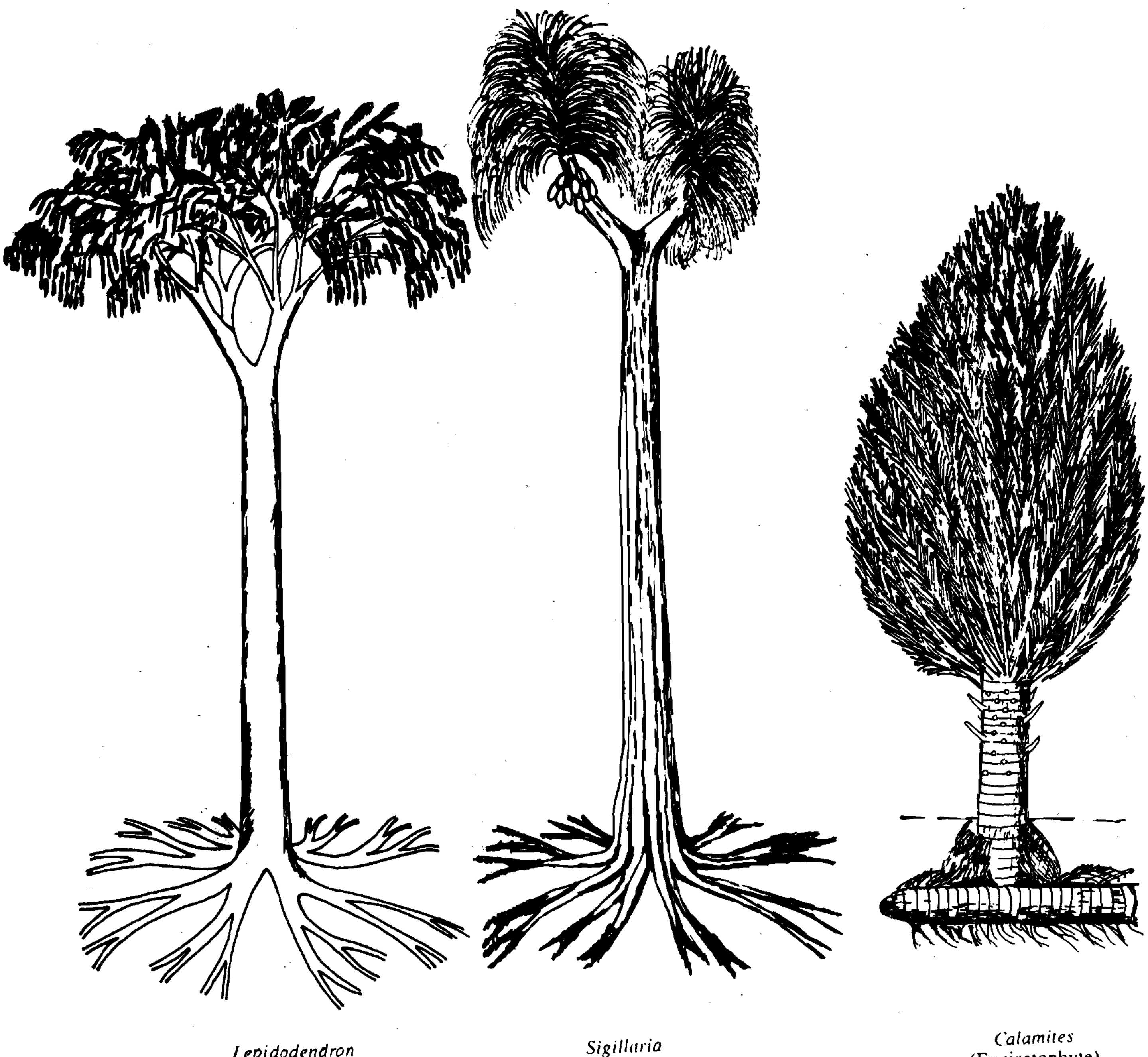

Fig. 2.10 : Reconstruction of Carboniferous lycopods and equisetophyte. All three were very large plants

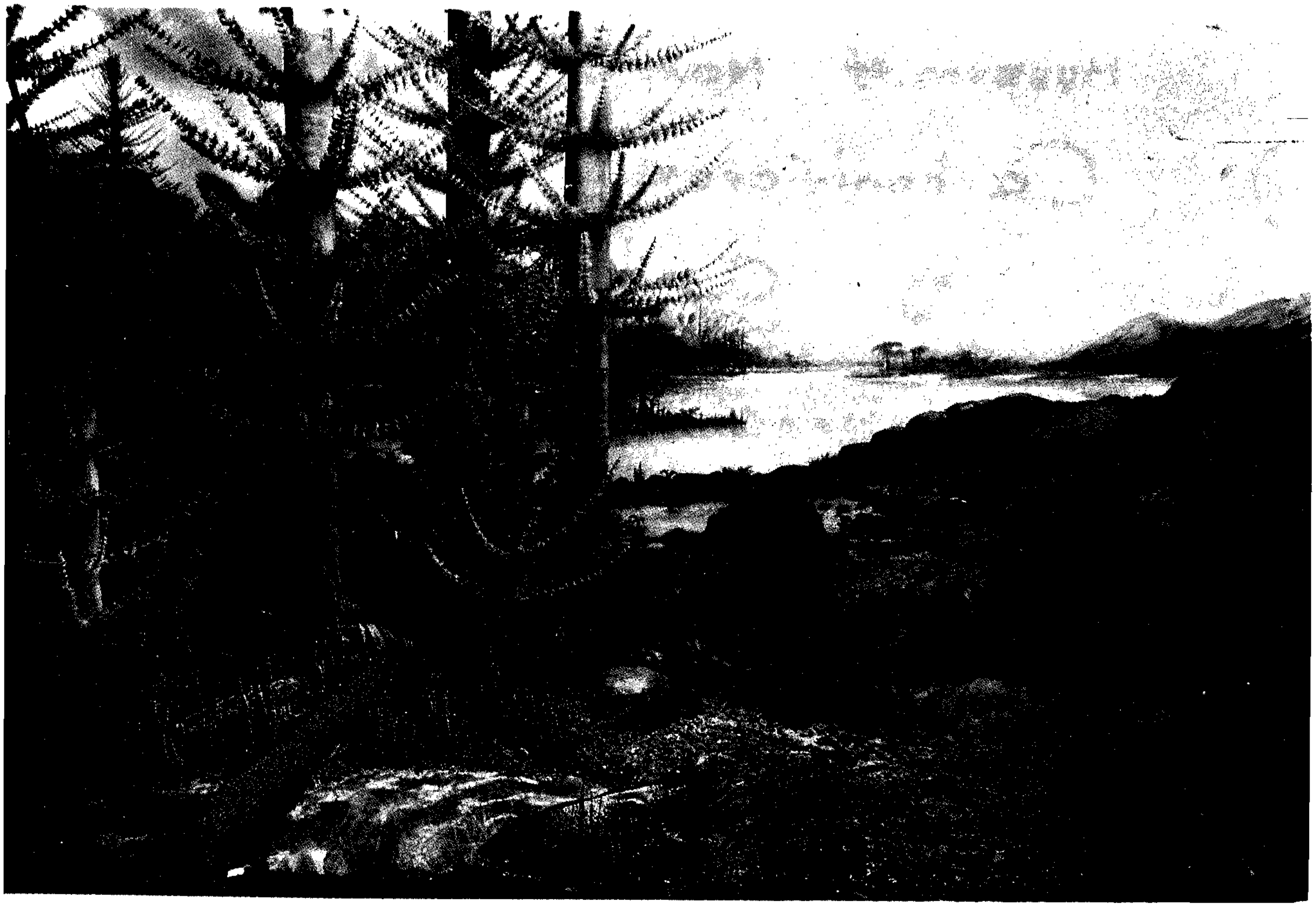

Fig. 2.11 : Reconstructon (at Univ. of Michigan Museum of Natonal History) of Carboniferous landscape dominated by *Calamites*.

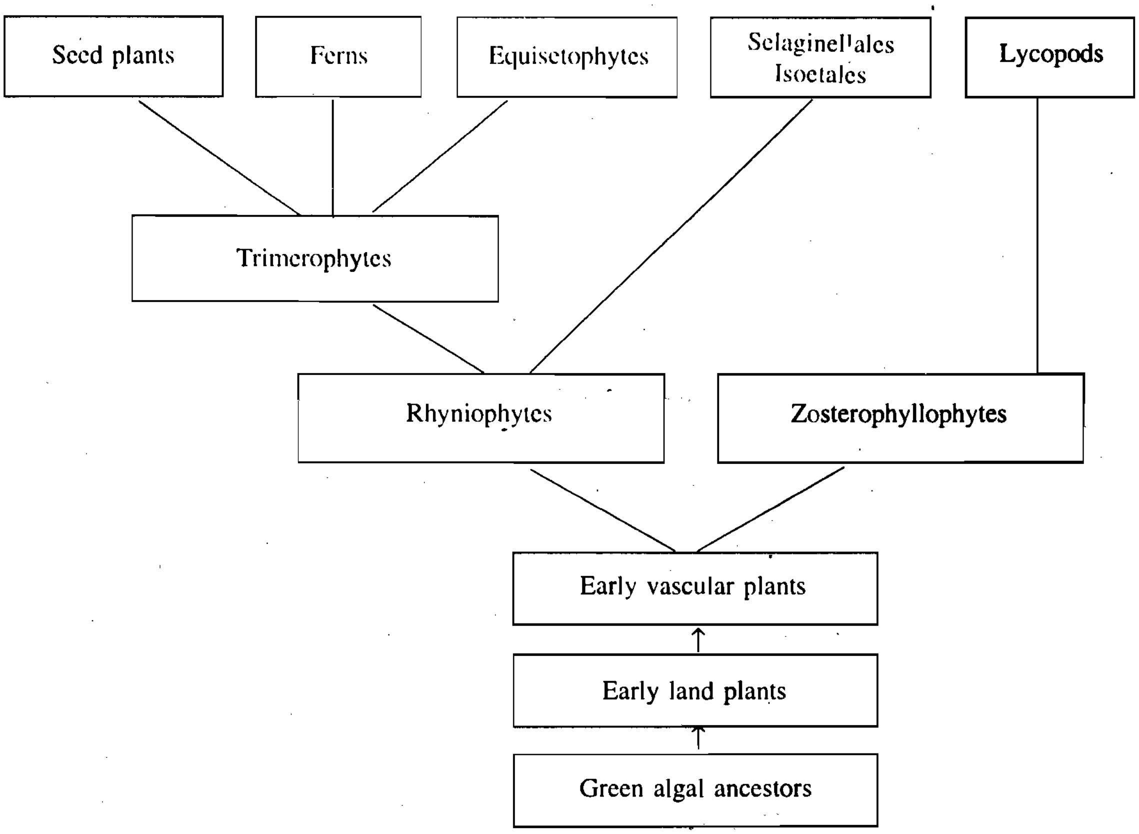

Fig. 2.12 : Evolution and relationships among vascular land plants.

SAQ 2.4

Choose the single best answer

i) Land plants are also known as
   a) gymnosperms
   b) embryophytes
   c) eukaryotes
   d) sporophytes
   e) gametophytes

ii) Land plants originated about
   a) 470 million years ago
   b) 200 million years ago
   c) 3.5 billion years ago
   d) 250,000 years ago.

iii) Bryophytes do not possess
   a) cholorophyll *b*
   b) cuticle
   c) vascular tissue
   d) embryos
   e) sporopollenin

iv) A plant group not included under the pteridophytes
   a) ferns
   b) rhyniophytes
   c) hormworts
   d) lycopods
   e) whisk ferns

v) Cooksonia was a
   a) liverwort
   b) trimerophyte
   c) equisetophyte
   d) rhyniophyte
   e) bryophyte

2.7 SUMMARY

In this unit you have learnt

- An overview of the position and classification of prokaryotes, fungi, algae, bryophytes and pteridophytes are presented.
- Cyanobacteria are prokaryotes related to other bacteria. They possess chlorophyll *a* and evolve oxygen during photosynthesis much like the eukaryotic higher plants.
- Cyanobacteria-like cells might have been the ancestors of the different kinds of chloroplasts found in modern algae.
- Fungi are eukaryotes and *nonphotosynthetic*.
- The slime molds and oomycetes, although included in the fungal kingdom, represent distinct lines of evolution, the former from protozoa and the latter from some algal group.
- The higher fungi, zygomycetes, ascomycetes and basidiomycetes lack flagellated cells and appear to be evolutionarily related to each other.

- Lichens are composed of fungal and algal partners. Most lichens have an ascomycete as the fungal component. The fungal component appears to determine the morphology of a lichen.
- A large number of fungi which do not reproduce sexually or whose sexual cycles have not yet been discovered are placed in the group, Deuteromycetes.
- Algae are eukaryotic photosynthetic organisms. The differences between algal groups can be traced back to their symbiotic acquisition of prokaryotic cells with different chlorophylls.
- The chromophytes, rhodophytes and chlorophytes are distinguished by the presence of chlorophylls *a* and *c*, *a* and *d* and *a* and *b* respectively.
- The prokaryotic *Prochloron* which has chlorophylls *a* and *b* represent the kind of ancestral cells that might have evolved into plastids of the green algae and land plants.
- The charophycean line of the green algae led to the evolution of land plants.
- Bryophytes and pteridophytes are land plants. Both possess multicellular embryos and hence are known as embryophytes. The bryophytes are nonvascular plants.
- Land plants evolved about 450 million years ago. Among the adaptations that helped colonise the land were a multicellular plant body, protective cuticle, stomata for gas exchange and resistant spore wall with sporopollenin. Vascular tissues evolved later in the vascular land plants.
- The ferns and their allies are descendants of ancient vascular, nonseed bearing plants. The Devonian period witnessed the emergence of rhyniophytes from which several vascular plant groups evolved, leading ultimately to vascular seed plants, the gymnosperms and angiosperms.

2.8 TERMINAL QUESTIONS

1. Why are cyanobacteria grouped with bacteria rather than with algae?

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2. With the help of a diagram show the possible evolutionary relationships among the various fungal groups.

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3. What are the characters useful in the classification of various algal groups? What chloroplast pigments are characteristic of different algal divisions?

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4. What are land plants? What adaptations were useful in the colonization of land by early plants?

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5. Describe the major course of evolution among the vascular plant groups.

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2.9 ANSWERS

Self-Assessment Questions

2.1 i) F, (ii) F, (iii) F, (iv) T, (v) T.

2.2 (i) chitin, (ii) saprotrophs, parasites, (iii) mycorrhizae, lichens (iv) oomycete, (v) zygomycetes, ascomycetes, basidiomycetes.

2.3 i) e, (ii) b, (iii) c, (iv) a, (v) d.

2.4 (i) b, (ii) a, (iii) c, (iv) c, (v) d

Terminal Questions

1. Refer to section 2.2.
2. Refer to section 2.3
3. Refer to section 2.4
4. Refer to section 2.5 and 2.6.
5. Refer to section 2.6.

GLOSSARY

Accessory Pigment : a pigment that absorbs light energy and transfers it to chlorophyll, e.g., carotenoids and xanthophylls in higher plants.

Actinomycete : A soil-dwelling gram-positive bacterium with its cells arranged in filaments. It may be used to produce antibiotics such as streptomycin.

Ascus : A sac-like cell in ascomycetes fungi in which ascospores are produced.

Basidium : An enlarged sexual reproductive cell in basidiomycete fungi in which meiosis occurs, resulting in the formation of basidiospores.

Coenocytic : Hyphae which consist of tubular masses of protoplasm containing many nuclei.

Coleochaete : An advanced green algae which has an upright system and a prostrate creeping system that anchors the plant in the substratum.

Gametophyte : The stage of an alternation of generations found in most plants, in which the haploid plant produces gametes by mitosis which fuse to form a zygote that develops into the sporophyte.

Gram's Stain : A stain used in the study of bacteria. Bacteria which take the violet stain are gram-positive while others that do not are gram-negative. Gram-positive bacteria are more readily killed by antibiotics.

Gram-Positive Bacterium : A bacterium that stains purple with Gram stain and it usually lacks an outer covering on its cell wall whereas Gram-negative bacterium stains pink with Gram stain and usually has an outer covering on its cell wall.

Mycoplasma : The simplest prokaryotic cell.

Mycorrhiza : The symbiotic association which may occur between a fungus and the roots of certain higher plants, especially trees.

Sporophyte : The stage of an alternation of generations found in most plants, in which the diploid plant (2n) produces spores by meiosis which then germinate to produce the gametophyte.

Sporopollenin : An oxidation polymer of carotenoid pigments and carotenoid esters found in spores and pollen grain walls that resists attack by most acids and is stable at temperatures up to 300° C.

Stromatolites : A fossil formed by layers of calcareous blue-green algae.

Tinsel : A flagellum with fibrillar appendages.

Tubulin : The protein which forms the major part of microtubules.

Whiplash : A smooth-surfaced flagellum.

UNIT 14 REPRODUCTION AND EVOLUTIONARY TRENDS IN BRYOPHYTES

Structure

14.1 INTRODUCTION

In the previous unit you have learnt about the morphological features of bryophytes. You have also read that algae are aquatic and bryophytes are first land plants. You must have noticed that during this transition, in the course of evolution from aquatic to land habitat, a number of changes occurred in the morphological features to adapt to new terrestrial environment. This shift to terrestrial environment also posed a number of problems in relation to sexual reproduction.

In this unit you will learn about the methods of reproduction adapted by these plants to meet the challenges posed by new environment. We will discuss in detail the structure of sex organs, development of sporophyte and gametophyte, and also the evolution of sporophyte in some of the representative genera.

Objectives

After studying this unit you should be able to:

- list general features of reproduction in bryophytes,
- compare structure and development of male and female reproductive organs in *Riccia*, *Marchantia*, *Pellia*, *Anthoceros*, *Sphagnum* and *Funaria*,
- compare structure and development of sporophyte in the above taxa,
- enumerate methods of vegetative reproduction in different taxa, and
- describe evolutionary trends in the structure of sporophyte in bryophytes.

14.2 GENERAL FEATURES OF SEXUAL REPRODUCTION IN BRYOPHYTES

Like algae and fungi, in bryophytes also, reproduction takes place either by vegetative methods (include asexual methods) or sexual method.

Vegetative reproduction includes methods such as

i) death and decay of older posterior parts leading to separation of branches forming new plants, and

ii) formation of gemmae, tubers and adventitious branches.

In sexual reproduction, the pattern is more or less uniform in all the bryophytes.

In the following account we will learn about the general pattern of sexual reproduction in this group of plants.

While learning about reproduction in algae, you noticed that in primitive forms the sexual reproduction was isogamous. During evolution, other forms of reproduction such as anisogamy and oogamy evolved. Since bryophytes are advanced in comparison to algae, they show only oogamous type of reproduction. You may recall that oogamy involves fusion of a large, non-motile female gamete with the smaller motile male gamete.

During migration from water to land, the need of protecting the gametes arose. So the sex organs developed a layer of sterile cells forming a jacket around gametes. You have learnt that in bryophytes the male and female reproductive organs are known as antheridia and archegonia, respectively. An antheridium consists of a single layer of protective sterile cells enclosing the mass of antherozoid mother cells or androcytes (Fig. 14.1 F), each of which gives rise to a single, biflagellated motile antherozoid. The position and shape of antheridia varies in different species. The archegonium is so characteristic of bryophytes, pteridophytes and gymnosperms, that these three groups are collectively known as the **Archegoniatae**. The archegonium is a multicellular, more or less flask-shaped structure. Its swollen basal portion is known as venter, and the upper elongated portion as the neck. It consists of an axial row of cells surrounded by a sterile jacket. The axial row of cells can be distinguished into **neck canal cells** (which are variable in number according to the species), a **ventral canal cell** (venter canal cell) and a single larger basal cell the egg or **oosphere** (Fig. 14.2 H). The archegonium provides nourishment and protection to the egg and after fertilization to the developing embryo.

In bryophytes the male gametes are ciliated and therefore require water to swim in order to reach up to the neck of an archegonium and also for their passage through the neck canal to the venter. A single antherozoid fertilises the egg and the zygote is formed. The zygote begins to grow at once, and by repeated cell divisions (mitoses) develops into a multicellular embryo. You may note that there is no resting period for the embryo as in higher plants. You may recall that in higher plants the embryo remains dormant till the onset of favourable conditions for germination of seed.

The embryo is not liberated, but retained within the archegonium. After fertilisation the basal portion of wall of archegonium enlarges, becomes multilayered, and forms a protective envelop around the developing embryo which eventually grows into the sporophyte. The protective envelop is known as **calyptra**. The development of sporophyte is very limited and the short embryogeny is soon followed by spore formation. The **sporophyte** or **sporogonium** is a simple structure. Unlike other land plants, it is not differentiated into stem, leaves and roots. Generally, it is distinguishable into a **foot, seta** and a terminal spore producing **capsule** or sporangium. In certain species, seta is absent and more rarely the foot also. The spore mother cells develop inside the capsule and they represent the last stage of sporophytic generation. Spore mother cells divide by meiosis to form tetrads of haploid spores which usually separate before discharge from the capsule. As you have learnt that in bryophytes, sporophyte has no connection with the soil and it is wholly dependent on the gametophyte for its water and mineral nutrients. Since in the majority of bryophytes the sporophyte has chloroplasts, it is able to photosynthesise.

In bryophytes spores produced by a species are morphologically similar. Such a condition is konwn as **homospory**. In bryophytes, spore has an outer protective coat made up of two layers: the outer **exospore** and inner **endospore**. These haploid spores germinate under favourable conditions and produce a juvenile or protonemal phase. In liverworts the protonema is short-lived and soon produces the adult plant. In mosses the protonema produces buds which develop into leafy gametophores. The gametophyte at maturity starts developing sex organs or gametangia and the cycle is repeated.

SAQ 14.1

Which of the following statements regarding bryophytes are true or false? Write **T** for a true and **F** for false in the given boxes.

i) Bryophytes show oogamous type of sexual reproduction. ☐

ii) Ascogonium is the female reproductive orga:ı. ☐

iii) Antheridium is the male sex organ. ☐

iv) Bryophytes do not require water for fertilisation. ☐

v) Sporophyte is differentiated into stem, leaves and roots. ☐

vi) Sporophyte is dependent on gametophyte for water and mineral nutrients. ☐

vii) The male gametes are biflagellated. ☐

viii) The embryo is retained inside the archegonium. ☐

14.3 STUDY OF REPRODUCTION IN REPRESENTATIVE GENERA

You have learnt in the previous unit that *Riccia* is one of the simplest members of bryophytes, so we begin our study with this plant. In the following account you will learn about the types of reproduction, structure and development of gametangia and details of sporophyte in this plant.

14.3.1 *RICCIA*

Vegetative Reproduction

This is the simplest method of reproduction. In *Riccia* it takes place by the progressive death and decay of the older parts of the thallus from posterior end. You have learnt that *Riccia* shows dichotomous branching (Unit 13, Fig. 13.4 A to C). When decay reaches a dichotomy two surviving branches become isolated and grow independently, resulting in the formation of two new thalli.

In some species adventitious branches arise from the ventral surface of the thallus, and separation of these branches results in the formation of new thalli, e.g. in *Riccia fluitans* (aquatic species) such adventitious branches are formed in large numbers.

In some species like *R. discolor,* at the end of growing season the apex of the thallus grows down into the soil and becomes thick. In the next season it grows up and forms a new plant. Sometimes in *Riccia glauca* a young thallus is formed at the apex of rhizoid and in such cases the tip of the rhizoid behaves like a germ tube and forms a thallus. In species like *R. discolor* and *R. billardieri,* at the end of growing season the thalli develop perennating tubers at the apices of branches (Fig. 14.1 A). These help in tiding over the unfavourable conditions and also serve for vegetative reproduction.

Sexual Reproduction

You have learnt that the male and female reproductive organs are antheridia and archegonia, respectively. In some species of *Riccia* both reproductive organs are produced on the same thallus. Such species are known as monoecious. *R. crystallina, R. glauca* and *R. gangetica* are the examples of monoecious species. Whereas in some species antheridia and archegonia are borne on separate thalli. Such species are termed dioecious. Examples of dioecious species are: *R. discolor, R. frostii, R. bischoffii, R. perssonii* and *R. curtisii.* You may recall that on the dorsal surface of *Riccia* thallus, there is a conspicuous median longitudinal furrow. The antheridia and archegonia develop singly inside the thallus along the furrow (Unit 13, Fig. 13.3 B, C). They are produced continuously and therefore it is possible to observe all the stages of their development in one thallus. Both antheridia and archegonia arise in an acropetal manner, i.e. the youngest is towards the apex of lobe. In a monoecious thallus, both antheridia and archegonia are formed in succession.

The development of sex organs begins from any cell on the dorsal surface of the thallus. This cell is close to the apical cell. Simultaneously, there is growth of the surrounding tissue around them. Due to this, antheridia or archegonia as the case may be gradually become embedded in the cavities formed by overarching of the surrounding tissue. In antheridia, the antheridial chambers open externally on the dorsal surface of the thallus by narrow cylindrical canals and the antheridia are completely enclosed within. But in archegonia, the necks project beyond the archegonial chamber.

Development of Antheridia

The superficial cell (refers to cell present on the surface of any structure) which develops into antheridium is known as antheridial initial (Fig. 14.1 B). It becomes papillate (a small fleshy

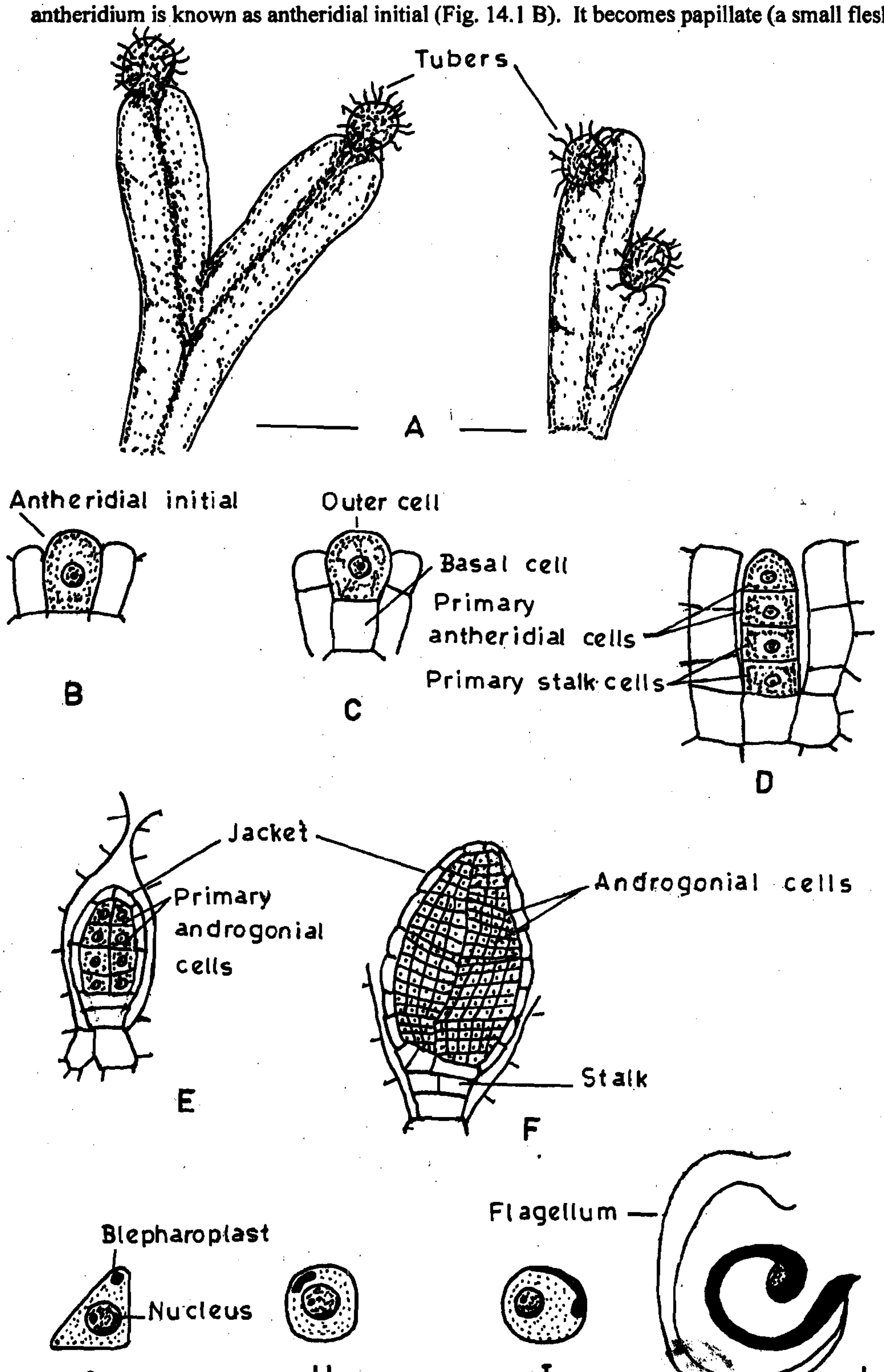

Fig.14.1: *Riccia*: A) thalli showing tubers, B-E) stages in the development of antheridium, F) a mature antheridium, G-J) stages in metamorphosis of androcytes into antherozoids.

projection of a plant) and divides by a transverse division into lower basal cell which is embedded in the thallus and an outer cell projecting above the surface of thallus (Fig. 14.1 C). The basal cell forms the stalk of antheridium. The rest of the antheridium develops from outer cell. By transverse divisions outer cell forms a filament of four superimposed cells (Fig. 14.1 D). The two upper cells of this filament are the primary antheridial cells and two lower ones the primary stalk cells which along with basal cell form the stalk of the antheridium. The primary antheridial cells by two successive vertical divisions at right angles to each other, form two tiers of four cells each. Then periclinal division in these cells results in an outer layer of eight sterile jacket initials and a central group of eight fertile primary androgonial cells (Fig. 14.1 E). The jacket initials by further divisions form a single layered jacket of the antheridium, whereas the primary androgonial (spermatogenous) cells undergo repeated divisions and form large number of androcyte mother cells in mature antheridium (Fig. 14.1 F).

In the antheridium each androcyte mother cell divides diagonially to form two triangular androcytes or antherozoid mother cells (Fig. 14.1 G). Then androcytes metamorphose into antherozoids. In each androcyte a small extranuclear granule known as **blepharoplast** appears near the periphery (Fig. 14.1 H). The androcyte becomes rounded and the blepharoplast elongates as a cord extending about three-fourth of the way around the cell (Fig. 14.1 I). The nucleus becomes crescent-shaped and comes in contact with the blepharoplast. One end of the blepharoplast gets conspicuously thickened to form the head, from which two long flagella are produced. The two flagella are morphologically similar (Fig. 14.1 J) but differ in function. One of them serves for propulsion and the other for rotation and for changing direction. A small part of the cytoplasm remains attached to the posterior end of antherozoid in the form of a small vesicle.

The mature antheridium is an oval stalked structure with a flat base and rounded or conical apex. It ruptures on absorbing water. The semifluid mucilaginous mass containing the antherozoids oozes out of the antheridium through the canal of the antheridial chamber, which you may recall is toward the dorsal surface of the thallus.

Development of Archegonia

Like antheridium, the archegonium also develops from a single superficial papillate cell on the dorsal surface just close to the apical cell which acts as archegonial initial (Fig. 14.2 A). Like antheridial initial it also divides by a transverse wall into a basal cell and an outer cell (Fig. 14.2 B). The basal cell forms the embedded portion of the archegonium. In the outer cell three successive vertical intersecting walls appear, resulting in three peripheral initials, surrounding the primary axial cell.

A vertical section of the archegonium at this stage would show a large primary axial cell bounded by only two peripheral initials (Fig. 14.2 C), but all three peripheral initials can be seen in transverse section (Fig. 14.2 D). These three peripheral initials divide again by radial longitudinal walls to form six jacket initials (Fig. 14.2 E). The jacket initials also divide by transverse walls to form two superimposed tiers of six cells each. The upper tier of cells forms a tube-like neck, composed of six vertical rows, 6-9 cells in height. The lower tier of cells forms the venter.

Simultaneous to the division of peripheral initials, the primary axial cell divides by a transverse wall into an upper - small primary cover cell and the lower larger central cell (Fig. 14.2 F). The small primary cover cell, by two successive vertical walls at right angles to one another, forms four equal cover cells. The central cell divides transversely into a primary neck canal cell (neck initial) and a primary ventral (venter initial) cell (Fig. 14.2 G). Primary neck canal cell, by more transverse divisions, forms a vertical row of usually four neck canal cells in the neck of the archegonium. Primary ventral cell divides further into a small ventral canal cell and a large egg (Fig. 14.2 H).

At maturity, the neck canal cells and the ventral canal cell disintegrate and form a mucilaginous mass, which on absorbtion of water swells and causes the separation of the cover cells. As a result an open canal for the entry of antherozoids is formed (Fig. 14.2 I).

As you have learnt earlier that the antheridia rupture when they come in contact with water and antherozoids are liberated. Antherozoids swim in a film of water and reach up to the archegonium. The film of water is usually available in the dorsal furrow, after rain or heavy dew. When the antherozoids come near the archegonium they are chemotactically attracted to the open neck of the archegonium. The chemotactic substances are usually present in the mucilage formed by the disintegration of neck canal cells and ventral canal cell. Many antherozoids may swim up to the neck and down the neck canal, but only one penetrates the egg. Fusion of the nucleus of the antherozoid with that of the egg results in the formation of zygote (Fig. 14.3 A).

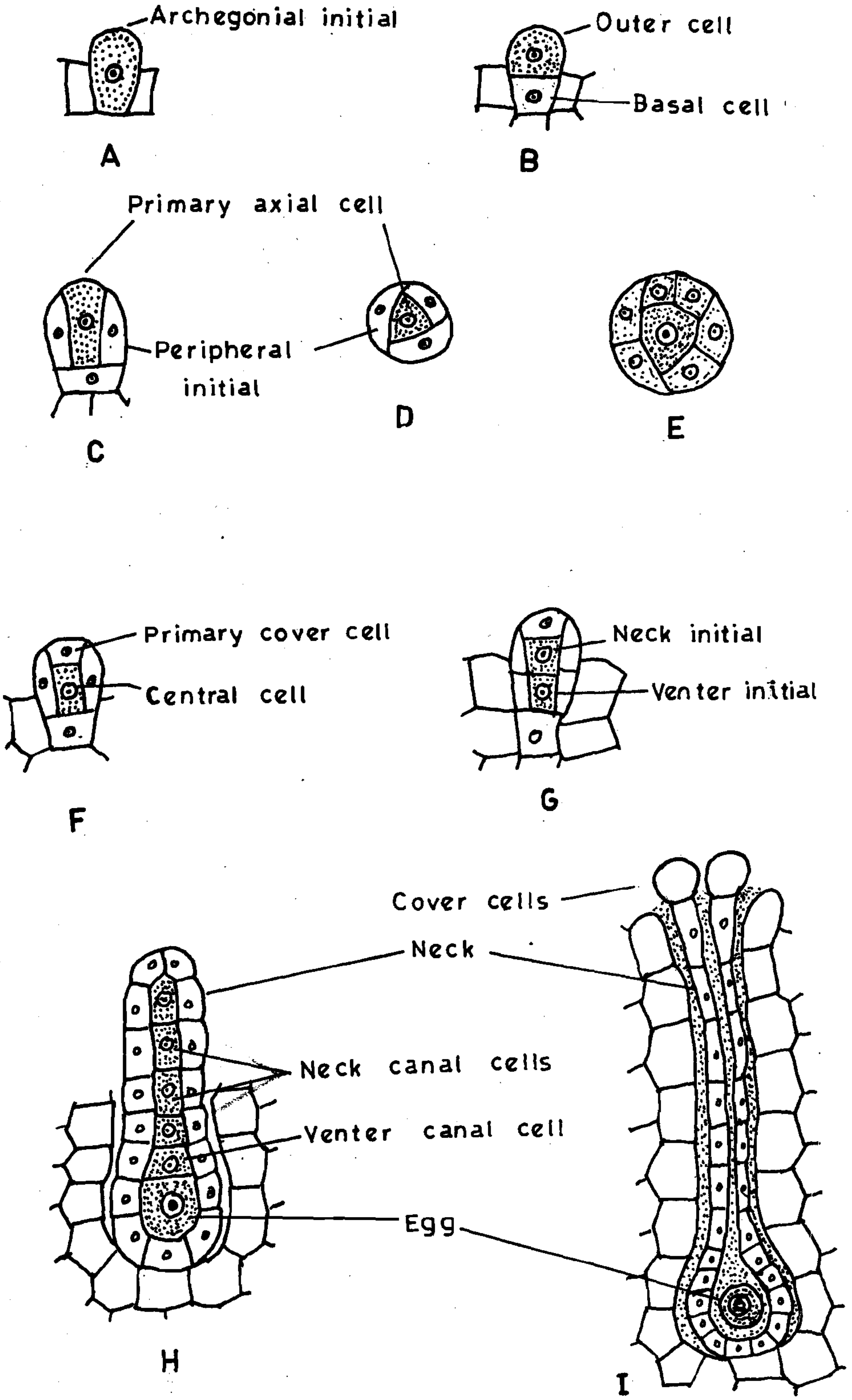

Fig.14.2: ***Riccia*****: A-H) various stages in the development of archegonium, I) a mature archegonium just before fertilization.**

Development of Embryo

As you have learnt earlier that zygote is the first cell of sporophytic generation. It divides mitotically soon after its formation by transverse division into two cells (Fig. 14.3 B) which divide again by two vertical walls at right angles to each other so that eight equal cells are formed (Fig. 14.3 C, the four cells behind are not seen). They are protected by the calyptra. This stage is known as octant stage. After this further divisions take place without any

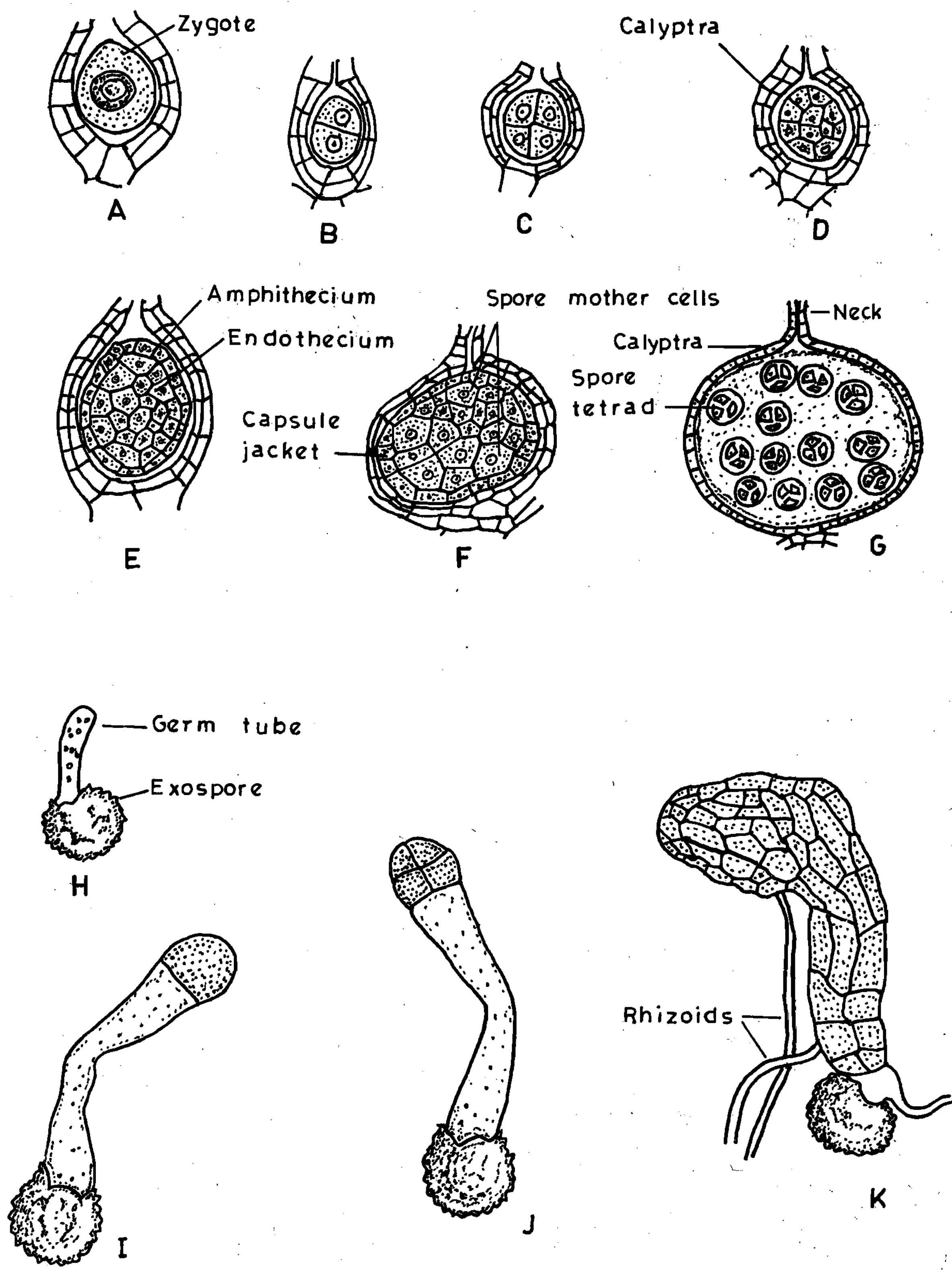

Fig.14.3: *Riccia*: A-G) development of sporophyte, (H-K) development of gametophyte. A) Zygote formed after fertilization, B) zygote showing first division, C) embryo at four-celled stage (quadrant stage), D) initial stage of differentiation, E) embryo showing formation of endothecium and amphithecium, F) differentiation of spore mother cells and jacket of capsule, G) L.S. of nearly mature sporophyte, H-K) various stages in the formation of thallus from germinating spore.

Periclinal division
-a cell division that occurs parallel to the surface of an organ.

Anticlinal division
-the division of a plant cell perpendicular to the organ surface.

definite sequence, and a spherical mass of 20 to 40 cells is formed (Fig. 14.3 D). Periclinal divisions in this mass result in the formation of an outer layer known as **amphithecium** and inner central mass of cells, the **endothecium** (Fig. 14.3 E). The amphithecium by further divisions forms the single layered envelope of sporogonium. The cells of this layer grow mainly in length and breadth and divide by radial walls (anticlinal divisions). The endothecium forms the first generation of the sporogenous cells known as **archesporium**. Last division of the sporogenous cells results in the formation of potential spore mother cells, also called sporocytes (Fig. 14.3 F). The outer layer of the sporogonium disintegrates, but the time of the disintegration of this layer varies in different species. The dividing spore mother cells are usually surrounded by a large amount of viscous nutritive fluid which provides nutrition to the developing spore mother cells and spores. Each spore mother cell divides meiotically and forms four haploid spores (Fig. 14.3 G). Each group of spores is tetrahedrally arranged and spores remain together until they are nearly mature. However, in some species of *Riccia* spores remain together even at the time of dispersal, and the subsequent germination tends to give rise to compact groups of four plants.

As mentioned above, the envelope of the sporogonium disintegrate quite early before the spores have ripened. The mass of mature spores surrounded by a single layered calyptra is designated as the mature sporogonium of *Riccia* (Fig. 14.3 G). The mature spores are the first cells of the new gametophyte. In *Riccia* there is no special mechanism for the dispersal of spores. They are dispersed by the progressive death and decay of the calyptra and the adjoining tissue of the thallus.

Germination of Spore

The spore germinates under suitable conditions and **exospore** ruptures. The **endospore** comes out in the form of a germ tube (Fig. 14.3 H). It elongates and divides by a transverse wall near the distal bulging end which is densely protoplasmic (Fig. 14.3 I). One more transverse wall is laid down and two cells formed divide again by two vertical intersecting walls at right angles to one another. As a result of these divisions two tiers of four cells each are formed (Fig. 14.3 J). One of the cells in the distal tier functions as an apical cell and cuts off segments alternately right and left eventually forming a multicellular thallus (Fig. 14.3 K).

SAQ 14.2

In the following statements regarding *Riccia* choose the alternative correct word given in parentheses.

i) The species that bear both antheridia and archegonia in the same thallus are called (monoecious/dioecious).
ii) Antheridia are embedded in the thallus in the (median furrow/ apical notch).
iii) Sex organs develop from (deep-seated cells/ superficial cells).
iv) The jacket of antheridium is (unilayered/ multilayered).
v) The antherozoids are (uniflagellated/ biflagellated).
vi) The archegonia arise (singly/ in groups).
vii) Water is (essential/not essential) for fertilisation.
viii) Archesporium develops from (endothecium/amphithecium).
ix) Spore mother cells divide by (mitosis/ meiosis) to produce four spores each.

14.3.2 *Marchantia*

In the previous section you have studied the methods of reproduction in *Riccia*, the simplest member of bryophytes. Now you will learn about the reproduction in a more advanced form, *Marchantia*. As you know it also belongs to Division Hepaticopsida. Like *Riccia*, *Marchantia* also reproduces by vegetative as well as sexual methods. In the following account you will learn about both the methods in detail.

Vegetative Methods

You may recall that in *Riccia*, the progressive death and decay of the thallus near the dichotomy causes separation of the branches, and each branch independently forms a new thallus. In some species of *Marchantia* adventitious branches arise from the ventral surface of the thallus. They also arise though rarely from the archegoniophores. These branches get detached from the parent tissue and form new thalli.

The most common method of vegetative reproduction in *Marchantia* is by characteristic asexual bodies known as gemmae (sing. gemma). The gemmae are produced in large numbers in gemma cups which are present on the dorsal surface of the thallus and have colourless, fringed margins (Unit 13, Fig. 13.4 A).

The gemmae arise from epidermal cells on the floor of gemma cups (Fig. 14.4 A). An epidermal cell becomes papillate and functions as gemma initial.

At maturity each gemma is a multicellular, biconvex, bilaterally symmetrical, disc-like structure which is vertically inserted in the gemma cup with one-celled hyaline stalk (Fig. 14.4 B). Each gemma has two growing points, one in each of the two lateral shallow notches (Fig. 14.4 B). Most of the cells of the gemma contain chloroplasts, but the marginal cells contain oil bodies instead of chloroplasts. Many colourless densely protoplasmic cells are present on both flattened faces and they are slightly larger than neighbouring cells. These cells are known as rhizoidal cells as they form rhizoids on germination. Some club-shaped hairs present on the floor of the gemma cup secrete mucilage. This mucilage swells on absorbing water and causes the gemmae to break away easily from their stalks. The detached gemmae are finally washed away by rain drops. Gemmae are also detached by the pressure exerted by the growth of new gemmae.

When a gemma falls on the soil and conditions are favourable for its germination, the rhizoidal cells in contact with soil form rhizoids. The apical cells in the two marginal notches become active simultaneously and form two young thalli growing in opposite directions. After sometime, the central part of the gemma disintegrates, resulting in the separation of two new thalli. They produce more rhizoids from the lower surface and grow into adult thalli.

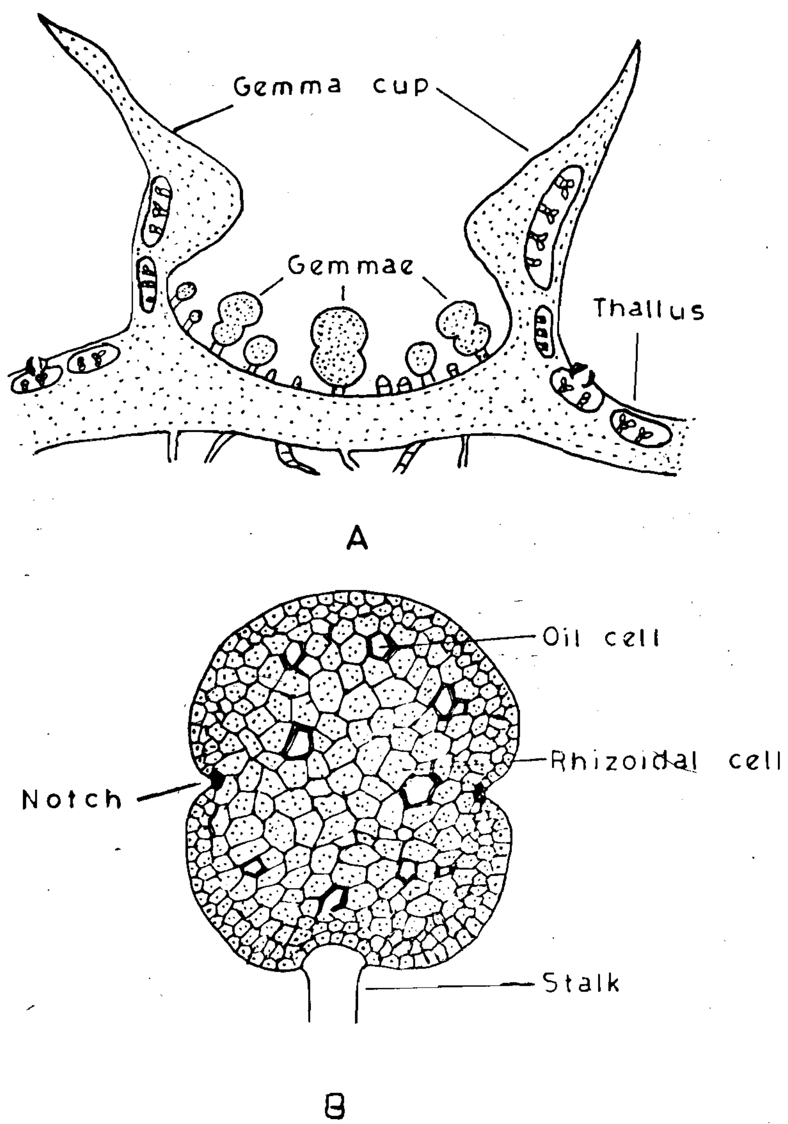

Fig. 14.4: Reproduction in *Marchantia*. A) V.S. of gemma cup showing many gemmae, B) a single gemma.

Sexual Reproduction

You have learnt in Unit 13 that unlike *Riccia*, in *Marchantia* antheridia and archegonia are borne on special erect, branches of the thallus called antheridiophores and archegoniophores, respectively (Unit 13, Fig. 13.4 D and E). As *Marchantia* is dioecious the antheridiophores and archegoniophores are borne on separate thalli. These erect sexual branches are continuation of the thallus and grow vertically upwards through the notches at the end of the prostrate branch.

Look at Fig. 13.4 D (Unit 13). An antheridiophore consists of a stalk with an eight-lobed disc at its apex. In fact, it represents a much modified branch system in which each lobe is comparable to the apex of a branch. This disc is formed as a result of repeated localized forkings of the young antheridial branch. A transverse section of antheridiophore shows the dorsi-ventral symmetry, typical of the thallus. The side corresponding to the ventral surface of the thallus usually has two deep furrows containing rhizoids and scales. The middle of the terminal disc has anatomy similar to that of the thallus, with an upper epidermis interrupted by barrel-shaped pores that open into air chambers containing branched chlorophyllous filaments. In addition to the air chambers, there are many flask-shaped cavities which also have openings on the upper surface. Antheridia are produced inside these cavities (Fig. 14.5 A). Each growing point of the disc produces a number of antheridia in acropetalous manner.

The development of antheridium is similar to that in *Riccia*. A mature antheridium consists of a short stalk and a globular body. The jacket of the body is formed by a single layer of thin-walled cells and it encloses a large number of androcytes (Fig. 14.5 A and B).

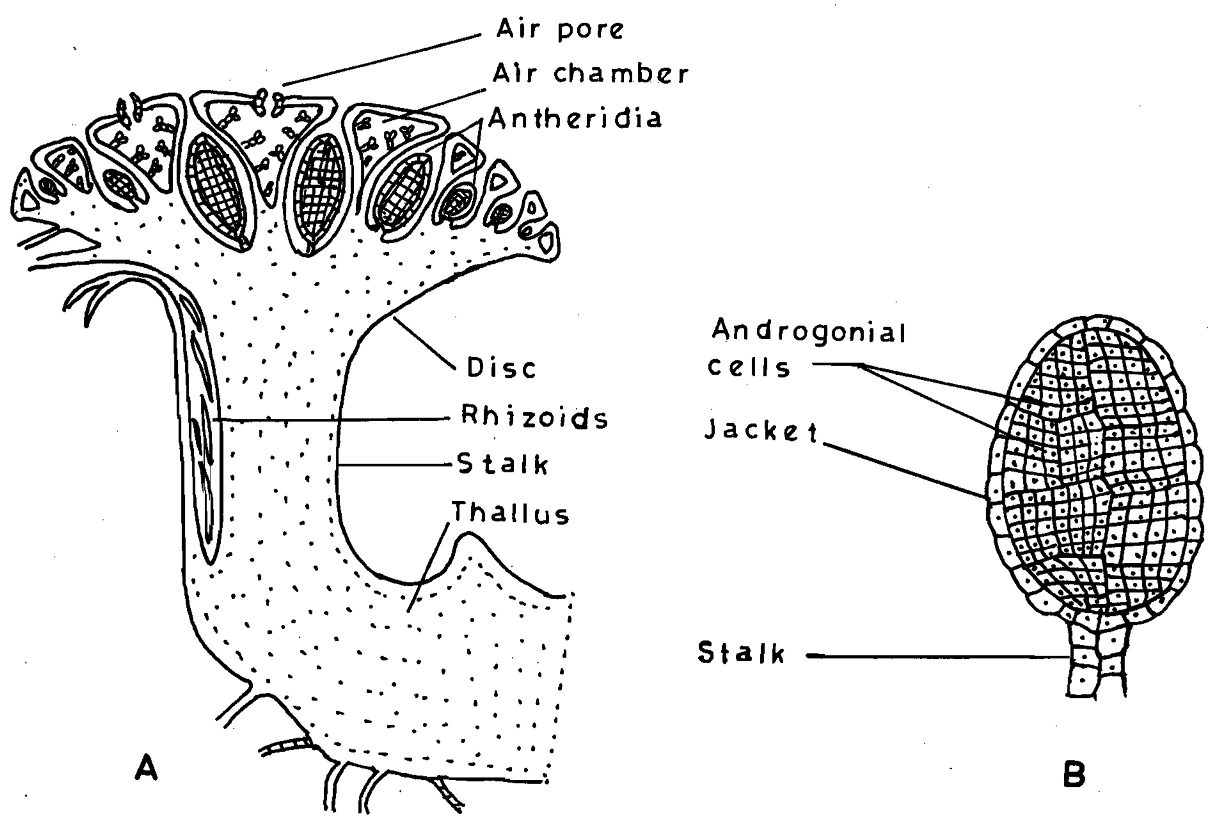

Fig.14.5 : *Marchantia*: A) L.S. of antheridiophore and a portion of thallus, B) a mature antheridium.

When water enters into the slightly concave disc of antheridiophore it moves through the narrow canal into the antheridial cavity. Now, some cells of the upper portion of jacket of the antheridium disintegrate. The androcytes come out from the dehisced antheridium and form biflagellated antherozoids.

The position of archegoniophores on the thallus is similar to that of antheridiophores. An archegoniophore also consists of stalk and lobed disc. The stalk has two longitudinal furrows running along the length as seen in transverse section (Fig. 14.6 A). Internal structure of the disc is similar to that of the thallus.

Like antheridia the archegonia are produced in acropetal succession from cells cut off by apical cells on the dorsal face of each lobe. Soon, eight groups of archegonia develop on the upper surface of the disc corresponding to eight growing points of the disc. Initially, when the stalk of the archegoniophore is very short, the archegonial necks are directed upwards and fertilisation occurs at this stage (Fig. 14.6 B). After fertilisation, the stalk of archegoniophore elongates and the central part of the disc shows considerable growth due to which the marginal apical region of the disc alongwith the groups of archegonia is pushed over to the lower surface of the disc. Finally, the growing apices become incurved, and lie close to the stalk of archegoniophore. Now the archegonial necks are directed downwards, and the youngest archegonium is near the stalk and the oldest towards the periphery of the disc (Fig. 14.6 C). Subsequently, each group, containing 12 to 15 archegonia, is enclosed by a two-lipped pendent involucral sheath. This involucral sheath is known as **perichaetium** and it hangs down vertically from the lower surface of the lobe of the disc. In many species green cylindrical processes arise from the periphery of the disc, between the groups of archegonia. These processes are known as **rays**. In *Marchantia polymorpha* the rays are usually nine in number.

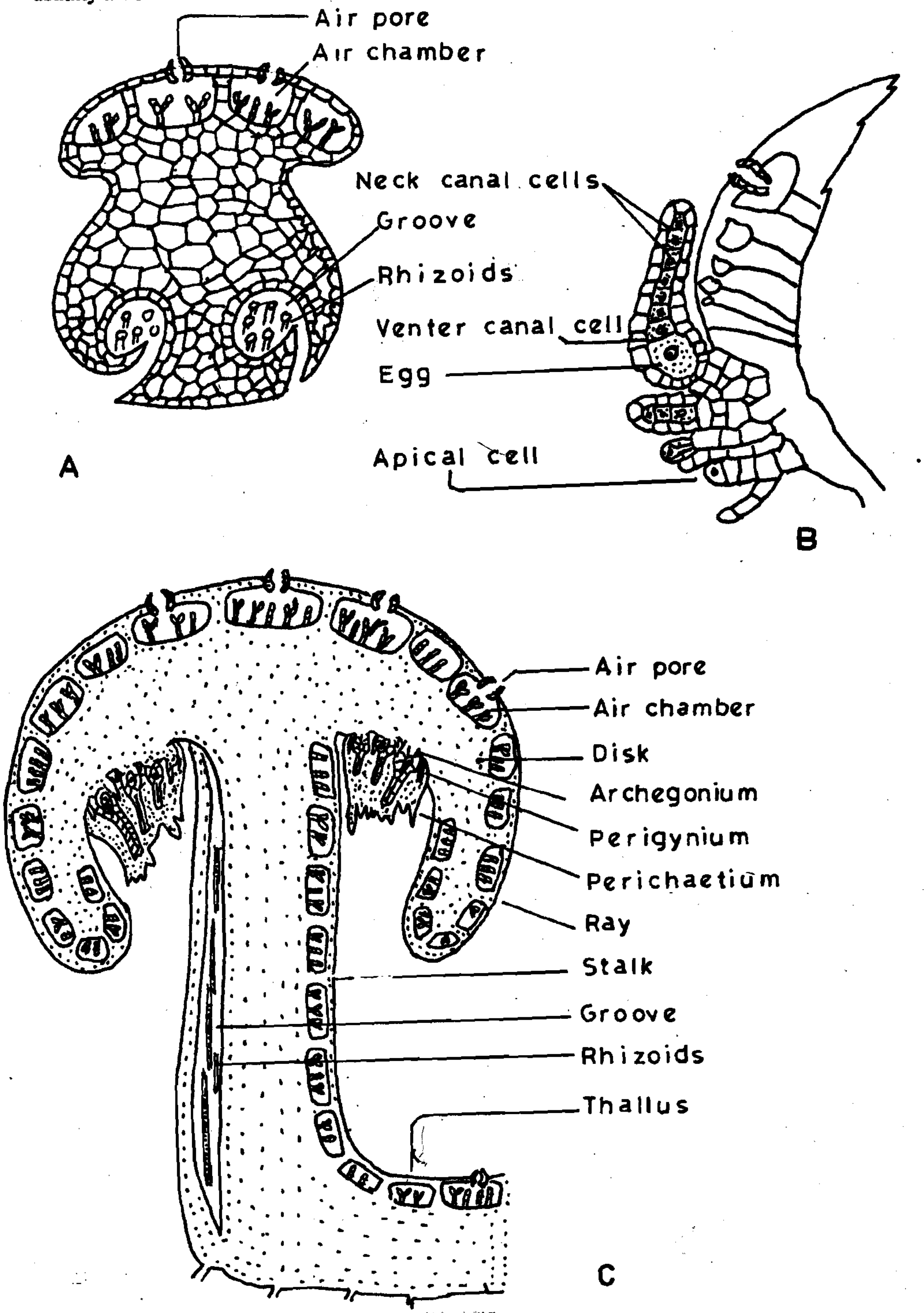

Fig. 14.6: *Marchantia* : A) T.S of stalk of archegoniophore, B) L.S. of a young archegoniophore showing archegonia orginating on the upper surface of the disc, C) L.S. of archegoniophore and a

At maturity the archegoniophore consists of a long stalk with terminal nine-rayed disc. Archegonia are arranged on the lower surface of each lobe in radial rows and are located between the rays. Each group of archegonia is protected by a perichaetium. As mentioned above, the archegonia are in an inverted position.

The development of archegonia is similar to that in *Riccia*. A nearly mature archegonium is a flask-shaped structure with short stalk, swollen venter and a long neck (Fig. 14.6 B). Inside the single layered venter wall is a large egg and a ventral canal cell. The neck is composed of six vertical rows of jacket cells surrounding four or more neck canal cells.

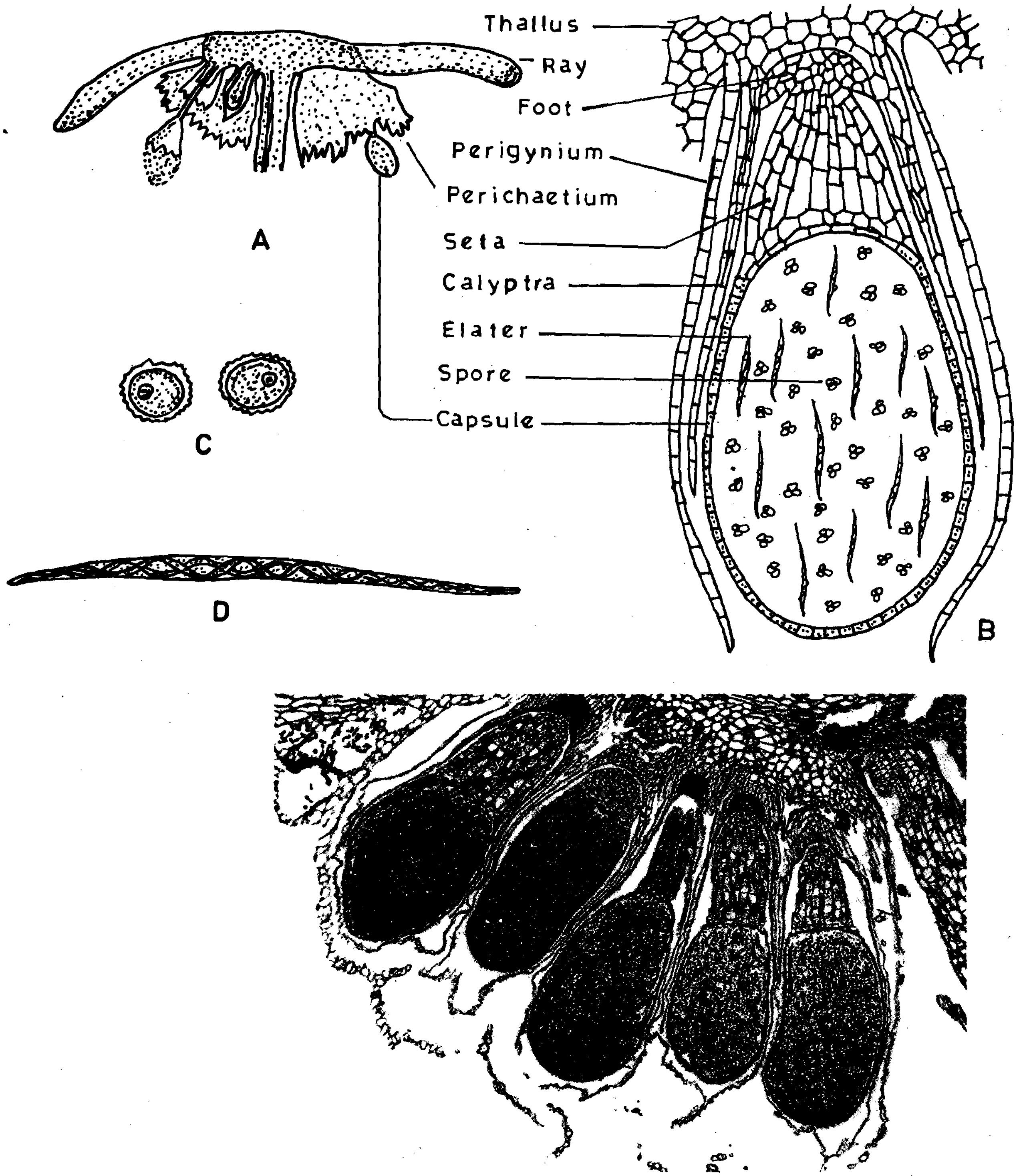

Fig.14.7: Sporophyte of *Marchantia*: A) V.S. of disc of the archegoniophore, B) L.S. of nearly mature sporophyte, C) spores, D) an elater showing spiral thickenings, E) photograph of L.S. showing sporangia and associated structures (courtsey of P. Dayanandan).

The antherozoids are transferred from the upper surface of the discs of the longer-stalked archegonium and enter through the neck. One of the antherozoids fertilises the egg, and a zygote is formed. Simultaneously, the stalk of archegoniophore elongates and the wall of the venter divides periclinally forming two to three-layered calyptra. Calyptra surrounds the developing sporogonium. An additional collar-like cylindrical outgrowth arises from the base of the venter. This is known as **pseudoperianth** or **perigynium** (Figs. 14.6 C and D, 14.7 B).

Just as in *Riccia* the zygote divides transversely into an upper epibasal and a lower hypobasal cell. The second wall is generally formed at right angles to the first and four equal cells are formed. It is followed by one more vertical division which is at right angles to the first. At this stage embryo is composed of eight equal cells (octant stage). In *Marchantia polymorpha* the epibasal quadrant forms the capsule and the hypobasal quadrant forms the foot and seta.

Is it any different from *Riccia*?

....

....

Periclinal divisions in the upper capsular region of the developing sporophyte result in the formation of the outer amphithecium and the inner endothecium. The amphithecium forms the jacket of the capsule. The endothecium gives rise to the archesporium, which by repeated divisions develops into a massive sporogenous tissue. Nearly half of the sporogenous cells divide transversely a number of times to form vertical rows of more or less cubical spore mother cells. Rest of the sporogenous cells become long, have tapering ends and develop two spiral thickenings in their walls. These spindle-shaped cells are known as **elaters** (14.7 B).

A mature sporogonium of *Marchantia* is differentiated into foot, seta and capsule (Fig. 14.7 B and E). The foot is bulbous or spreading structure directed towards the base of the archegonium. It absorbs water and nutrients from the surrounding tissue of the gametophyte for the developing sporophyte. The seta is short and thick, and it connects the foot and capsule. The capsule is almost spherical. Its wall is composed of a single layer of cells. with ring-like thickened bands. Inside the capsule are spores and elaters (Fig. 14.7 C and D). The elaters are hygroscopic. They coil and uncoil with changes in the humidity of atmosphere. By these movements elaters help in separation and dispersal of spores.

After maturation of spores the seta elongates considerably. Consequently, capsule breaks through the protective coverings (calyptra, pseudoperianth and perichaetium). It hangs down from the underside of the disc of the archegoniophore (Fig. 14.7 A). After exposure to the outer atmosphere the wall of capsule splits longitudinally from apex to the middle, into a number of lobes. These lobes are reflexed, exposing spores and elaters to outer atmosphere. Spores are finally dispersed by wind.

A spore germinates under favourable conditions. The exospore ruptures, and the endospore comes out in the form of germ tube which divides by transverse divisions forming a short filament. After some time the terminal cell begins to function as an apical cell and cuts off segments alternately to the right and left. Finally, the apical cell is replaced by a row of cells and a thallus is formed.

SAQ 14.3

In the following statements regarding *Marchantia* fill in the blank spaces with appropriate word(s).

i) *Marchantia* reproduces by the formation of specialised discoid, bilaterally, symmetrical bodies known as.......................................

ii) When antheridia and archegonia are borne on different thalli, the condition is called ....

iii) The sex organs are borne on stalked structures called ....

iv) Archegoniophores represent modified .... systems.

v) Antheridia are produced in antheridial chambers present on the .... surface of disc of antheridiophore.

vi) In mature archegoniophores, archegonial necks are directed ....

vii) The archegonial neck is composed of .... of neck cells.

viii) The mature capsule contains spores and ....

14.3.3 *Pellia*

In the previous unit you have learnt that *Pellia* differs from *Riccia* and *Marchantia* in the structure of vegetative thallus. Now you will study the process of reproduction in this liverwort and compare it with that in *Riccia* and *Marchantia*.

Vegetative Reproduction

Like *Riccia* and *Marchantia*, *Pellia*, also reproduces by the formation of adventitious branches which arise from the superficial cells on the ventral surface of the thallus or from the margins. The separation of these branches from the parent plant leads to the formation of many new thalli. Similarly, death and decay of older posterior portions of thalli near the dichotomies result in the formation of many new thalli which grow independently from the parent plant.

Sexual Reproduction

In *Pellia* some species are monoecious while others are dioecious.

What is the condition in *Riccia* and *Marchantia*?

....

....

In monoecious species such as *Pellia epiphylla* both antheridia and archegonia are produced on the same thallus, whereas in dioecious species like *P. endiviaefolia* and *P. neesiana* archegonia and antheridia are borne on separate thalli. In monoecious species antheridia are formed earlier than archegonia . This condition is known as **protandrous**.

The antheridia are produced on the dorsal surface of the thallus along the midrib, and their presence is marked by numerous wart-like projections. Each projection marks an antheridial cavity containing an antheridium (Fig. 14.8 A).

Try to recall the position of gametangia in *Riccia* and *Marchantia*. (You may like to refer to Figs. 13.3 B, C and 13.4 D). Now let us see how does an antheridium develop in *Pellia*? It develops from a superficial, papillate dorsal cell which acts as antheridial initial (Fig. 14.8 B). It divides transversely forming an outer cell and a basal cell (Fig. 14.8 C). The outer cell divides further by transverse wall into a lower primary stalk cell and upper primary antheridial cell (Fig. 14.8 D). The primary stalk cell gives rise to the stalk of the antheridium. The entire antheridium develops from primary antheridial cell. The mature antheridium is a nearly spherical, stalked structure. It is situated in a flask-shaped antheridial chamber opening on the dorsal surface by a narrow pore (Fig. 14.8 E). The single layered jacket of the antheridium encloses numerous androcytes, each of which produces a single antherozoid (Fig. 14.8 F).

You may note in figure 14.8 E that the archegonia are directed horizontally and are protected by an involucre. The involucre may be cylindrical, tubular or flap-like. The involucre opens towards the apex of the thallus. In between the archegonia short mucilaginous hairs are also present. In *Pellia* any superficial cell near the growing apex may act as archegonial initial and there is no regular succession in the formation of archegonia. Archegonial initial divides by a transverse wall to form an outer cell and a basal cell. As in *Riccia*, three intersecting vertical walls are laid down in the outer cell, thus forming a central primary axial cell surrounded by three peripheral initials. Of the three peripheral initials, one is much smaller and usually does not divide by a vertical wall, whereas the two larger peripheral initials divide by vertical walls. As a result of which five jacket initials are formed (Fig. 14.9 A).

Can you recall how many jacket initials are formed in *Riccia*?

....

....

Each archegonium has a short, multicellular stalk, a venter and a long neck (Fig. 14.9 B). The neck is not very clearly differentiated from the venter. The jacket of the neck consists of five vertical rows of cells. It encloses usually 6 to 8 neck canal cells.

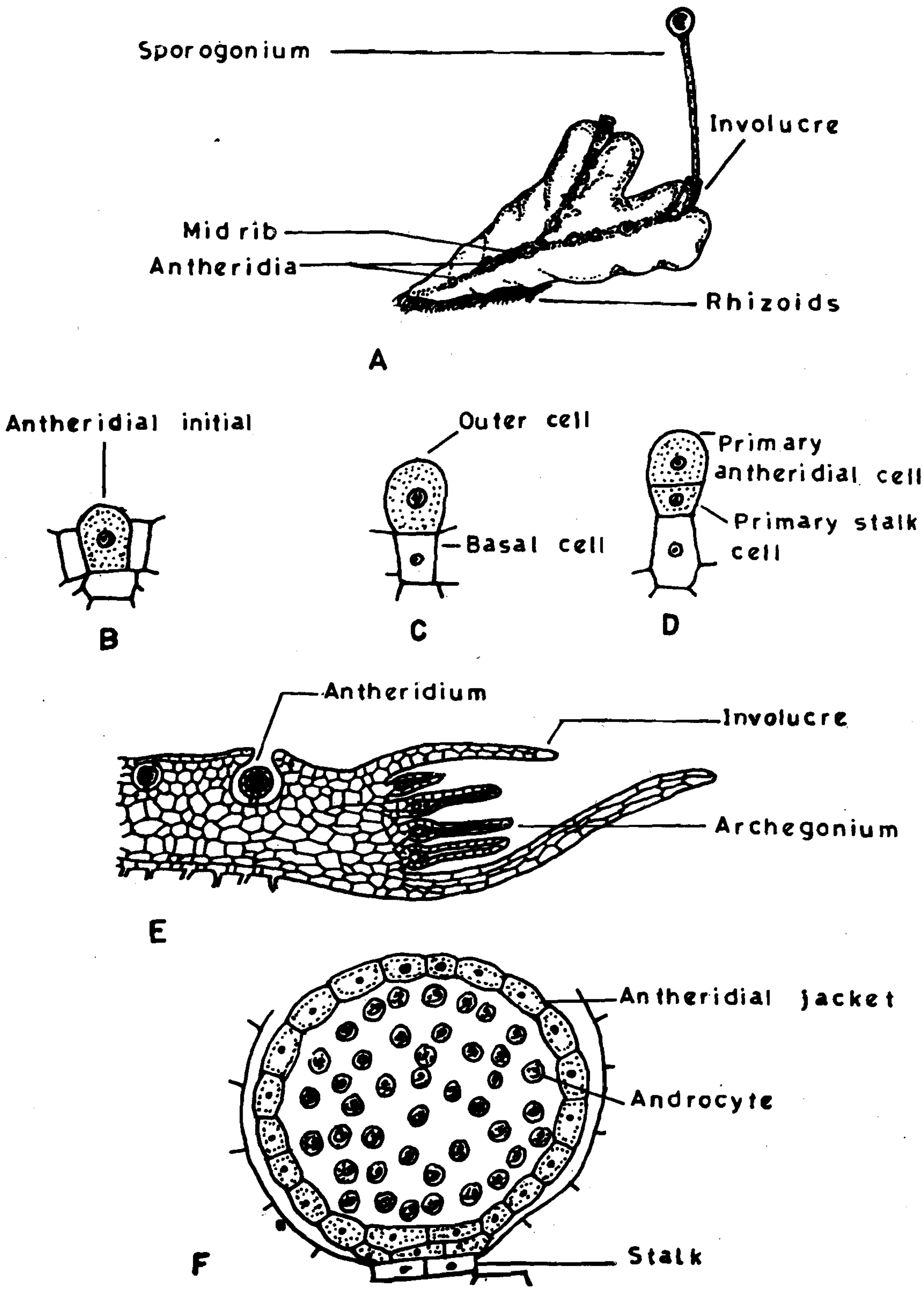

Fig. 14.8 : *Pellia*: A) thallus of monoecious species showing antheridia and sporogonium, B-D) initial stages in the development of an antheridium, E) L.S. of thallus through sex organs, F) a mature antheridium.

The process of fertilisation is similar to that in *Riccia* and *Marchantia*. You have learnt that the tip of the mature antheridium disorganizes when in contact with water. The mucilaginous mass containing a large number of biflagellated antherozoids oozes out. Some of them enter the neck of an archegonium but only one fuses with the egg, forming the zygote.

The wall of venter grows and forms calyptra. The first division of zygote is transverse forming an upper epibasal cell and lower hypobasal cell. The hypobasal cell forms a suspensor which is haustorial. The epibasal cell gives rise to a group of 8 cells, arranged in two tiers of four cells each. The upper tier of cells forms the capsule and the lower 4 cells form the seta and the foot. Periclinal division in the upper tier results in the formation of outer amphithecium and inner endothecium. Like *Riccia* and *Marchantia* the endothecium forms archesporium, and archesporial cells by repeated divisions form a mass of sporogenous cells. During early stages, a mass of larger sterile cells differentiates at the base of the capsule. These cells develop spiral thickenings on their walls and form the **elaterophore**, to which some of the elaters are attached (Fig. 14.9 C). The sporogenous cells give rise to spore mother cells and elaters. The elaters elongate rapidly and develop spiral thickening (Fig. 14.9 D). In *Pellia* the spore mother cells become conspicuously four

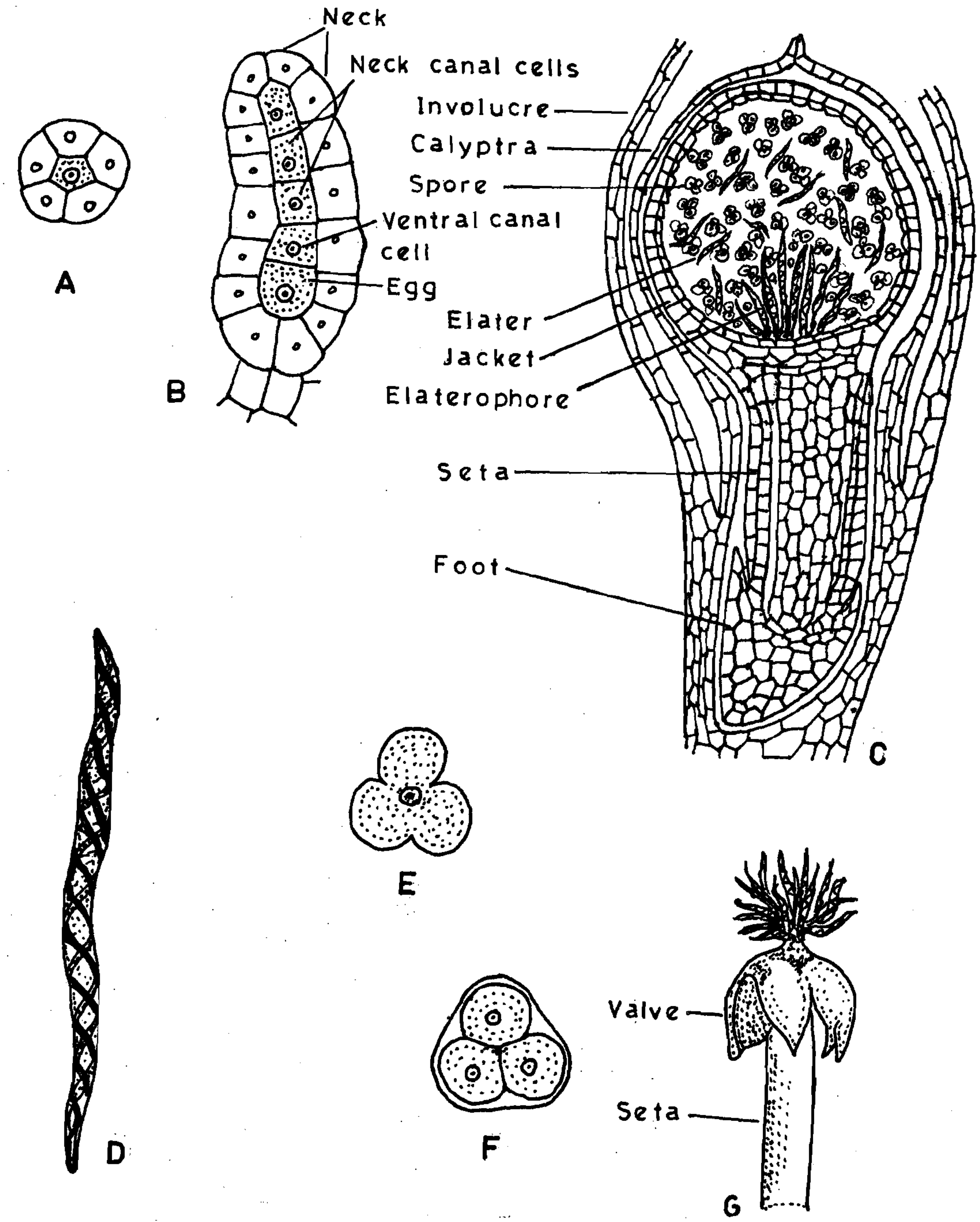

Fig.14.9: ***Pellia:*** **A) Cross section of achegonium, B) L.S. of a mature archegonium, C) L.S. of mature sporophyte, D) an elater, E) a spore mother cell ready to divide, F) spore tetrad, G) ruptured capsule.**

lobed before the division of the nucleus (Fig. 14.9 E, one of the lobe is below therefore, only three can be seen). The nucleus divides meiotically resulting in the formation of four haploid spores (Fig. 14.9 F). As in *Marchantia*, the mature sporogonium of *Pellia* consists of a foot, seta and capsule. The foot is conical with its edges produced around the base of seta like a collar. Initially seta is short, but when spores mature it elongates rapidly and attains a length of up to 8 cm within 2 to 3 days. This results in the bursting of the calyptra and exposure of capsule to the atmosphere. The mature capsule is globose with two layered thick jacket. The capsule wall splits into four valves which are reflexed and hang downwards (Fig. 14.9 G). The elaters by their hygroscopic movements help in the dispersal of spores.

In *Pellia* the spore begins to germinate while retained within the capsule and forms an oval mass of cells consisting of several tiers of cells. All the cells contain chlorophyll, but some basal cells are lighter in colour. The dehiscence of the capsule occurs at this stage and the germinated multicellular spores fall on moist soil. The lower lighter cell develops into rhizoid and the green cell mass soon develops into a new thallus.

SAQ 14.4

Which of the following statements regarding *Pellia* are true and which are false? Write **T** for true and **F** for false statement.

i) *Pellia* is strictly monoecious. ☐

ii) The antheridia are present on dorsal side of the thallus in antheridial cavities. ☐

iii) The archegonia are protected by an involucre. ☐

iv) The neck of the archegonium is clearly differentiated from the venter. ☐

v) The sporophyte is differentiated into seta and capsule. ☐

vi) An elaterophore is present inside the capsule. ☐

vii) Spores of *Pellia* start germinating inside the capsule. ☐

14.3.4 *Anthoceros*

In the above sections you have learnt in detail about the methods of reproduction in some members of Hepaticopsida. Now you will learn about the process of reproduction in *Anthoceros*.

Vegetative Reproduction

Like the three members of Hepaticopsida *Riccia*, *Marchantia* and *Pellia* vegetative reproduction in *Anthoceros* also occurs by the growth of apical region of the thallus and the progressive death of posterior, older portion causing the separation of branches of a dichotomy and formation of two new independent thalli. However, this method is not so common in *Anthoceros*. The common method of vegetative reproduction is by the formation of tubers (Fig. 14.10 A and B). Tubers are formed by thallus under unfavourable conditions and also help the species to tide over the period of drought. The tubers readily form new plants when conditions become favourable.

Which member(s) of Hepaticopsida form(s) the tubers under unfavourable conditions?

....

A tuber has 2-3 outer layers of cells with corky hyaline cell walls. These protect the inner tissue. The cells of the inner tissue contain starch grains, oil globules and small aleurone granules. The location of tubers varies in different species. The tubers may develop at the growing points, or along the margins of the thallus. In some species the tubers are stalked and arise from the ventral surface or from the margins (Fig. 14.10 A,B). As in *Marchantia*, some species of *Anthoceros* also propagate by means of gemmae. They may form gemmae along the margins and on the surface of the thallus. These gemma detach from the parent plant and develop into new thalli.

Sexual Reproduction

Like *Pellia*, the thalli of *Anthoceros* may be monoecious or dioecious. In the monoecious species, the development of antheridia usually precedes that of archegonia, i.e., they are protandrous. Both types of sex organs are embedded in the dorsal region of the thallus and are initiated just behind the growing point.

In contrast to members of Hepaticopsida antheridium in *Anthoceros* develops from a hypodermal cell. A superficial cell (Fig. 14.10 C) on the dorsal side of the thallus divides by a periclinal wall. The upper daughter cell functions as roof initial (Fig. 14.10 D) and by further divisions forms roof of the antheridial chamber. The lower cell acts as antheridial initial which may develop into a single antheridium or may divide to give rise to many antheridia (Fig. 14.10 E to H). The antheridial initial divides transversely to form a primary stalk cell below and a primary antheridial cell above. Further development of antheridium is similar to that in *Riccia* and *Marchantia*. A mature antheridium shows a more or less slender stalk bearing somewhat spherical antheridium containing the mass of androcytes (Figs. 14.10 H and 14.11). The jacket is generally one or more layered thick and becomes green or orange at maturity. Each androcyte forms a biflagellate antherozoid.

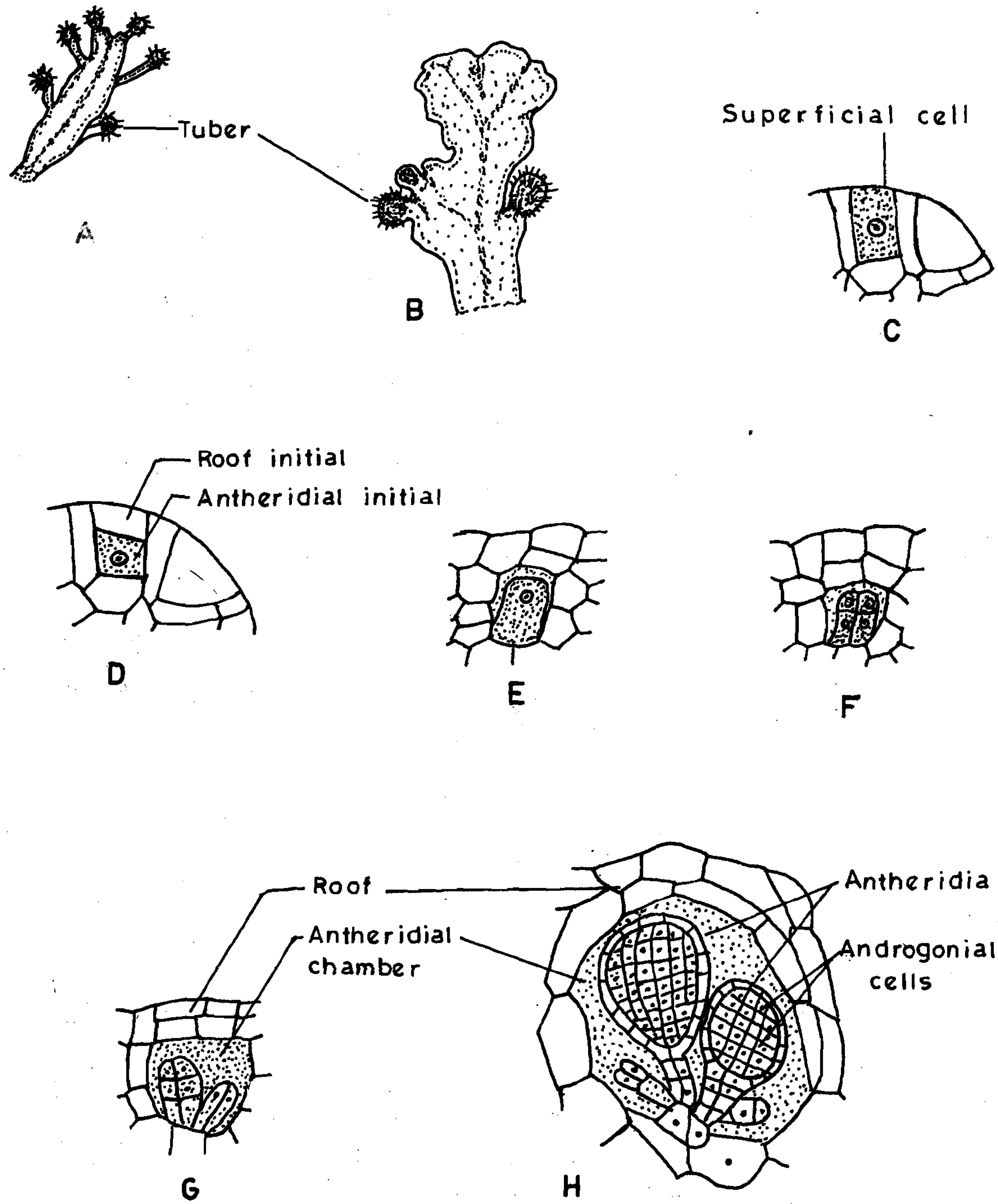

Fig.14.10: Reproduction in *Anthoceros*: A,B) thalli showing tubers, C-H) various stages in the development of antheridia.

The archegonia are produced acropetally from superficial dorsal cells close to the apex. The archegonial initial functions directly as the primary archegonial cell, there being no stalk (Fig. 14.12 A). Three vertical walls cut off three outer jacket initial cells and a central primary axial cell (Fig. 14.12 B and C). This axial cell divides transversely into two cells.

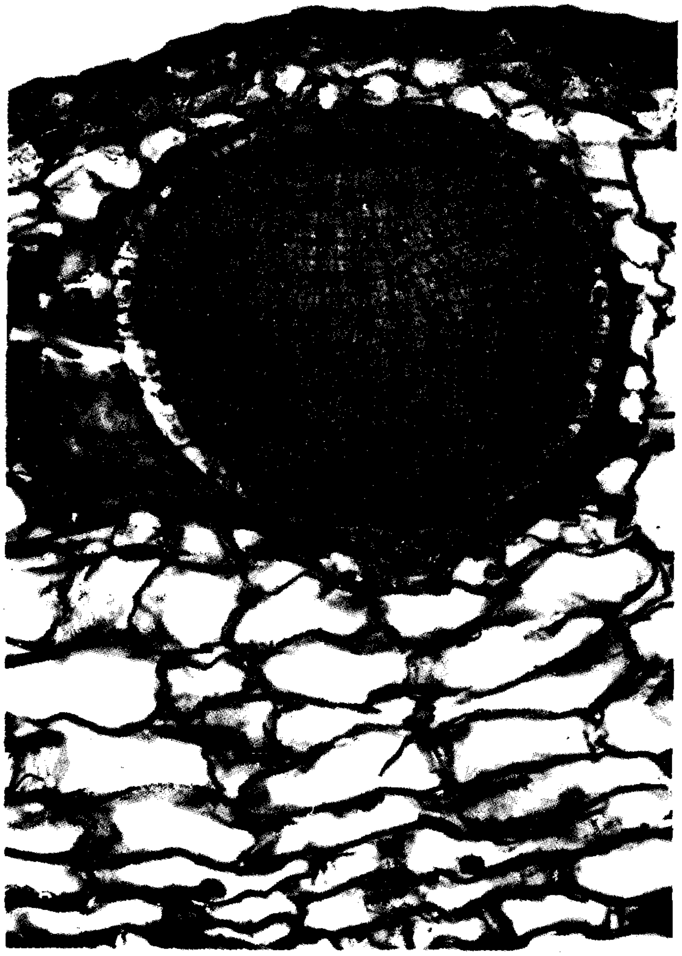

Fig.14.11: Photograph of C.S. of antheridium (coutsey of P. Dayanandan).

The lower cell becomes the primary ventral cell and the upper cell divides again forming a top cover initial and a lower primary neck canal cell (Fig. 14.12 D,E). The cover initial forms four cover cells, whereas the primary neck canal cell gives rise to a vertical row of 4 or more neck canal cells. The primary ventral cell forms the ventral canal cell and the egg (Fig. 14.12 F, G). As in *Riccia* and *Marchantia*, the neck is composed of six vertical rows of cells. A mound of mucilage generally covers the developing archegonia which develop singly and are completely embedded in the thallus. They are in direct contact with the surrounding vegetative cells, without projecting above the surface of the thallus. As a result the jacket of the archegonium is indistinguishable from the adjacent cells of the thallus.

After fertilization the zygote divides by two successive divisions at right angles to each other. This is followed by one more vertical division at right angle to the first vertical division resulting in the formation of eight cells, arranged in two tiers of four cells each. The lower tier forms the sterile foot after repeated divisions. The upper tier of cells divides and its lower daugther cells form an **intercalary meristematic tissue**. Periclinal divisions in the upper cells result in the formation of inner endothecium and outer amphithecium. The endothecium forms a structure composed of 16 vertical rows of cells. This is known as **columella** (Fig. 14.13 A). The amphithecial cells divide periclinally again and its outer layer forms 4 to 16 cells thick jacket of mature sporophyte. The epidermis has cutinised outer walls and stomata. The inner cells of jacket are chlorophyllous. The inner cells of the amphithecium behave as archesporium.

Can you recall the origin of archesporium in the members of Hepaticopsida that you have studied in the previous sections? Is it from amphithecium or endothecium?

....

....

....

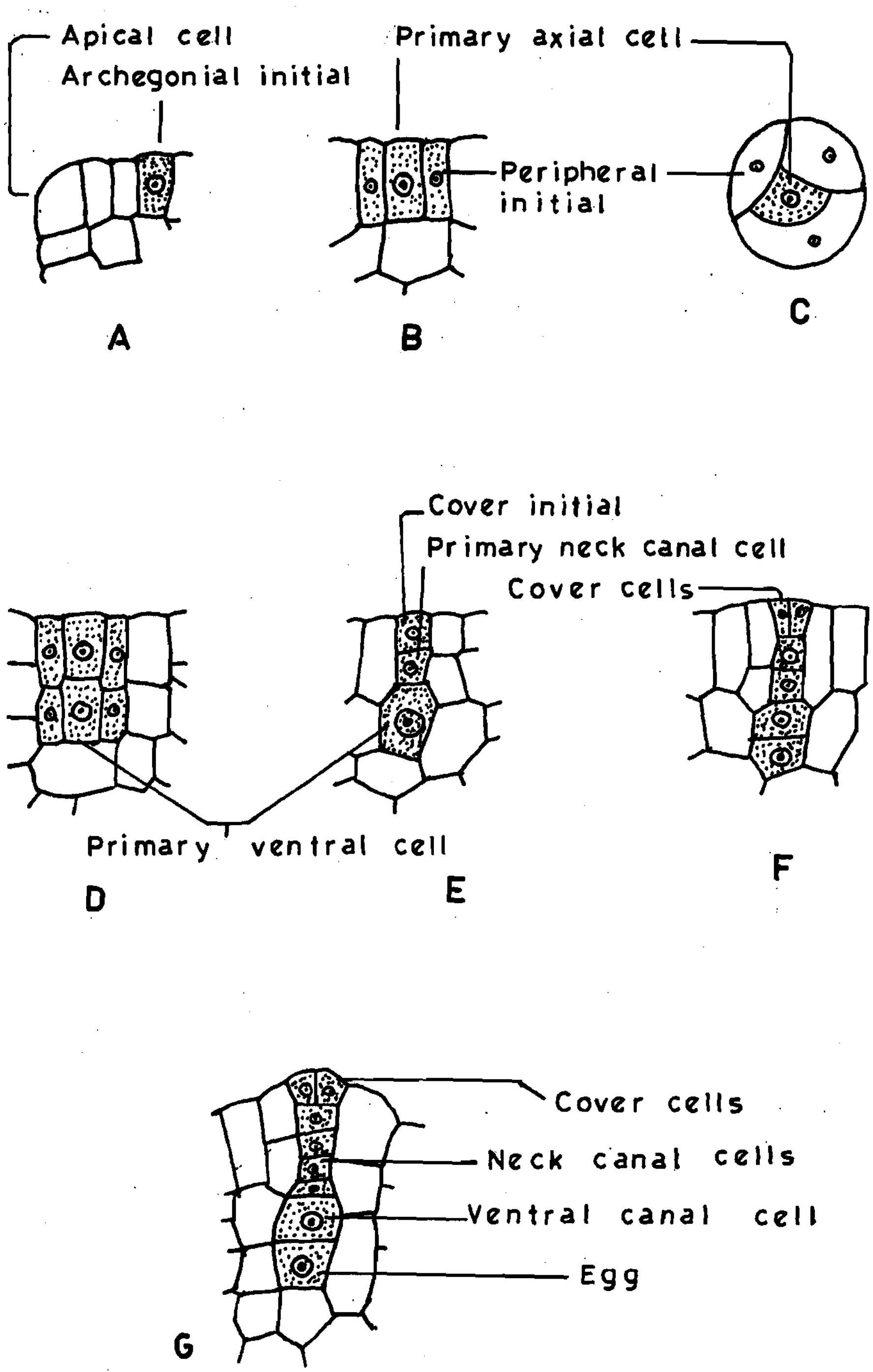

Fig.14.12: Development of archegonium in *Anthoceros*: A-F) various stages in the development of an archegonium (A,B,D-F in L.S. and C in T.S.), G) a mature archegonium.

The archesporium overarches the rounded apex of the columella. Alternate transverse tiers of the archesporium become spore mother cells and sterile cells (Fig. 14.13 A). The spore mother cells divide meiotically and form spore tetrads, whereas the sterile cells undergo mitotic division to produce, 4-celled, filamentous pseudoelaters (Fig. 14.13 C). You have earlier learnt that in *Marchantia* and *Pellia* the elaters are spindle shaped, single celled and have spiral thickenings. However, in *Anthoceros* they are multicellular and without thickening that is why they are called pseudoelaters.

A mature sporophyte of *Anthoceros* has a bulbous foot embedded in the gametophytic tissue. Above the foot is the horn-like erect, cylindrical capsule. The base of the capsule is surrounded by a collar-like involucre which is formed by the gametophytic tissue (Fig. 13.7 A, Unit 13). As mentioned earlier, in *Anthoceros* instead of seta a short intermediate

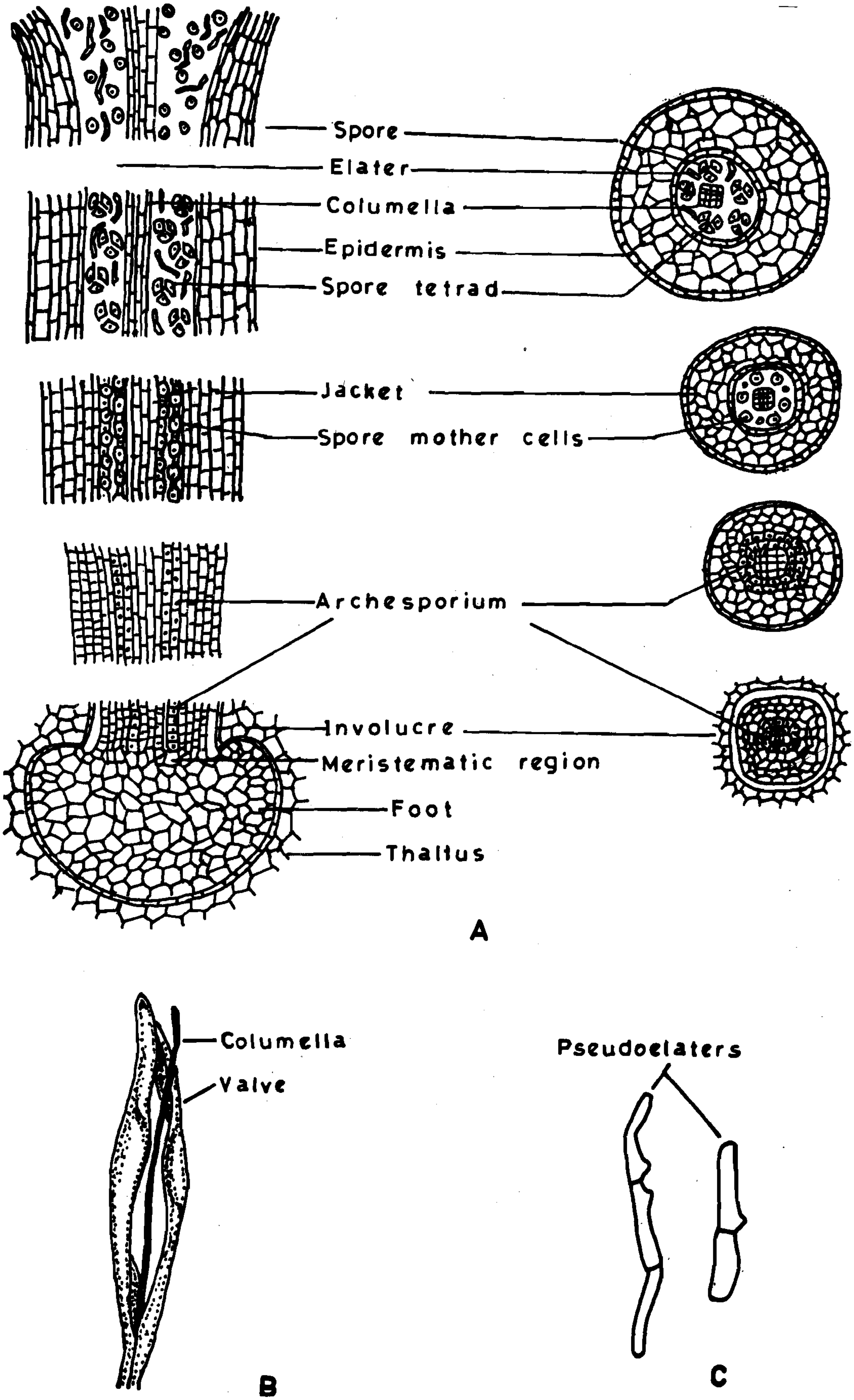

Fig.14.13: Sporophyte of *Anthoceros*: A) L.S. through different portions of sporogonium showing cross sections at the four levels, B) dehiscence of capsule showing flagellum-like columella, C) pseudoelaters.

meristematic zone is present. Because of this the growth of sporophyte is indeterminate and various stages of development are seen in the same capsule (Fig. 14.13 A). The centre of the capsule is occupied by the columella. Archesporial zone occurs around columella in the form of cylinder. Archesporium is one layerd at the base, it gradually shows differentiation into spore mother cells and pseudoelaters upwards. At the top mature spores and pseudoelaters are present. When capsule matures a split appears below the tip and it extends downwards. Hygroscopic movement of the pseudoelaters helps in the dispersal of mature spores and the tip of columella projects out like a flagellum (Fig. 14.13 B). The tip of the capsule appears twisted at this stage.

Under favourable conditions spores germinate. The exospore ruptures and endospore emerges out of the spore wall in the form of germ tube. By divisions of the germ tube a new gametophyte is formed at the tip of germ tube.

SAQ 14.5

a) Which of the following statements regarding *Anthoceros* are true and which are false? Write **T** for true and **F** for false in the given boxes.

   i) Vegetative reproduction occurs by the formation of tubers on the margins and near apices of the thalli. ☐

   ii) The thalli are always monoecious. ☐

   iii) The sporophyte in *Anthoceros* is differentiated into a bulbous foot, an intermediate meristematic zone and a horn-like capsule. ☐

   iv) Capsule wall is many celled thick and it has numerous air spaces and stomata. ☐

   v) Capsule contains spores and true elaters. ☐

b) In the following statements choose the appropriate alternative word given in the parentheses.

   i) The antheridia are (superficial/ hypodermal) in origin.

   ii) Archegonial necks (project/do not project) above the surface of thallus.

   iii) Antheridia are produced in (roofed/open) antheridial chambers.

14.3.5 *Sphagnum*

In the preceding account you have learnt about the process of reproduction in thalloid forms of bryophytes. Now you will learn about various aspects of reproduction in mosses which are regarded as more advanced forms. Among mosses, the most primitive form is *Sphagnum*. First we will describe the process of reproduction in this genus and then in *Funaria* in the section that follows.

Vegetative Reproduction

You may recall that in *Sphagnum* gametophores are perennial. The branches get detached from the shoots by decay of the lower parts. These detached branches later form independent plants.

Sexual Reproduction

In *Sphagnum* both monoecious and dioecious conditions are known to occur. In monoecious condition antheridia and archegonia are always borne on separate antheridial and archegonial branches. This condition is known as **autoicous** condition. In monoecious species, antheridial branches appear earlier near the apex of the main shoot. Antheridial branch possesses shorter and pigmented leaves which are **imbricately** arranged. Look at Fig. 14.14 A and B. The antheridia appear acropetally below the leaves. The top leaves usually do not develop antheridia and the apex continues to grow even after maturation of antheridia. Each antheridium develops from superficial cell of the stem. This cell develops into a short filament with an apical cell having two cutting faces. The top cell later forms the antheridium. Development of antheridium is somewhat similar to that in *Pellia*. As you may note in Figure 14.14 C a mature antheridium possesses a long stalk and a one-celled thick jacket enclosing a mass of androcytes. Androcytes develop into antherozoids which are coiled, biflagellated structures.

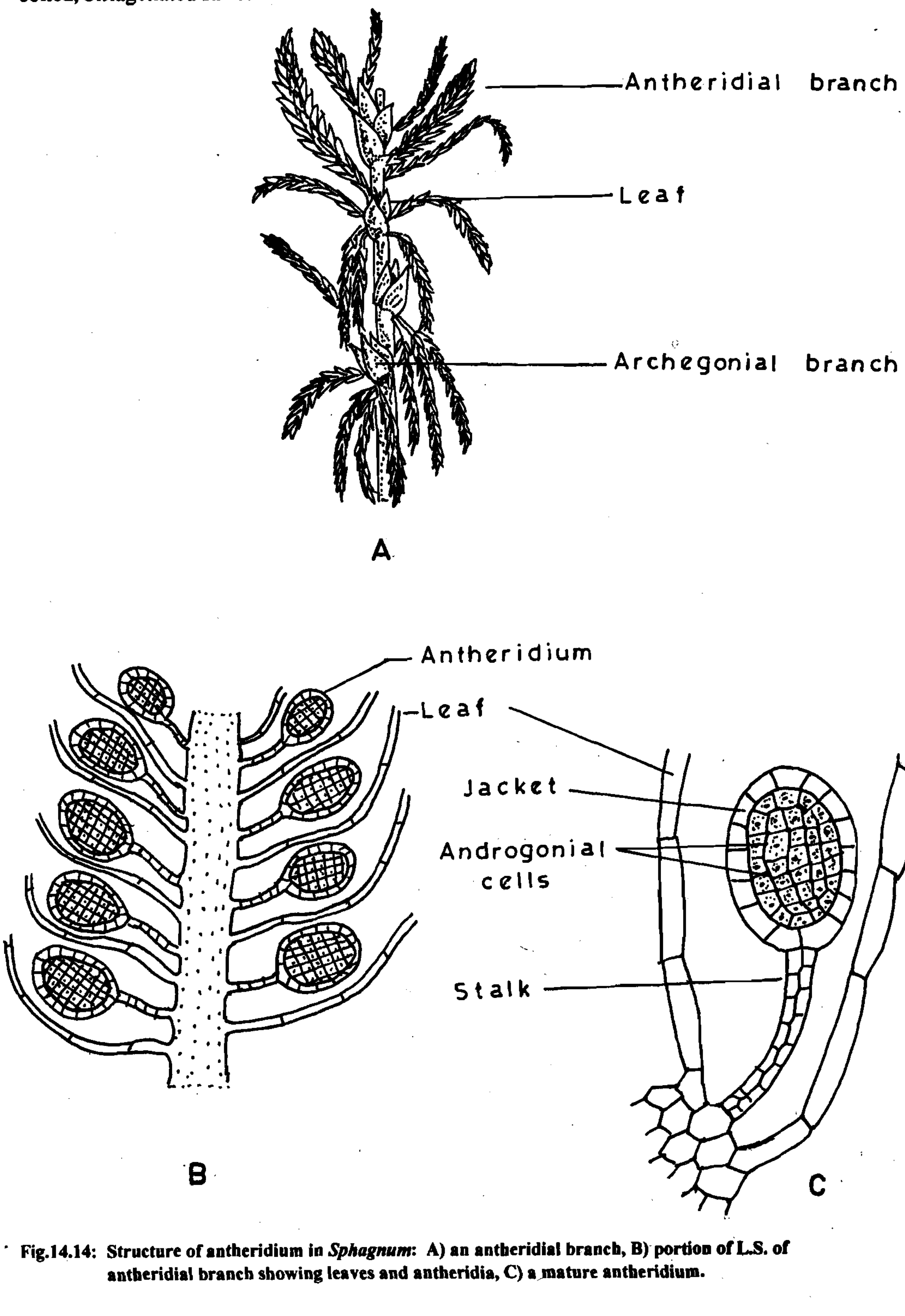

Fig.14.14: Structure of antheridium in *Sphagnum*: A) an antheridial branch, B) portion of L.S. of antheridial branch showing leaves and antheridia, C) a mature antheridium.

The archegonia are borne on the tips of archegonial branches. You may note that this branch has larger leaves with less fibrose hyaline cells (Fig. 14.15 A). The apical cell of this branch forms the primary archegonium, and therefore growth of the archegonial branch stops. Segments produced by the apical cell develop into secondary archegonia (Fig. 14.15 B). Usually, three archegonia are present at the tip of a mature archegonial branch. As shown in figure 14.15 C the primary archegonial initial divides to form a short filament of four to six cells. The terminal cell of this filament cuts off three jacket initials and a primary axial cell.

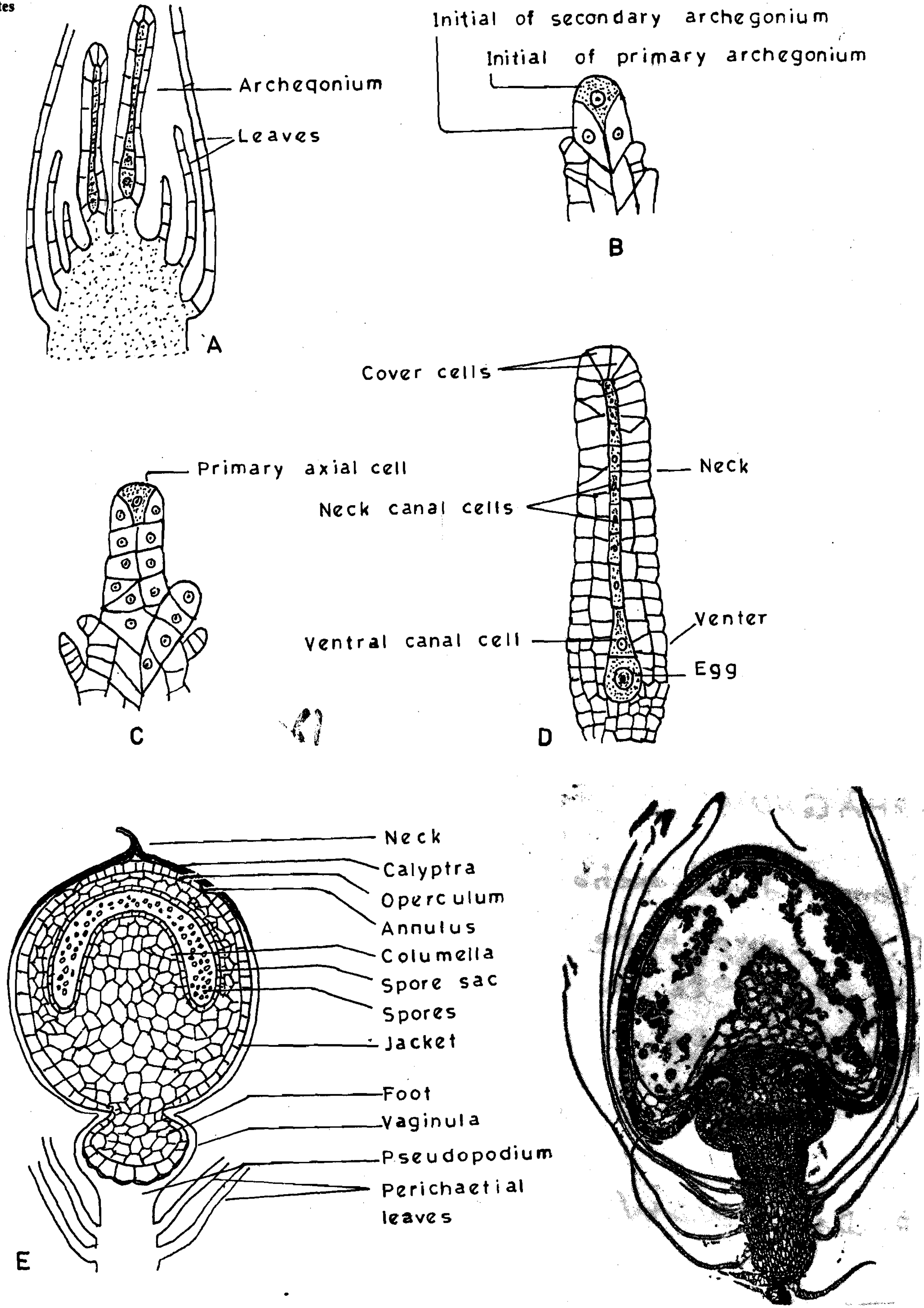

Fig.14.15: ***Sphagnum*: A) L.S. archegonial branch, B-D) stages in the development of archegonium, E) L.S. of nearly mature sporogonium attached to gametophyte, F) photograph of L.S. of a sporophyte attached to a gametophyte (courtsey of P. Dayanandan).**

Further development of archegonium is somewhat similar to that in *Pellia*. Figure 14.15 D shows a mature archegonium of *Sphagnum*. It possesses a stalk, a twisted neck with 8 to 9 neck canal cells, a ventral canal cell and an egg in the venter. The wall of venter becomes multi-layered even before fertilisation.

When fertilisation occurs, in each archegonial branch the zygote of only one archegonium develops into an embryo. The zygote divides many times and 6- to 7-celled long filament is formed. The lower half of this filament forms a bulbous foot, whereas upper cells of the filament divide periclinally forming an outer amphithecium and an inner endothecium. The entire endothecium gives rise to a dome-shaped columella (Fig. 14.15 E). The inner layers of amphithecium form 2- to 4-layered thick archesporium, while the outer layers form jacket. Let us look at Figure 14.15 E and F showing a mature sporophyte. The sporophyte shows a spherical capsule which is black to dark brown in colour, and a bulbous foot connected by a very short constricted structure. You may note that there is no proper seta and its function is performed by the tissue of the gametophyte, which develops into a long stalk. It is known as **pseudopodium** and it raises the sporophyte (Fig. 14.15 E). The archesporium forms the spore mother cells which divide meiotically resulting in the formation of spores. The cup-shaped, terminal part of the female branch surrounding the foot, is called the **vaginula**. The jacket of the capsule is 4-to 6-layered and the spore sac overarches the dome-shaped columella. The outermost layer of the jacket becomes thickened and develops some non-functional stomata. The top of capsule jacket is differentiated into a lid-like structure known as **operculum** which is delimited from the rest of the capsule wall by a ring of thin-walled cells known as **annulus**. Spore dispersal in *Sphagnum* occurs in hot weather by an explosive mechanism. Air present in the spore sac expands by heat and exerts pressure inside the capsule. As a result the operculum is blown off with a sound and spores are blown away by the air.

The spore germinates under favourable conditions and a small thalloid protonema develops. This protonema is prostrate, green, irregularly lobed one-celled thick structure attached to the substratum by multicellular rhizoids. A bud develops on this protonema from a marginal cell and this bud finally develops into a new leafy gametophore.

SAQ 14.6

a) Which of the following statements regarding *Sphagnum* are true and which are false? Write **T** for a true and **F** for false in the given boxes.

   i) Antheridia and archegonia are produced on the same branch.

   ii) Leaves surrounding the archegonia are larger than vegetative leaves.

   iii) The tissue of gametophyte forms a long stalk, called pseudopodium.

   iv) The dome-shaped structure in the developing sporophyte is called columella.

b) In the following statements fill in the blank spaces with appropriate word(s).

   i) Secondary archegonia are produced by segements cut off from .... cell.

   ii) Function of seta is performed by ....

   iii) The top of capsule jacket is differentiated into a lid-like structure known as ....

   iv) The spore sac overarches the ....

14.3.6 *Funaria*

Now you will learn about reproduction in *Funaria* the last genus included in your course.

Vegetative Reproduction

Like *Sphagnum, Funaria* may reproduce vegetatively by producing branches which are detached from the parent plant by decay and give rise to independent plants. Vegetative reproduction also occurs by the development of secondary protonema from different parts of the gametophyte. On this protonema buds are borne which develop into leafy gametophores.

Sexual Reproduction

Funaria is monoecious and autoicous i.e., antheridia and archegonia develop on the same plant but on separate branches. Antheridia are borne on the main shoot, whereas archegonia develop on lateral branches. However, after fertilization archegonial branch grows more vigorously and soon becomes higher than the main shoot (unit 13, Fig. 13.10 A)

In the antheridial shoot (Fig. 14.16 A) many club-shaped, stalked antheridia are surrounded by perigonial leaves. Note many multicellular, uniseriate structures among antheridia. These are **paraphyses**. Their tips are swollen.

The archegonia develop in clusters acropetally on archegonial shoots (Fig. 14.16 B).

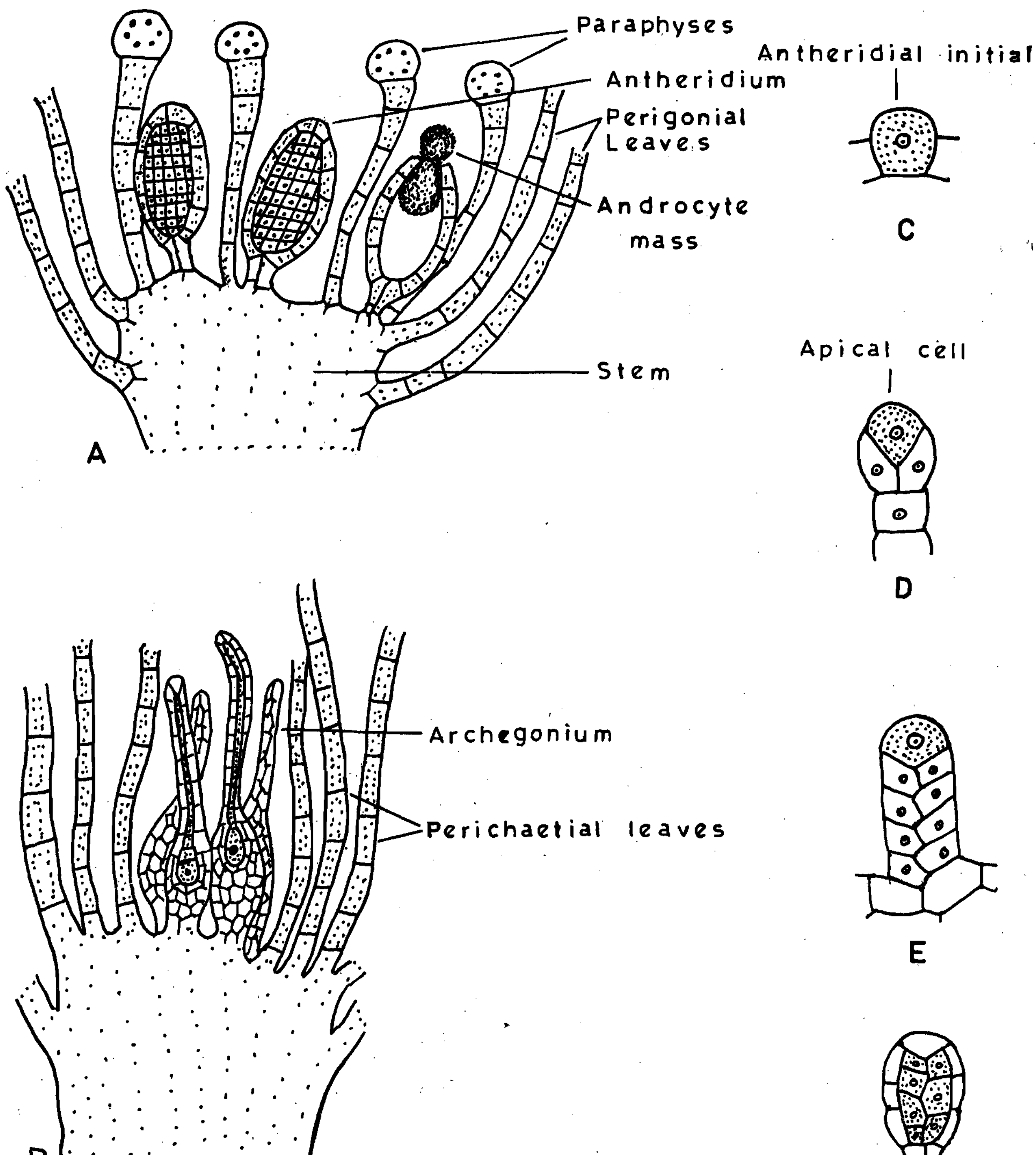

Fig.14.16: Reproduction in *Funaria*: A) L.S. of tip of male branch showing antheridia, paraphyses and leaves, B) L.S. of tip of female branch showing archegonia and leaves, C-F) stages in the development of an antheridium.

As in other plants, the development of an antheridium begins with an antheridial initial cell. This cell with two cutting faces forms a short filament which by further divisions in various planes forms an antheridium (Fig. 14.16 C to F).

During initial stages of archegonial development an apical cell forms the stalk of an archegonium. Subsequently, the same apical cell cuts off three segments which form three peripheral initials and a central axial cell (Fig. 14.17 A to F). Further development of archegonium is more or less similar to that in *Sphagnum.*

After fertilisation the zygote divides by a transverse wall into an epibasal cell and a hypobasal cell. Further divisions give rise to a spindle-shaped young embryo with an apical cell at each end. The lower end forms the foot and the upper end gives rise to seta and capsule. The mature sporophyte shows a poorly developed conical foot, embedded in the apex of the archegonial branch, a long, reddish-brown and twisted seta and a pear-shaped, asymmetrical, slightly curved, bright orange coloured capsule at the tip.

The lowermost portion of the capsule is known as apophysis and it is connected with seta (Fig. 14.18 A and B). The lower part of the axis of the apophysis is composed of thin-walled

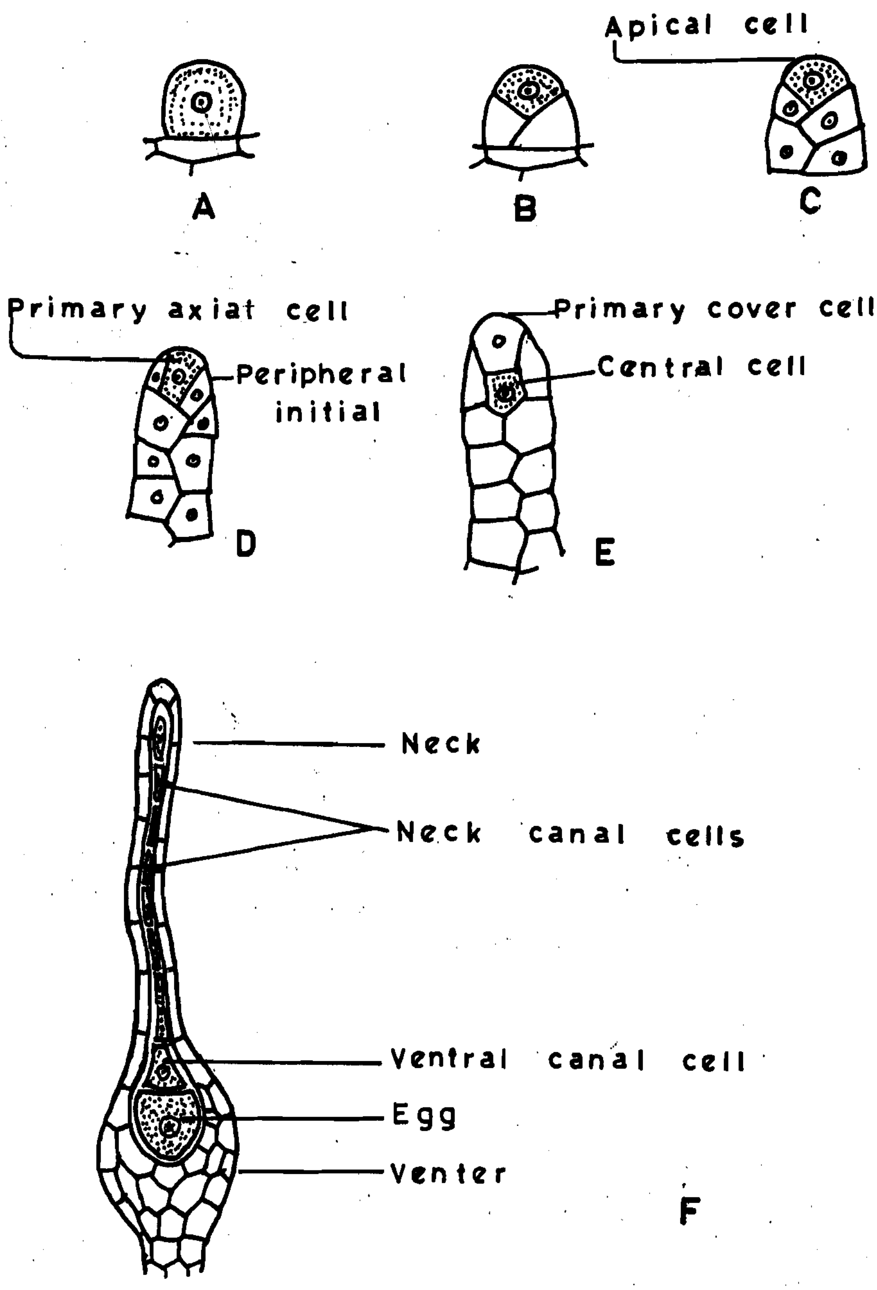

Fig.14.17: Development of archegonium in *Funaria*: A-E) stages in the development of an archegonium. F) a mature archegonium.

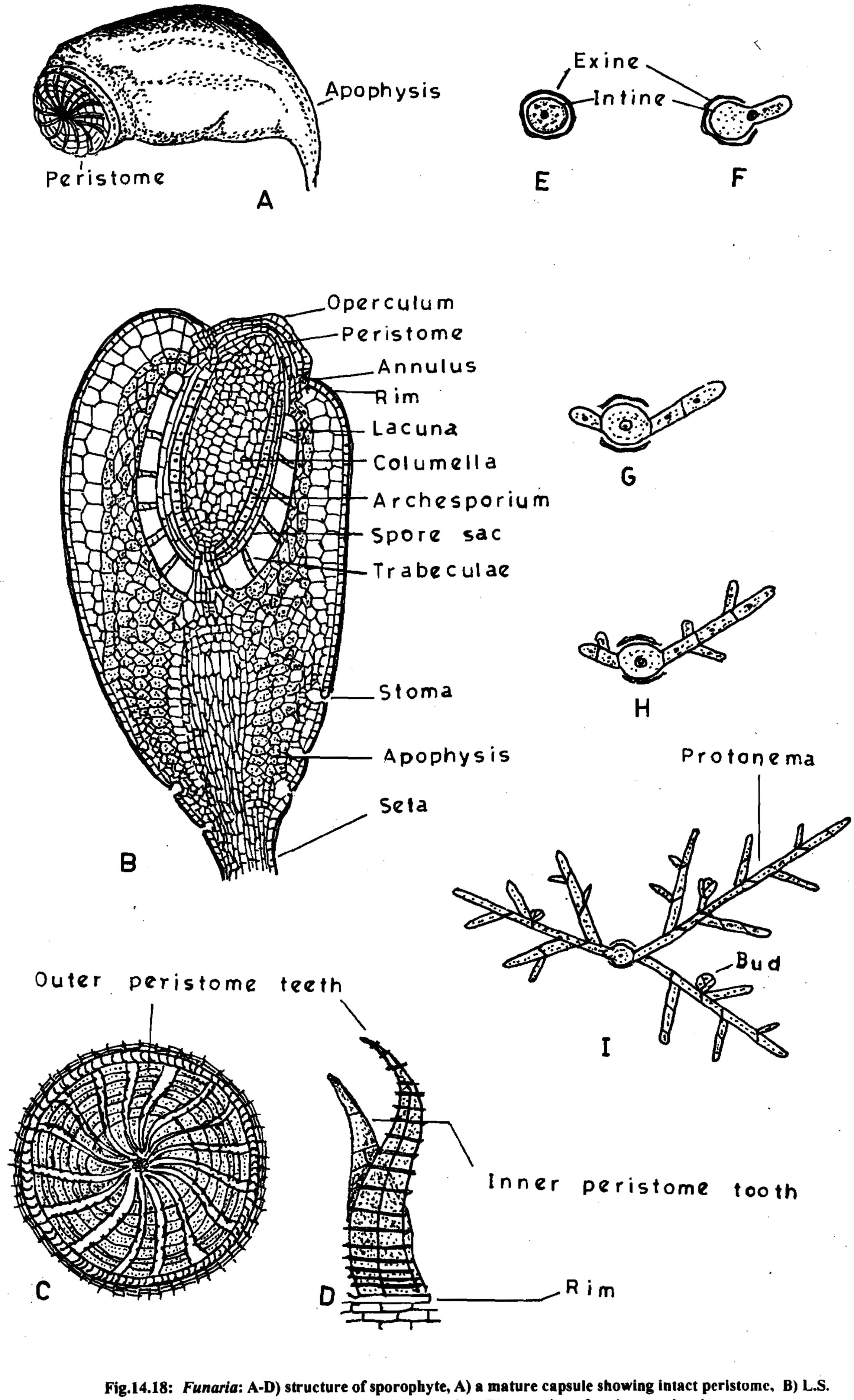

Fig.14.18: ***Funaria*****: A-D) structure of sporophyte, A) a mature capsule showing intact peristome, B) L.S. capsule, C) outer peristome in surface view, D) a portion of peristome showing one outer peristome tooth and one inner peristome tooth, E) spore. Development of gametophyte F-I) successive stages in the germination of spore and formation of protonema and buds.**

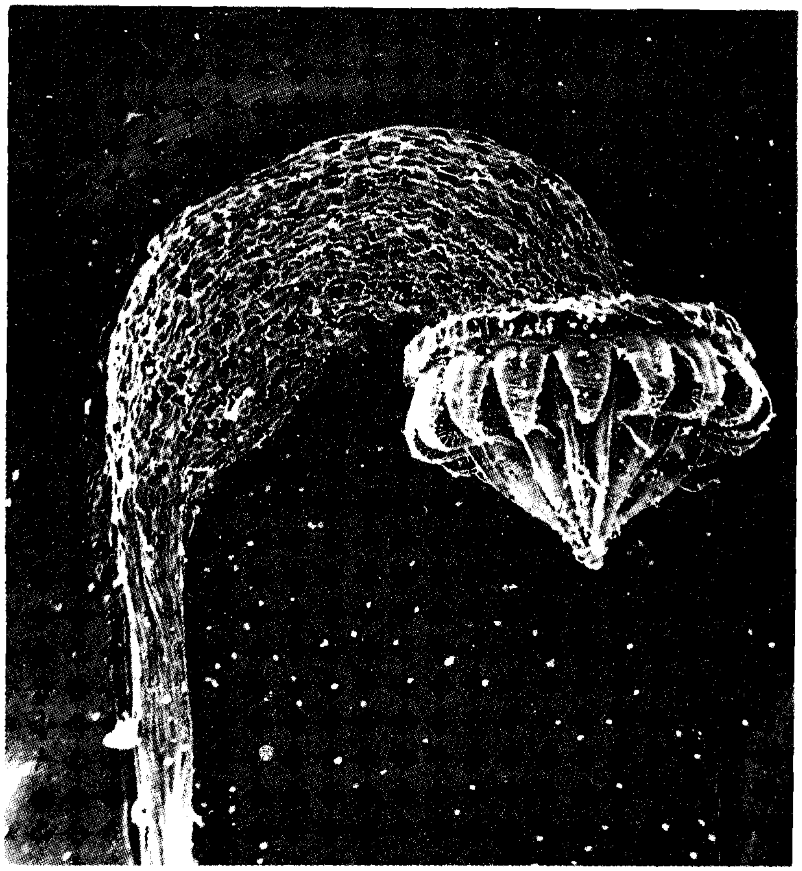

Fig. 14.19 : Scanning electron micrograph of moss capsule after removal of calyptra. Peristome teeth and spores are seen (courtsey of P. Dayanandan).

Fig.14.20: A young moss gametophyte developing from protonema (courtsey of P. Dayanandan).

elongated cells and it merges with columella present above it. The axis is surrounded by a green spongy tissue formed out of the endothecium. This spongy tissue is photosynthetic and has numerous air spaces. The spongy tissue is surrounded by an epidermis having stomata which are connected to air spaces below them. The main upper part of the capsule is a slightly curved cylindrical structure. It consists of columella in the centre surrounded by spore sac in which single-layered archesporium is located. Do you remember the position of collumella in *Anthoceros* and *Sphagnum*? See Figs. 14.13 A and 14.15 E for comparison. The columella and the inner wall of the spore sac develop from endothecium, whereas the outer wall of the spore sac and the tissues surrounding it develop from the amphithecium. A big cylindrical cavity is present on the outer side of the spore sac. This space is traversed by numerous green, elongated filaments known as trabeculae. The capsule wall is composed of parenchymatous cells. Its outermost layer is epidermis which is devoid of stomata, intially it is green but becomes dark-brown or orange when mature.

The upper region of the capsule is highly modified for dispering spores. It possesses operculum and peristome. This region is marked off from the fertile portion or theca by a constriction. Just below the constriction there is a rim which streches inwards from the epidermis of the capsule wall and joins the peristome to the epidermis. Immediately above the rim is the annulus. It is composed of 5-6 superimposed layers of epidermal cells. It helps in dehiscence of capsule. The peristome consists of two rows of curved narrow triangular plate-like teeth. In each row sixteen teeth are present and these teeths are twisted spirally to the left (Fig. 14.18 C). The teeth of outer row (exostome) are red and are ornamented with thick transverse bars, whereas teeth of inner row (endostome) are colourless, shorter and delicate (Fig. 14.18 D). The mouth of the capsule is covered by the operculum.

At maturity, the cells of the annulus absorb moisture and swell rapidly. This results in the breaking of the annulus from the rim and also in the detachment of operculum. Consequently, the peristome teeth are exposed. The members of the exostome are hygroscopic. They move out and in with changes in relative humidity of the atmosphere, and help in the dispersal of spores.

The spores germinate under favourable conditions. The exine or exospore ruptures after absorbing water (Fig. 14.18 E). Intine or endospore comes out in the form of germ tube which elongates (Fig. 14.18 F). It divides by transverse divisions forming multicellular, branched, filamentous green protonema (Figs. 14.18 H, I and 14.19). After sometime the protonema turns brown and its cross walls becomes obliquely oriented. Buds arise on this protonema and finally devlop into leafy gametophores.

SAQ 14.7

Indicate whether the following statements regarding *Funaria* are true or false by placing a letter T (True) or F (False) in the given boxes.

i) Sporophyte is differentiated into foot, seta and capsule. ☐

ii) The antheridia and archegonia are formed on the same plant but on its different branches. ☐

iii) In between antheridia in antheridial heads, many multicellular hair-like structures are present. ☐

iv) Capsule of *Funaria* is spherical and straight. ☐

v) Archesporium in *Funaria* overarches the columella. ☐

vi) Peristome teeth present near the rim of capsule help in providing nutrition. ☐

Let us now sum up the main features of three classes of bryophytes.

Hepaticopsida

1. Gametophyte is usually dorsi-ventral, either thallose or leafy. When leafy, leaves are without midrib.
2. Internally gametophyte is either simple or composed of many tissues, but the photosynthetic cells always contain numerous chloroplasts without pyrenoids.
3. Rhizoids are unicellular and unbranched.
4. Sex organs develop from dorsal superficial cells of the thallus.
5. Sporophyte may be simple; or differentiated into a foot and capsule; or into a foot, seta and capsule.
6. Archesporium develops from the endothecium of an embryo.
7. Elaters are generally present.

   Examples : *Riccia, Marchantia, Pellia*

Anthocerotopsida

1. Like Hepaticopsida the plant body is dorsi-ventral but shows no internal differentiation.
2. Each cell of the thallus usually has a single chloroplast with a conspicuous central pyrenoid.
3. Rhizoids are smooth walled, scales are absent.
4. Sex organs are hypodermal in origin and are embedded in the gametophyte.
5. Sporophyte consists of bulbous foot, a meristematic region and a long cylindrical capsule.
6. Sporophyte shows continuous growth due to the presence of intercalary meristem.
7. Archesporium develops usually from amphithecium.
8. Pseudoelaters are present.

   Examples : *Anthoceros*

Bryopsida

1. Gametophyte is differentiated into stem-like axis and leaf-like structures.
2. Rhizoids are branched, multicellular with oblique cross walls.
3. Gametophyte has two stages of development - first protonemal stage represented by multicellular branched, filamentous protonema, which is followed by next stage represented by erect leafy gametophores produced on the protonema.
4. Sex organs are situated at the apex of erect gametophore.
5. Sporophyte is generally differentiated into foot, seta and capsule. Capsule wall consists of many layers with functional or non-functional stomata. Archesporium develops from endothecium or amphithecium.
6. Peristome is present for dispersal of spores.

   Examples : *Funaria*

14.4 EVOLUTION OF SPOROPHYTE IN BRYOPHYTES

While studying the sporophytes of various genera you must have noticed a gradual increase in complexity in the structure of sporophytes from *Riccia* to *Funaria*. Bower (1935) put forward the view that from a simple (most primitive) sporophyte of *Riccia* the more complex sporophytes of higher bryophytes evolved. According to him *Riccia* is nearest to the hypothetical ancestor, and during evolution a progressive sterilization of potentially sporogenous tissue occurred. In other words, more and more sporogenous tissue was diverted for functions other than spore formation. A part of this potentially sporogenous tissue formed foot which helped in absorption and anchorage. Some of it formed chlorophyllous tissue with intercellular spaces and stomata for manufacturing food. A portion of this potentially sporogenous tissue was diverted towards the formation of elaters, operculum, peristome, seta and columella etc., which perform various functions such as storage and dispersal of spores.

From the simple and primitive sporophyte of *Riccia* an ascending series of increasing complexity up to the most complex type can be arranged. Many of the examples cited here are not included in your course for the detailed study of reproduction, but are essential for a complete story.

In the simplest form as in *Riccia*, sporophyte is represented only by a capsule with single layered jacket enclosing a mass of spores only. Next stage in this series is found in forms like *Corsinia*, which also belongs to Hepaticopsida, where a very small sterile foot develops. Their capsule has a single-layered jacket, but inside the capsule some of the sporogenous cells, instead of forming spores, form sterile nutritive cells. In the next stage represented by *Targionia*, the foot becomes larger and a narrow seta as well as elaters also develop from the potentially sporogenous tissue. The next stage is seen in *Marchantia* sporophyte which as you know has broad foot, well developed seta and long elaters with spiral thickenings. The sterilization of sporogenous tissue continued as is evident in *Pellia* in which sterile tissue consists of a massive foot, a long, seta and capsule with multilayered jacket, normal elaters as well as an elaterophore. The actual sporogenous tissue has been reduced to a small percent of the total sporophyte.

Further, a marked reduction in the sporogenous tissue due to still more sterilization is found in *Anthoceros*. The sterile tissue comprise foot, 4-6 layered wall of capsule having stomata, chlorophyllose tissue, central columella of elongated cells, and pseudoelaters. The sporogenous tissue is represented only by sporocytes. Among the bryophytes, the highest degree of sterilization of potentially sporogenous tissue is seen in mosses, e.g., *Funaria*. In this moss the sterile tissue consists of a foot, a long seta, the apophysis, the many-layered wall of the capsule, the columella, the wall of the spore sac, the peristome, annulus and operculum.

In the following Block on Pteridophytes, you will learn that sporophyte becomes the *dominant phase* in life cycle.

14.5 SUMMARY

In this unit on reproduction in bryophytes you have learnt that

- In bryophytes sexual reproduction is of oogmaous type in which female gamete is non-motile and male gamete is motile. Male and female sex organs are known as antheridium and archegonium, respectively. The sex organs are protected by a layer of cells appearing like a jacket. The zygote shows no resting period and it produces an embryo by mitoses. Subsequently spores develop in the capsule by meiotic divisions. The spore on germination produces protonema which gives rise to gametophyte.
- In *Riccia* sex organs are embedded in the median furrow on the dorsal surface of thallus. Sporophyte is represented only by capsule. Foot and seta are absent. Archesporium forms only spores.
- In *Marchantia* antheridia and archegonia are borne on stalked receptacles, antheridiophore and archegoniophore, respectively. Sporophyte is differentiated into foot, seta and capsule which has one celled thick wall. Besides spores the capsule has elaters.
- In *Pellia* antheridia are embedded in the thallus, whereas archegonia arise on dorsal surface and are protected by an involucre. Sporophyte is differentiated into conical foot, long seta and spherical capsule with multilayered jacket. Inside the capsule spores, elaters and a fixed elaterophore are present. A special feature is the germination of spores inside the capsule.
- In *Anthoceros* antheridia are produced in roofed cavities, and neck of archegonium does not project above the thallus. The sporophyte has bulbous foot, a meristematic zone and horn-like capsule with columella in the centre surrounded by spores and pseudoelaters.

- In *Sphagnum* antheridia and archegonia are produced on separate branches. Antheridia are borne below the leaves, whereas archegonia are terminal. Sporophyte is differentiated into globose capsule and bulbous foot, seta being absent. Columella which is dome-shaped is overarched by archesporium. Sporophytes are raised by a gametophytic stalk-like structure known as pseudopodium.
- In *Funaria* antheridia and archegonia are produced on separate branches on the same plant. Paraphyses are present among the sex organs which are produced in terminal clusters. Sporophyte is differentiated into foot, a long seta and pear-shaped capsule which is bent slightly. Capsule has columella in the centre surrounded by one-celled thick archesporium, a large air space, and many celled thick capsule wall. On the upper part of capsule two rings of peristome teeth are present which are covered by an operculum.
- During evolution of sporophyte in bryophytes, a progressive sterilization of potentially sporogenous tissue occurred.

14.6 TERMINAL QUESTIONS

1. Draw labelled diagrams of L.S. of the sporophytes of *Riccia*, *Anthoceros* and *Sphagnum* and compare their structure.

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2. Describe briefly the development of antheridium in *Anthoceros*. How is it different from that in *Marchantia*.

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3. Describe the evolution of sporophyte in bryophytes.

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4. Draw a labelled diagram of L.S. of a capsule of *Funaria*.

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5. Enumerate major steps of life cycle of a bryophyte.

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14.7 ANSWERS

Self-assesment Questions

14.1
i) T
ii) F
iii) T
iv) F
v) F
vi) T
vii) T
viii) T

14.2
i) monoecious
ii) median furrow
iii) superficial cells
iv) unilayered
v) biflagellated
vi) singly
vii) essential
viii) endothecium
ix) meiosis

14.3
i) gemmae
ii) dioecious
iii) gametangiophores
iv) branch
v) upper
vi) downwards
vii) six
viii) elaters

14.4
i) F
ii) T
iii) T
iv) F.
v) F
vi) T
vii) T

14.5
a) i) T
ii) T
iii) T
iv) T
v) F

b) i) hypodermal,
ii) do not project,
iii) roofed

14.6
a) i) F
ii) T
iii) T
iv) T

b) i) apical,
ii) pseudopodium,
iii) operculum,
iv) collumella

14.7
i) T
ii) T
iii) T
iv) F
v) F
vi) F

Terminal Questions

1. Ref. to sec. 14.3.1, 14.3.4, 14.3.5
2. Ref. to sec. 14.3.2 and 14.3.4
3. Ref. to sec. 14.4
4. Ref. to Fig. 14.17
5. Ref. to sec. 13.2.

UNIT 2 INTRODUCTION TO CYANOBACTERIA, FUNGI, ALGAE AND LOWER PLANTS

Structure

2.1 INTRODUCTION

In Unit 1 you learnt about the origin of life, diversity of living things, classification of organisms and what are the different groups of organisms that are studied by botanists. The rest of this course on plant diversity is devoted to a study of individual groups, namely, algae, fungi, bryophytes and pteridophytes. The gymnosperms and angiosperms are discussed in Plant Diversity – 2.

In this Unit you are briefly introduced to the characteristics of the different groups, from cyanobacteria to the pteridophytes. Table 1.2 gives a broad outline of classification of organisms into kingdoms and divisions. In this Unit current views on further classification of different groups are summarised. You will note that modern classification schemes are strongly phylogenetic and try to bring out the evolutionary history and relationship among the various taxa in each group.

The purpose of this Unit is to give an overview of the different groups of organisms you will be studying. These groups are: 1) The cyanobacteria which are prokaryotic and along with bacteria, are members of the kingdom Monera. 2) The fungi which are eukaryotic and nonphotosynthetic members of the fungal kingdom. 3) The algae, all of which are eukaryotes, photosynthetic and may be unicellular or multicellular in organisation. All these are members of the kingdom Protista. 4) The bryophytes which are true land plants that produce embryos but do not have highly developed vascular tissues for conduction of food and water, and 5) The pteridophytes which have embryos and well-developed vascular tissues. They include the familiar ferns and a number of allied plants of ancient lineages. The bryophytes and pteridophytes are true members of the plant kingdom.

Objectives

After reading this Unit you will be able to

- describe the characteristics of different groups of organisms,
- contrast the characteristics that are the basis of categorising the organisms in different groups,
- discuss the diversity within each group of organisms,
- explain how biologists classify each group and
- discuss the evolutionary history of each group.

2.2 CYANOBACTERIA

The cyanobacteria are true bacteria (singular, bacterium). They are prokaryotes and do not possess a true nucleus or membrane-bound organelles such as mitochondria or plastids. Like other prokaryotes they have 70S ribosomes. Although there are other bacteria which can photosynthesise, the cynaobacteria are unique in possessing the pigment chlorophyll *a*. This pigment is also present in algae and plants and is responsible for the evolution of oxygen during photosynthesis. The photosynthetic bacteria possess a different kind of pigment, bacteriochlorophyll which does not permit oxygen evolution during bacterial photosynthesis.

The term "cyan" in cyanobacteria refers to the colour, blue. Cyanobacteria possess certain accessory pigments such as phycocyanin and phycoerythrin. The presence of these pigments and chlorophyll *a* together impart characteristic colour to these organisms. *It is for this reason that the cyanobacteria are commonly known as blue-green algae.* Like true algae they also evolve oxygen during photosynthesis and often occupy habitats where algae occur, in fresh, marine and brackish water bodies and on moist soil surface. However, true algae are eukaryotic and the two are not immediately related.

Since the affinities of the cyanobacteria are with the other bacteria we must briefly examine these organisms *for a more complete picture of the position of cyanobacteria in* the world of living things. About 4,000 species of bacteria have been described so far. These include about 1,700 species of cyanobacteria. Although small in number of species, bacteria are the most abundant of all organisms. They are also the most ancient. (Not the amoeba, which is a eukaryote of later origin). Bacteria are known in the fossil record as far back as 3.5 billion years ago. Bacteria are morphologically and anatomically the simplest of organisms. Yet, metabolically they are very diverse. Many bacteria are identified not by the morphology of the individuals but by their characteristics in culture.

Bacteria are very small, ranging in size between 1 to few µm. A most unusual discovery was made in 1993 of a bacterium living in the intestinal tracts of a surgeonfish that is 600 µm in length! Bacteria vary in shape. Some are rod-shaped, others spherical and yet others spiral or even comma-shaped. Tiny as they are, bacteria are responsible for activities that strongly affect our lives. Many are agents of serious diseases of human beings, animals and plants. Others ferment food and are thus useful in making varied products such as curd or 'idli' as well as many industrial chemicals. Some are the source of life-saving antibiotics.

Bergey's Manual of Determinative Bacteriology is the standard reference for the classification of bacteria. Since sufficient information is not available to place all bacteria into a hierarchical system of classification, the Bergey's Manual recognises 19 major groups such as the spirochaetes, Gram-positive cocci, gliding bacteria, mycoplasma and actinomycetes. Cyanobacteria is included in one such group. The classification of bacteria is an active area of research. In recent years molecular biologists have analysed the structure of ribosomal RNA (rRNA) and the sequence of rRNA nucleotides in bacteria and other organisms. Such analysis has revealed fundamental differences among two major bacterial groups, the ARCHAEBACTERIA and EUBACTERIA. Differences have also been noted in the chemical composition of the cell membranes of these two bacterial groups and the eukaryotes.

The American scientist Carl Woese considers that the differences between the archaebacteria and the eubacteria are as fundamental as between these groups and the eukaryotes. Thus, life on this planet is considered to comprise of three ancient and primary lineages. The three ancient domains are shown in Fig. 2.1. The cyanobacteria are members of the true bacterial lineage. The archaebacteria include members that live in most unusual environments such as very hot and acidic pools or in waters with extremely high salt contents. Some members of this group live in deep sea vents several kilometres below the ocean surface. The bacteria which produce methane gas are called methanogens.

Cyanobacteria are of great evolutionary interest. According to the endosymbiont theory some ancestral cyanobacterial cells became the plastids of different algal groups. The plastids of red algae resemble the cells of cyanobacteria and both possess chlorophyll *a* and biliproteins. The green algae and plants possess both chlorophylls *a* and *b*. Although most cyanobacteria possess only chlorophyll *a* at least three organisms are known to contain both the chlorophylls. *Prochloron didemni* live as symbionts in the gut walls of sea squirts. *Prochlorothrix hollandica* was recently discovered in lakes in Holland. More recently *Prochlorococcus* was discovered as a free-floating form in open seas. All these organisms possess chlorophylls *a* and *b*, and their cells resemble the chloroplasts of green algae and plants. For this reason, some authors describe them as prochlorophytes and include the three genera in a separate division or class. Some ancestral prochlorophyte was perhaps the endosymbiont that evolved into the green plant chloroplast.

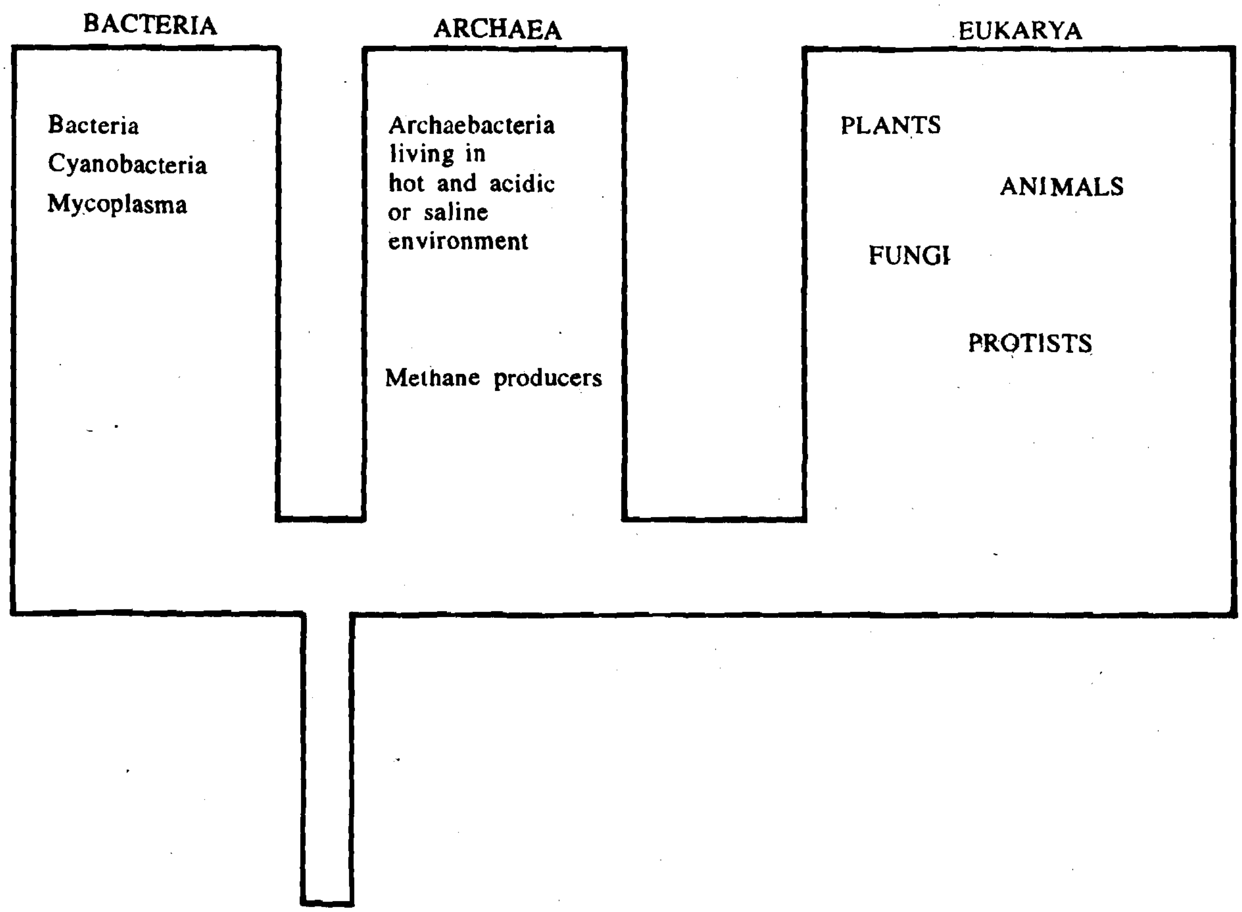


Fig. 2.1 : Three domains of organisms representing ancient and primary lineages.

SAQ 2.1

Indicate whether the following statements are **true** (T) or **false** (F) by pacing the appropriate letters in the space provided.

i) Blue-green algae are closely related to the green algae rather than to the bacteria. ☐

ii) Cyanobacteria possess chlorophyll *a* and evolve oxygen during photosynthesis. ☐

iii) Archaebacteria are prokaryotes and eubacteria are eukaryotes ☐

iv) *Prochloron* is an unusual prokaryote with chlorophylls *a* and *b*. ☐

v) Bacteria are among the simplest of organisms in terms of structural organisation. ☐

2.3 FUNGI

Fungi are a vast assemblage of 95,000 organisms. All of them completely lack photosynthesis. They are heterotrophs that depend upon other living or dead matter for nutrition. As parasites many are serious pathogens on other plants. As saprotrophs they, along with bacteria, degrade dead organisms and release organic chemicals and nutrient elements so they can be recycled. About 13,500 fungal species have a unique association with some algal partners resulting in symbiotic structures known as lichens. The majority of higher plants possess mycorrhizal association where some species of fungi live as symbionts inside or around the roots.

Fungi are eukaryotes. They are an ancient group. Fossil evidence shows that all major fungal groups known today had already evolved by the end of the Paleozoic era, about 280 million years ago. At a time when all living things were grouped under either the animal or the plant kingdom the fungi were thought to be plants. We now place all fungi in the kingdom, Fungi (Myceate). Members of this kingdom lack plastids. They are mostly filamentous in construction. Except in one group their walls contain chitin rather than cellulose. Fungi do not store starch as plants do. The filamentous structures that make up the fungal body are known as mycelia (singular, mycelium). Although the filaments are microscopic, the extensive growth of fungal mycelium can be seen as a fuzzy mass. The reproductive bodies of some fungi such as the mushrooms are made up of well defined aggregates of mycelia. Complex tissues and organs characteristic of the plants are never found among the fungi. Fungi reproduce by spores (before you read on have a good look at the figures of fungi in Unit 7, Block 2).

In spite of the many features that seem to unite the members of the fungal kingdom the fungi are a heterogenous group. Fungi are classified into 7 divisions (Table 1.2). Relationships among these groups are shown in Fig. 2.2. The slime molds (Myxomycota) are not true fungi. They appear to have evolved independently from some protozoan ancestors. In their vegetative phase the slime molds lack a cell wall. The wall-less cells aggregate to form an amoeba-like mass that moves around and engulfs bacteria and other organic matter. Two groups of slime molds are known: the plasmodial slime molds with a multinucleate true plasmodium and the cellular slime molds. The vegetative body of cellular slime molds is a pseudoplasmodium where the aggregating cells retain their cell membranes and individuality. Slime molds produce motile spores.

The oomycetes or water molds differ from other fungi by the possession of cellulose in their cell walls. The fungal body is diploid rather than haploid as in other true fungi. These and other features of reproduction and metabolism suggest that the oomycetes are not related to other fungal groups. They might have evolved from some green or yellow-green algal ancestors after losing their plastids.

The chytrids are simple water molds that live as parasites or saprotrophs. Because they possess motile spores they are often classified with the oomycetes. However, the chytrids have chitin and their filaments are haploid. They are probably distantly related to the bread molds and other true fungi.

The zygomycetes (bread molds), ascomycetes (sac fungi) and basidiomycetes (club fungi) are evolutionarily related as shown in Fig. 2.2. None of them produce motile cells at any stage of their life cycle. The fungal filaments do not have septa (cross walls) in the zygomycetes. The mycelium is septate in the other two groups.

Fungi reproduce asexually and sexually. In sexual reproduction the ascomycetes produce characteristic structures known as asci (singular, ascus). Basidia are the equivalent structures among the basidiomycetes. A fungal species can be assigned to either one of these groups only when they produce an ascus or basidium. A vast number of fungi, about 22,000 species, reproduce only asexually, *or* sexual cycle has not been observed yet. Because their life cycle is imperfectly known and they cannot be assigned with confidence to either one of the groups they are known as **Fungi Imperfecti**. The divisional name Deuteromycota is often used for this group of imperfect fungi. When the sexual life cycle is known the species is automatically assigned to either the ascomycetes or the basidiomycetes.

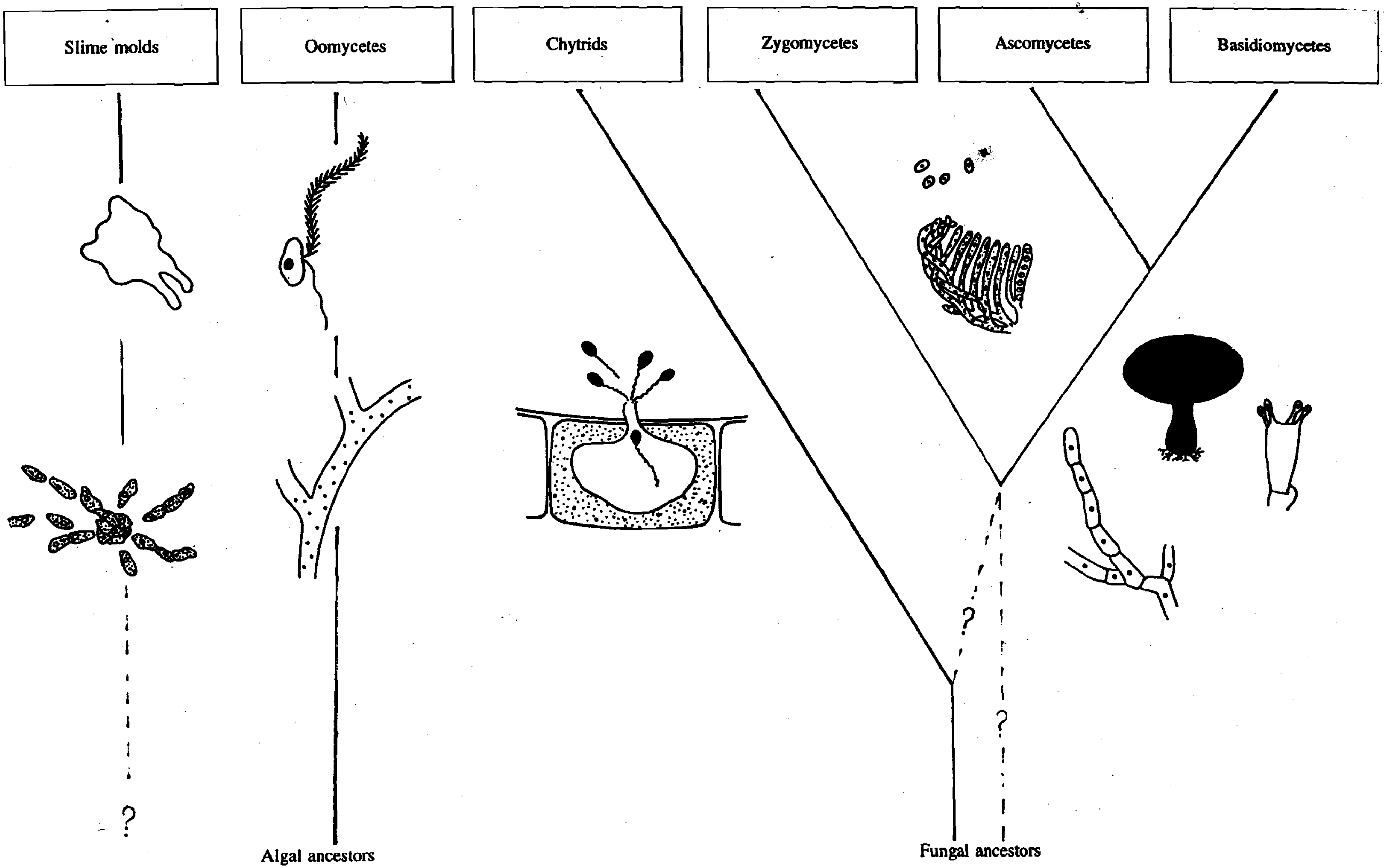


Fig. 2.2 : Relationship among fungal groups.

Lichens are unique organisms consisting of a fungal and an algal partner. Less than 40 algal or cyanobacterial species enter into this association. Yet, there are about 13,500 species of lichens! The characteristic form of each lichen appears to be determined by the fungal component. About 2% of the species have either a basidiomycete or an imperfect fungus as the fungal partner. The remaining 98% of lichens are composed of ascomycete species. The lichens are not considered to be a separate taxonomic category. Rather, they are treated as members of the respective fungal divisions, and the name of a lichen refers to the name of its fungal partner.

In Table 2.2 the fungi are divided into 7 formal divisions. In other classifications only two divisions are recognised, the Myxomycota (slime molds) and Eumycota (true fungi). The latter is divided into subdivisions and classes etc.

SAQ 2.2

Fill in the blanks with suitable sentences.

i) Cell walls of most fungi contain .... rather than cellulose.

ii) Fungi are heterotrophs and obtain their carbon compounds as .... or ....

iii) The association of fungi with roots of plants is known as .... while their association with algae result in organisms known as ....

iv) The .... fungi have cellulose in their walls and might have evolved from algal ancestors.

v) Flagellated cells are completely lacking in ...., ... and ....

2.4 ALGAE

Algae are eukaryotes. Most algae live in marine and fresh water habitats. In the five-kingdom system described in Fig. 1.3 all algae are included in the kingdom Protista. This is clearly an artificial grouping, for some of the green algae are more related to true plants than to other algae. Some algal members such as the unicellular euglenoids and cryptomonads are probably protozoans that acquired plastids through endosymbiosis. Indeed of the 36 genera of euglenoids 25 genera do not possess chloroplasts and live as heterotrophs.

There are about 24,000 species of algae described so far. The algae as a group is autotrophic, synthesising food through photosynthesis. During photosynthesis they evolve oxygen as the plants do. Plants and algae differ in many respects. One major difference between the two groups concerns the way in which reproductive structures are organised. The reproductive structures of algae are not covered by a protective sterile tissue. Instead all cells are converted into spores or gametes. In plants a sterile jacket is present as an essential part of reproductive structures.

How can we classify this vast assemblage of algae? Phycologists (also known as algalogists), use a variety of characters to help delimit the different algal groups. These are summarised below.

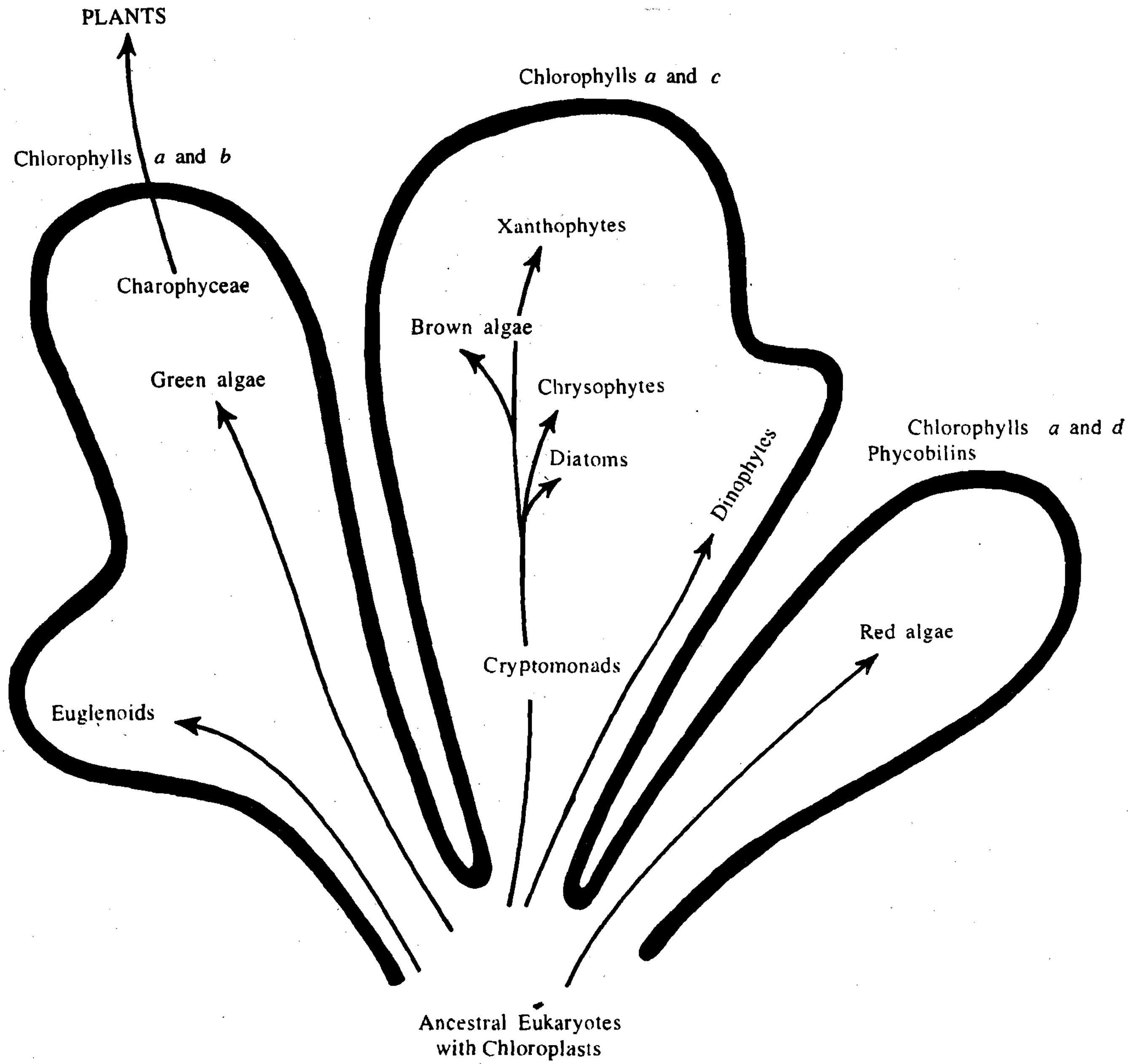


Fig. 2.3 : Relationship among algal groups

Pigments in plastids. The presence of different chlorophyll pigments and photosynthetic accessory pigments (Fig. 2.3).

Food reserves. Different algal groups store food as starch, oils etc.

Cell wall. The cell walls may contain cellulose or other polysaccharides. Some algae have naked cells. Cell walls may be incrusted with silica, calcium carbonate and scaley structures.

Flagella. The number and kinds of flagella as well the location of flagella are helpful. Whiplash flagella have a smooth surface while the tinsel flagella possess fine hairs. Flagella are completely lacking in the red algae (Fig. 2.4).

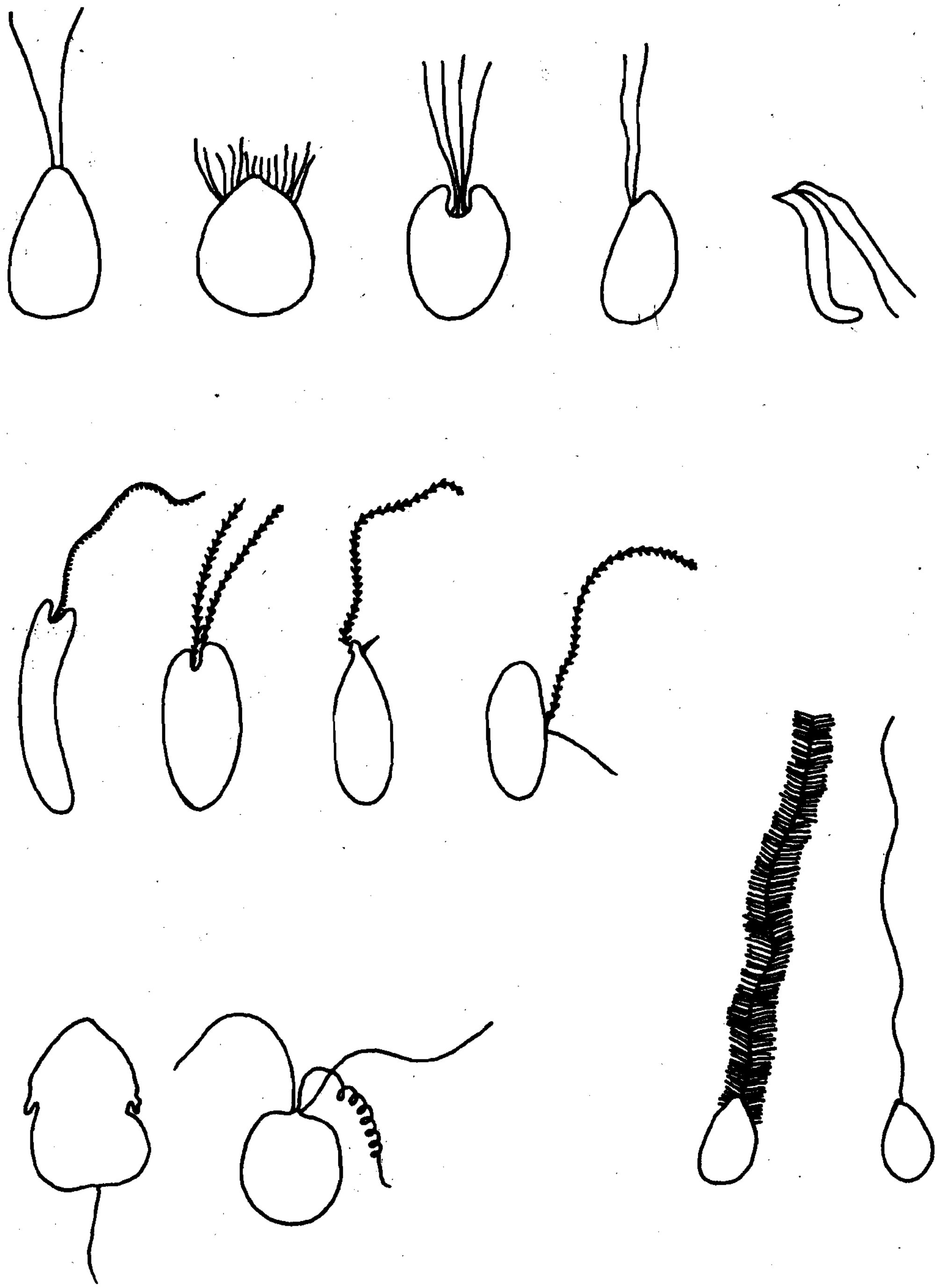


Fig. 2.4 : Structure and arrangement of flagella in different algal groups. Note that a flagellum can be smooth or feathery. Flagella are inserted terminally or laterally and singly or more than one per cell.

Cell division. Four different kinds of cytokinesis are known in algal groups: furrowing, cell division by phycoplast and two kinds of phragmoplasts (Fig. 2.5)

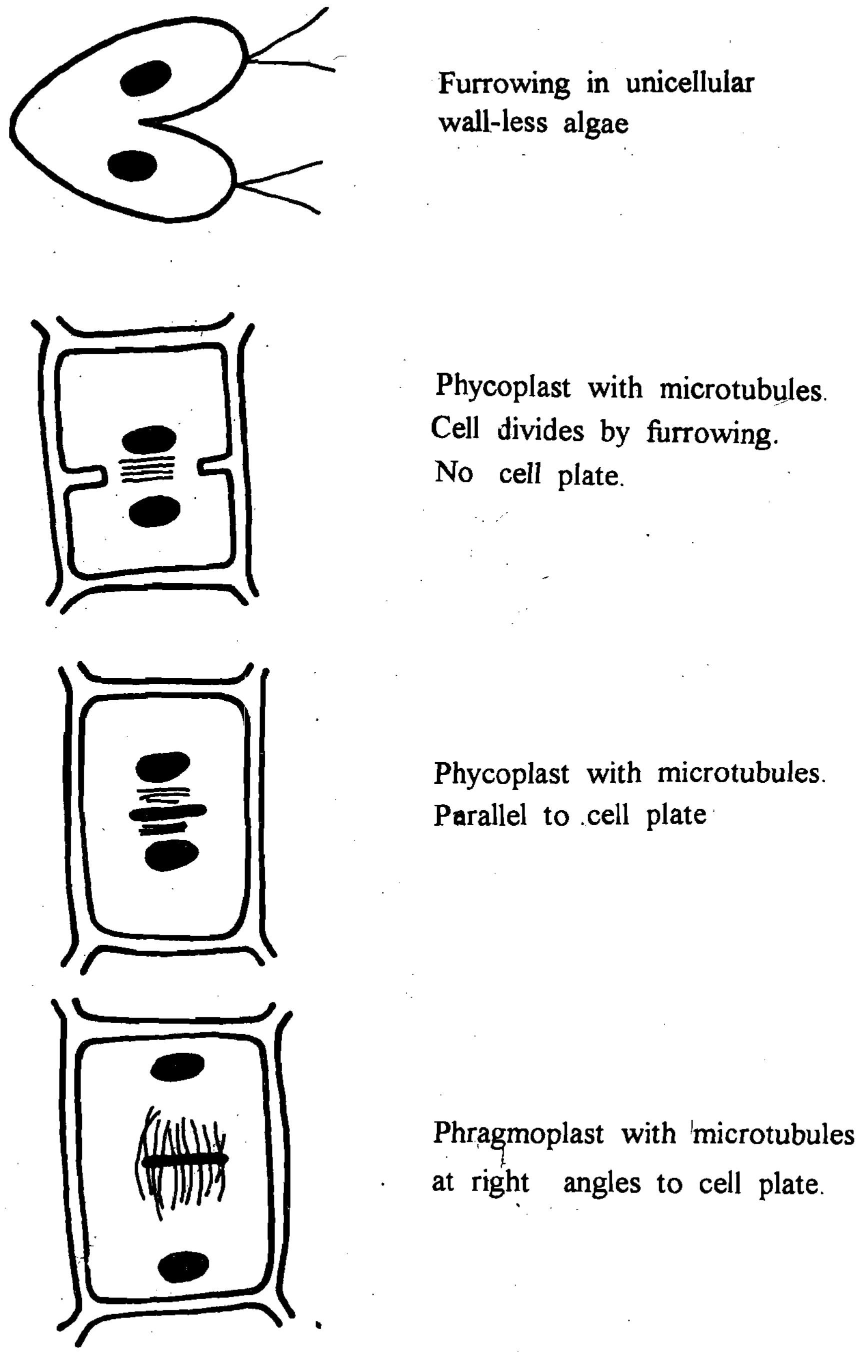


Fig. 2.5 : Cytokinesis in Algae.

Chloroplast organisation. Ultrastructure of chloroplast reveals differences in the organisation of photosynthetic and surrounding membranes (Fig. 2.6).

Morphological organisation. Algal thallus may be unicellular, motile, sessile, colonial, filamentous, branched, coenocytic or multicellular with parenchymatous organisation.

Life cycle. The morphology of the haploid and diploid generations also helps in the recognition of different algal groups. Reproduction in algae is covered in detail in Unit 4 of Block 1-B, Algae.

Figure 2.3 summarises one possible scheme of relationships among the different algal groups. The red algae (Rhodophyta) probably evolved from some ancestral eukaryotes after the symbiotic acquisition of a cyanobacterial cell as the chloroplast. Red algal chloroplasts are remarkably similar to cyanobacterial cells in ultrastructure and chemical

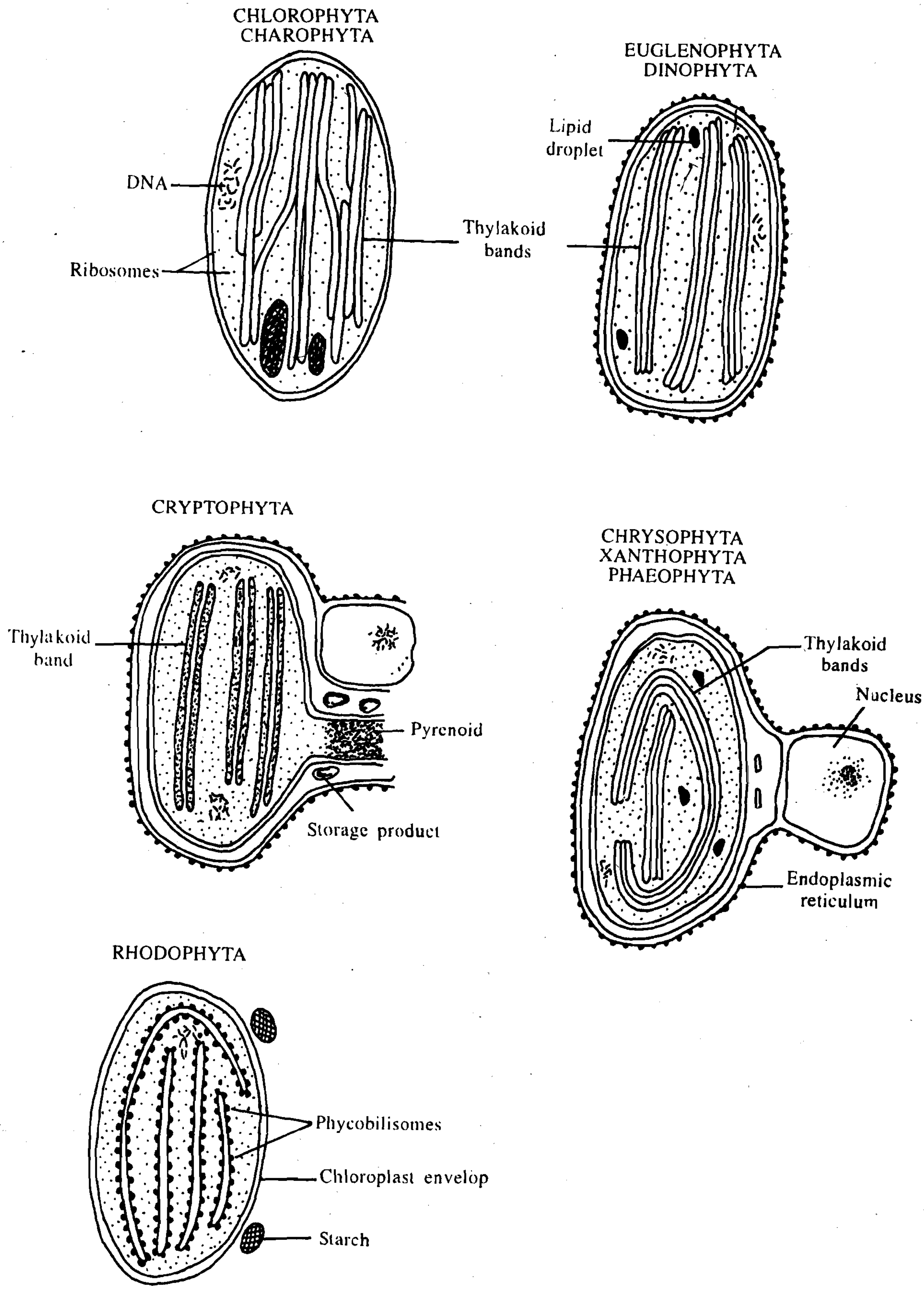


Fig. 2.6 : Ultrastructure of chloroplasts in different algal groups.

composition. As in cyanobacteria, the red algae possess chlorophyll *a* and the biliproteins. In addition the red algae possess chlorophyll *d*.

Several algal groups treated as divisions in Table 1.2 are sometimes collectively known as **chromophytes**. The chromophytes are characterised by the presence of chlorophyll *a* and *c* This group includes the cryptomonads (Cryptophyta), dinoflagellates (Dinophyta), diatoms and golden-brown algae (Chrysophyceae), yellow-green algae (Xanthophyta) and brown algae (Phaeophyta). Unlike the red algae all the chromophytes possess motile cells at some stage of their life cycles. The dinoflagellates do not possess histones that are characteristic of other eukaryotes. The chromosomes remain permanently condensed. These and other features suggest that the *dinoflagellates* might represent an independent line of evolution.

The green algae (Chlorophyceae) and the euglenoids (Euglenophyceae) possess both chlorophyll *a* and *b*. In this respect they resemble higher plants. However, the euglenoids are probably more related to the protozoans. The green algae include an important subgroup, the charophytes, which is considered to be the ancestors of true plants. As discussed earlier the plastids of green algae might have originated from cells similar to *Prochloron* by endosymbiosis. This prokaryote is unusual in possessing both chlorophylls *a* and *b*. Many green algae including charophytes and red algae are known from fossils dated to be 400 million years old.

In Table 1.2 we have grouped algae under 8 different divisions. Some authors recognise only 4 divisions: Chromophyta, Rhodophyta, Euglenophyta and Chlorophyta and include others as classes under Chromophyta. It should be emphasised that while phycologists may study the blue-green algae (cyanobacteria) along with other algal groups the cyanobacteria are true prokaryotes related to the bacteria and are hence members of the kingdom Monera.

SAQ 2.3

Match the words in column A with the most suitable words in column B

	Column A		Column B	
i)	red algae	(a)	dinoflagellates	( )
ii)	diatoms	(b)	chrysophyceae	( )
iii)	green algae	(c)	chlorophylls *a* and *b*	( )
iv)	condensed chromosomes	(d)	chlorophylls *a* and *c*	( )
v)	chromophytes	(e)	chlorophylls *a* and *d*	( )

2.5 BRYOPHYTES

Bryophytes are true plants. Three other groups of organisms are also members of the plant kingdom. These are the pteridophytes, gymnosperms and angiosperms. Together they are also known as **land plants** and **embryophytes**. All members of the above four groups of plants produce a multicellular embryo that is nutritionally dependent upon the maternal tissue and represents the next sporophytic generation. The embryos within the seeds of flowering plants are familiar to you.

The bryophytes differ from the other embryophytes by the absence of specialised vascular tissues characteristic of the pteridophytes, gymnosperms and angiosperms. These more advanced groups possess xylem and phloem. The xylem is composed of dead conductive cells whose cell walls are reinforced by a highly resistant polyphenolic compound, lignin. All land plants other than the bryophytes are also known as vascular plants. Bryophytes are nonvascular land plants. Some members, such as certain mosses, of the bryophytes do possess conductive tissue that transport water but these conductive cells do not possess lignified thickenings characteristic of vascular plants.

Some botanists restrict the term 'land plants' to vascular land plants. However, it is more desirable to include the bryophytes also as land plants. Land plants have recently been defined as photosynthetic organisms customarily living on land and having relations with other plants living on land. Land plants have several adaptations that enable them to survive on a terrestrial habitat. These include protective coverings over the plant body and pores known as stomata. Land plants must obtain water from the soil. To prevent evaporation and desiccation the epidermis of land plants is covered with a highly water impermeable **cuticle**. Spores and pollen are minute reproductive cells released into the air. Their walls too are made up of one of the most resistant organic chemicals known, **sporopollenin**. In order to regulate entry of carbondioxide and exit of water vapour the epidermis is also provided with stomata. A stomatal apparatus consists of two kidney-shaped cells surrounding a pore. Most land plants including many bryophytes possess stomata.

One of the most interesting fields of plant biology is the study of the origin of land plants. Fossil evidence indicates that authentic land plants lived about 400-430 million years ago. During this period known as the Silurian there were small, dichotomously branched plants known as **Cooksonia**. *Cooksonia* was a vascular land plant. Microfossils of spores, cuticles and conductive tubes have been discovered from 450-470 million year old sediments suggesting that land plants might have existed millions of years before the arrival of *Cooksonia*. Bryophytes are not known from such early periods. This may be because the fragile thallus of the bryophytes may not have been well preserved in fossils.

Scientists now believe that land plants might have originated from some fresh water algal members about 470 million years ago. They were probably derived from green algal ancestors of the group related to modern green algae such as the stoneworts (*Chara* and *Nitella*) and **Coleochaete**. These charophycean members share several structural and biochemical similarities with the land plants. The ancestors of land plants might have resembled some modern Coleochaete. The earliest land plants would have been nonvascular embryophytes, not unlike some liverworts. It is likely that two subsequent lines of evolution might have resulted in the bryophyte and vascular land plant groups.

There are about 23,000 species of bryophytes described so far. All these are small green plants, measuring in centimetres, and devoid of roots. They occur in a variety of moist terrestrial habitats. As is true of other land plants they are multicellular and parenchymatous. Life cycle consists of a prominent gametophytic and less prominent sporophytic alternation of generations. Bryophytes include the familiar mosses, the less familiar liverworts and hornworts. Bryologists consider these three groups to be closely related and classify them as three classes under the division Bryophyta.

Division: Bryophyta
Classes: Hepaticopsida (liverworts)
Anthocerotopsida (hornworts)
Bryopsida (mosses)

Some bryologists who consider members of the three classes to be much less related to each other elevate them to divisional levels: 1.Hepatophyta 2. Anthocerotophyta, and 3. Bryophyta. In species abundance the bryophytes are dominated by mosses (14,000) followed by liverworts (8,500) and hornworts (350).

2.6 PTERIDOPHYTES

Pteridophytes are vascular land plants. Unlike the bryophytes they possess typical xylem and phloem tissue characteristic of vascular plants. Like the bryophytes they are also embryophytes. Pteridophytes reproduce by spores but never by seeds. Thus, it is convenient to further classify the vascular plants into non-seed producing pteridophytes (also known as vascular cryptogames) and seed producing gymnosperms and angiosperms. The later two groups will be discussed in the course Plant Diversity – 2.

The pteridophytes include ferns and their allies. In Table 1.2 the fern allies are classified under three divisions: Psilotophyta, Lycopodiophyta and Equisetophyta. There are about 1,000 species of fern allies. They are descendants of very ancient groups of vascular plants and are therefore of great interest to students of plant evolution (Fig. 2.7). About 10,000 species of ferns are included in the division, Pterophyta. We have a rich collection of fossils that represent many extinct members of pteridophytes including major groups that are known only from fossils. In recent years scientists have studied these groups in detail and have established possible evolutionary relationships among the early vascular plants (Fig. 2.11). Although you may not study representatives of all these groups it is essential that we list the major divisions of living and extinct pteridophytes to fully comprehend the diversity and importance of early vascular plants:

Extinct pteridophytes known only from fossil record

Rhyniophyta
Zosterophyllophyta
Trimerophyta

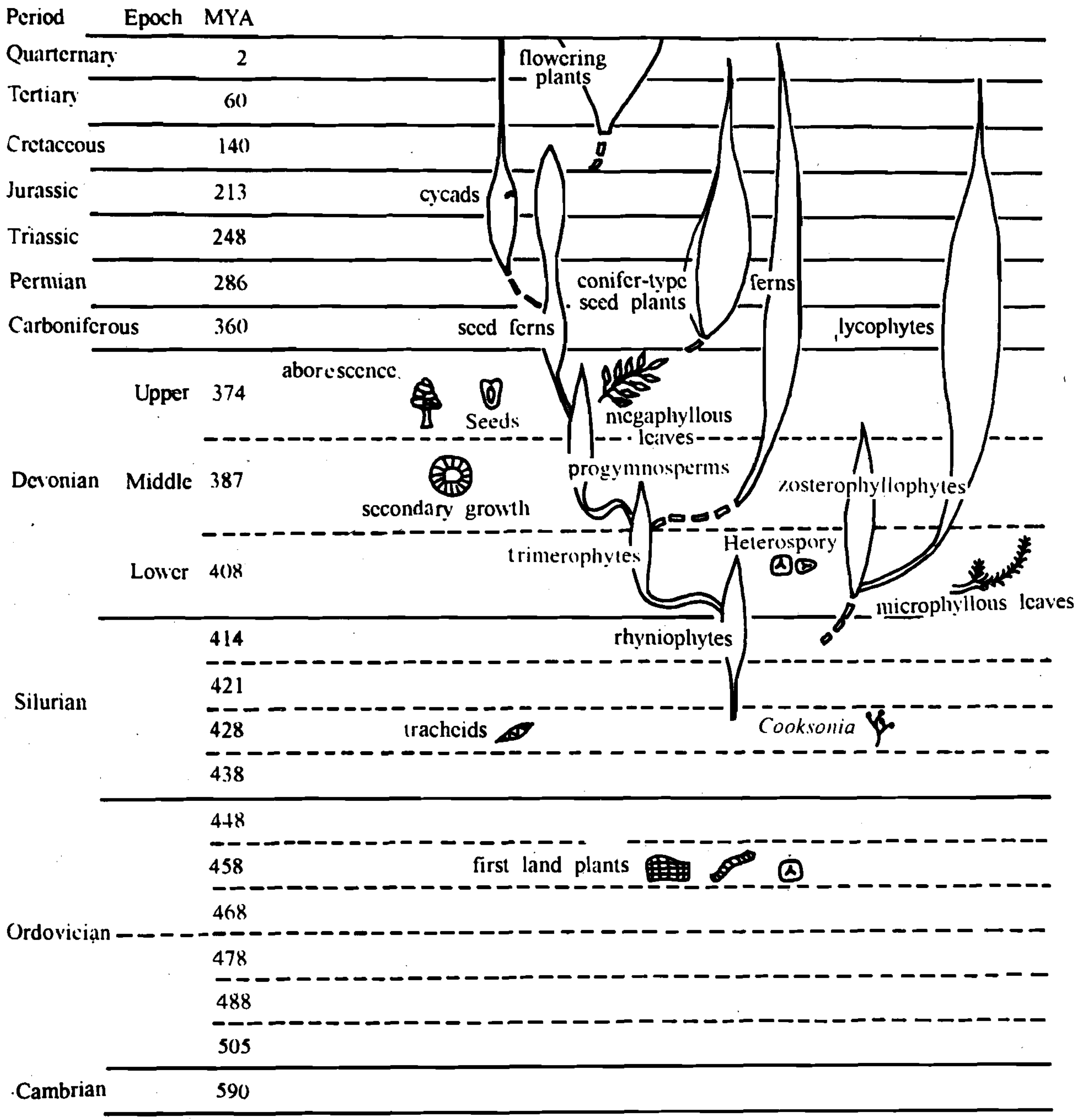


Fig. 2.7: Geological time chart. This chart illustrates the time of appearance of land plants and different groups of vascular plants. Time is given in millions of years ago (MYA). (After Gensel and Andrews)

Living pteridophytes
Psilotophyta
Lycopodiophyta
Equisetophyta
Pterophyta

Some members of the fossil pteridophytes are illustrated in Figs. 2.8 – 2.10. The geological time chart (Fig. 2.7) is an important aid in our understanding of the history of plant life. The chart depicts not only the time when various plant groups evolved or became extinct but also the relationships among the different groups and the abundance of species in each group during the course of its history. You should also refer to Figure 2.11 that presents a simplified version of possible evolutionary relationships among extinct and living land plants.

The earliest group of vascular plants known from about 420 million-year-old sedimentary rocks is the rhyniophytes. The earliest and best known genus of this group is *Cooksonia* (Fig. 2.9).

The genus *Rhynia* evolved soon after. These early vascular plants had adaptations suited to live on land. In addition to cuticle, stomata, sporopollenin and a multicellular body these plants also possessed true xylem tissue consisting of lignified tracheids. The rhyniophytes might have evolved from more primitive vascular plants which in turn might have evolved from some ancestral bryophytes or directly from some ancestral green algae. A number of well preserved fossils from the Rhynie chert indicate that some of them are gametophytes rather than sporophytes (Fig. 2.9). It is likely that plants superficially resembling each other might have represented haploid and diploid generations of the same species.

Another major Devonian vascular plant group was the zosterophyllophytes. It is likely that an offshoot of this group developed into the lycopodiophytes (lycopods). The lycopods were a successful group that dominated the earth's vegetation in the Carboniferous period (Fig. 2.10). Today the lycopods are represented by only about 200 species. About 700 species of *Selaginella* and more than 60 species of *Isoetes* are usually studied along with *Lycopodium*. However, these are more directly related to the rhyniophytes rather than to the zosterophyllophytes.

The trimerophytes also evolved from the rhyniophytes (Fig. 2.11). This is an important group from which three major vascular plant groups evolved — the equisetophytes, ferns and seed plants. The former is now represented by the single genus *Equisetum* with about 15 species. *Calamites* was a giant member of this group that lived during the Carboniferous period (Fig. 2.10).

The division Psilotophyta includes two living genera, *Psilotum* and *Tmesipteris*. Structurally these are the simplest known living vascular plants. Unfortunately nothing is known of their fossil history to relate them to extinct groups. Some pteridologists consider these interesting plants to be highly reduced members of ferns rather than any fern allies.

Fig. 2.8 : A reconstruction of the Devonian landscape, some 400 million years ago showing some of the early vascular plants that lived then. (After Gensel and Andrews)

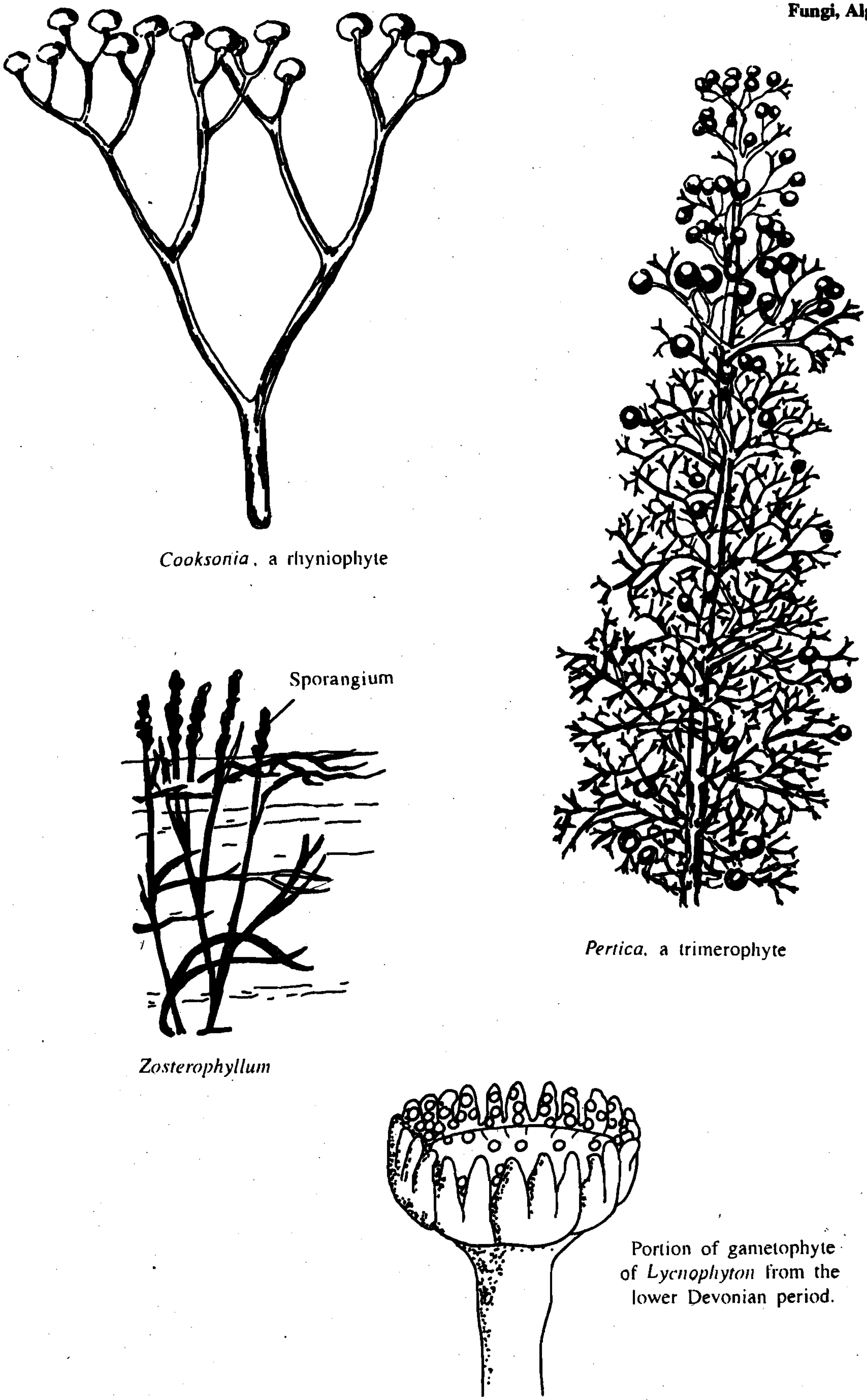
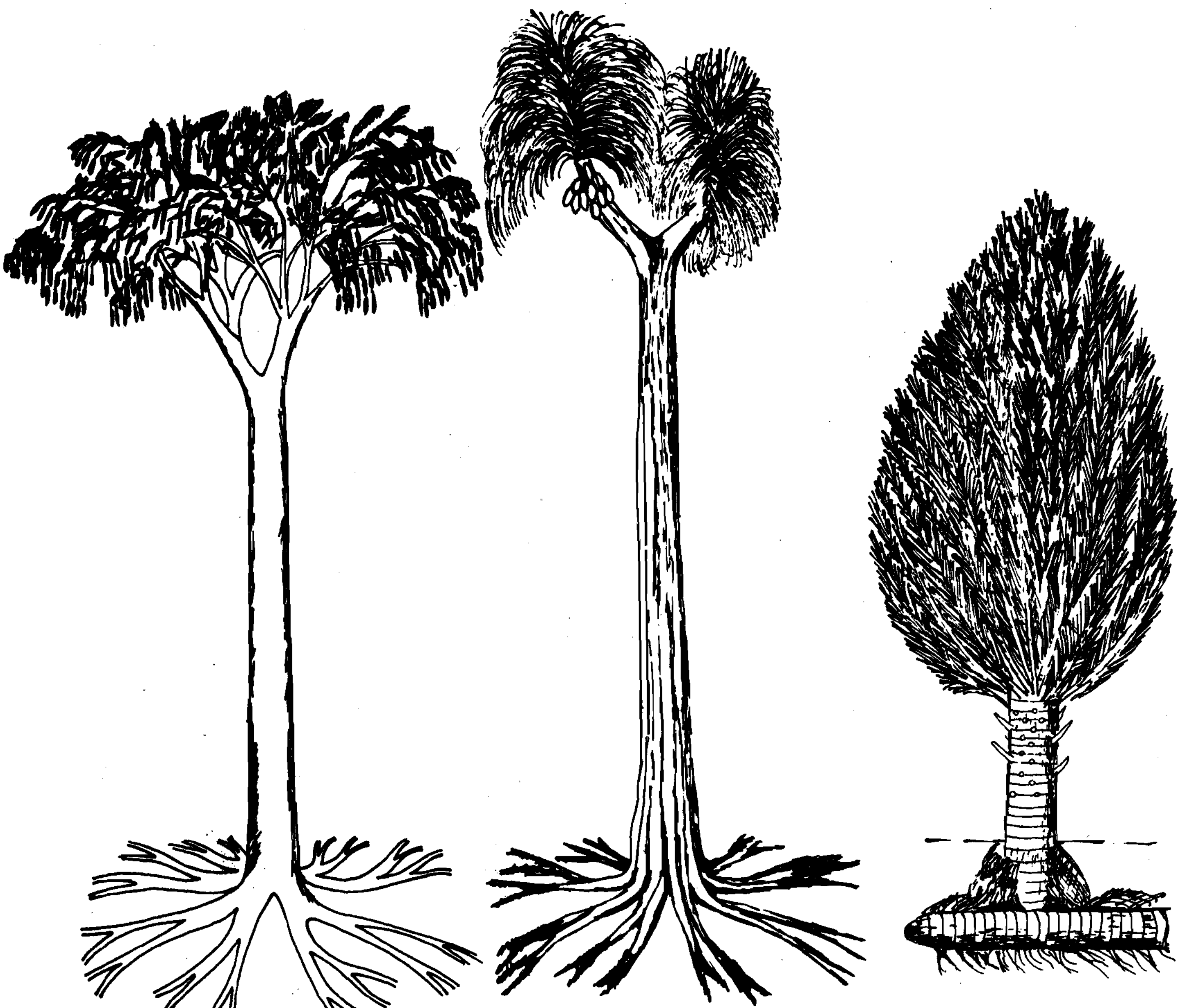


Fig. 2.9 : Reconstruction of three members of early vascular plants representing three important groups of evolutionary interest



Lepidodendron
(Lycopod)

Sigillaria
(Lycopod)

Calamites
(Equisetophyte)

Fig. 2.10 : Reconstruction of Carboniferous lycopods and equisetophyte. All three were very large plants

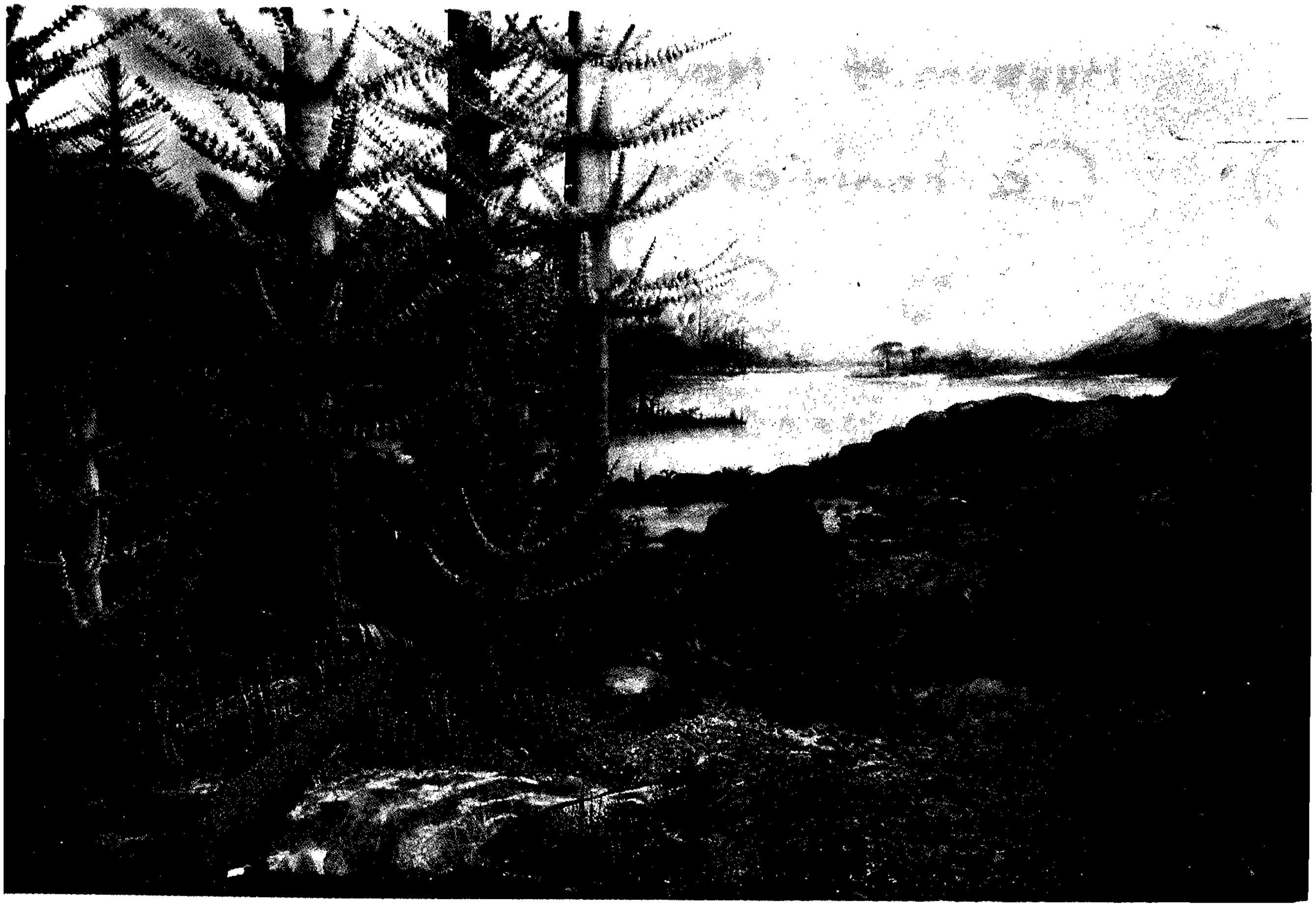


Fig. 2.11 : Reconstructon (at Univ. of Michigan Museum of Natonal History) of Carboniferous landscape dominated by *Calamites*.

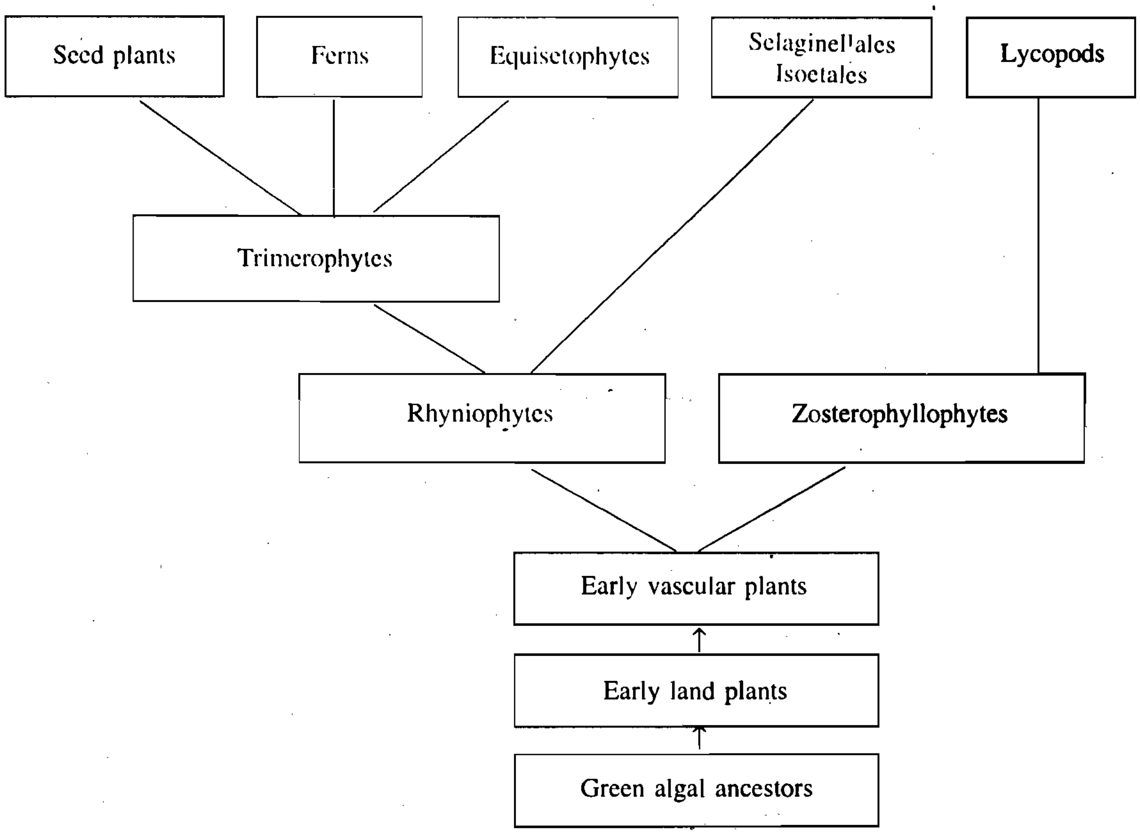


Fig. 2.12 : Evolution and relationships among vascular land plants.

SAQ 2.4

Choose the single best answer

i) Land plants are also known as
   a) gymnosperms
   b) embryophytes
   c) eukaryotes
   d) sporophytes
   e) gametophytes

ii) Land plants originated about
   a) 470 million years ago
   b) 200 million years ago
   c) 3.5 billion years ago
   d) 250,000 years ago.

iii) Bryophytes do not possess
   a) cholorophyll *b*
   b) cuticle
   c) vascular tissue
   d) embryos
   e) sporopollenin

iv) A plant group not included under the pteridophytes
   a) ferns
   b) rhyniophytes
   c) hormworts
   d) lycopods
   e) whisk ferns

v) Cooksonia was a
   a) liverwort
   b) trimerophyte
   c) equisetophyte
   d) rhyniophyte
   e) bryophyte

2.7 SUMMARY

In this unit you have learnt

- An overview of the position and classification of prokaryotes, fungi, algae, bryophytes and pteridophytes are presented.
- Cyanobacteria are prokaryotes related to other bacteria. They possess chlorophyll *a* and evolve oxygen during photosynthesis much like the eukaryotic higher plants.
- Cyanobacteria-like cells might have been the ancestors of the different kinds of chloroplasts found in modern algae.
- Fungi are eukaryotes and *nonphotosynthetic*.
- The slime molds and oomycetes, although included in the fungal kingdom, represent distinct lines of evolution, the former from protozoa and the latter from some algal group.
- The higher fungi, zygomycetes, ascomycetes and basidiomycetes lack flagellated cells and appear to be evolutionarily related to each other.

- Lichens are composed of fungal and algal partners. Most lichens have an ascomycete as the fungal component. The fungal component appears to determine the morphology of a lichen.
- A large number of fungi which do not reproduce sexually or whose sexual cycles have not yet been discovered are placed in the group, Deuteromycetes.
- Algae are eukaryotic photosynthetic organisms. The differences between algal groups can be traced back to their symbiotic acquisition of prokaryotic cells with different chlorophylls.
- The chromophytes, rhodophytes and chlorophytes are distinguished by the presence of chlorophylls *a* and *c*, *a* and *d* and *a* and *b* respectively.
- The prokaryotic *Prochloron* which has chlorophylls *a* and *b* represent the kind of ancestral cells that might have evolved into plastids of the green algae and land plants.
- The charophycean line of the green algae led to the evolution of land plants.
- Bryophytes and pteridophytes are land plants. Both possess multicellular embryos and hence are known as embryophytes. The bryophytes are nonvascular plants.
- Land plants evolved about 450 million years ago. Among the adaptations that helped colonise the land were a multicellular plant body, protective cuticle, stomata for gas exchange and resistant spore wall with sporopollenin. Vascular tissues evolved later in the vascular land plants.
- The ferns and their allies are descendants of ancient vascular, nonseed bearing plants. The Devonian period witnessed the emergence of rhyniophytes from which several vascular plant groups evolved, leading ultimately to vascular seed plants, the gymnosperms and angiosperms.

2.8 TERMINAL QUESTIONS

1. Why are cyanobacteria grouped with bacteria rather than with algae?

....

....

....

....

2. With the help of a diagram show the possible evolutionary relationships among the various fungal groups.

....

....

....

....

3. What are the characters useful in the classification of various algal groups? What chloroplast pigments are characteristic of different algal divisions?

....

....

....

....

4. What are land plants? What adaptations were useful in the colonization of land by early plants?

....

....

....

....

5. Describe the major course of evolution among the vascular plant groups.

....

....

....

....

2.9 ANSWERS

Self-Assessment Questions

2.1 i) F, (ii) F, (iii) F, (iv) T, (v) T.

2.2 (i) chitin, (ii) saprotrophs, parasites, (iii) mycorrhizae, lichens (iv) oomycete, (v) zygomycetes, ascomycetes, basidiomycetes.

2.3 i) e, (ii) b, (iii) c, (iv) a, (v) d.

2.4 (i) b, (ii) a, (iii) c, (iv) c, (v) d

Terminal Questions

1. Refer to section 2.2.
2. Refer to section 2.3
3. Refer to section 2.4
4. Refer to section 2.5 and 2.6.
5. Refer to section 2.6.

GLOSSARY

Accessory Pigment : a pigment that absorbs light energy and transfers it to chlorophyll, e.g., carotenoids and xanthophylls in higher plants.

Actinomycete : A soil-dwelling gram-positive bacterium with its cells arranged in filaments. It may be used to produce antibiotics such as streptomycin.

Ascus : A sac-like cell in ascomycetes fungi in which ascospores are produced.

Basidium : An enlarged sexual reproductive cell in basidiomycete fungi in which meiosis occurs, resulting in the formation of basidiospores.

Coenocytic : Hyphae which consist of tubular masses of protoplasm containing many nuclei.

Coleochaete : An advanced green algae which has an upright system and a prostrate creeping system that anchors the plant in the substratum.

Gametophyte : The stage of an alternation of generations found in most plants, in which the haploid plant produces gametes by mitosis which fuse to form a zygote that develops into the sporophyte.

Gram's Stain : A stain used in the study of bacteria. Bacteria which take the violet stain are gram-positive while others that do not are gram-negative. Gram-positive bacteria are more readily killed by antibiotics.

Gram-Positive Bacterium : A bacterium that stains purple with Gram stain and it usually lacks an outer covering on its cell wall whereas Gram-negative bacterium stains pink with Gram stain and usually has an outer covering on its cell wall.

Mycoplasma : The simplest prokaryotic cell.

Mycorrhiza : The symbiotic association which may occur between a fungus and the roots of certain higher plants, especially trees.

Sporophyte : The stage of an alternation of generations found in most plants, in which the diploid plant (2n) produces spores by meiosis which then germinate to produce the gametophyte.

Sporopollenin : An oxidation polymer of carotenoid pigments and carotenoid esters found in spores and pollen grain walls that resists attack by most acids and is stable at temperatures up to 300° C.

Stromatolites : A fossil formed by layers of calcareous blue-green algae.

Tinsel : A flagellum with fibrillar appendages.

Tubulin : The protein which forms the major part of microtubules.

Whiplash : A smooth-surfaced flagellum.

UNIT 3 COMPARATIVE MORPHOLOGY AND CELL STRUCTURE IN ALGAE

Structure

3.1 INTRODUCTION

In the previous block you have learnt that algae are placed in Kingdom Protista along with protozoa. Earlier they were classified with plants as they are photosynthetic autotrophs - possess chlorophyll and chloroplasts and superficially appear like plants. Since their gametes do not have protective cells around them they are no longer classified with plants.

Traditionally, on the basis of physical features, Plant Kingdom is divided into four groups or divisions - Thallophyta, Bryophyta, Pteridophyta, Spermatophyta. The first three divisions are collectively called *Cryptogames* or flowerless or seedless plants as they never bear flowers. The last division spermatophyta in known as *Phanerogames* or flowering plants.

In this first unit on algae you will study the morphology and cell structure of algae and also of cyanobacteria (commonly known as blue-green algae). Algae are widely distributed in nature wherever there is plenty of water and sunshine. They even inhabit harsh habitats. Although simple in structure, lacking differentiation, algae exhibit great diversity in size and appearance. Their size ranges from simple microscopic to giant thallus extending several metres in length as in kelps. Algal morphology varies from simple unicellular form to complex thallus as found in seaweed. While studying the morphology of representative genera included here you will note the various stages in the evolution of multicellular thallus that led to the development of first land plants.

The kelps have fronds as large as 100 metres and grow at a rate of about 60 cm per day.

The study of their cell structure under electron microscope has revealed one major fact that blue-green algae have prokaryotic type of cell like that of bacteria and hence they are more related to them than to other algae with which they were traditionally grouped. All other algae have eukaryotic type of cell.

The reproductive processes found in algae are discussed in the subsequent unit. Algae are widely distributed in nature and are diverse in habitat. We have given in unit 6 a detailed account of habitats and distribution particularly in India.

Objectives

After studying this unit you will be able to:

- describe the basic types of thallus in algae,
- compare the morphology of unicellular, colonial, filamentous, heterotrichous, thalloid and polysiphonoid forms of algae,
- draw the morphology of *Anacystis, Chlamydomonas, Microcystis, Volvox, Nostoc, Ulothrix, Oedogonium, Draparnaldiopsis, Coleochaete, Ectocarpus, Ulva, Fucus* and *Polysiphonia* and describe their special features,
- draw and label the parts as seen in ultrastructure of cells of prokaryotic and eukaryotic algae and list their distinguishing features,
- describe briefly the basic features of various cell organelles present in prokaryotic and eukaryotic algae and
- explain the evolution of thallus in algae.

3.2 ALGAL MORPHOLOGY

The science or study of algae is called 'Phycology'. One who specialises in the study of algae is called 'Phycologist' or 'Algologist'.

The body of an alga is called thallus. In unicellular algae it is simple consisting of a single cell. All multicellular organisms start their life as single cells. When a cell divides and the daughter cells form a packet enclosed in a mucilaginous mass, a colony is formed. While the division of a cell continuously in the same plane, with the daughter cells sticking together, results in a row of cells forming a filament. Some of the cells of a filament divide only once by a vertical plane followed by transverse divisions repeatedly and thus produce filamentous-branched thallus. Further, when all the cells of a filament undergo divisions in cross and vertical planes it results in a sheet of one or more cells in thickness. Such multicellular thallus may show complicated differentiation as in seaweed. All multicellular algae show the above stages during their development.

In the following account you will study the specific examples of the above basic types of thallus in algae. It is to be noted that all the above forms may not be found in all algal divisions but some are predominently multicellular, some filamentous and some include only unicellular forms. A gradual complexity in form also indicates how the evolution of thallus has taken place, in algae.

Morphologically algae can be distinguished as unicellular, colonial, filamentous, heterotrichous, thalloid and polysiphonoid forms. Each of these type is described below.

3.2.1 Unicellular Forms

Anacystis

Single cells, cylindrical, short or long; sometimes very long snake forms (Fig. 3.1 A). Cells divide by constriction, the two daughter cells get separated, rarely they remain together to form a 2-celled filament.

Individual single cells may have their own mucilagenous cover around them. Several such cells may be enclosed in common colourless mucilage giving the impression of a colony.

Chlamydomonas

This single celled alga contains a nucleus, a cup-shaped chloroplast in which one **pyrenoid** is commonly present (Fig. 3.1 B and Fig. 3.8 B). The chloroplast on the anterior side shows 2 to 3 rows of fatty red coloured granules. This is known as **eyespot** or **stigma** which is helpful for the alga to respond to light. The cell wall is firm and distinct. A small contractile vacuole is found at the base of each flagellum.

Chlamydomonas cells under partially dry conditions divide and the daughter cells without flagella remain enclosed by a common mass of mucilage. Such a colony is known as **palmella stage** of *Chlamydomonas* (Fig. 3.1 C). This is only a temporary stage and on flooding with water individual cells develop flagella and escape swimming away from the colony. Thus the beginning of the colony construction found in *Volvox* can be seen in *Chlamydomonas*.

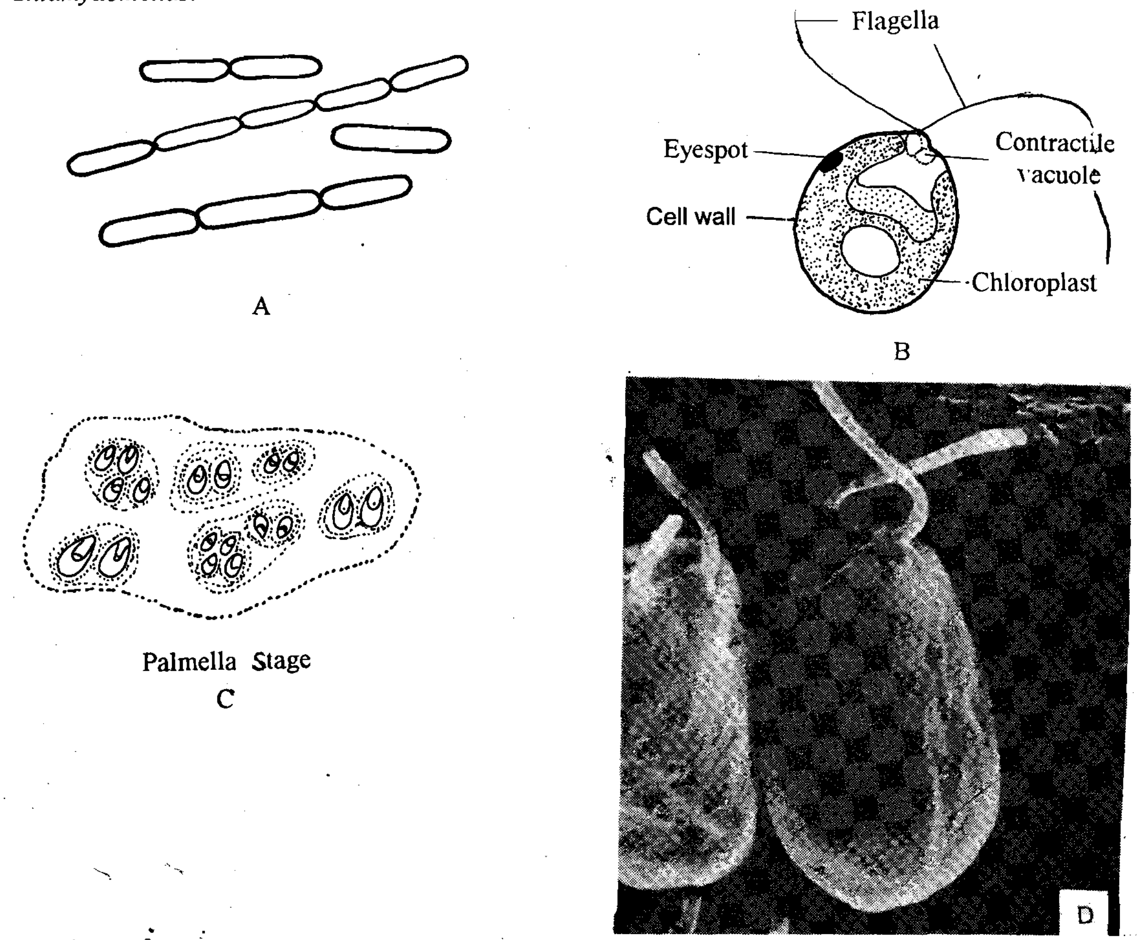


Fig. 3.1 : Unicellular algae; A) ***Anacystis nidulans*****, B)** ***Chlamydomonas*****, C) palmella stage of** ***Chlamydomonas*****, D) Scanning electron micrograph of** ***Chlamydomonas reinhardii*** **growing on a solid culture medium (Courtesy of P. Dayanandan).**

3.2.2 Colonial Algae

When a cell divides and the daughter cells formed remain together within a common mucilage mass, it is known as a colony. A colony may contain large number of cells. Sometimes it may be so big that one can see it with unaided eyes.

Microcystis

This is a colonial alga, most common in polluted ponds and lakes in India (Fig. 3.2 A). Sometimes the colonies are big and can be seen by unaided eyes. They accumulate on the surface of water forming quite a thick layer in some seasons (water blooms).

Single cells are spherical and colony is formed because of loose aggregates of several thousand cells held by mucilage (Fig. 3.2 B). The colonies float on the surface of water because of the presence of elongated cylindrical gas vesicles inside the individual cells. Reproduction is by division of cells called binary fission.

Volvox

The colonies of *Volvox* are spherical, ball-like and big enough to be seen with unaided eye (Fig. 3.2 C). Each colony contains 1000-5000 cells arranged on the outside of a mucilagenous ball called **coenobium.** Two types of cells can be seen generally, vegetative or **somatic** and **gonidia**. In younger colonies cytoplasmic connections - plasmodesmata between individual cells can be seen under the microscope.

Coenobium - it is a colony in which the number of cells is fixed at the time of formation. No further addition of cells occurs. Generally the cells are also in a special arrangement.

Vegetative cells are more or less like *Chlamydomonas* with two flagella, cell wall, single cup-shaped chloroplast, eyespot, pyrenoid, contractile vacuole and a nucleus (Fig. 3.2 D). The cells on the posterior side of the colony may be larger than in the front.

Gonidia-cells meant for sexual reproduction are on the posterior side and they lose their flagella early. They divide and give rise to daughter colonies. After the rupture of the parent colony the daughter colonies are liberated into the water.

The daughter colonies produced from gonidia may later develop into male colonies that produce spermatozoa or female colonies that produce eggs. *Volvox* colonies are generally unisexual but some species are bisexual.

It is to be noted that *Volvox* colony is much more advanced than a *Microcystis* colony. The individual cells in *Microcystis* after division remain suspended in a common mass of mucilage without any contact between them. Each cell may go on dividing continuously forever as long as conditions are suitable.

In *Volvox* all the cells of a colony are derived from a single parental cell. They are arranged on the surface of mucilaginous ball, connected with other cells by cytoplasmic connections. Some cells behave as sex cells meant for reproduction whereas others remain vegetative and ultimately grow old and die. This differentiation into vegetative and reproductive cells is a very important feature in the development of multicellular organisms.

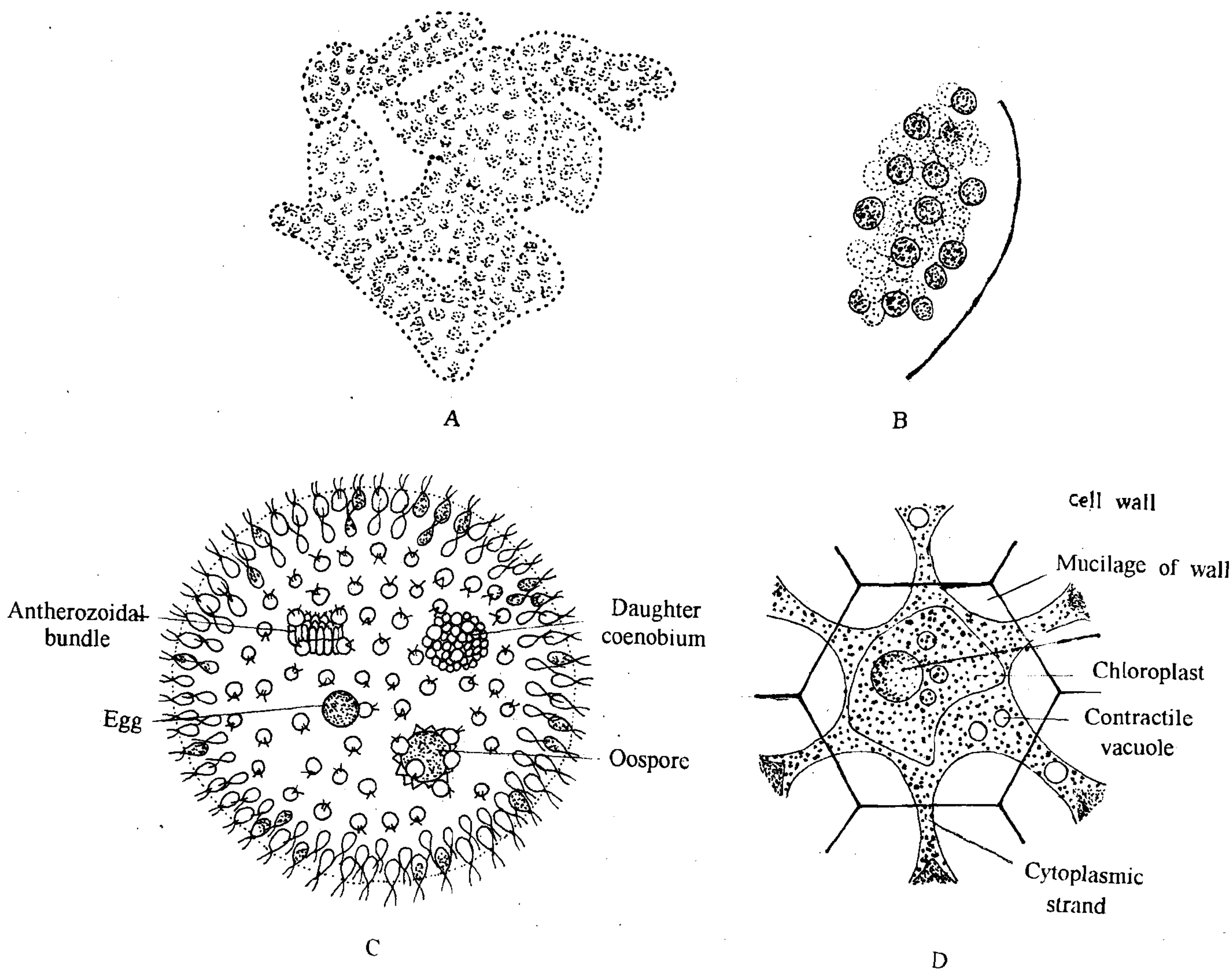


Fig. 3.2 : Colonial algae; A) *Microcystis aeruginosa*, B) portion of A magnified, C) *Volvox aureus*, D) cells of C in the interior polar view.

3.2.3 Filamentous Forms

When a cell divides always cross-wise and the daughter cells do not separate from each other, it results in a linear row of cells as in *Nostoc, Ulothrix* and *Oedogonium*. However, the three algae show different levels of differentiation.

Nostoc

This is a simple filamentous form, a single row of cells, uniseriate (Fig. 3.3 A). Several filaments of *Nostoc* are generally enclosed within a common mucilage envelop to form a colony (Fig. 3.3 B). Some cells in between the vegetative cells are modified into **heterocysts.** All the vegetative cells are capable of developing into spores called **akinetes.**

Heterocyst – a highly differentiated cell in some filamentous blue-green algae that is a site of nitrogen fixation.

Ulothrix

This is also a filamentous alga but differentiated into narrow basal holdfast by which it is attached to the rock in water (Fig. 3.3 C). Fig. 3.3 D shows the structure of cells of *Ulothrix* with girdle shaped chloroplasts. The cells at the apical end are relatively broad. These undergo division and produce within, a large number of motile cells meant for reproduction.

Akinete – a thick-walled, nonmotile reproductive cell found in algae.

Uniseriate – Single row of cells in the form of filament.

Oedogonium

The filaments of *Oedogonium* are unbranched, usually differentiated at one end into a holdfast (Fig. 3.3 E). The cylindrical cells are short or longer than broad. The growth of the filaments is due to the division of specific cells called **cap cells** which show caps (or ring like scars) on their walls (Fig. 3.3 F). Such cells may divide many times and the number of caps present on a cell indicates the number of divisions it has undergone.

SAQ 3.1

a) Indicate which of the following statements are true or false. Write T for true and F for false in the given boxes.

i) Cap cells of *Oedogonium* serve as holdfast. ☐

ii) Holdfast is found in *Nostoc.* ☐

iii) *Chlamydomonas* floats because of the presence of gas vesicles. ☐

iv) Plasmodesmata are not found in *Microcystis.* ☐

b) Choose the correct answer in the following.

i) Which of the following alga is colonial in form?
1) *Microcystis*
2) *Anacystis*
3) *Chlorella*
4) *Chlamydomonas*

ii) Heterocysts are present in
1) *Microcystis*
2) *Nostoc*
3) *Volvox*
4) *Ulothrix*

c) In the following statements fill in the blank spaces with appropriate words

i) .... is a unicellular alga.
ii) In younger colonies of *Volvox*, the cells of the colony are connected with ....
iii) The colony of .... floats on the surface of water because the individual cells have gas vesicles.
iv) Under partially .... conditions, the cells of *Chlamydomonas* divide and get enclosed in a mucilagenous mass.

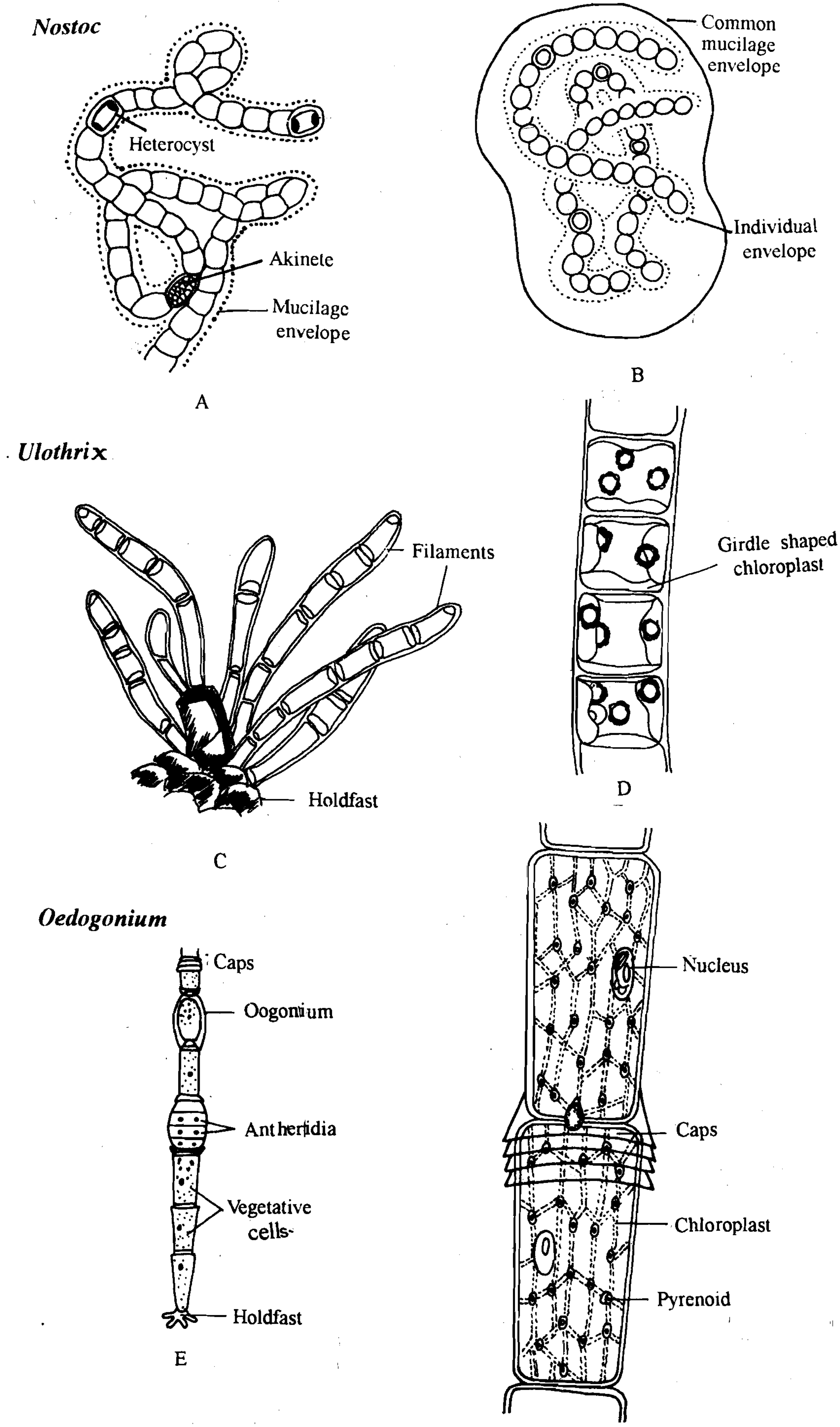


Fig. 3.3 : Filamentous algae ; A) filaments of *Nostoc* showing akinetes and heterocysts, B) an aggregate of *Nostoc* filaments forming a ball, C) germlings of *Ulothrix*, D) cell structure of *Ulothrix* showing gridle shaped chloroplasts, E) filament of *Oedogonium* showing vegetative and reproductive cells. F) part of filament of *Oedogonium* showing cell structure and cap cell with four caps.

3.2.4 Heterotrichous Forms

When some cells of a filament divide vertically it results in a branch. Many filamentous forms show extensive branching of the main filament giving it a bushy appearance.

In some algae the branches at the base remain horizontal, attached to the substratum known as prostrate system from which erect system of vertical branched filaments arise. This type of body is known as heterotrichous habit. Heterotrichous habit is the most highly developed filamentous construction in algae.

Draparnaldiopsis

It is a heterotrichous alga which shows greater differentiation in plant body. The prostrate system is very much reduced. The main axis contains long internodal cells alternating with short nodal cells (Fig. 3.4). The short nodal cells bear a bunch of short branches. Some of the side branches may develop into long colourless hairs or setae. The main axis produces at the base long multicellular colourless rhizoids in large number to form a kind of cortex. Their main function is to attach the alga to the substratum.

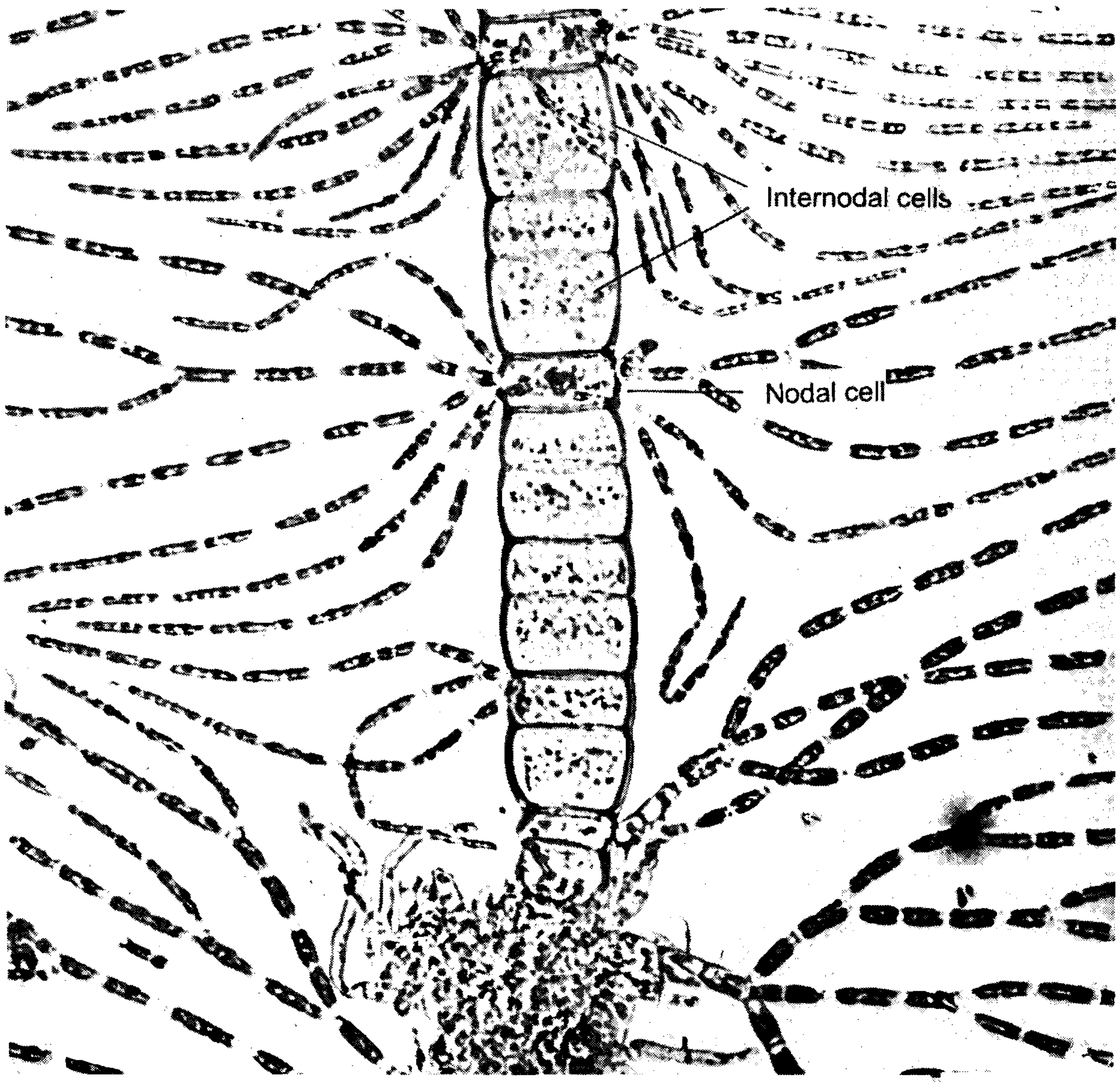


Fig. 3.4 : *Draparnaldiopsis indica* (photograph by late Prof. Y.B.K. Chowdary).

Coleochaete

Coleochaete is an aquatic alga growing on the surface of water plants (Fig. 3.5 A). *C.pulvinata* is heterotrichous. The erect system is in the form of branched filaments. In *C.scutata* the erect system is absent and the prostrate system is made of short repeatedly branched filaments that form a compact disc (Fig. 3.5 B). In both the forms some cells produce hair like bristles, known as setae from their upper surface.

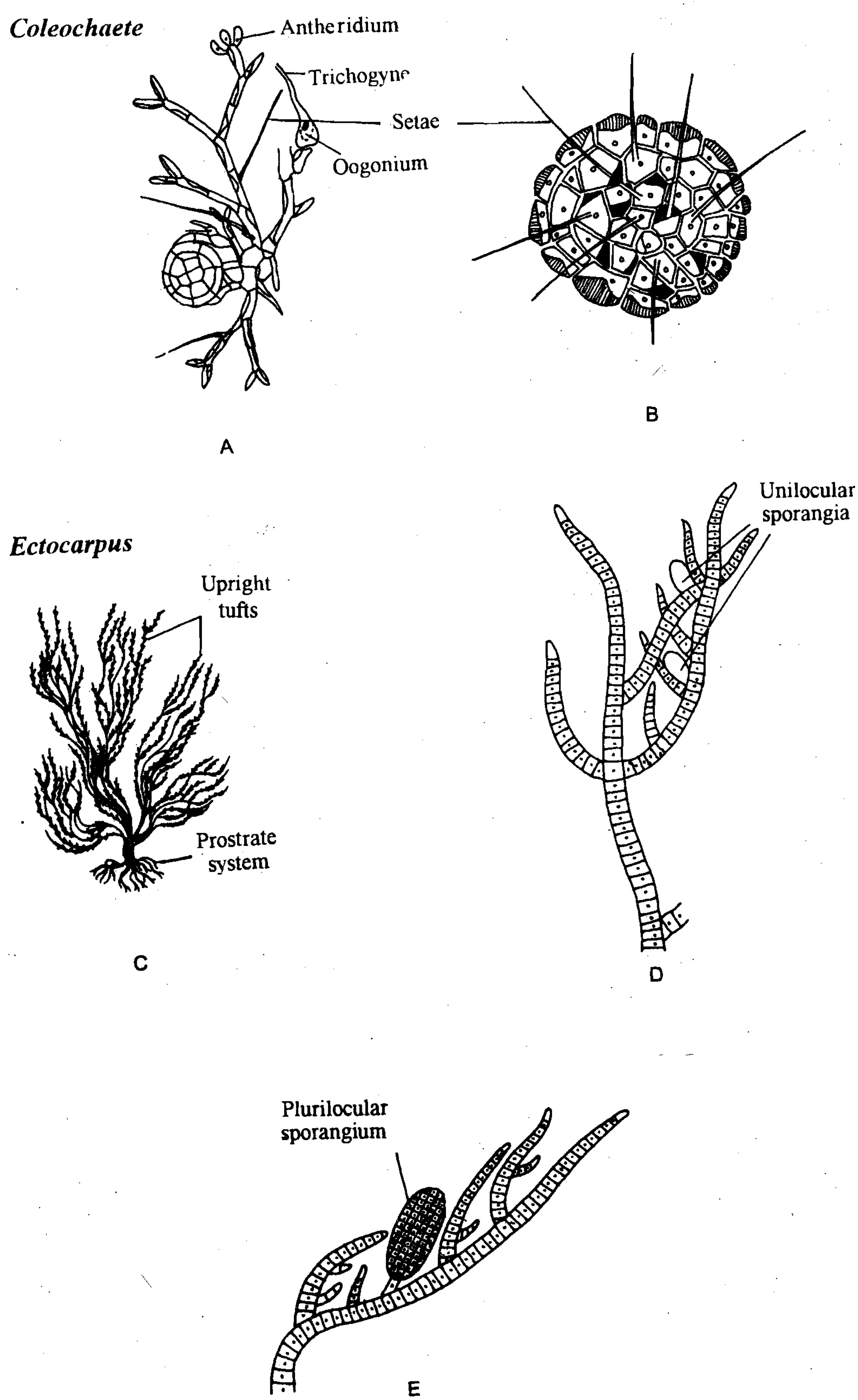


Fig. 3.5: Heterotrichous algae; A and B) *Coleochaete*, C) *Ectocarpus* showing habit, D and E) thalli with unilocular and plurilocular sporangia or gametangia.

Ectocarpus

It is another heterotrichous alga (Fig. 3.5 C).The prostrate system which attaches the alga to the substratum is made of branched filaments. The erect system is in the form of uniseriate (single row of cells) branched filaments forming loose tufts of 1 mm to 10 mm or more.The asexual thallus may be with unilocular or plurilocular sporangia (Fig. 3.5 D and E).

The branches arise just below the cross walls of the cells of the main filament. Most of these branches terminate in elongated hairs.

3.2.5 Thalloid Forms

When the cells of a filament divide in more than one plane, that is not only cross-wise but also lengthwise it results in a sheet of cells. The thallus may be one cell or many cells in thickness.

Ulva

Ulva is a very common alga found on rocky coasts of sea (Fig. 3.6 A). The thallus is attached to the substrate such as rocks by rhizoids at the base. When a sheet of the thallus is cut, one can observe two layers of cells, pressed to each other. Together they form a single sheet (Fig. 3.6 B).

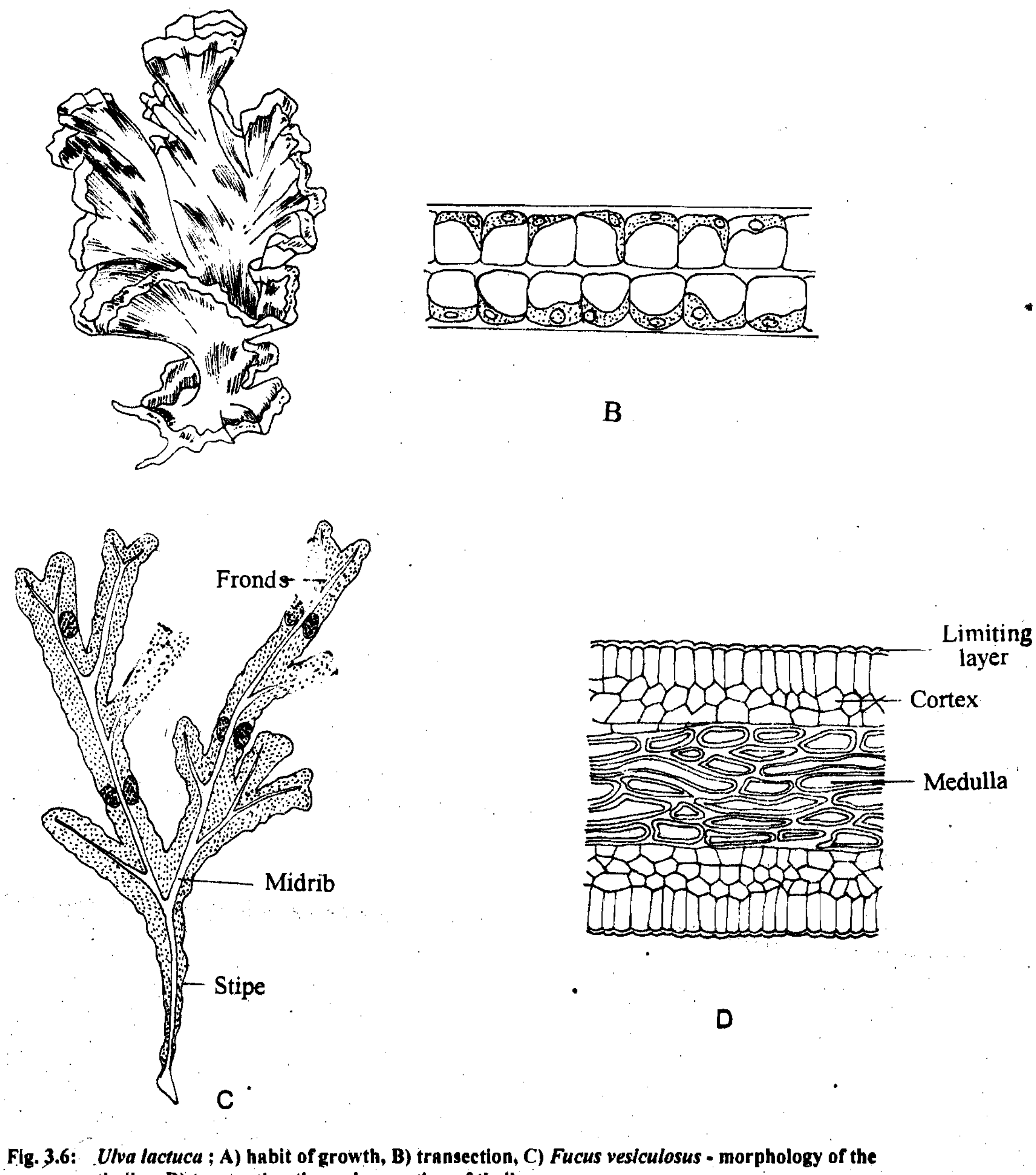


Fig. 3.6: *Ulva lactuca* ; A) habit of growth, B) transection, C) *Fucus vesiculosus* - morphology of the thallus, D) transection through a portion of thallus.

Frond - the term generally is used for large well divided leaf of fern. The large blade-like thallus of algae is also called frond.

Chromatophore - are plastid containing Chl *a* and other pigments but lack Chl *b*. Plastids containing both Chl *a* and Chl *b* are called chloroplasts.

Dichotomous branching- branching pattern in which the two arms of the branch are more or less equal in length.

Fucus

Fucus is a brown algal seaweed common on the rocky coasts of sea in temperate countries (Fig. 3.6 C). The body of *Fucus* is large about half a metre or so in length. It has a basal discoid holdfast, a short stipe and long flat and dichotomously branched fronds or blades. At the tip of the blade are found air bladders which make the plant float in water.

Fucus is multicellular and has a complex internal structure showing three regions (Fig. 3.6 D). The outer layer is epidermis, the central cortex and the inner medulla. The growth of the thallus is due to the division of apical cell situated in a hollow depression at the tip of a branch. The epidermis and the other layers of cortex contain **chromatophores** which take part in photosynthesis. Cortical region stores food materials and the medullary cells take part in the transport of food to different regions of the fronds.

3.2.6 Polysiphonoid Forms

This form of algae has more complex than the earlier described forms. It is found in the red alga *Polysiphonia* (Fig. 3.7) which is marine in habitat.

Polysiphonia

The algae shows in general heterotrichous habit. The prostrate system is in the form of an elongated rhizoid which attaches the algae to the substratum. The erect system is highly branched. The branches are of two kinds, some are long and some short and hair-like. The main filament grows by the division of a single apical cell. The mature plant body is made up of central row of cells - central siphon, surrounded by vertical rows of cells, 4 to 24 - pericentral siphons.

All the pericentral cells are connected with the cells of central siphon and are also connected with each other.

When the cytoplasm of one cell is connected to the cytoplasm of the neighbouring cell through a pit in their wall, it is known as **pit connection**. In *Polysiphonia* although all the cells are separate, their cytoplasm is connected by means of pit connections.

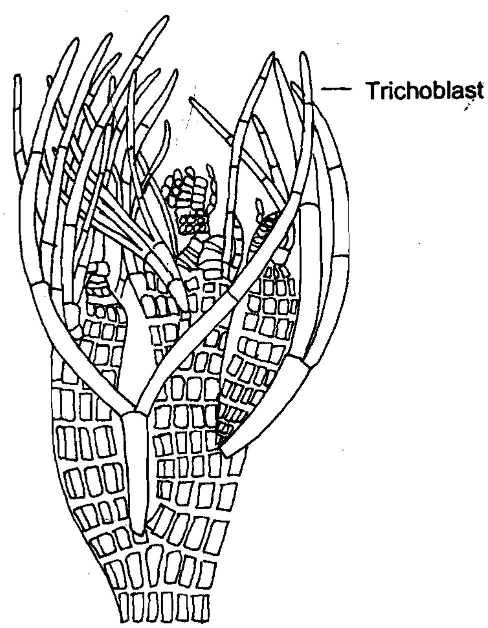


Fig. 3.7: *Polysiphonia*; habit showing multicellular construction of several interconnected rows of siphons of cells.

New branches may develop from the cells of central siphon or from the pericentral cells. The **trichoblasts** which are simple or branched hair-like lateral branches arise from the pericentral cells.

SAQ 3.2

a) In the following statements fill in the blank spaces with appropriate words.

i) In heterotrichous habit the erect filaments of alga arise from the ....
....

ii) The three layers of *Fucus* thallus are outer epidermis central ....
and inner ....

iii) When algal cells divide vertically as well as ...., a sheet of cells is formed.

iv) In the thallus of .... two layers of cells are pressed to each other forming a single sheet.

v) The fronds of *Fucus* can float because .... are present in their tips.

b) Which of the following characteristics features are special to *Draparnaldiopsis*?

i) Presence of nodal and internodal cells
ii) Reduced prostrate system
iii) Absence of erect system
iv) Sheet like thallus
v) Multicellular colourless rhizoids

c) Which of the following alga is thalloid in morphology?

i) *Fucus*
ii) *Ectocarpus*
iii) *Coleochaete*
iv) *Oedogonium*

d) Indicate whether the following statements are true or false. Write **T** for true and **F** for false in the given boxes.

i) In *Polysiphonia* all the peripheral cells are connected with central siphon. ☐

ii) In *Fucus* the food material is stored in inner cells of the medulla. ☐

iii) Uniseriate filaments are characteristics of *Ectocarpus*. ☐

iv) *Coleochaete* is a terrestrial algae. ☐

3.3 STRUCTURE OF ALGAL CELL

In Unit 1 and 2 you have learnt the general features of algae and their position among various other groups of organisms. Alage show two distinct basic types of cell structure, hence they can be divided into two groups - Prokaryotes and Eukaryotes. Prokaryotes include the so called blue-green algae classed earlier as *Cyanophyceae* or *Myxophyceae*, but now designated as Cyanobacteria because their cells are prokaryote type. Eukaryotic algae are quite diverse in cell structure and morphology, which is taken into account for classification. In recent years, use of electron microscopy has brought much new information regarding the ultrastructure of cellular components of algae. The chemical composition and functions are determind by breaking the cell and isolating each of its organelles separately. Such studies reveal that eukaryotic algae show many features that are similar to higher plant groups.

In the following account you will study the basic features of cell of both prokaryotic and eukaryotic algae and various cellular organelles present in them.

3.3.1 Prokaryotic Algal Cell

You have learnt that cyanobacteria closely resemble bacteria in their ultrastructure (see Unit 1, Section 1.5, Page 10). However, you must note that cyanobacteria are not flagellated. The specific features of their cellular components shown in Fig. 3.8 A are describes below.

Cell Wall and Cell Sheath

The cells of cyanobacteria are enveloped by a gelatinous sheath and also have a distinct cell wall outside the plasma membrane. This can be removed by digesting it with enzyme–lysozyme. Its chemical analysis shows that it is made of mucopolysaccharide (peptidoglycan) like that of bacterial cell wall. It has a complex structure, made of a polymer of N- acetylmuramic acid and N-acetylglucosamine, that are cross linked by peptides and other compounds. The wall in fact, shows at least four layers and the outermost may contain lipo-polysaccharides and proteins.

Plankton – free-floating or motile, mostly microscopic, aquatic organisms. Photo - synthetic plankton are called as phytoplanktons. A large number of unicellular algae float in open sea, ocean and lakes. They dominate open sea or lakes and provide food as primary producers to aquatic organisms and thus sustain life in water. It is estimated that 1/3 of oxygen of atmosphere is released by these organisms.

In many cyanobacteria the cell wall is enveloped by gelatinous mucilage. It may be thin and colourless as in planktonic forms. In subaerial forms the sheath is thick, firm and coloured yellow or orange brown and is multilayered. Some aquatic forms like *Scytonema, Petalonema* may also have multilayered and coloured sheath.

Photosynthetic Lamellae

Cyanobacteria have no chloroplasts but only pigmented membranes which occupy the peripheral region of the cells called **chromatoplasm.** In this area photosynthetic lamellae or thylakoids are present. The lamellae are folded double membranes in which the photosynthetic pigments–chlorophyll *a*, and several types of carotenoid are embedded. On the surface of the thylakoids are found rows of granules called **phycobilisomes**, that contain phycocyanin, allophycocyanin and sometimes also phycoerythrin, characteristic of cyanobacteria. It has been found that the thylakoids also contain enzymes required for respiration.

Phycobilisomes – a protein and phycobilin pigment complex located on the thylakoid membrane in blue-green and red algae.

In *Gloeobacter* thylakoids are absent. The photosynthetic pigments are associated with its cell membrane.

Granular Inclusions of Cytoplasm

The ultrastructure of cyanobacterial cytoplasm shows several types of granules. Between the thylakoids glycogen is found in the form of granules of different sizes. Protein granules called cyanophycin granules made up of polymer of two aminoacids aspartic acid and arginine are for storage of nitrogen. Another type of granule common in algae growing in waters rich in phosphate, is polyphosphate, a storage form of phosphate. Some algae also contain granules of polybetahydroxybutyrate as big crystals.

Another unique granules found in cyanobacteria are polyhedral crystalline bodies known as **carboxysomes.** They are made up of ribulose-biphosphate carboxylase (Rubisco) enzyme which as you know is required in the photosynthetic fixation of carbon dioxide.

Like all bacterial cells cyanobacteria also contain ribosomes needed for protein synthesis. They are dispersed in the cytoplasm. All prokaryotic ribosomes are of 70s type unlike the 80s type found in eukaryotes.

Recently introns have been identified in the chromosomes of cyanobacteria.

Gas Vesicles

Many planktonic cyanobacteria like *Microcystis* contain in their cells elongated, cylindrical vesicles singly or in bundles known as gas vesicles. They make the cells float on the surface of water. When, the gas escapes they collapse, become flat, and the cells sink to the bottom. The wall of the vesicle is made of single layer of protein molecules and is permeable to gases but not to water.

Nucleoplasm

The central portion of the cell usually referred as nucleoplasm contains the genetic material, DNA, equivalent to the nucleus of eukaryotes. It appears as a net work of fibrils, and like that of bacteria it is a long thread in the shape of a ring, generally referred to as circular chromosome.There may be multiple copies of it in a cell. The histone proteins found in eukaryotic cells are not associated with the DNA of cyanobacteria.

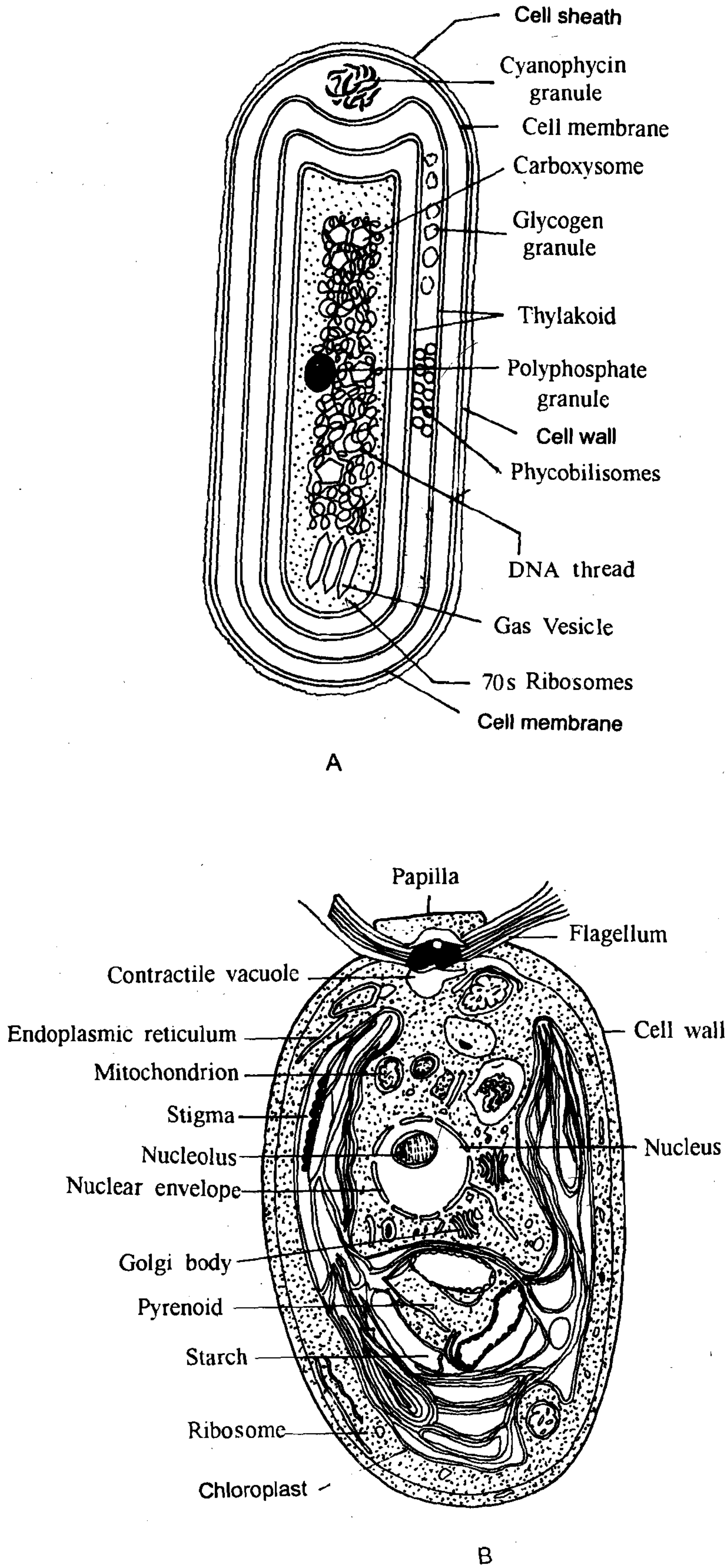


Fig. 3.8: Line drawing of the ultrastructure of A) a prokaryotic and B) eukaryotic cell.

Plasmids

Like in bacteria, DNA is also found in the cells of cyanobacteria as a small covalently linked circular molecule known as plasmid which has genes that make the organism resistant to antibiotics. Plasmids are not a permanent feature of cells, they may be lost and regained further, they can also multiply inside the host cells.

Specialised Cells of Cyanobacteria

As you have learnt that besides the common vegetative cells, filamentous cyanobacteria show two other types of structures, heterocysts and akinetes. These are breifly described below.

Heterocysts

These are thick walled cells found in filamentous cyanobacteria either in between the vegetative cells (intercalary) or at the ends (terminal) of a filament (Fig. 3.3). Most important function of heterocysts is fixation of atmospheric nitrogen as they contain the necessary enzyme system, nitrogenase.

Formation of Heterocyst

Vegetative cells differentiate into heterocysts when dissolved mitrogen compounds are low in surroundings.

Heterocystous cyanobacteria
Anabaena
Nostoc
Calothrix
Gloeotrichia
Scytonema
Tolypothrix
Stigonema

Structure of Heterocyst

Look at the structure of heterocyst given in figure 3.9. Unlike a vegetative cell, heterocyst has a thick wall with three layers which are structurally different. The inner most layer contains certain glycolipids which make the heterocyst impermeable to oxygen, otherwise O_2 inhibits the action of nitrogenase and prevents nitrogen fixation.

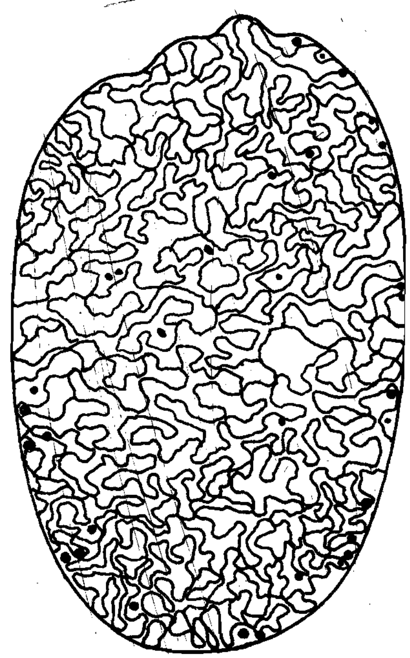


Fig. 3.9 : Heterocyst of *Anabaena* (line drawing of electronmicrograph, adapted from G.B. Chapman).

The heterocysts are connected with the adjacent cells through fine protoplasmic strands, plasmodesmata at the poles and also with large shiny granules - polar granules made up of cyanophycin.

The heterocysts also contain many photosynthetic lamellae, but these are less dense than in the vegetative cells. The lamellae contain chlorophyll *a* and carotenoids. However, phycocyanin is lost when a vegetative cell changes into a heterocyst. Therefore, mature heterocysts cannot fix carbon dioxide, so O_2 is not liberated in light. Polyphosphate and glycogen granules, carboxysomes and gas vesicles are entirely absent in the cytoplasm of the heterocyst.

Akinetes

These are thick walled cells also known as spores, meant for perennation. All the vegetative cells of a filament or only a few cells like those adjacent to a heterocyst may develop into spores.

Akinetes have thick walls and they are generally light brown, deep brown or black in colour. The contents of the cell are highly granular with glycogen but polyphosphate is lacking.

Akinetes can withstand prolonged desiccation and under suitable conditions germinate giving rise to new filaments.

SAQ 3.3

a) List the types of inclusions present in the cytoplasm of cyanobacteria and describe them briefly.

....

....

....

....

....

b) In the following statements choose the alternative correct word given in parentheses.

i) The heterocysts of cyanobacteria fix (CO_2/N_2).

ii) Cyanobacteria contain (circular DNA/DNA filaments) in the nucleoplasm.

iii) A gelatinous sheath outside the cell wall is (present/absent) in cyanobacteria.

iv) The ribosomes in blue-green algae are (70s/80s) type.

c) In the following statements fill in the blank spaces with appropriate words.

i) The cell wall of cyanobacteria is made up of .... like that of bacteria.

ii) The pigments containing granules present on the surface of photosynthetic lamellae are called ....

iii) The innermost layer of heterocyst is impermeable to oxygen as it contains certain ....

iv) In cyanobacteria the region of cytoplasm where pigmented photosynthetic lamellae are present is called ....

3.3.2 Eukaryotic Algal Cell

Eukaryotic algae comprise several divisions each having its own cell structure and other specific characters. However, the basic features as shown in Fig. 3.8 common to all groups are - presence of membrane bound nucleus, chromosomes, plastids, mitochondria, golgi bodies, and 80s type of ribosomes. Besides cell division by mitosis, many groups show sexual method of reproduction involving fusion of gametes and meiosis (reduction division). The following account gives important features of algal cells of various groups.

Cell Wall

Algal cell wall is mainly made up of cellulose. Other additional compounds may be added to it during development. In brown algae hemicelluloses, alginic acid, fucin, fucoidin are also present. In diatoms the wall material is mainly silica.

Coccolithophorides - Those organisms that possess coccoliths. Coccoliths are calcified scales covering the cells of unicellular, primarily marine organisms closely related to golden-brown algae.

The cells of Division Chrysophyta have no proper cell wall. They are covered by scales of silica (e.g. *Mallomonas*), **In coccolithophorides** elaborate scales contain calcium carbonate (calcite). The cell wall of red algae contains polysulphate esters of carbohydrates in addition to cellulose and pectin.

Calcium carbonate deposits are found over the surface of algae belonging to different groups of many marine seaweed, known as **calcarious algae**, for example, *Neomeris, Udotia* (green algae). *Corallina* (red alga), *Padina* (brown alga) and fresh water alga *Chara.*

Coralline algae are a group of red algae that secrete calcium carbonate around their cells and form stiff thalli. Coralline algae are important builders of coral reefs in tropical water, contrary to the believe that coral animals alone make up coral reefs.

Plastids

All photosynthetic algae show plastids - chloroplasts whose basic structure is similar to the chloroplasts of higher plants. The shape and location of chloroplasts in algae varies from species to species. When located at the centre of a cell, they are called axile, and when located near the periphery they are called parietal. Their number also varies from one to many, but fixed for a species. Under the microscope, the following shapes of chloroplasts can be easily recognised: cup like (*Chlamydomonas*), girdle like (*Ulothrix*), spiral band (*Spirogyra*) and stellate (star-shaped-*Zygnema*) These are shown in the Fig.3.10 given below.

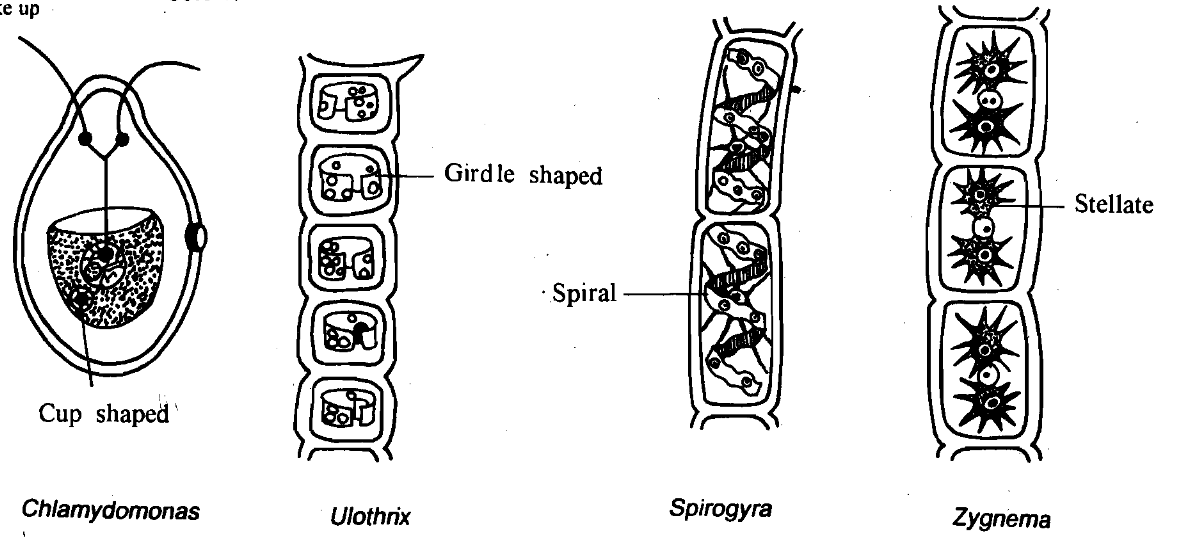


Fig. 3.10 : Various shapes of chloroplasts of algae.

Ultrastructure

The ultrastructure of algal chloroplast is similar to that of higher plants. It is enveloped by a double membrane. A number of thylakoid lamellae are spread into the matrix - the stroma. The lamellae are made of lipoprotein complexes interspersed with molecules of chlorophylls and carotenoids. When phycobilins are present as in the case of red algae, they are present in the form of granules known as phycobilisomes, attached to the membrane surface in linear rows (Fig. 3.11). The stroma of chloroplast contains several enzymes connected with photosynthetic carbon fixation.

The arrangement of thylakoids in chloroplasts varies in different algae. They may be very closely stacked to form grana (sing. granum), as in green, brown algae and euglenophytes. In red algae they are widely separated from each other (see Fig. 2.6, Unit 2).

One important feature of chloroplast is the presence of circular or ring like DNA. Plastids of *Euglena, Acetabularia, Chlamydomonas*, diatoms,. members of Chrysophyceae, Xanthophyceae, Phaeophyceae all have been shown to contain circular DNA. Chloroplasts give rise to new plastids by simple division.

Chloroplasts contain ribosomes of 70s type not 80s type which are present in the cytoplasm. They also contain the complete machinery for protein synthesis. Ribosomes of 70s type are characteristic of prokaryotes like cyanobacteria. Because of this fact it is believed that chloroplasts of eukaryotes were indeed cyanobacteria which became endosymbiontic during the course of evolution.

Pyrenoids

Plastids of many green algae have prominent proteinaceous granules called pyrenoids around which starch is deposited. In many cases one can see photosynthetic thylakoids traversing the matrix of the pyrenoid or at least closely associated with it. When the chloroplasts divide, pyrenoids also divide to give rise to new pyrenoids.

Fig. 3.11 : Chloroplast of red alga *Porphyridium*.

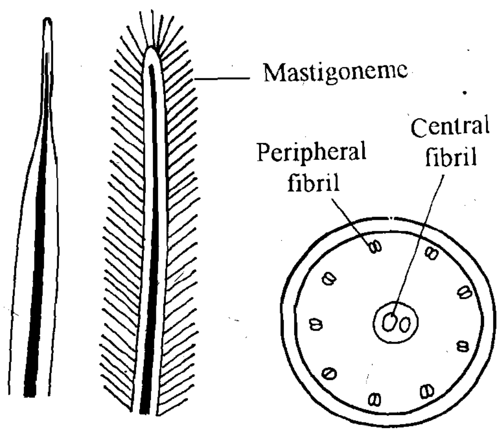


Fig. 3.12 : Pyrenoid of *Chlamydomonas* (line drawing of electron micrograph)

Nucleus

Many algae contain only one nucleus per cell. However, green algae like *Cladophora, Caulerpa* and *Vaucheria* (Xanthophyceae) contain more than one nucleus (multinucleate).

Like the eukaryotic plant and animal nuclei, algal nucleus is enveloped by a distinct double membrane punctured by pores. During the interphase (not dividing, resting nucleus) uncoiled, fine chromatin threads are visible in the nucleus. As you know chromatin is complex of DNA, histone and non-histone proteins. During the cell division, it condenses to form the chromosomes.

Many algal nuclei contain globular **nucleoli**, one or more in number, sometimes attached to the specific region of a chromosome nucleolus organiser. Nucleolus may degenerate and disappear during the cell division but reappear during the interphase. It is now known that the nucleolus is involved in the synthesis of cytoplasmic ribosomes.

The structure of nucleus in the algal groups Euglenophyta and Dinophyta is quite unique and is different from all other eukaryotes. During the interphase, the nucleus inside its membrane shows not uncoiled chromatin fibres but highly condensed chromosomes. Further, unlike in other organisms, they do not contain histone proteins.

The number of chromosomes present in each genus or species of an alga has no relation with its systematic position. The smallest number recorded is n=2 and the highest may be 600 or more. The size of individual chromosomes is also variable. Large chromosomes are found in *Oedogonium, Cladophora* and *Chara.*

Other Organelles of the Eukaryotic cells

Mitochondria

The number of mitochondria in algal cells varies from one as in some flagellates to many in other algae. Their size and shape also varies widely. The ultrastructure shows a double membrane, the inner one folded inwardly forming cristae protruding into the lumen. New mitochondria arise by the division of the mitochondria present in the parent cell, much like plastids. It is believed that mitochondria originated from endosymbiotic bacteria adapted to intracellular existence inside the ancestral host eukaryotic cells. Like the chloroplasts, they also contain circular DNA, RNA, 70s ribosomes and machinery for protein synthesis.

Golgi bodies

These are also known as dictyosomes and are widely found in algal cells. They are made up of 2-20 lamellae or membranes arranged in stacks. They play an important role in the formation of cell wall material as in the case of red algae. In many algae they are connected with secretory function.

Flagella

Flagella are means of locomotion for the motile cells of algae, found in all divisions except Rhodophyta. The alga may itself be motile (as in unicellular and colonial algae) or at some stage in its life cycle produce reproductive motile cells - zoospores and gametes.

The flagella of algae differ in their number, length, appendages and place of insertion on the cell. The surface of the flagellum may be smooth (**acronematic**) may have one or more lateral hairs (**pleuronematic**). When two flagella are found they may be equal in length (**isokonton**) or one flagellum shorter than the other (**heterokonton**).

Ultrastructure of a flagellum shows that it is made up of microtubules, two at the centre surrounded by nine pairs or doublets in a ring, 9+2, all enclosed by a membrane.

Flagellar surface is generally smooth or covered with prominent hairs, **mastigonemes**. Some green algae and the members of Phaeophyta, Chrysophyta, Dinophyta show two flagella, one with smooth surface and the other with fine hairs.

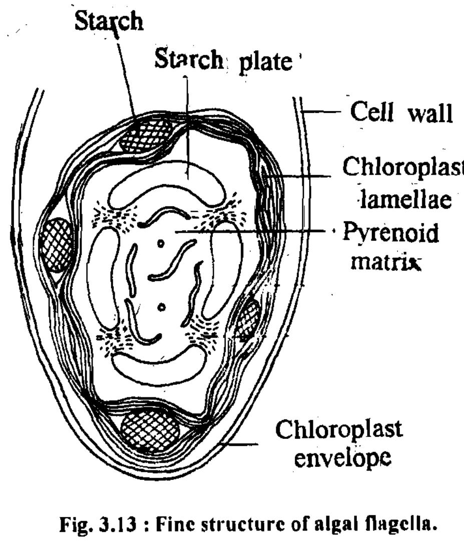


Fig. 3.13 : Fine structure of algal flagella.

Eyespots

Motile cells of algae belonging to Chlorophyta, Phaeophyta, Euglenophyta, Chrysophyta contain orange - red coloured eyespots. In some algae eyespot may form a part of the chloroplast and it is located at the base of the flagellum, but in *Euglena* it is quite distinct and away from the chloroplasts.

The common type of eyespot as found in green algae e.g. *Chlamydomonas* appears to have a row of orange coloured lipid granules as a part of thylakoids at the anterior portion of the chloroplast. The granules are found to contain carotenoids, β-carotene being most prominent.

SAQ 3.4

a) Match the algae given in column 1 with the shapes of chloroplast given in column 2.

	Column 1		Column 2
a)	*Chlamydomonas*	i)	Stellate
b)	*Ulothrix*	ii)	Spiral band
c)	*Zygnema*	iii)	Cup shaped
d)	*Spirogyra*	iv)	Girdle shaped

b) Indicate whether the following statements are true or false. Write T for true and F for false in the given boxes.

i) The thylakoids in red algae are closely stacked together to form grana. ☐

ii) Unlike higher plants the chloroplast and mitochondria of algae lack circular DNA and ribosomes of 70s type. ☐

iii) Pyrenoids are present in the chloroplasts of green algae. ☐

iv) All algal cells are uninucleate.

v) 70s ribosomes are present in golgi bodies. ☐

vi) Flagella are present in all divisions of algae except Rhodophyta. ☐

3.4 SUMMARY

In this unit you have learnt that:

- Algae are diverse group of organisms ranging from microscopic unicellular to giant thalloid forms anchored to the rocks in the sea. Morphologically they can be distinguished as unicellular, colonial, filamentous, heterotrichous, thalloid and polysiphonoid forms.

- The unicellular algae are simplest in morphology. Some advancement is observed in colonial forms. The cells of a colony may communicate through plasmodesmata. There is division of labour between cells, some remain vegetative while others take part in reproduction.

- Filamentous forms have evolved as a result of repeated divisions of a single cell in the same plane. Some cells of a filament may show differentiation into specialised cells like holdfast, cap cells, hairs, hetrocysts etc.

- Some algae have a prostrate system attached to the substratum and an erect system of vertical branches This is called heterotrichous habit.

- Thalloid forms are sheet like with one or two cells in thickness. Polysiphonoid forms are more complex. They possess rhizoids and branched erect system. Mature thallus consists of central row of cells-central siphon surrounded by pericentral siphon. Complex multicellular thallus with external and internal differentiation represents most advanced state of thallus development in algae.

- The cells of cyanobacteria are prokaryotic type. Like bacteria, their cell wall is made up of mucopolysaccharides. They lack membrane bound nucleus, chloroplasts and mitochondria. Like bacteria, they contain only naked circular DNA, and 70s type of ribosomes. Their thylakoid membranes contain photosynthetic pigments and are the site of photosynthesis. The cells show several types of granules.

- The eukaryotic algal cells show a distinct cell wall, a well organised nucleus with nuclear membrane and chromosomes. Their chloroplasts are distinct organelles that contain stacked thylakoids with photosynthetic pigments. and are sites of photosynthesis. Mitochondria which are also made of membranes are the site of respiration. Both the chloroplasts and mitochondria have their own circular DNA, RNA and ribosomes of 70s type unlike the cytoplasmic ribosomes which are 80s type. The algal cells show various organelles like pyrenoids, golgi bodies, vacuoles and eyespots. Motile cells of algae have flagella made up of microtubules. The cell wall is made of cellulose and some marine algae may contain complex polysaccharides, silica or calcium carbonate.

3.5 TERMINAL QUESTIONS

1. Illustrate with an example the most highly developed filamentous construction in algae.

....

....

....

....

....

2. Draw and label the morphological structure of various types of algae you have studies in this unit.

3. Match the algae given in column 1 with the morphological forms given in column 2.

Column 1	Column 2
a) *Ulva*	i) Heterotrichous
b) *Ulothrix*	ii) Colonial
c) *Microcystis*	iii) Thalloid
d) *Ectocarpus*	iv) Filamentous

4. Choose the correct answer in the following:

a) Thallus is filamentous and highly branched in
   i) *Ulva*
   ii) *Fucus*
   iii) *Draparnaldiopsis*
   iv) *Anacystis*

b) Multicellular thallus with most advanced plant body is found in
   i) *Nostoc*
   ii) *Ectocarpus*
   iii) *Fucus*
   iv) *Ulothrix*

5. Indicate which of the following statements are true or false. Write **T** for true and **F** for false in the given boxes.

i) A branched filament results when its cells divide vertically. ☐

ii) Setae or colourless hairs are found in *Ulothrix*. ☐

iii) Heterotrichous algae are attached to the substratum by holdfast. ☐

iv) Palmella stage is found in *Volvox*. ☐

v) Filaments of *Oedogonium* are attached to substratum by holdfast. ☐

vi) Algal cells do not form complex organs or tissues. ☐

vii) The cells of algal thallus are more or less independent of each other. ☐

3.6 ANSWERS

Self-assessment Questions

3.1 a) i) F, ii) F, iii) F, iv) T
    b) i) 1 ii) 2
    c) i) *Chlamydomonas*, ii) plasmodesmata, iii) *Microcystis*, iv) unfavourable

3.2 a) i) prostrate system, ii) cortex, medulla, iii) horizontally, iv) *Ulva*, v) air bladders
    b) i), ii) and v)
    c) i)
    d) i) T, ii) F, iii) T, iv) F

3.3 a) Elaborate the following and draw a diagram to show their location in the cell.
    i) Glycogen granules of different sizes
    ii) Cyanophycin
    iii) Polyphosphate granules
    iv) Carboxysomes.
    b) i) N_2, ii) circular DNA, iii) present, iv) 70s
    c) i) mucopolysaccharides, ii) phycobilisomes, iii) glycolipids , iv) chromatoplasm

3.4 a) a) iii, b) iv, c) i, d) ii
    b) i) F, ii) F, iii) T, iv) F, v) F, vi) T

Terminal Questions

1. Ref. to section 3.3.6.
2. See the figures given in the text.
3. a) iii, b) iv, c) ii, d) i.
4. a) iii, b) iii.
5. i) T, ii) F, iii) F, iv) F, v) T, vi) T, vii) T.

UNIT 4 REPRODUCTION IN ALGAE

Structure

4.1 INTRODUCTION

In unit 3 you have learnt that algae vary in size from small microscopic unicellular forms like *Chlamydomonas* to large macroscopic multicellular forms like *Laminaria*. The multicellular forms show great diversity in their organisation and include filamentous, heterotrichous, thalloid and polysiphonoid forms. In this unit we will discuss the types of reproduction and life cycle in algae taking suitable representative examples from various groups. Algae show all the three types of reproduction vegetative, asexual and sexual. Vegetative method solely depend on the capacity of bits of algae accidentally broken to produce a new one by simple cell division. Asexual methods on the other hand involve production of new type of cells, zoospores.

In sexual reproduction gametes are formed. They fuse in pairs to form zygote. Zygote may divide and produce a new thallus or it may secrete a thick wall to form a zygospore.

What controls sexual differentiation, attraction of gametes towards each other and determination of maleness or femaleness of gametes? We will discuss this aspect also.

You will see that sexual reproduction in algae has many interesting features which also throw light on the origin and evolution of sex in plants. This will be discussed in the last section of this unit.

Objectives

After studying this unit you should be able to:

- describe with suitable examples the three types of reproduction vegetative, asexual and sexual in algae,
- distinguish the three types of union of gametes - isogamy, anisogamy and oogamy in algae,
- illustrate diagrammatically reproduction and life cycle in *Chlamydomonas, Ulothrix, Ulva, Laminaria* and *Fucus* and describe their special features,
- describe the four basic types of life cycle found in algae and
- discuss the origin and evolution of sex in algae.

4.2 TYPES OF REPRODUCTION

Reproductive processes found in various groups of algae can be broadly divided into three types: vegetative, asexual and sexual methods.

4.2.1 Vegetative Reproduction

The most common type of reproduction in algae is by binary fission. In unicellular prokaryotic algae like *Anacystis* it is the only method of reproduction found in nature. In filamentous and multicellular forms, the algae may get broken accidently into small pieces, - each developing into a new one. The above methods of propagation are known as vegetative reproduction.

4.2.2 Asexual Reproduction

When vegetative reproduction takes place through specialised cells (other than sex cells), it is described as asexual reproduction.

Anabaena* and *Nostoc

The cells accumulate food materials, develop thick walls to become spores or **akinetes** (Fig. 4.1). Akinetes can withstand dryness (lack of water) and high temperature for a long time, but when conditions are suitable they germinate to form new filaments.

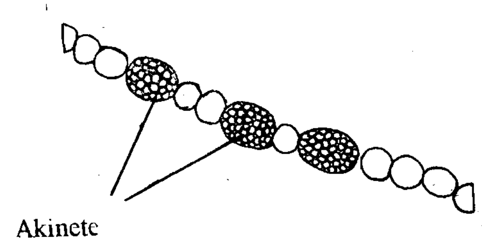


Fig. 4.1: *Anabaena* showing akinetes.

Ulothrix

Filamentous algae (like *Ulothrix*) may reproduce by producing motile cells called **zoospores** (Fig. 4.2). The protoplast of a single cell divides many times by mitosis to produce several zoospores. Each zoospore has 2-4 flagella with which it swims for sometime and then settles by its anterior end. It subsequently divides into a lower cell which becomes the **holdfast** and the upper cell which by further divisions becomes the vegetative filament. Zoospores are produced in other algae also.

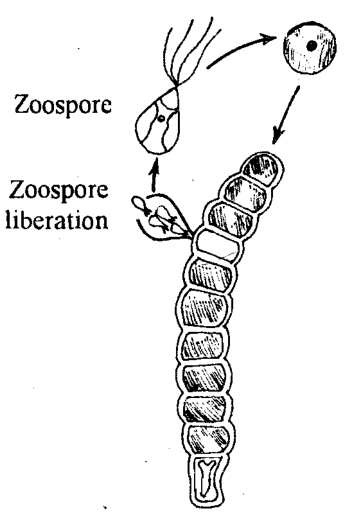


Fig. 4.2 : Formation of zoospores in *Ulothrix*.

Asexual reproduction in other algae is described below.

Chlamydomonas

Although this is a unicellular motile algae but it produces zoospores. The parent cell divides inside the cell-envelop and each daughter cell develops two flagella each. These zoospores look exactly like the parent cell except they are smaller in size. When the zoospores are fully developed the parent cell wall disolves, releasing them free into the surrounding water (Fig. 4.3).

Sometimes when there is less water outside, zoospores may lose flagella and round up. These non-motile spores are called **aplanospores** which develop into thick walled **hypnospores.**

On moist soil when zoospores can not be released due to lack of free water, they get embedded within a gelatinous material formed from parent cell wall. Such cells do not have flagella but whenever they become flooded with water they develop flagella and swim away in the water. These gelatinous masses containing thousands of non-motile cells are known as **palmella stage** of *Chlamydomonas.*

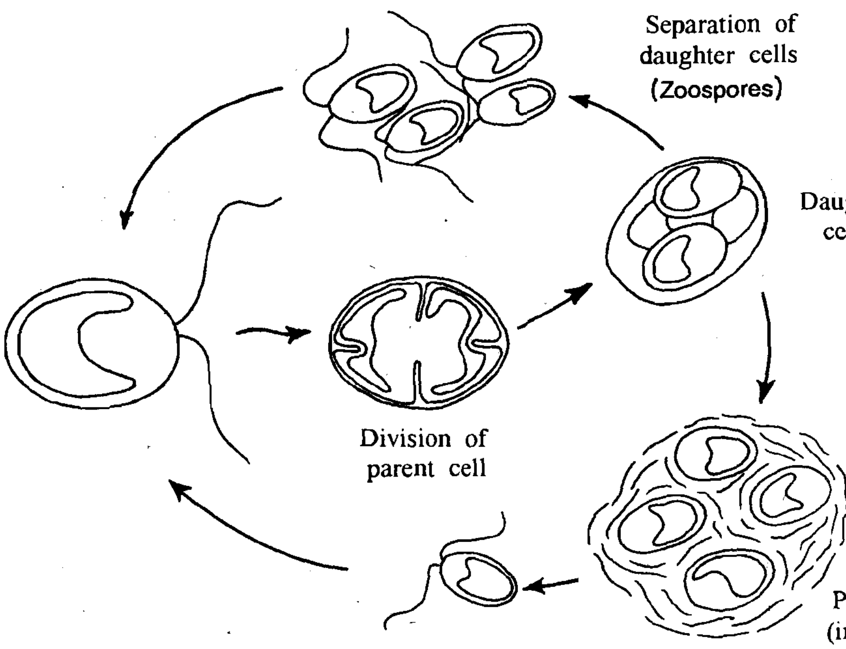


Fig. 4.3: Formation of zoospores and palmella stage in *Chlamydomonas*.

Oedogonium

Zoospore are produced singly in a cell. Each has one nucleus and a crown of flagella at the apex.

Draparnaldiopsis* and *Ulva

Many zoospores are produced from a single cell, as in *Ulothrix.* They have single nucleus and 2-4 flagella.

Ectocarpus

Zoospores are produced in sporangia which are of following two types:

i) **Plurilocular Sporangia**: The sporangium is made up of many cells and several biflagellate zoospores are produced (Fig.4.4).

ii) **Unilocular Sporangia**: The sporangium is made up of one cell which produces single biflagellate zoospore (Fig.4.4).

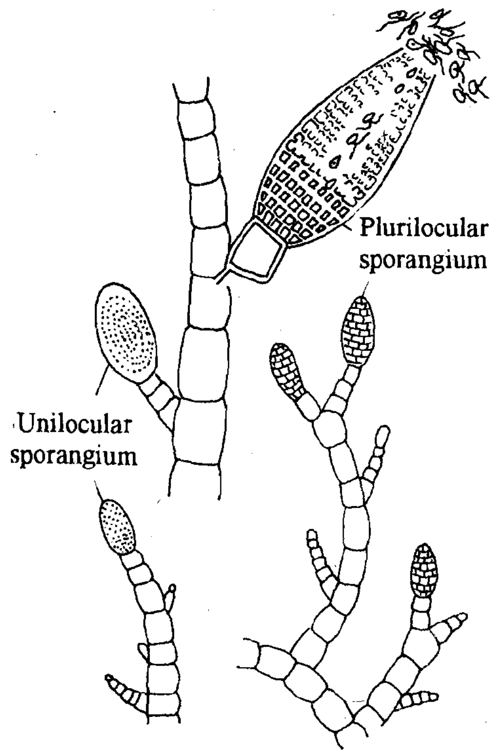


Fig.4.4: Unilocular and Plurilocular sporangia of *Ectocarpus*.

4.2.3 Sexual Reproduction

Sexual reproduction in algae like in other organisms involves the fusion of two cells from opposite sex called gametes, resulting in the formation of a zygote. Some basic features of this method of reproduction are as follows:

Gametes are always haploid and may or may not be different in morphology. If both the sex cells look alike, they could be male called **plus (+) or female called minus (-) mating types or strains**. Gametes can fuse only when one is plus and the other is minus.

Both of them + and - may be produced by a single parent. This is called **monoecious** or **homothallic** condition. When they come from different plus or minus thallus types it is called **dioecious or heterothallic** condition.

There are three types of gametic fusion (Fig. 4.5):

a) **Isogamy**: When both the gametes are of the same size and morphology.
b) **Anisogamy**: The two gametes are distinctly different in size or shape, the larger of the two is minus (female) type.
c) **Oogamy**: The female gamete, egg or ovum is big in size and has no flagella hence it is non-motile. Male gametes are flagellated and highly motile. They are also known as **antherozoids**, **spermatozoids** or sperms.

The male gametes are attracted by the female cells because of special hormones called gamones (a volatile hydrocarbon) produced by them. Fusion of the gametes leads to the formation of a zygote. If the conditions are unsuitable for growth, the zygote may develop a thick wall and become a resting zygospore. Gametes being haploid, are produced by mitosis in a haploid thallus. If the thallus is diploid as in *Fucus* the reproductive cells undergo meiosis or reduction division to form haploid gametes.

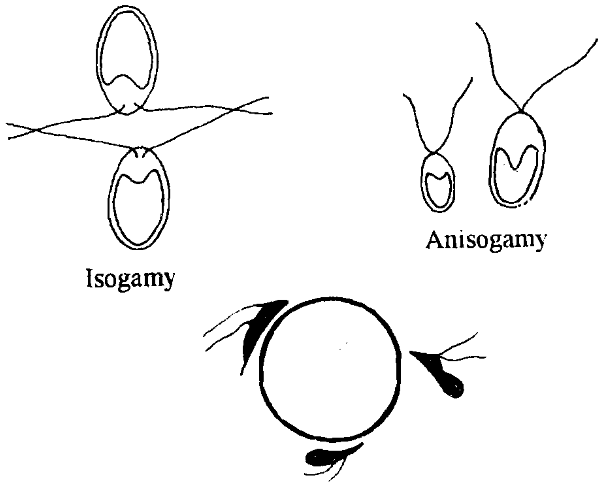


Fig. 4.5: Three types of gametic fusion.-isogamy, anisogamy and oogamy.

In haploid thallus, after the fusion of gametes, the diploid zygote undergoes meiosis during germination. However, in diploid algae a zygote may divide mitotically and give rise to a diploid thallus (*Fucus*). Both haploid and diploid thallus are found in *Ulva*. They look very similar in size and shape.

SAQ 4.1

a) Which of the following algae reproduce **only** by binary fission?
   i) *Volvox*
   ii) *Chlamydomonas*
   iii) *Anacystis*
   iv) *Microcystis*

b) In the following statements fill in the blank spaces with appropriate words:
   i) .... is an enlarged cell in blue- green algae which accumulates food reserve, develops a thick wall and functions as a resting spore.
   ii) Under unfavourable conditions the zoospores lose their flagella and round up, they are called ....
   iii) When a filamentous alga is accidently broken it develops into a ....
   iv) The stage when thousands of zoospores of *Chlamydomonas* cluster together in a gelatinous mass is called ....
   v) When both plus (+) and minus (–) strains are produced by the same parent the condition is called ....
   vi) When two gametes (plus and minus) arise from different parent algae the condition is called ....
   vii) Fusion of gametes of same size and morphology is called ....
   viii) In anisogamy the two gametes are of ....

c) In the following statements choose appropriate alternative word given in the parenthesis:
   i) In algae gametes are always (haploid/diploid).
   ii) The chemical substance produced by (female/male) gamete that attracts the (female/male) gamete is called (gamones/chemone).
   iii) In algae the product of fusion of male and female gametes is called (zoospore/zygospore/zygote).

4.3 REPRODUCTION AND LIFE CYCLE

We have given above the basic modes of reproduction in algae. Now we take up some specific algal types to illustrate their life cycle in nature. It is to be noted that the life cycle of an alga is very much controlled by environmental factors like temperature, light, seasons, and availability of nutrients, and also salinity, wave action and periodicity of tides in the case of marine forms. Observations made by people during different times from various geographical locations and sometimes experimentally studied under controlled conditions, give us fairly comprehensive if not a complete picture of the life cycle of an alga.

4.3.1 *Chlamydomonas*

Sexual reproduction in this alga shows all the three different types depending on the species (Fig. 4.6). Isogamy is found in *C.moewusii, C.reinhardii, C.gynogama* and *C.media*

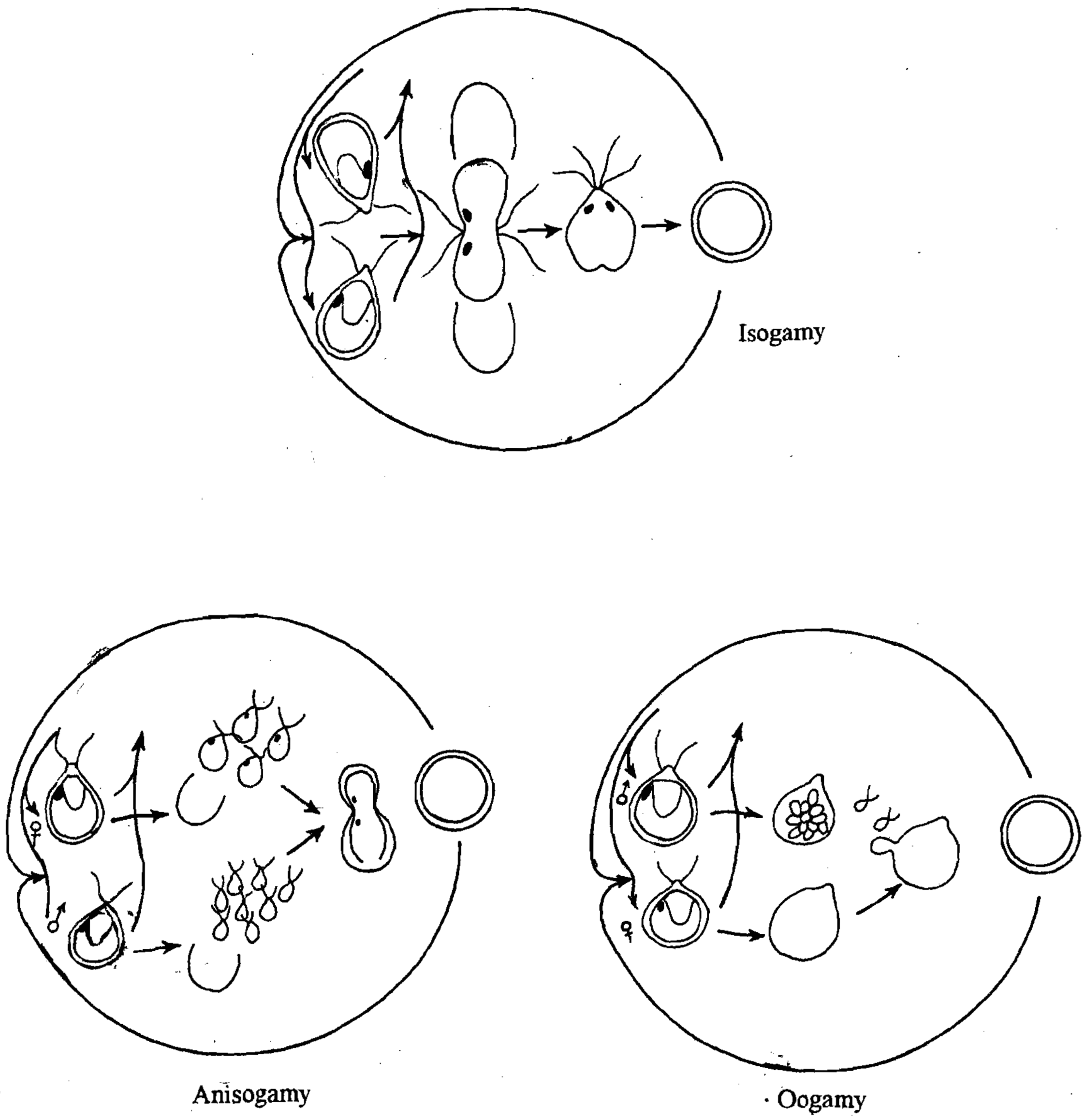


Fig. 4.6 : Sexual reproduction in *Chlamydomonas:* Isogamy ,anisogamy and oogamy.

Isogamy is of two types:

In **clonal populations** (cells obtained by the repeated divisions of a single parent cell) fusion may take place between gametes which are homothallic or in self compatible strains. For example, fusion occurs between any two cells of *C.gynogama* and *C.media*.

In *C.moewusii* and *C.reinhardtii* fusion of gametes can take place only when they come from two different unrelated (heterothallic, self incompatible) strains.

In many isogamous species the parent cell may divide to produce 16 to 64 biflagellate gametes while in some the adult cells themselves may directly behave as gametes and fuse.

Anisogamous form of gametic fusion is found in *C.braunii*. A female cell divides and produces four large cells. Each of these cells have two flagella but are less active. The male cells are about 8 in number but smaller in size.

Oogamy is the advanced type of sexual reproduction found in *C. coccifera*. A parent cell discards its flagella and directly becomes a non-motile egg or ovum. While male parent cell by repeated divisions produces sixteen male gametes. These are biflagellate and highly motile.

The process of gametic attraction, fusion and related phenomena have been studied in some detail in the laboratory. Under proper light condition and carbon dioxide concentration, production of gametes can be initiated by nitrogen starvation. The formation of male or female gametes (even in the case of isogamy) is attributed to the varying concentration of gamones produced by them. The attraction between gametes was found due to the presence of glycosidic mannose at the tips of the flagella of one strain which in a complementary way binds with the substance present in the flagella of the gamete of the opposite strain. Once this sticking of the flagella of plus and minus gametes takes place, flagella twist about each other bringing the anterior ends of the gametes close. This is followed by cellular and nuclear fusion.

The zygote secretes a thick wall and accumulates large amount of food materials like starch, lipids and orange- red pigments. It is now known as **zygospore** which remains dormant till the environmental conditions are favourable for its germination.

It has been shown that during germination of zygospore meiosis takes place followed by mitosis resulting in haploid *Chlamydomonas* cells.

Life Cycle

Chlamydomonas is unicellular, haploid and reproduces asexually many times by forming zoospores. Under unfavourable environmental conditions it produces gametes which fuse to form diploid zygospores. During germination reduction division takes place and haploid cells are formed (Fig. 4.7).

Chlamydomonas is of great interest to biologists. Its study has brought to light several interesting features of biological importance, some of which are listed below:

i) Presence of DNA in the chloroplasts of the alga.
ii) Presence of cytoplasmic genes.
iii) Production of genetic mutations- affecting nutrition, photosynthesis and production of mutants without flagella or cell wall.
iv) Discovery of gamones and their role in sexual reproduction.
v) Presence of isogamy, anisogamy and oogamy in a single genus.
vi) Control of reproduction by environmental conditions.

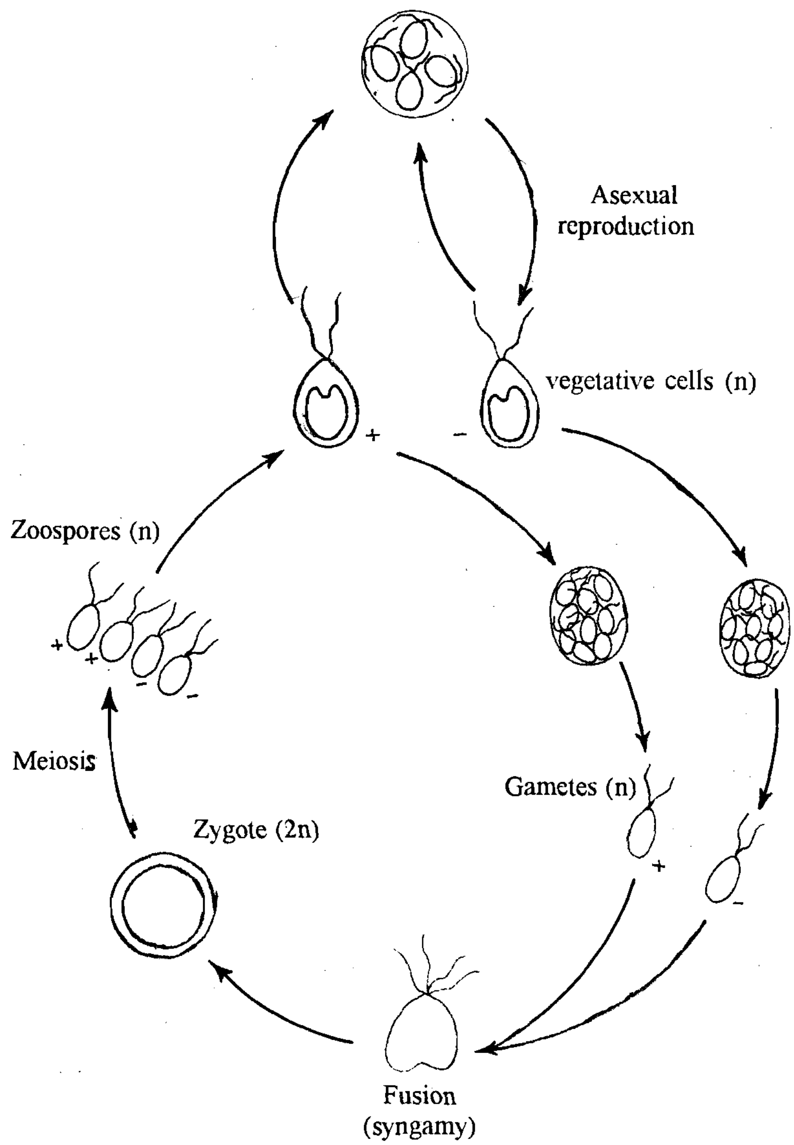


Fig. 4.7: Life cycle of *Chlamydomonas*.

4.3.2 *Ulothrix*

Sexual reproduction takes place by means of isogamous, biflagellate gametes. Fusion takes place only between plus and minus mating types. The gametes are from different filaments (heterothallic). The zygote develops a thick wall and remains dormant till the conditions are favourable for germination. When conditions become favourable meiosis takes place and 4-16 haploid zoospores are produced which settle down and give rise to vegetative filaments (Fig. 4.8).

It has been found that *Ulothrix* produces gametes when grown under long day conditions while short day conditions initiate the formation of zoospores.

Life Cycle

Look at Fig. 4.8 showing the life cycle of *Ulothrix*.

Which is the diploid stage of the algae?
The thallus of *Ulothrix* is haploid and the diploid stage is represented by the zygote only.

We would like to draw your attention to the fact that in some species (*U.speciosa, U.flcca* and in *U.implexa*) the zygote develops into an independent, unicellular thallus which is diploid in nature. It produces zoospores asexually by meiosis. The zoospores develop into haploid filaments.

Thus in *Ulothrix* two types of life cycles can be distinguished:

- **Haplobiontic:**

  The thallus is haploid and only the zygote is diploid e.g. ***U.zonata***?

- **Diplobiontic:**

  In diplobiontic cycle, the alga consists of a haploid thallus that produces gametes and a diploid unicellular stalked thallus which produces zoospores after meiotic division. The two generations - haploid and diploid, alternate with each other. (alternation of generations). Because the two thalli are very different in size and morphology it is known as **heteromorphic, diplobiontic** life cycle.

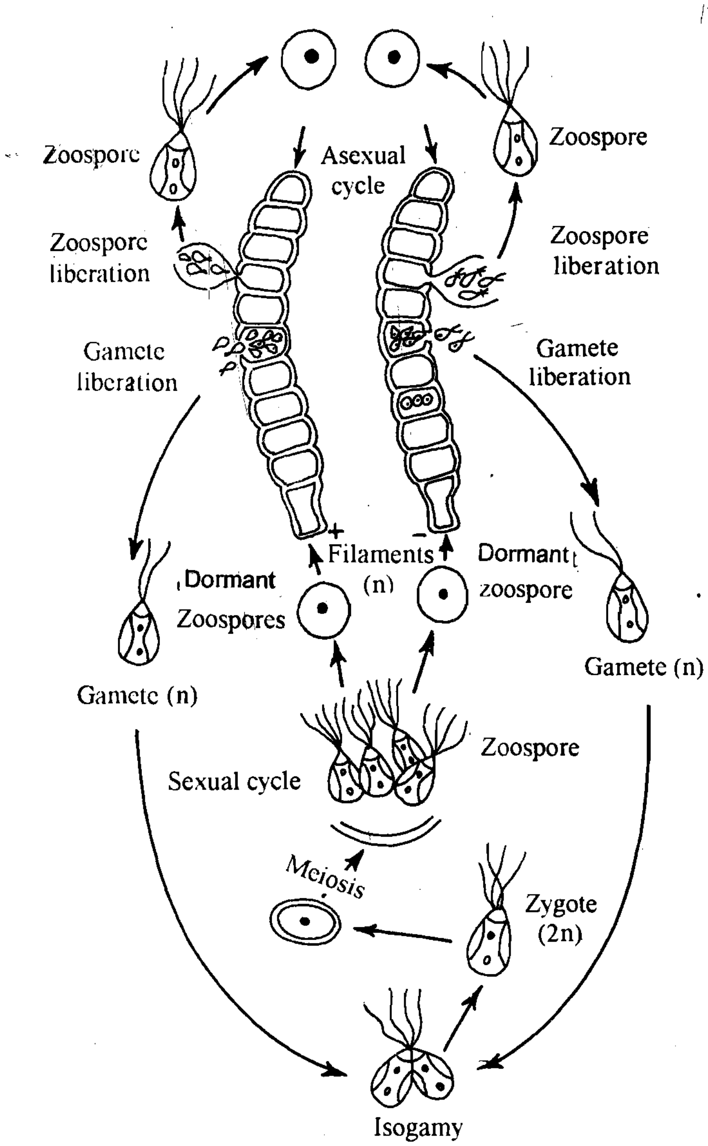


Fig. 4.8 : Life cycle of *Ulothrix*.

Box Item 1

> **Alternation of Generations**
> The type of life cycle of an organism in which reproduction alternates with each generation between sexual reproduction and asexual reproduction is called alternation of generations. The two generations are termed as **gametophytic** and **sporophytic** generations. The gametophytic generation is haploid(n) and the sporophytic generation is diploid (2n).
>
> The fusion of two gametes(n) results in zygote(2n) which on germination forms the plant / thallus called sporophyte. The sporophyte in turn produces haploid spores by meiosis. When a spore germinates it develops into gametophyte which bears male or female gametes or both on the same plant / thallus.
> In some bryophytes the gametophytic generation is more conspicuous. While in ferns the sporophytic generation is more prominent. In angiosperms main plant body is sporophyte and the gametophytic generation is reduced to a few cells. You will see that all type of situations prevail in algae. In some algae gametophyte is prominent while in others sporophyte is prominent

4.3.3 *Ulva*

The life cycle of *Ulva* is shown in Fig. 4.9. Note the thalli of sporophyte and gametophyte. Both are morphologically alike. However, the gametophyte is haploid (n) whereas the sporophyte is diploid (2n). The haploid gametophyte produces gametes and the diploid sporophyte produces after meiosis zoospores that germinate to form haploid gametophytes.

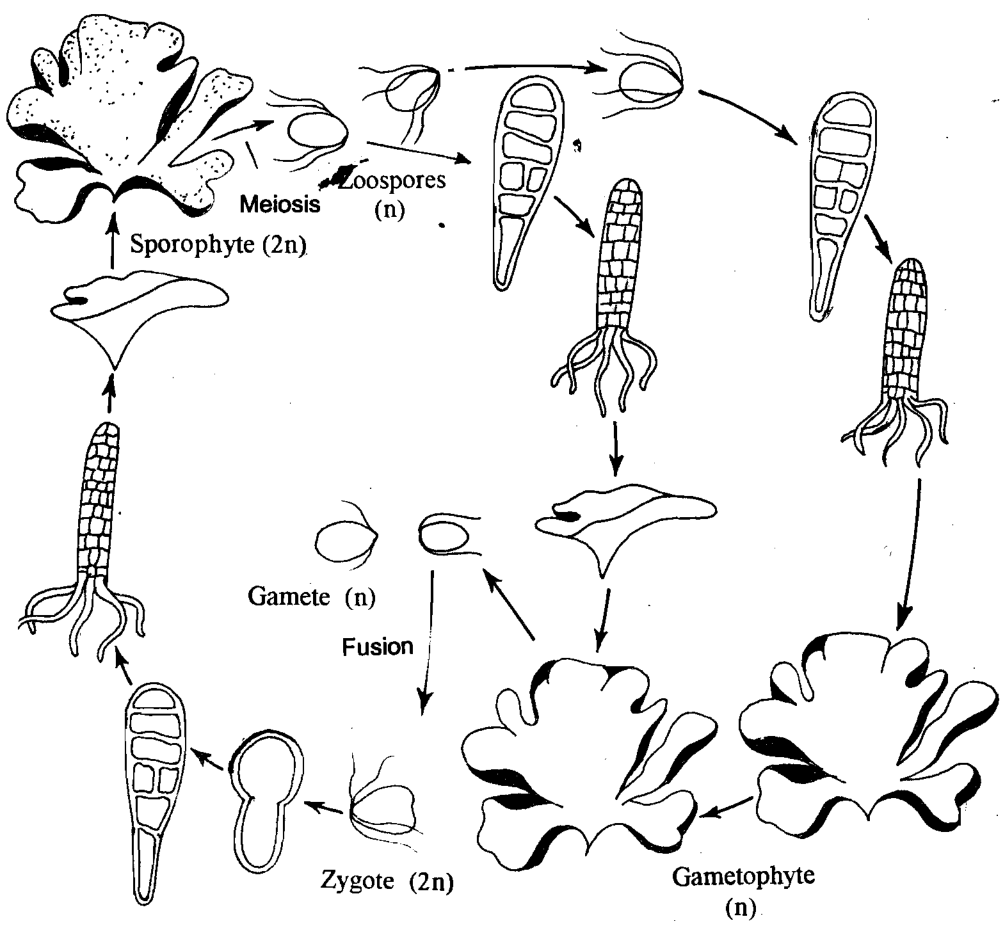


Fig. 4.9: Life cycle of *Ulva*. Note the isomorphic alternation of generations.

The gametophytes of *Ulva* produce gametes which are isogamous or anisogamous. After fusion the zygote is formed which develops into a diploid sporophyte.

The life cycle of *Ulva* is described as **isomorphic, diplobiontic** type.

4.3.4 *Laminaria*

Sexual reproduction in *Laminaria* is oogamous type.

The mature diploid thalli of sporophytes produce sori or unilocular sporangia on the surface of the lamina. Each sporangium divides by meiosis to give rise to 32 biflagellate zoospores which germinate to form male and female gametophytes (Fig. 4.10).

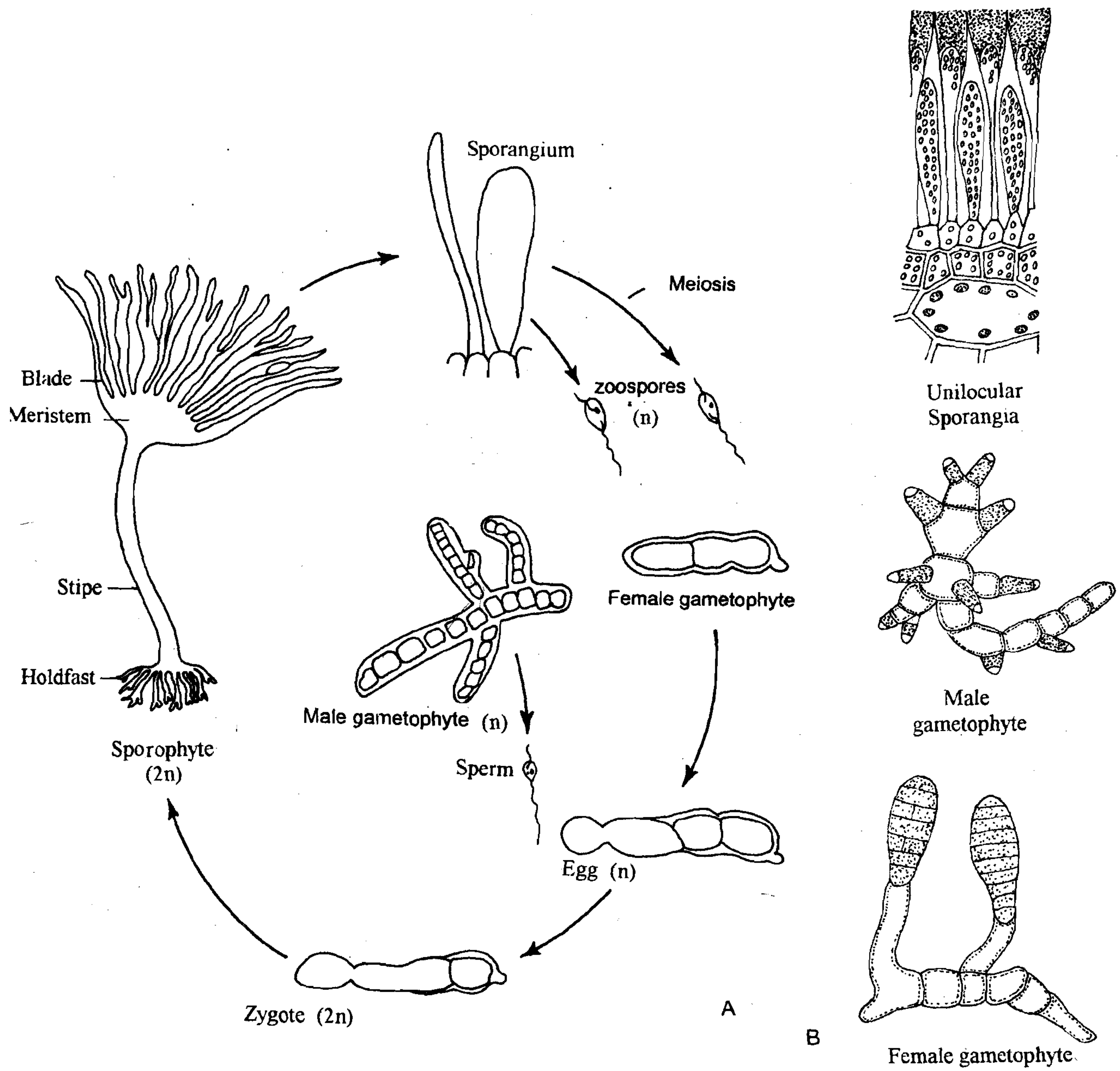


Fig. 4.10: A) Life cycle of *Laminaria*. B) The sporophyte is macroscopic and the male and female gametophytes are microsopic.

The gametophytes of both sexes are microscopic with a few branches and their fertility is controlled by environmental conditions.

Any cell of the female gametophyte can develop into an oogonium, the contents of which form a single egg. The egg protrudes out when mature but remains attached to the mouth of the empty oogonial cell.

Antheridia are produced singly as lateral outgrowths of the male gametophyte. Only one sperm is produced from each antheridium, which is pear shaped and has two flagella of unequal length.

After fertilization the zygote immediately divides mitotically without any resting period and develops into a sporophyte (Fig, 4.10).

Life Cycle

In *Laminaria* there is a distinct alteration of haploid gametophyte and a dominant diploid sporophyte.

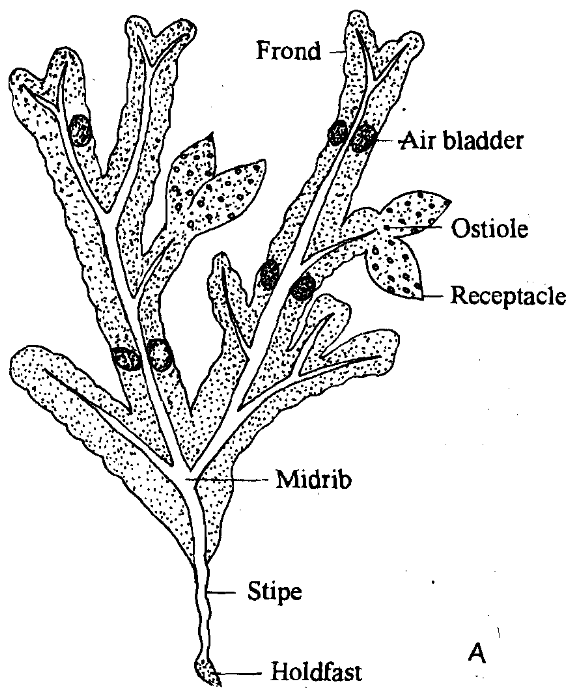
Reduction division takes place in the sporangia of sporophyte before the formation of zoospores, which germinate to form the male and female gametophytes.

The two dissimilar generations - one simple filamentous gametophyte and the other highly differentiated, complex multicellular thallus - alternate with each other - hence the life cycle is termed **heteromorphic alternation of generations.**

4.3.5 *Fucus*

Fucus has advanced type of reproductive structures, termed as **receptacles,** which are swollen at the tips of branches (Fig. 4.11 A).

Distributed over the surface of each receptacle are small pores, known as **ostioles** which lead into the cavities, called **conceptacles** (Fig. 4.11B). Each conceptacle may produce only eggs, only sperms or as in some cases both. A thallus may be unisexual - either having male receptacle or only female ones.



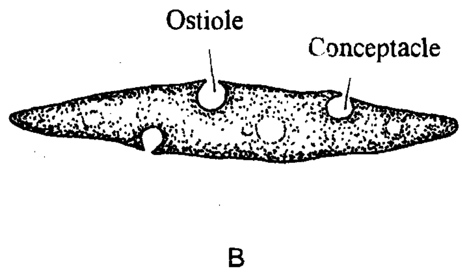


Fig. 4.11 : ***Fucus*: A) Structure of thallus, B) Enlarged receptacle.**

At the base, inside the conceptacle is a fertile layer of cells which develops into oogonia (Fig. 4.12A and 4.14A). Each oogonium has a basal stalk cell and an upper cell which undergoes reduction division and produces eight haploid eggs (4.12 C and D). These are liberated in the conceptacle (Fig. 4.12E). Some of the cells inside the conceptacle produce unbranched multicellular hairs called **paraphyses** which emerge out of the ostiole as tufts.

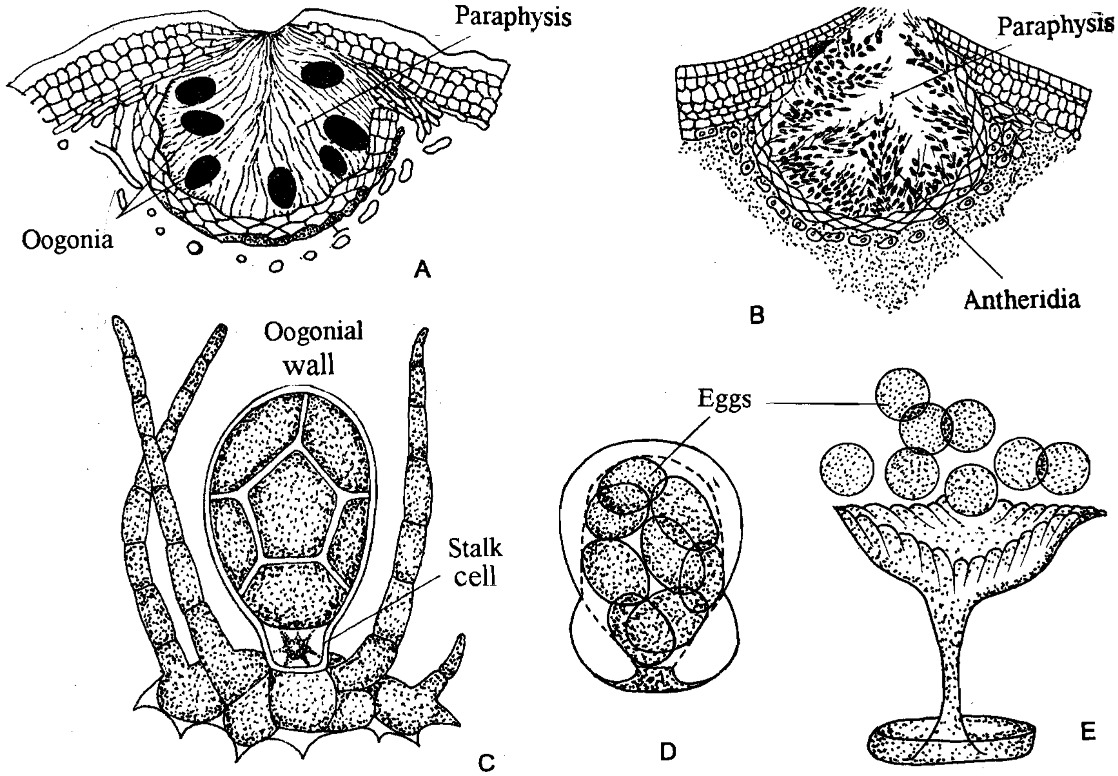


Fig. 4.12: *Fucus* **A) T.S. through female conceptacle showing oogonia, B) T. S. through male conceptacles showing antheridia, C) structure of an oogonium, D and E) formation and liberation of eggs.**

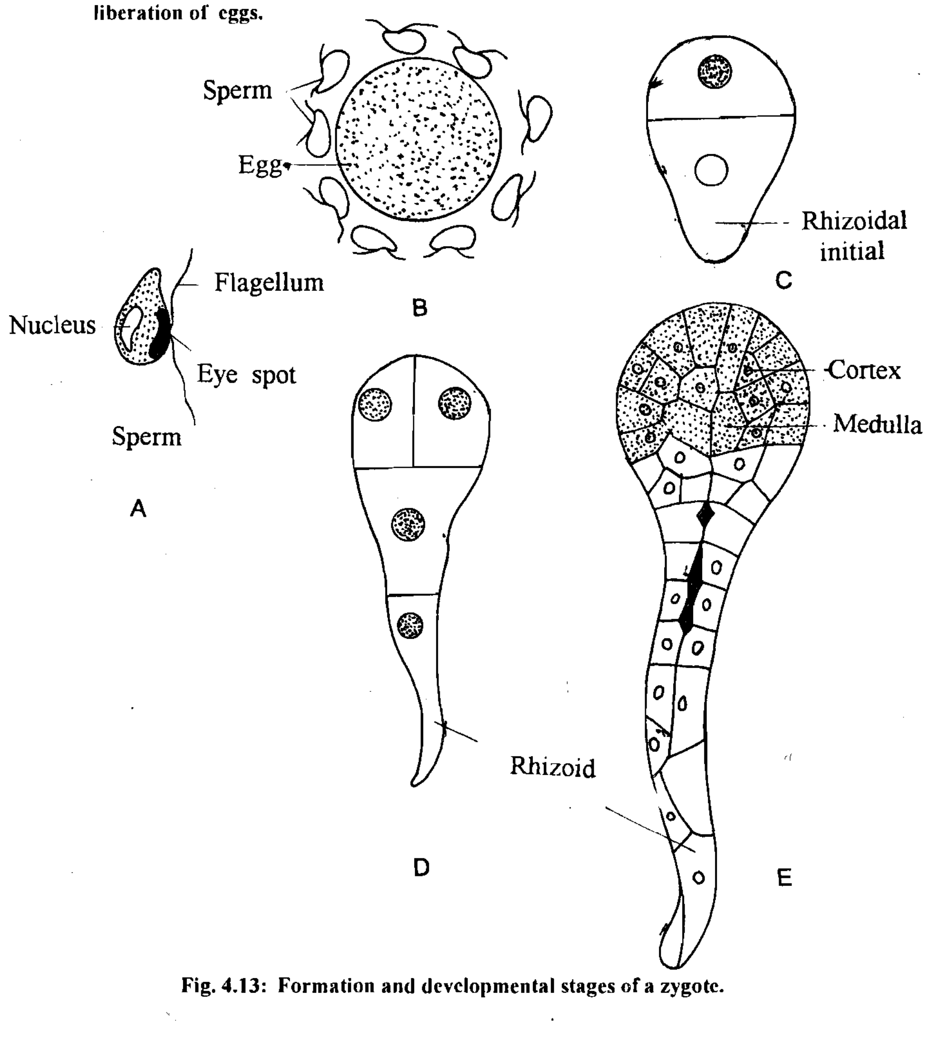


Fig. 4.13: Formation and developmental stages of a zygote.

Antheridia are produced on branched paraphyses inside the conceptacle (Fig 4.12B and 4.14B). Each antheridium is like a unilocular sporangium which divides meiotically and then by further divisions produces 64 haploid sperms. The biflagellate sperm has a longer flagellum pointing backwards and a shorter one projecting towards the front. It has a single chloroplast and a prominent orange eye spot (Fig. 4.14A).

The release of the gametes is connected with the sea tides. At low tide, *Fucus* fronds shrink due to loss of water, and when such fronds are exposed to an on coming tide, the eggs and sperms are released into the surrounding sea water.

The eggs of *Fucus* are known to attract sperms (Fig.4.13 A and B) by secreting a gamone . Immediately after fertilization a wall is secreted around the zygote. It has been shown that unfertilized eggs can develop into germlings parthenogenetically if treated with dilute acetic acid.

The diploid zygote germinates by producing a rhizoidal outgrowth on one side. It is later cut by wall formation to form a lower rhizoidal cell and apical cell (Fig. 4.13C) which by further divisions (Fig. 4.13 D and E) gives rise to the *Fucus* fronds.

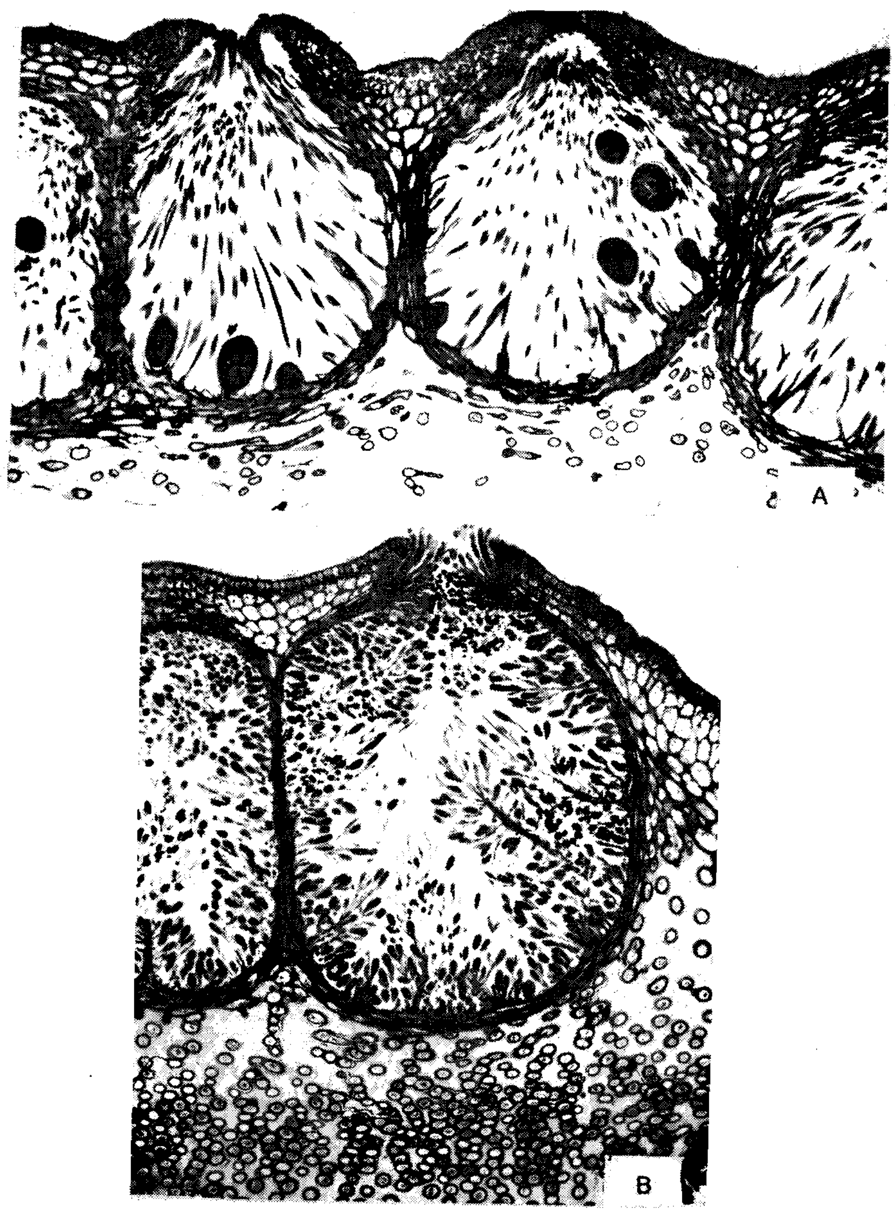


Fig. 4.14: ***Fucus*: A) C.S. of a female conceptacle and B) C. S. of male conceptacle.**

Life Cycle

Fucus plants are diploid and the haploid stage is represented by gametes only. The life cycle of *Fucus* is described as diplontic life cycle.

The four basic types of life cycles described above are summerised in Fig. 4.15.

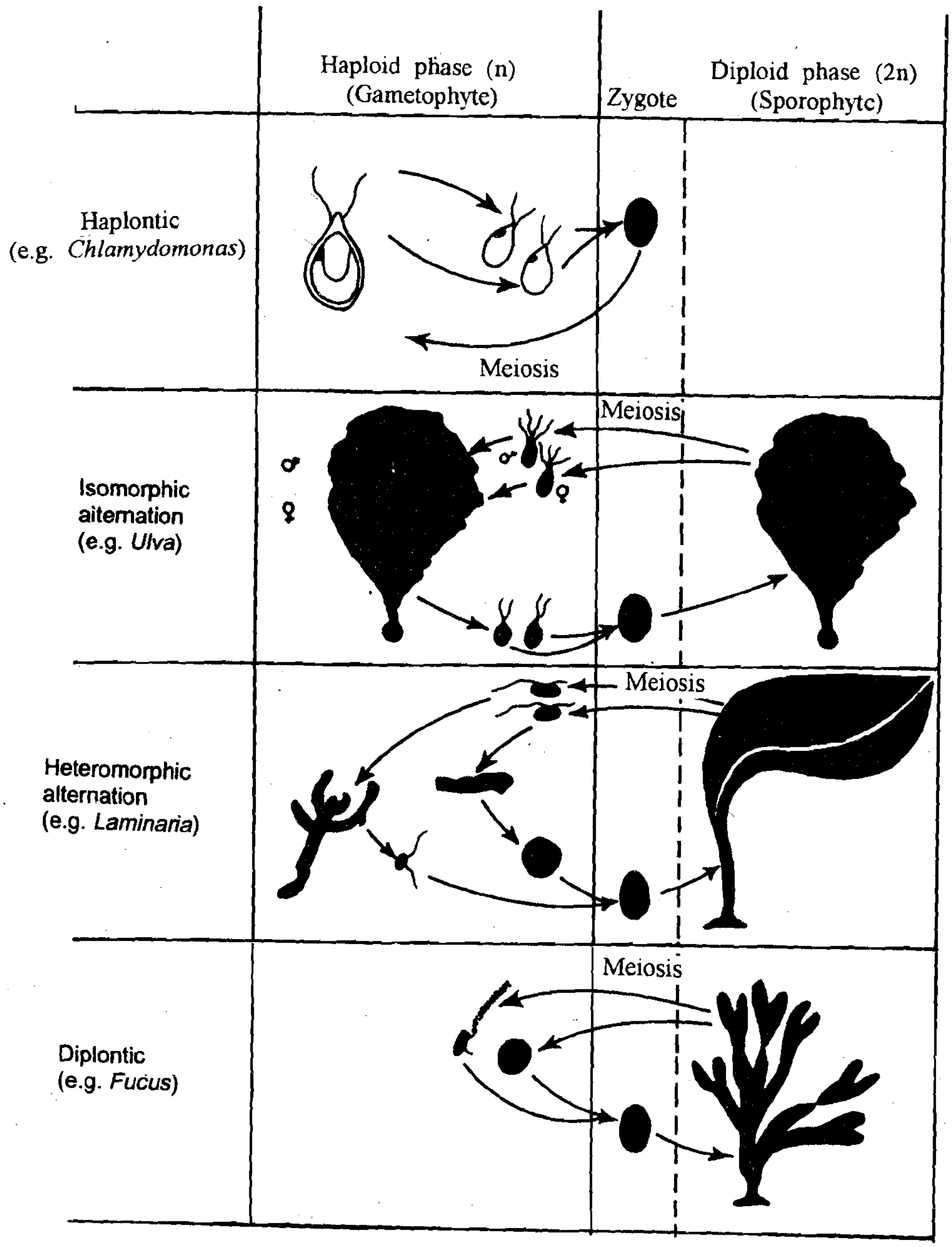


Fig.4.15 : Four basic types of life cycles in algae.

When the dominant phase is the haploid gametophyte, the life cycle is termed as haplontic life cycle. In this cycle diploid state or sporophyte is represented by zygote which produces spores by meiosis that develop into gametophytes.

In diplontic cycle the main or dominant phase is the diploid sporophyte. The zygote directly germinates into a sporophyte. Later meiosis takes place producing haploid gametes that fuse to form the zygote. In the diplontic algae it is to be noted that no free living haploid thalli are found.

When both the gametophyte and the sporophyte are equally developed and look morpholoigically similar, we have isomorphic alternation of generations. However, if gametophyte is underdeveloped compared to the sporophyte the life cycle is known as heteromorphic alternation.

SAQ 4.2

a) In the following statements choose the correct alternative word given in the parentheses.

   i) Zygote of *Chlamydomonas* undergoes (meiosis/mitosis) during germination.

   ii) Short-day condition initiates the formation of (zoospores/gametes) in *Ulothrix*.

   iii) In haplontic life cycle, the alga is (haploid/diploid), only the zygote is (haploid/diploid).

   iv) In (haplontic/diplontic) type of life cycle the alga producing gametes is haploid and the alga producing zoospores is diploid.

   v) The reproductive structures present at the swollen tips of branches in *Fucus* are called (receptacles/conceptacles).

   vi) The small pore present on the (receptacle/conceptacle) leads to a cavity called (receptacle/conceptacle).

b) In the following statements fill in the blank spaces with appropriate word(s):

   i) The alternation of generations where gametophyte and sporophyte of a given species are morphologically distinct from each other; the gametophyte generally microscopic is called ....

   ii) In .... the thallus of gametophyte and sporophyte are morphologically alike. Such type of alternation of generations is called ....

   iii) Ostioles are the .... on the surface of receptacles that lead into the cavity called ....

   iv) In *Fucus* sperms are ....

   v) In *Fucus* the eggs secrete .... to attract sperms.

   vi) The life cycle of *Fucus* is of .... type of alternation of generations.

4.4 ORIGIN AND EVOLUTION OF SEX

4.4.1 Origin of Sex

The basic feature of sex is the fusion of two cells – gametes which are of two types, male (plus) and female (minus).

What factors lead to the fusion of cells as such is not clear but fusion brings about mixing of two different (but related) genomes together, one probably compensating for the deficiencies of the other. This particular feature is a biological advantage for the survival of the species. It is no wonder that almost all organisms developed sexual method of reproduction.

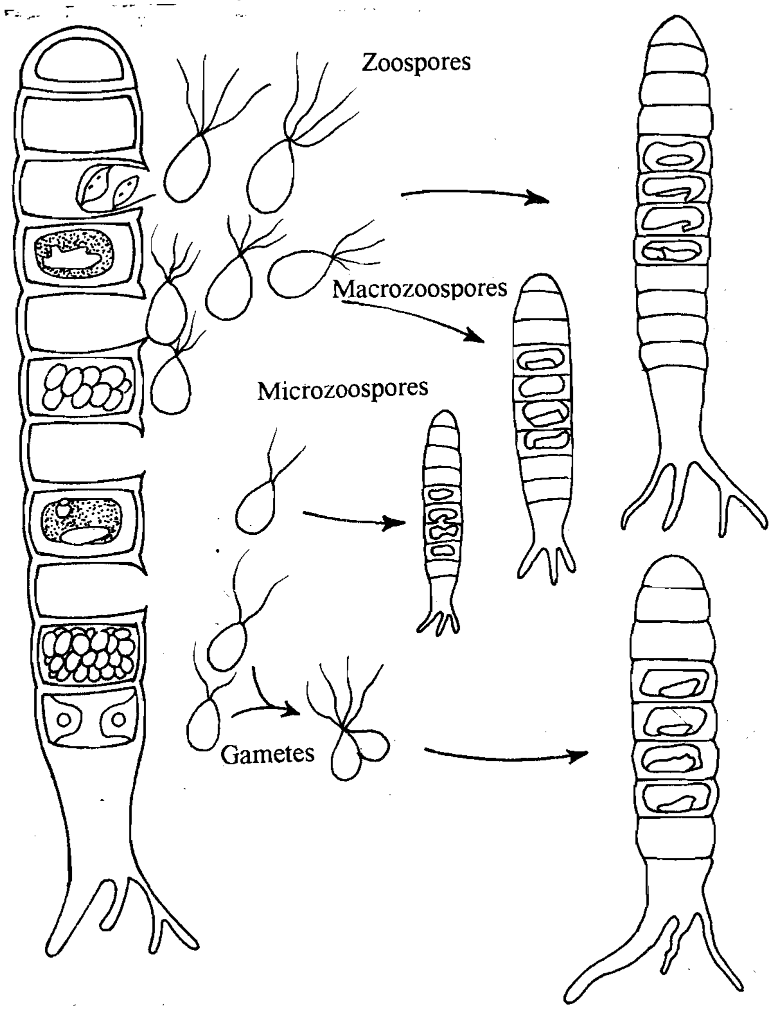


Fig. 4.16 : Hypothetical diagram illustrating the origin of sex in *Ulothrix* (Adapted from Kumar and Singh, 1990).

Even in the case of prokaryotic cyanobacteria, and also in other bacteria different mechanisms were discovered (para-sexual mechanisms) whose essential feature is exchange or mixing of genes or complete genomes between a donor and a recipient.

In all eukaryotic algae as in all plants and animals, fusion of cells is the method by which sexual reproduction takes place. The question is how this fusion of cells originated and further how this phenomenon was preserved and refined during evolution. The study of the sexual processes found in the present day algae provide some answers to the above questions.

In lower algae like *Chlamydomonas*, *Ulothrix* and others asexual reproduction takes place through motile swarmers called zoospores. In *Ulothrix* depending on the number of divisions that a cell undergoes, at least two types of zoospores are produced, small **microzoospores** and large **macrozoospores**. The microzoospores often fail to germinate to produce new plants, probably due to deficiency or low level of some vital substances needed for cell division and growth. However, such swarmers are found to fuse in pairs occasionally and then develop into *Ulothrix* filaments. It appears that macrozoospores are self sufficient and do not require any such fusion.

In many algae one can not make out any difference in structure between a zoospore and a gamete, except for their behaviour - a zoospore directly develops into a filament whereas a gamete needs fusion with another gamete for further development. If certain type of zoospores - small microzoospores can behave like gametes, at times gametes which fail to fuse may behave like zoospores and develop directly into thallus - a phenomenon called **parthenogenesis** reported to be present in diverse organisms. Such observations indicate that gametes are modified zoospores and gametic fusion originated through accidental fusion of small and weak zoospores. As such fusions in general help by genetic mixing, to acquire characters useful for biological survival, the essential features of sex were retained and improved further during evolution.

4.4.2 Evolution of Sex

Isogamy, fusion of identical gametes seems to be the earliest state of sex. However, the morphologically similar gametes may be different in origin, arising from two different gametic mating types, plus and minus strains (heterothallic).

The simplest early state appears to be the fusion (not any more accidental but regularised) of morphologically similar gametes, perhaps arising from the same thallus - homothallic isogamy. This is improved further by heterothallic isogamous fusion, in which though gametes looked morphologically similar but with genetical and biochemical differences to encourage fusion of opposite mating types, plus and minus only.

Anisogamy constitutes an intermediary state as it may involve fusion of gametes with distinct size difference. Although both gametes are flagellated, the bigger one may be less active than the smaller male gamete. Further refinement ultimately led to oogamy - which is the most common and the only form of sexual reproduction in higher thalloid algae.

Oogamy is characterised by big non-motile egg and a small motile spermatozoid. The gametes may be produced in oogonia and antheridia. The oogonia may produce only a few eggs (eight) or as in some algae a single egg, while the number of sperms formed is always very large.

Generally, the eggs are liberated into the surrounding water but there is a tendency to retain the egg inside the oogonium itself, where fertilization also takes place. The zygote or oospore may develop further inside the empty oogonium.

It is to be noted that the above account of the origin and evolution of sex is entirely based on the study of reproductive process of various algae. Biologists in recent years discovered that in algae, sex has genetic and biochemical basis. In *Chlamydomonas* gametes produce a volatile substance that attracts the gametes of the opposite sex. The eggs of *Fucus, Laminaria, Oedogonium* and many other algae have been shown to produce species-specific chemicals to attract the spermatozoids. Such chemicals are known by a collective name 'gamones or pheromones' or sex hormones.

In algae, several other processes connected with reproduction like gametogenesis, chemotaxis of gametes, adhesion and fusion of gametes of opposite sex - are known to be controlled by pheromones.

SAQ 4.3

a) Indicate which of the following statements are true or false. Write **T** for true and **F** for false in the given boxes.

   i) In many algae zoospores and gametes cannot be distinguished from their morphology. ☐

   ii) In algae at times zoospores behave like gametes and gametes behave like zoospores. ☐

   iii) Plus and minus gametes are genetically alike. ☐

4.5 SUMMARY

In this unit you have learnt that:

- Algae reproduce by vegetative, asexual and sexual methods,
- Asexual reproduction involves the formation of various types of spores formed in any vegetative cell or in specially differentiated cells,
- Sexual reproduction in algae involves fusion of two gametes.
- The gametes may not have clear morphological differences to be called male or female, hence designated as plus and minus mating types. The fusion product is known as zygote.
- In isogamy both the gametes are equal in size and flagallated, in anisogamy both are flagellated but one gamete is bigger in shape and size called female or minus type. In Oogamy the bigger one, is without flagella, non-motile egg and male gametes, spermatozoids are small and motile.
- Haploid gametes are produced by mitosis in a haploid thallus or by meiosis in a diploid thallus. A complete life cycle of an alga involves two phases - haploid phase and a diploid phase.
- In different algae the haploid and diploid phases show a variety of morphology and the two phases alternate with each other known as alternation of generations, even though both phases occur within a single life cycle.
- Algae show haplontic, diplontic, isomorphic and heteromorphic alternation of generations.

4.6 TERMINAL QUESTIONS

1. List the factors that control the life cycle of an algae.

   ....

   ....

   ....

   ....

   ....

   ....

2. With the help of a labelled diagram describe the three types of gametic fusion in sexual modes of reproduction.

   ....

   ....

   ....

3. What is the special advantage of sexual reproduction to a particular species?

   ....

   ....

   ....

   ....

4. "Gametes are modified zoospores" Comment.

....

....

....

....

4.7 ANSWERS

Self-assessment Question

4.1 a) *Anacystics,* and *Microcystis*

b) i) Akinete, ii) aplanospores, iii) new filament, iv) palmella stage, v) homothallic or monoecious, vi) heterothallic or dioecious, vii) isogamy, viii) distinctly different in size.

c) i) haploid, ii) female, male, gamone, iii) zygote

4.2 a) i) meiosis, ii) zoospore, iii) haploid, diploid, iv) diplontic, v) receptacles, vi) receptacle, conceptacle

b) i) dimorphic
ii) *Ulva*, isomorphic,
iii) small pores, conceptacle
iv) biflagellate
v) gamone
vi) diplontic

4.3 i) T, ii) T, iii) F

Terminal Questions

1. Temperature
Light
Availability of nutrients
Seasons
Wave action
Periodicity of tides
2. Isogamy
Anisogamy
Oogamy
3. There is mixing of two different but related genomes, one compensating for the deficiency of the other. This is particularly advantageous for the survival of species.
4. In many algae one can not make out any difference in structure between a zoospore and a gamete, except for their behaviour - a zoospore directly develops into a filament whereas a gamete needs fusion with another gamete for further development. If certain type of zoospores - small microzoospores can behave like gametes, at times gametes which fail to fuse may behave like zoospores and develop directly into thallus - a phenomenon called **parthenogenesis** reported to be present in diverse organisms. Such observations indicate that gametes are modified zoospores and gametic fusion originated through accidental fusion of small and weak zoospores.

UNIT 5 MACROMOLECULES OF THE CELL

Structure

5.1 INTRODUCTION

In Unit 4, you have learnt about the small basic molecules present in a cell-like water, amino acids, nucleotides, sugars and fatty acids and also about various techniques used for the isolation and purification of macromolecules.

In this unit you will study about large molecules present in various life forms ranging from bacteria to man. These macromolecules namely proteins, nucleic acids, lipids and carbohydrates have a common molecular organisation in different forms of life. These macromolecules of life are constantly in a state of flux. Here, you will study the various types of bonds and non-bonded interactions which help to unite the basic molecules to form these macromolecules and give them a structure and shape.

In the previous unit, you have studied about amino acids, which are the basic structural unit of proteins. Here, information is provided about how these molecules play a key role in all biological processes, and how polypeptides chains fold upon themselves and produce the specific three-dimensional structure of proteins. Proteins play an important role in carrying information from cytoplasm to nucleus, for example some promotors and repressor are proteins in nature. Proteins also mediate a wide range of other functions, such as mechanical support, transport and storage, coordinated movements, excitability, immune protection, and the control of growth and differentiation. The other important informational molecules in the cell are the nucleic acids which store, transmit and carry out the genetic infonnation from one generation to the next. We will also discuss here about the structure and general properties of carbohydrates and lipids which are also called "non-informational molecules". Carbohydrates are the immediate source of energy, whereas lipids store energy and are the essential components of membrane structure.

Before you go in details of this unit, it is important that you must have studied Unit 4 carefully. You should also refresh your memory about the structure of an atom.

Objectives

After you have studied this unit you should be able to:

- explain different types of bonds that hold atoms and molecules together,
- identify the primary, secondary, tertiary and quaternary structures of a protein,
- distinguish between the structures of DNA and RNA,
- define polysaccharides, mucoplysaccharides, glycoproteins, proteoglycans, glycosaminoglycans, and
- list important lipids and the site of their occurrence.

5.2 TYPES OF BONDS

Macromolecules are held together by different types of chemical bonds. On the basis of energy required or released to break during bond formation or breakage, these bonds have been classified into two types, i.e., strong and weak bonds (Table 5.1). **Strong bonds** preserve the structure of macromolecules and require greater amount of energy to break. **Covalent bonds** are strong type of bonds (see Fig. 5.1(a)). Glycosidic, peptide, and nucleotide bonds are examples of covalent bonds. These are formed by sharing of electrons between two electronegative atoms. As you will proceed, you will study in detail about glycosidic, peptide and nucleotide bonds in Sections 5.3, 5.4 and 5.5. Hence, our main emphasis in this section will be on weak bonds. **Weak bonds,** called **non covalent bonds** help to carry the information and require much less energy to break. Weak bonds include hydrogen bonds, hydrophobic bonds, ionic bonds, and van der Waals forces (Table 5.1).

Table 5.1
Energies released/consumed during bond breakage/formation

Types of Bond		Bond energy kilojoules/mole
STRONG BONDS		
Covalent bonds		
Single bonds	O - H	462
	H - H	436
	S - S	426
	C - H	415
	C - O	356
	C - C	347
	C - N	292
Double bonds	C = O	723
	C = C	602
WEAK BONDS		
Ionic Bonds	NaCl	408
(In the absence of water)	NaI	304
Hydrogen Bonds		33 - 175
Hydrophobic Bonds		
(van der Waals attractions)		33

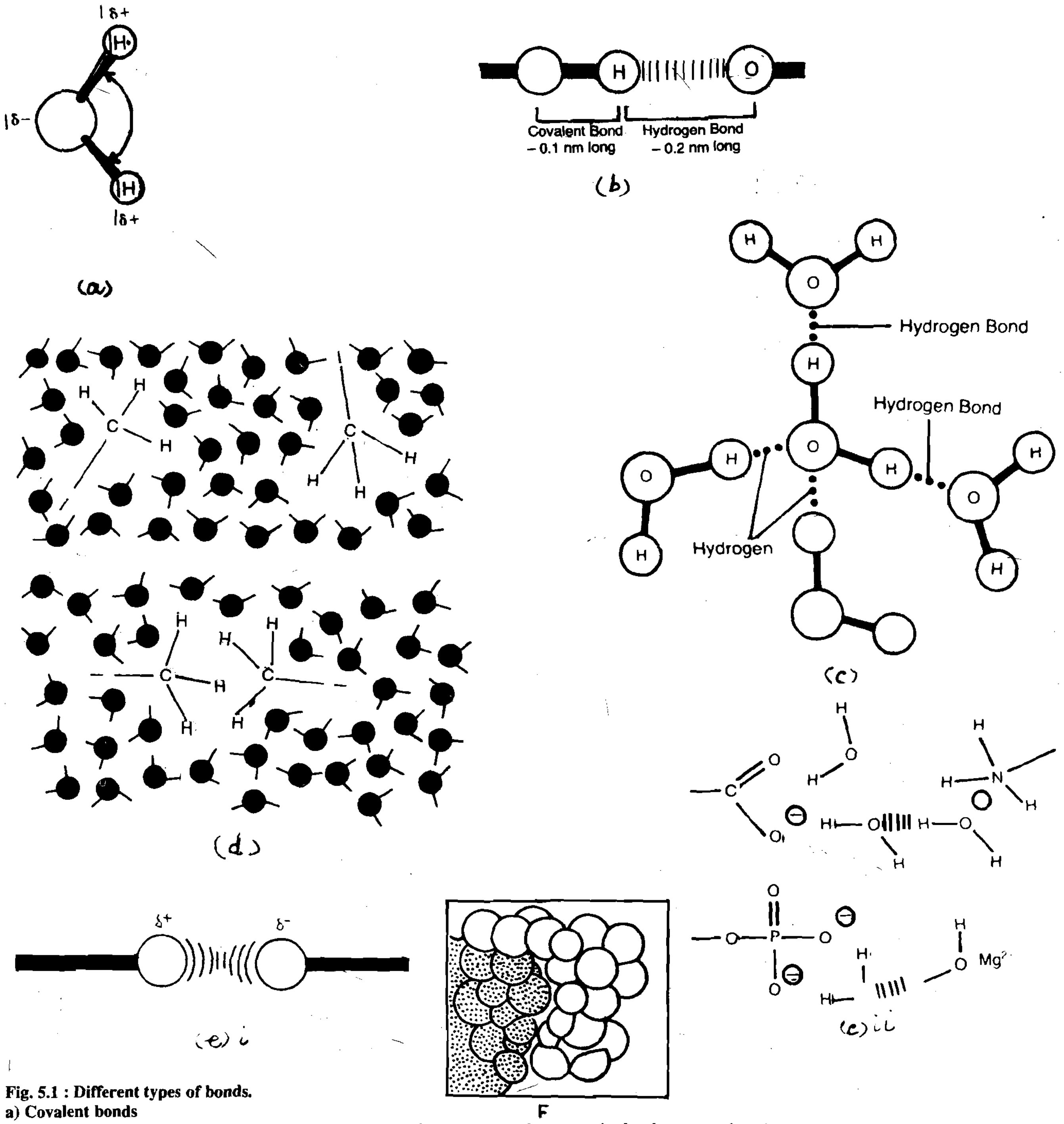
Hydrogen bonding is very common in biological systems. Hydrogen bonding is very important in maintaining three-dimensional structure of nucleic acids, protein molecules and specially of water (Fig 5.1b). In the absence of hydrogen bonding, water would have been in the gaseous state at room temperature and this would have made the existence of life impossible (Fig 5.1 c).

Non-polar molecules or groups tend to hold themselves together in the interior, when in water due to repulsion for water. These interactions are called **hydrophobic interactions** (hydro=water, phobia= repulsion). Dispersed oil droplets coming together in water to form a single large oil drop is a familiar example of hydrophobic interaction (Fig. 5.1 d).

Ionic or electrostatic bonds are formed by transfer of electrons between oppositely charged atoms, e.g., between Na^+ and Cl^-. Ionic bonds are very strong (like covalent bond) in the absence of water. However, they are quite weak (like hydrogen bond) in the presence of water (Fig. 5.1 e). Ionic bonds are very important in binding of enzyme and substrate.

Dipole: A molecule carrying positive and negative charges spatially separated at opposite ends of the structure.

When two atoms are not too far, i.e. distance between a pair of atoms is not more than one angstrom (1°A) they tend to interact due to the instantaneous dipoles induced. The fluctuating electrical charges set up between the nuclei and the electrons create a weak ionic interaction. This type of attraction is known as **van der Waals force** (Fig. 5.1 f). van der Waals forces break down easily when exposed to heat, because the strength of this bond is slightly more than the average molecular thermal energy at room temperature.



F

Fig. 5.1 : Different types of bonds.

a) Covalent bonds

Covalent bonds are strongest bonds formed by sharing of one or more electron pairs by the atoms. A water molecule consists of two hydrogen atoms and one oxygen atom joined by covalent bonds. The δ^+ and δ^- indicate a slight positive and negative charges on the molecules which is due to shifting of electrons to the more positively charged nucleus of oxygen.

b) Hydrogen bonds

For the formation of hydrogen bond a hydrogen atom is shared by two electronegative atoms, for example, the bond between an oxygen and nitrogen atoms and between two nitrogen atoms. Such bonds are predominantly found in proteins and nucleic acids.

c) Hydrogen bonds in water

Due to weak electrical charges, the water molecules are joined by hydrogen bonds transiently.

d) Hydrophobic bonds

A weak interacting force between water repelling, nonpolar residues and molecules, such as between fatty acid chains of membrane phospholipid or between aromatic bases in DNA.

e) Ionic bonds

These bonds are very strong in the absence of water. The force of attraction between the two charges, (+) and (–) is $F = \frac{q_1 q_2}{r^2 D}$. Where D= dielectric constant (1 for vacuum, 80 for water), r= distance between two molecules, q_1 and q_2 are the charges. Ionic bonds become weak in presence of water.

f) van der Waals force

A non specific, weak chemical interaction resulting from attractive forces produced two atoms or groups of atoms when they come near each other.

SAQ 1

Why do ionic bonds become weak in the presence of water?

....

....

....

....

5.3 PROTEINS

Proteins are nitrogenous compounds of high molecular weight. These are the major building material of cells and take part in controlling different activities of living systems. Proteins are made-up of amino acids that are covalently linked with each other by peptide bonds. The number of amino acids in a peptide chain varies. Simple proteins consist of only amino acids, whereas complex proteins have other substances like lipids and carbohydrates also.

Proteins are classified into seven types on the basis of their biological functions (Table 5.2).

Table 5.2
Classification of Proteins according to Biological Functions

	Class	Example	Functions
i)	Enzymes	Ribonuclease, Trypsin	Help in catalysing chemical reactions in living cells
ii)	Transport proteins	Haemoglobin, Serum albumin, Myoglobin, —Lipoprotein	Involved in the transport of molecules and ions across the membranes
iii)	Nutrient and storage proteins	Gliadin (wheat), Ovalbumin (egg), Casein (milk), Ferritin	Provide the essential components by storing them in the body
iv)	Contractile or motile proteins	Actin, Myosin, Tubulin, Dynein	Coordinate movements such as movements of chromosomes in mitosis
v)	Structural proteins	Keratin, Fibroin, Collagen, Elastin, Proteoglycans	Essential components of various cells and tissues
vi)	Defence proteins	Antibodies, Fibrinogen, Thrombin, Dotulinus toxin, Diphtheria toxin, Snake venoms Ricin	Help in protection against harmful agents such as bacteria and virus
vii)	Regulatory proteins	Insulin, Growth hormone, Corticotropin, Repressors	Control of growth and differentiation

The polypeptides which form proteins after being synthesised on ribosomes in linear chains are biologically inactive. But within a few seconds after their synthesis, the folding of polypeptide chain occurs in specific forms to give functionally active proteins which have many levels of organisation. These levels are expressed as primary, secondary, tertiary and quaternary structures. The **primary structure** of a protein refers to the number, type, and position of the individual amino acids in a polypeptide chain. A peptide bond is a covalent bond between the carboxyl group of one amino acid and the amino group of the adjoining amino acid. One molecule of water is removed in the formation of one peptide bond. A polypeptide chain thus will have only one free amino(-N or -NH_2) terminal and one free carboxyl (-C or -COOH) terminal (Fig. 5.2 a).

Secondary structure: The local structure of a polypeptide or nucleic acid chain arising from chemical bonding between the neighbouring residues to produce forms such as stem and loop of transfer RNA and α helix or beta sheet configuration in polypeptides.

α - helix is a major secondary structure in polypeptides, characterised by regularly repeated hydrogen bonding between C = O and N - H groups in the chain.

Secondary structure of a protein is determined entirely by the primary structure. The secondary structure is formed by the folding of a polypeptide chain. The folded chain is held together by hydrogen and disulphide bonds. Hydrogen-bonding interactions between peptide bonds are responsible for regular folding pattern like α-helix and β sheets. In an α-helix such as in α-keratin fibres and myoglobin the chain itself turns regularly to make a rigid cylinder. The tightly coiled polypeptide main chain forms the inner part of the rod, and the side chains extend outward in a helical array. The helix is stabilised by hydrogen bonds between residue one and five of the amino acids (Fig. 5.2 b, i & ii). Number of amino acid residues per turn comes to 3.6. In a β sheet such as in silk fibroin and parts of immunoglobulin, the polypeptide chain itself folds back and forth. In β pleated sheet, all peptide linkages participate in the formation of hydrogen bonds to provide stability. Many beta sheets are slightly twisted, which are known as beta turns. The same polypeptide may form α-helix as well as β sheets (Fig. 5.2 b, iii & iv).

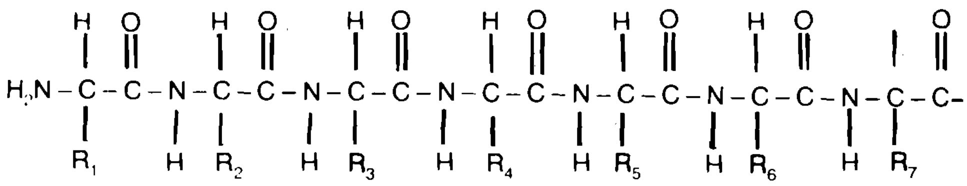
Tertiary structure of the protein is the characteristic overall shape assumed by arrangement and interrelationship of helical and non-helical regions of a polypeptide chain(s). It is the final folding of the chain involving non-covalent interactions between the distantly located residues. Functional regions of a protein are called domains such as the active site of an enzyme (Fig. 5.2 c).

Quaternary structure of a protein is made by the association of two or more polypeptide chains or subunits that fit together in a specific arrangement by non-covalent interactions—the stabilising force for such interactions. For example, haemoglobin molecule is formed by the association of two α polypeptide chains and two β chains (Fig. 5.2 d).

β pleated sheet is almost fully extended rather than being tightly coiled as in α helix. It is called β because it was their second structure. The α helix being the first.

Tertiary structure: The three dimensional folding of a polypeptide or polynucleotide chain brought about by interactions among side groups or other residues at some distance from one another in the primary structure of the molecule.

Quaternary structure: Specific assemblies in a protein composed of two or more polypeptide chains that have different properties in the protein molecules than they would as individual chains.



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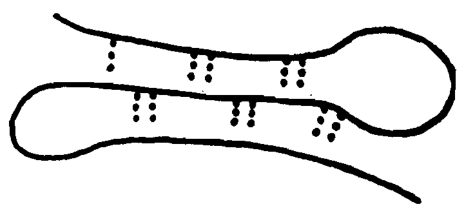

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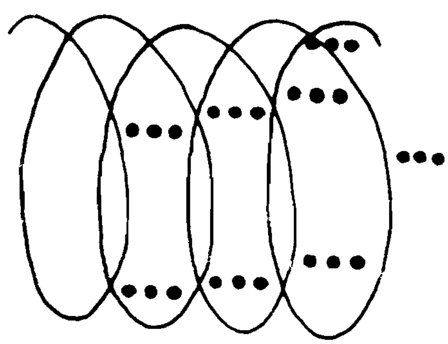

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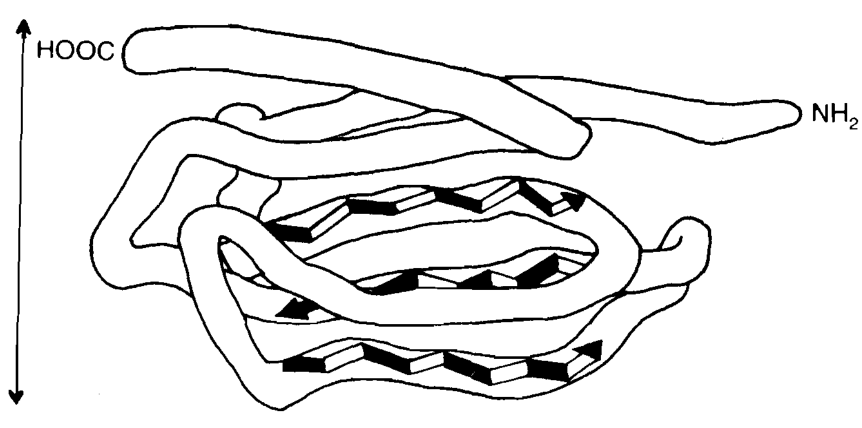

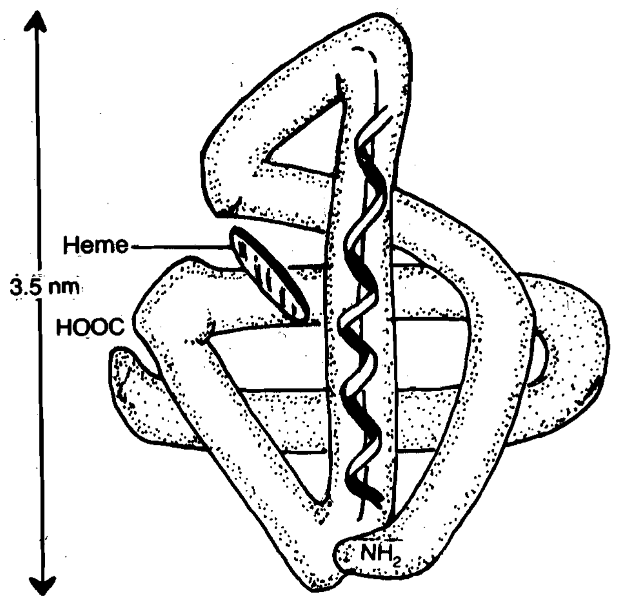

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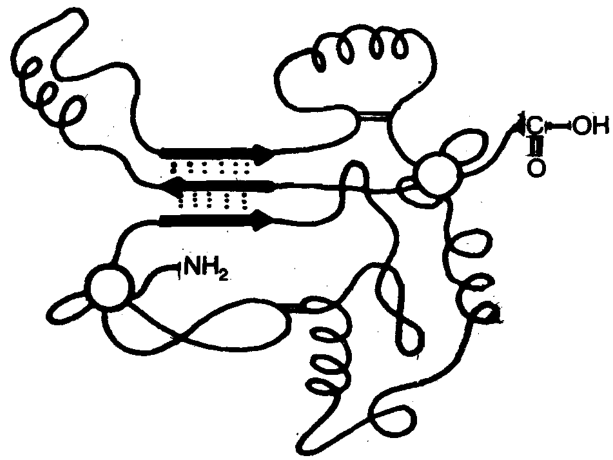

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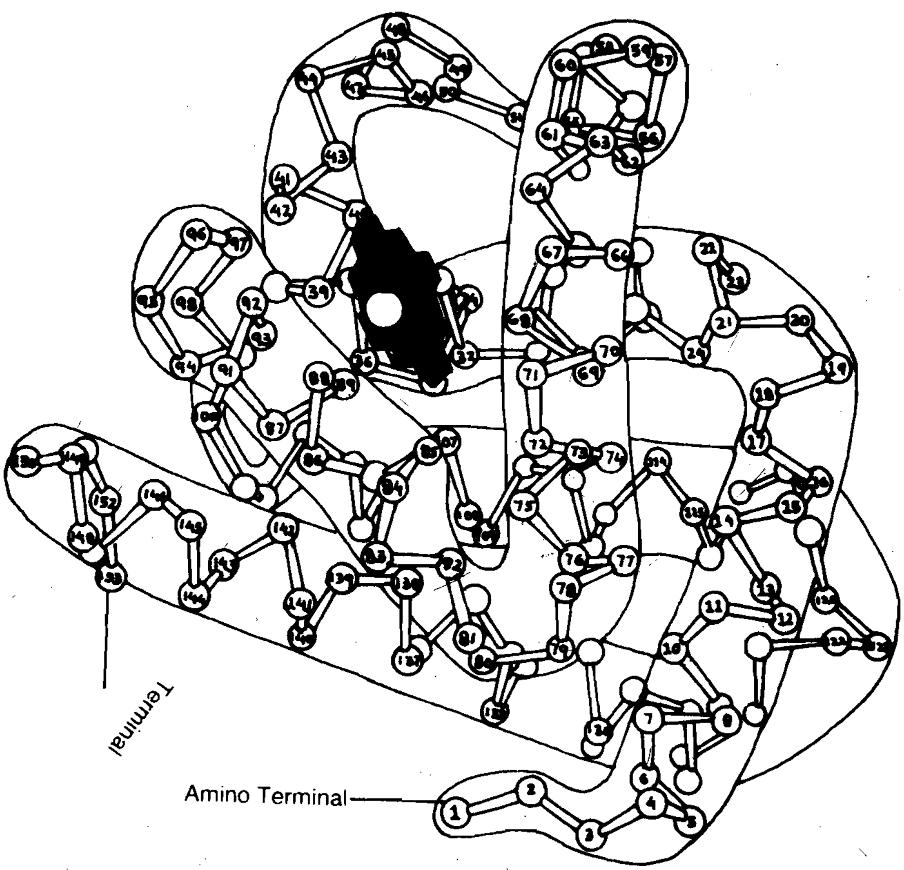

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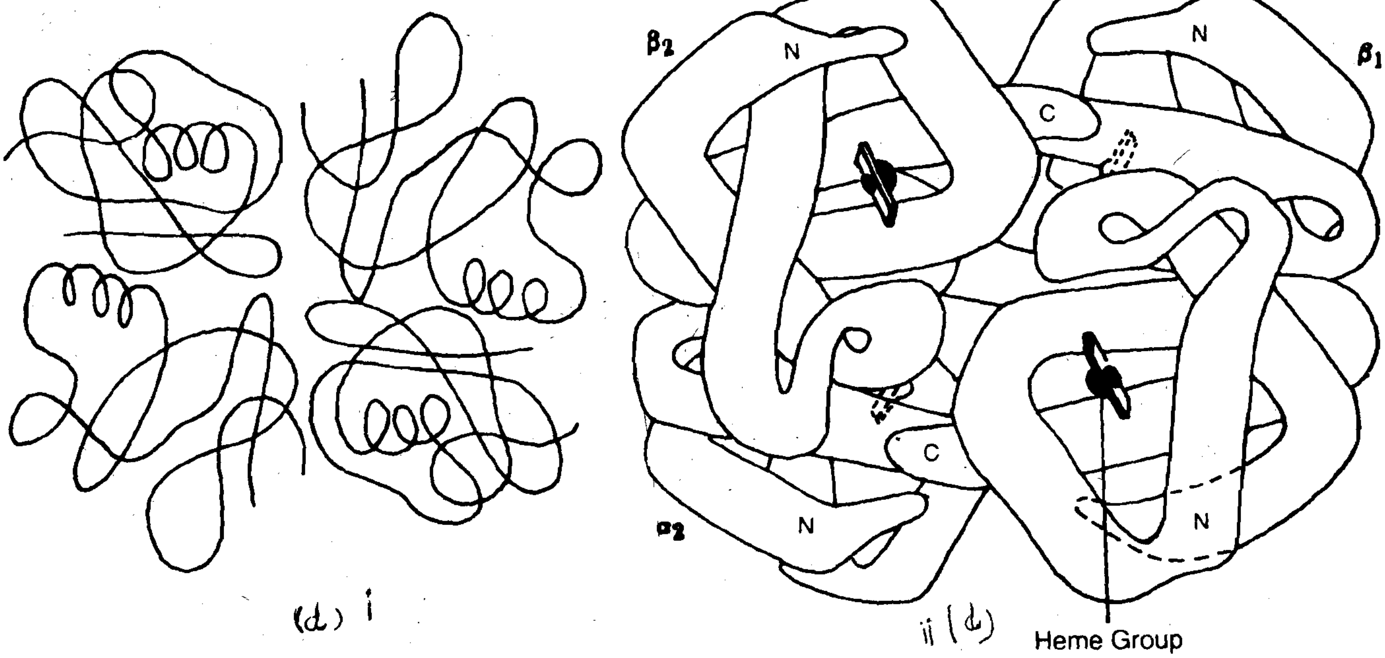


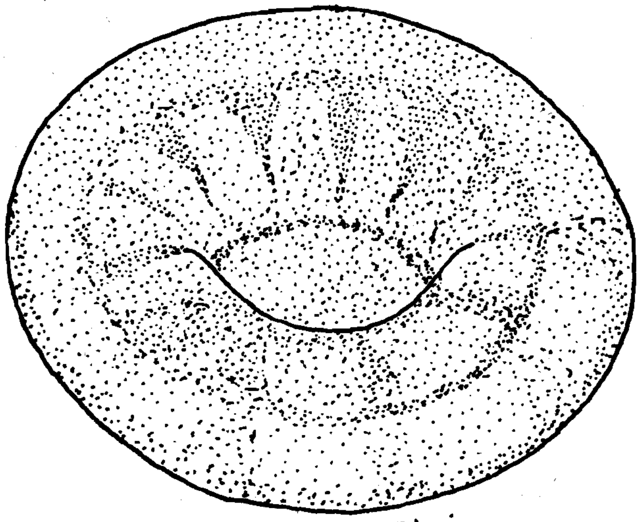
Fig. 5.2 : Different levels of protein structure
a) Primary structure. Amino acids in the chain are linked together by peptide bonds to form linear polypeptide chains with the removal of water molecule.
b) Secondary structure. In α-helix, the R groups of amino acids are directed radially away from the axis of helix. Every peptide bond is hydrogen bonded to a neighbour. Though the direction of helix can be right handed as well as left handed, right handed alpha helices are common. β-pleated arrangement of polypeptide are common and are present in many fibrous and most globular proteins.
c) Tertiary structure. Myoglobin molecule has eight helical segments. The spaces between loops of the chain are filled with R groups (not shown here).
d) Quaternary structure. The haemoglobin molecule consists of four polypeptide chains: two alpha globin and two beta globin chains. With each chain an oxygen binding heme group is attached.

Changes in pH or heating of protein molecules breaks protein polymers into monomers. The degradation results from loss of tertiary and secondary structure of monomers which leads to the loss of biological activity of the proteins. This disruption of native structure is termed as **denaturation**. Proteins regain their original structure when they return to their normal surroundings.

Diversity of protein molecules is due to the number, kinds and sequence of amino acids in a polypeptide chain. Change in amino acid sequence disrupts the structure of a protein, which thereby causes functional abnormality. For example, the change of even one amino acid residue in a chain of 146 residues of haemoglobin chain may bring about morphological and clinical changes in man causing the disease **sickle cell anemia** in which the capacity of red blood cells for oxygen uptake is impaired (Fig 5.3).

Residue: The main part of a molecule that is left after a small group has been removed in binding the molecule to another molecules.

	1	2	3	4	5	6	7	146
Hb A	Val –	His –	Leu –	Thr –	Pro –	[Glu] –	Glu –	Lys – – – –
	Val –	His –	Leu –	Thr –	Pro –	[Val] –	Glu –	Lys – – – –
Hb C	Val –	His –	Leu –	Thr –	Pro –	[Lys] –	Glu –	Lys – – – –



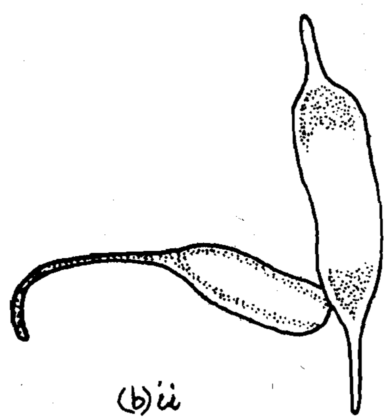


Fig. 5.3 : a) In normal haemoglobin of an adult (HbA), the sixth amino acid in the beta chain from the amino terminal is glutamic acid. In haemoglobin of the sickle cell (HbS), glutamic acid is replaced by valine, but the remaining 145 amino acids are unchanged.
b) Normal human red blood cells (i) are discoidal in shape; these-cells during low oxygen concentration become sickle shaped (ii) sickling of red blood cells causes the disease, known as sickle cell anaemia.

SAQ 2

Write the structure of the tetrapeptide derived from glutamic acid, lysine, asparagine and serine indicating the peptide bond clearly in the given space (see Section 4.2 of Unit 4 for structures of amino acids).

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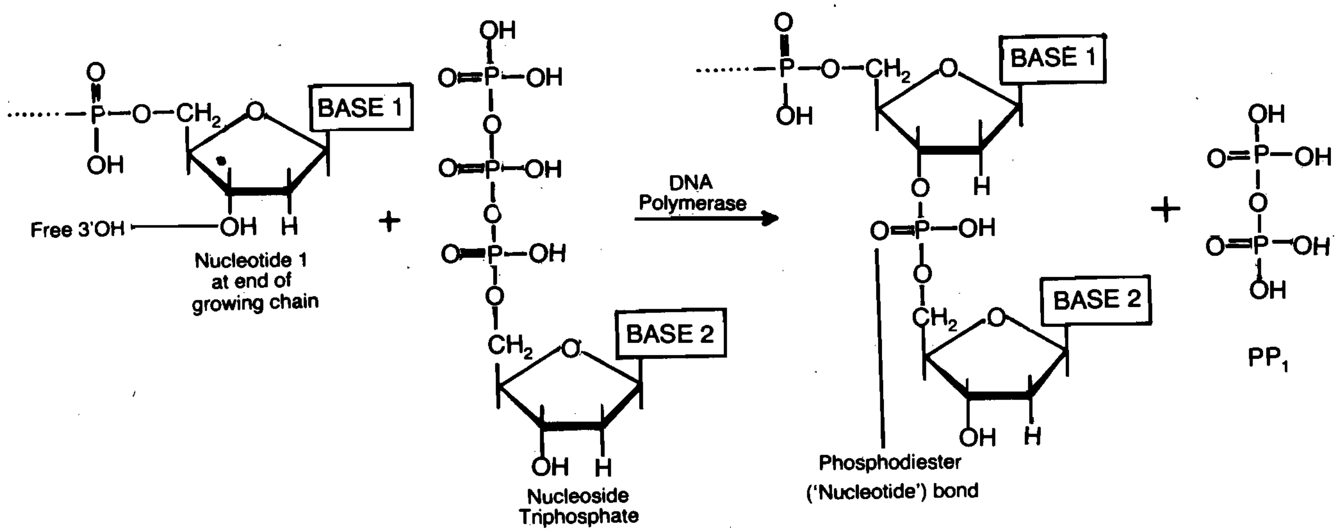
5.4 NUCLEIC ACIDS

Nucleic acids are the genetic material in living organisms. Genetic information contained in each cell is encoded as polynucleotide in the form of nucleotide sequence. Information in the form of base pairing interactions of the nucleic acids is passed on from one generation to the next. There are two types of nucleic acids: deoxyribose nucleic acid (DNA) and ribose nucleic acid (RNA). In Unit 4, you have already studied about the monomers of nucleic acids, the nucleotides. We shall now discuss about the structure of nucleic acids in more detail.

5.4.1 Deoxyribo Nucleic Acid (DNA)

DNA is a basic molecule found in the cells. In 1953 Watson and Crick of Cambridge University proposed a molecular model for DNA for which they were awarded the Nobel Prize in 1962. They based their model on the observation of X-ray diffraction studies and on chemical analysis. The total quantity of DNA in eucaryotic cells is much higher than in procaryotic cells (see Unit 1).



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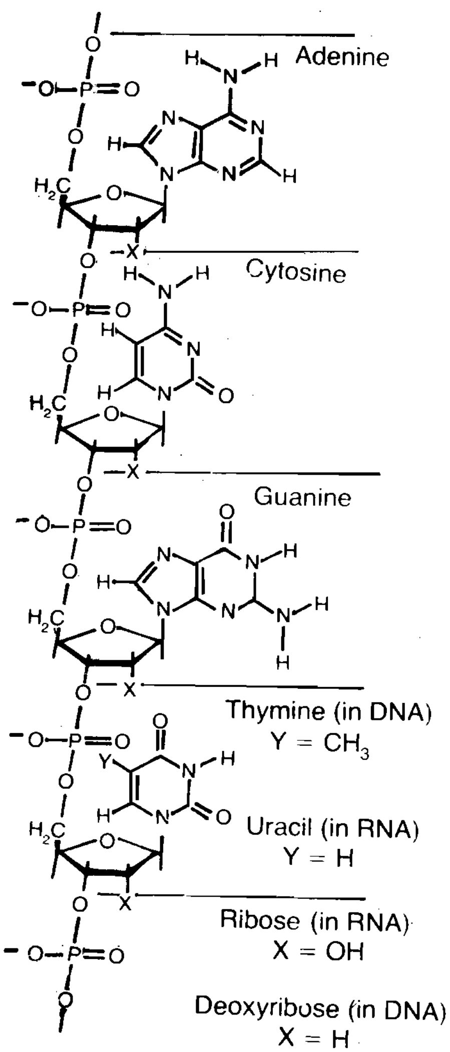

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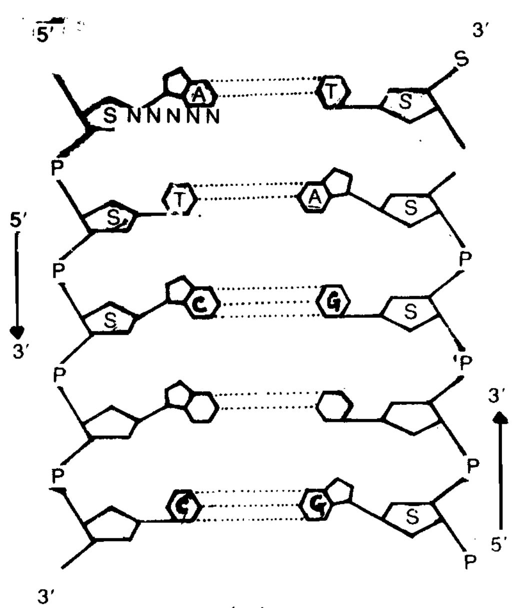

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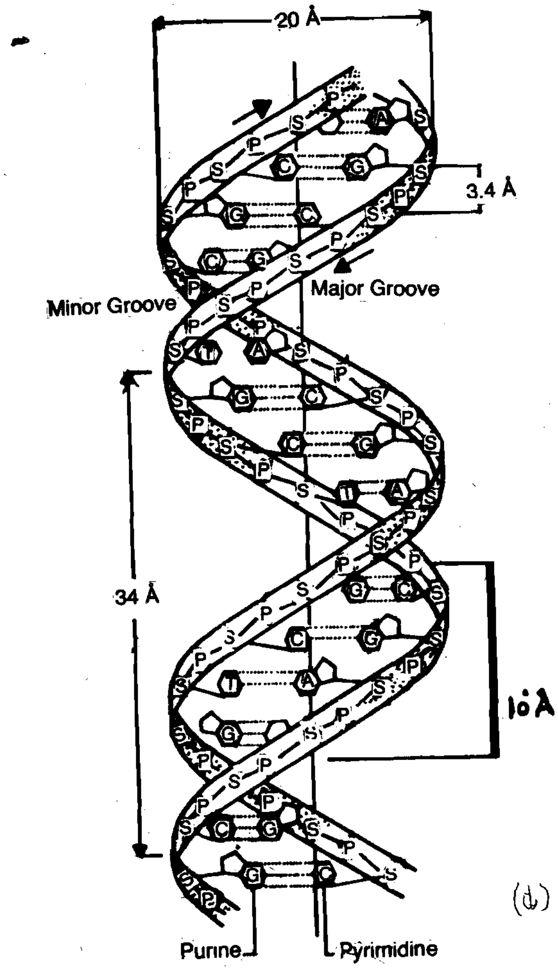


Fig. 5.4 : a) A nucleoside triphosphate. (Base 2) aligns itself to base 1 correctly. DNA polymerase enzyme links it to 3′ end and releases two phosphate groups as pyrophosphates (PPi).
b) A single nucleic acid chain showing the nucleotides. X=H in DNA (deoxyribose) and X=OH in RNA (Ribose). Y=CH_3 in DNA (Thymine) and Y=H in RNA (Uracil).
c) Molecular structure of DNA showing the pentose sugar (s)-phosphate(p) backbone of polynucleotide chain. The two strands are complementary and antiparallel in nature. By convention the base sequence in single strand of DNA is written from 5' end on left to 3' end on the right, or a p (for phosphate) is prefixed for free 5' making its - phosphoryl end.
d) DNA double helix showing major and minor grooves and some other molecular dimensions. The ribbons indicate phosphate deoxyribose backbones. Horizontal lines represent the base pairing. P=phosphate group, S=sugar.

The 5′ carbon of the deoxyribose sugar of one nucleotide is joined to 3′ carbon of deoxyribose sugar of the next nucleotide by a phosphodiester bond known as nucleotide bond or bridge (Fig 5.4 b). Phosphate group of the nucleotide can form an ester bond with both, the 3′ and 5′ -OH group of a pentose sugar and, therefore, the bond is known as **phosphodiester bond.**

A nucleic acid chain has one free 5' phosphoryl end and one free 3' hydroxyl end. The back-bone of DNA is highly polar due to the presence of phosphate group which is acidic at the pH of the cell.

Antiparallel: Alignment of the two DNA strands in a helix with their 3',5' phosphodiester linkages in opposite directions.

DNA molecule has two chains or strands which are known to be antiparallel as their 5'-3' polarity runs in opposite directions. Structure of a DNA molecule is helical and ladder-like, with steps made up of bases and the two sides (backbones) made up of sugar and phosphate residues (Fig. 5.4c). Nitrogenous bases of the two strands in a molecule are connected with each other by hydrogen bonds, which stabilise the DNA molecule.

The base pairing is one of the most fundamental concepts of DNA structure and function and always occurs between a purine and pyrimidine due to the geometry of the double helical structure (see below). Adenine (A) forms hydrogen bonds only with thymine (T); and guanine (G) only with cytosine (C). This is called as **complementary base pairing.** Three hydrogen bonds are formed between G and C (G≡C) but only two between A and T (A=T). The GC pairing is, therefore, chemically more stable than AT pairing.

SAQ 3
If one strand of double helix of DNA has a base sequence of 5'-ATCGAACGT-3', what would be the base sequence of the complementary DNA strand?

(**Hint**: Complementary base pairing A-T and G-C.)

....

....

DNA, The Double Helix

The two strands of the DNA form a helical structure, known as the **double helix**. It is important to mention here that DNA exists in five forms, i.e. A,B,C, D and E. Of these, B form is the most common about which we will discuss in detail here. It is a right handed helix and most commonly found in living system. The other forms have only minor differences. The spatial relationship between the two strands of the helix forms a major groove or wide groove and a minor groove or narrow groove (Fig. 5.4.d).

Double helix: Physical configuration typically adopted by the polynucleotide chains of DNA.

Each complete turn of helix is 3.4 nm long and contains 10 base pairs (bp). Therefore, the consecutive base pairs are 0.34 nm (3.4/10) apart and are inclined at 36° in relation to each other. The helix has a constant diameter of about 2 nm, hence, the dimensions of each base pair must be constant. Each base pair contains one two-ringed purine (1.2 nm long) and one single-ringed pyrimidine (0.8 nm long) so as to keep the dimensions of each base pair constant. A base pair formed by two purine bases or by two pyrimidine bases will, therefore, distort the helical structure.

DNA structure fulfils the basic requirement of the genetic material that means it must be copied accurately with every cell division. The accurate copying of DNA, i.e. DNA replication, is due to the complementary nature of the bases in the two strands of DNA: A pairing with T, and G pairing with C.

Complexes of DNA and Protein (Nucleosomes)
DNA in chromosomes is always associated with proteins and it coils on the protein to give rise to a highly compact tertiary structure.

A chromosome, which is a thread-like structure found in nucleus, consists of chromatin. Chromatin network contains about 60 per cent protein, 35 per cent DNA and 5 per cent RNA. On suitable treatment, chromatin can be seen under the electron microscope in its expanded form. It appears as "beads on a string" (Fig. 5.5) and these are known as **nucleosomes.** The "bead" or the nucleosome core is ellipsoidal in shape with a diameter of 11 nm, height of 6 nm and circumference of about 34 nm.

On biochemical analysis, a nucleosome is found to contain two molecules of each of the histones, H2A, H2B, H3 and H4 forming an octomeric protein disc, one molecule of histone H1 and a DNA strand of about 200 base pair long (Fig. 5.5).

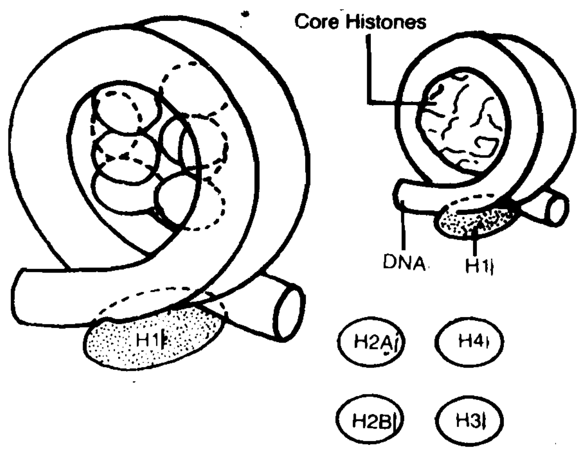
DNA fragment of 140 base pairs is wrapped like a ribbon around the histone octamer. It is because this much length of DNA (67nm) may not be squashed (pressed) inside the small protein disc. Sensitivity of DNA to enzymes also supports the idea of DNA being on the outside of the protein disc of the 200 base pair DNA because the increased surface area of DNA will provide more space for enzyme reaction. About 140 base pair is sufficient to make two turns around the protein disc.

The remaining 60 base pair act as a linker or spacer DNA and joins the repeated nucleosome cores. Histone H1 is associated with DNA, at the entry and exit points of DNA from the core. It is involved in close packaging of the nucleosomes to form a 30 nm thick chromatin fibre.

5.4.2 Ribose Nucleic Acid (RNA)

Transcription: Process by which an RNA molecule is synthesised on a DNA template with the aid of various enzymes.

As you have studied in the previous section, DNA stores the genetic information which is transferred from nucleus to cytoplasm by transcribing to the RNA molecules. These RNA molecules translate the information to synthesise proteins. The primary structure of RNA is



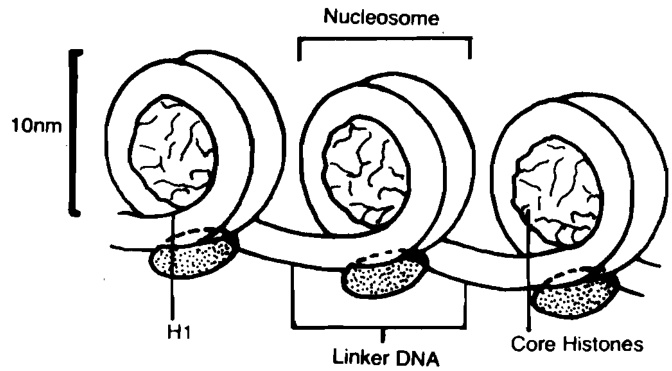


Fig. 5.5 : Chromatin appearing as beads on a string. Each nucleosome bead is connected to its neighbour by a linker DNA. Beads are released from chromatin by digestion of the linker DNA with micrococcal nuclease enzymes. Each bead has an octamer histone core around which 146 base pair DNA is wrapped.

comparable to that of DNA: a polynucleotide chain with 5′–3′ sugar phosphate backbone. But it differs from DNA as the pentose sugar in RNA is ribose instead of deoxyribose. Further, thymine is substituted by uracil in RNA (Table 5.3). All RNAs exist as non-helical single stranded structure. The molecules are much shorter than DNA and the ratio of purines and pyrimidines is not 1:1. However, RNA molecules may have complementary intramolecular regions. The complementary sequences in an RNA strand may fold back upon itself to form an antiparallel duplex structure known as the hairpin loop. Such complementary sequences are palindromic in nature. Palindrome is a stretch of DNA in which the base sequences read the same from the 3′ or 5′ end. In these regions, hydrogen bonds may be formed between A and U, and G and C. As in the case of DNA, base pairing provides stability to the RNA also.

Translation: Process by which a protein is synthesised from amino acids according to specifications encoded in the mRNA

Palindrome: A sequence of duplex DNA that is the same when the two strands are read in opposite direction such as **Malayalam** is a palindromic word with the sequence of letters on both sides of y being the same.

Table 5.3
Difference between DNA and RNA

Feature	DNA	RNA
1) Pentose sugar	Deoxyribose	Ribose
2) Nitrogenous base	Adenine, Thymine, Cytosine, Guanine	Adenine, Uracil, Cytosine, Guanine
3) Ratio of purines to pyrimidines	One	Variable
4) Secondary structure	Double stranded and helical	Single stranded and non-helical
5) Role in a eucaryotic cell	Carries genetic information	Synthesis of proteins
6) Localisation	Primarily in nucleus; also in mitochondria and chloroplast	Largely in cytoplasm, synthesised in nucleolus
7) No. of nucleotides	Contains a larger number of nucleotides, upto a few millions.	Contains much smaller number of nucleotides, upto a few thousands.

There are three major classes of ribonucleic acids (RNA) which can be distinguished structurally and functionally. These are messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA). All these types of RNA are synthesised in the nucleus and are involved in protein synthesis.

The mRNA carries the genetic message, and it is a single stranded polymer. The length of mRNA depends upon the number of polypeptides it codes for.

The tRNA molecule serves as adaptor for the translation of genetic information in the sequences of mRNA into specific amino acids. The primary structure of tRNA is a single stranded nucleotide which folds back to align with the complementary regions to form a secondary structure like a clover leaf. You will study the structure of tRNA in detail in Units 13 and 14 with reference to protein synthesis.

The rRNA is a component of ribosome. The ribosome has a nucleoprotein structure and is the site for protein synthesis.

A comparison of 'three kinds of RNA' is made in Table 5.4. You will study about all these types of RNAs in detail in Units 13 and 14.

Table 5.4
Comparison among three kinds of RNA

Property	**Ribosomal RNA**	**Messenger RNA**	**Transfer RNA**
Sedimentation coefficient (S units)	5-7, 18, 28	8	4
Number of nucleotides	120-5500	900-12000	75-85
Molecular weight	$0.5\text{-}1.1 \times 10^6$	500,000	25,000
Unusual bases	small amount of methylated bases	small amount of unusual bases	large amount of unusual bases
Percentage of total cellular RNA	about 80	upto about 5	about 15-20
Site of synthesis	nucleolus	nucleolus	nucleolus
Role	serves as template for synthesis of ribosomal proteins	carries genetic information from chromosomal DNA to cytoplasmic ribosomes where it participates in protein synthesis.	acts as adaptor for specific amino acid attachment and transfer to mRNA template.

SAQ 4

Which of the following statements (i-iv) apply to

a) DNA only
b) RNA only
c) Both DNA and RNA

Write your answer (s) in the space provided.

[**Hint**: If a particular statement applies to DNA only then the answer will be (a) and if to RNA only then the answer will be (b) and if to both DNA and RNA, then the answer will be (c).]

Statements

i) Found mainly in the nucleus.

....

ii) Polynucleotide chain in which sugar is ribose.

....

iii) Contains equal number of purine and pyrimidine bases.

....

iv) Contains linked nucleotides.

....

5.5 CARBOHYDRATES

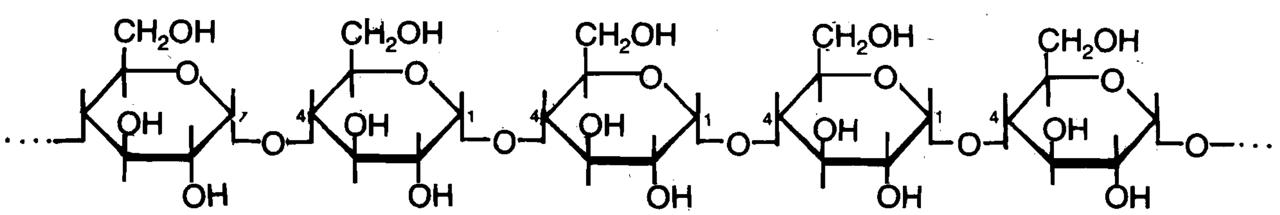
Carbohydrates, composed of carbon, hydrogen and oxygen, are the main source of cellular energy and are important structural components of cell walls and intercellular materials. Carbohydrates are classified into monosaccharides, disaccharides and polysaccharides according to the number of monomers they contain. You have studied in detail about monosaccharides and disaccharides in Unit 4, so we will discuss about the structure and function of polysaccharides in this unit.

Polysaccharides have the general formula $(C_6H_{10}O_5)_n$. They are polymers formed by condensation of large number of monomers such as glucose, fructose, etc. Major functions of polysaccharides are concerned with food storage and maintenance of cellular structure. In eucaryotes two structural polysaccharides are cellulose and chitin. Cellulose is found in plant cell wall, as well as in many algae and fungi. Chitin forms the exo-skeleton of many animals like arthropods (e.g. insects), many other invertebrates and also in many plants, e.g. fungi (Table 5.5).

Table 5.5
Some Naturally Occurring Polysaccharides

Distribution	Name	Chemical composition	Biological role
PLANTS	Cellulose	homopolymer of glucose, unbranched	the main structural component of plant cell walls
	Amylose	homopolymer of glucose, unbranched	food store : a component of starch
	Amylopectin	homopolymer of glucose, unbranched	food store : a component of starch
ANIMALS	Glycogen	homopolymer of glucose, more branched than amylopectin	food store, mainly in muscles and liver
	Chitin	unbranched non-glucose homopolymer of acetyl glucosamine and glucuronic acid	forms horny exo-skeleton in arthropods
	Chondroitin Sulphate	complex heteropolymer of galactosamine	structural component of cartilage

You have already learnt the structure of some common monosaccharides in Unit 4. Each monomeric unit is linked to the other by a glycosidic bond. The bond may be between carbon atom 1 of one monosaccharide and carbon atom 4 or 6 of the other monosaccharide. These may be α- or β-glycosidic bonds depending on the position of hydroxyl group at carbon atom -1. Amylose, cellulose and glycogen are all polymers of glucose molecules but differ in the way they are joined together (Fig. 5.6). Unlike mono and disaccharides (sugars), the polysaccharides are relatively insoluble in water and are therefore not sweet in taste.



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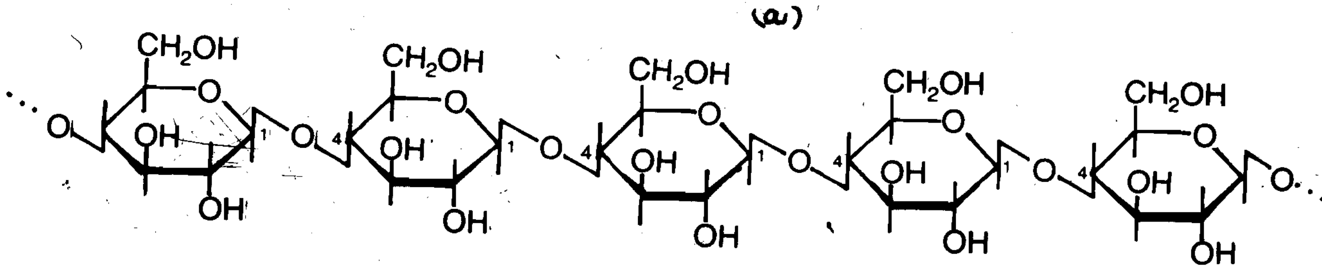

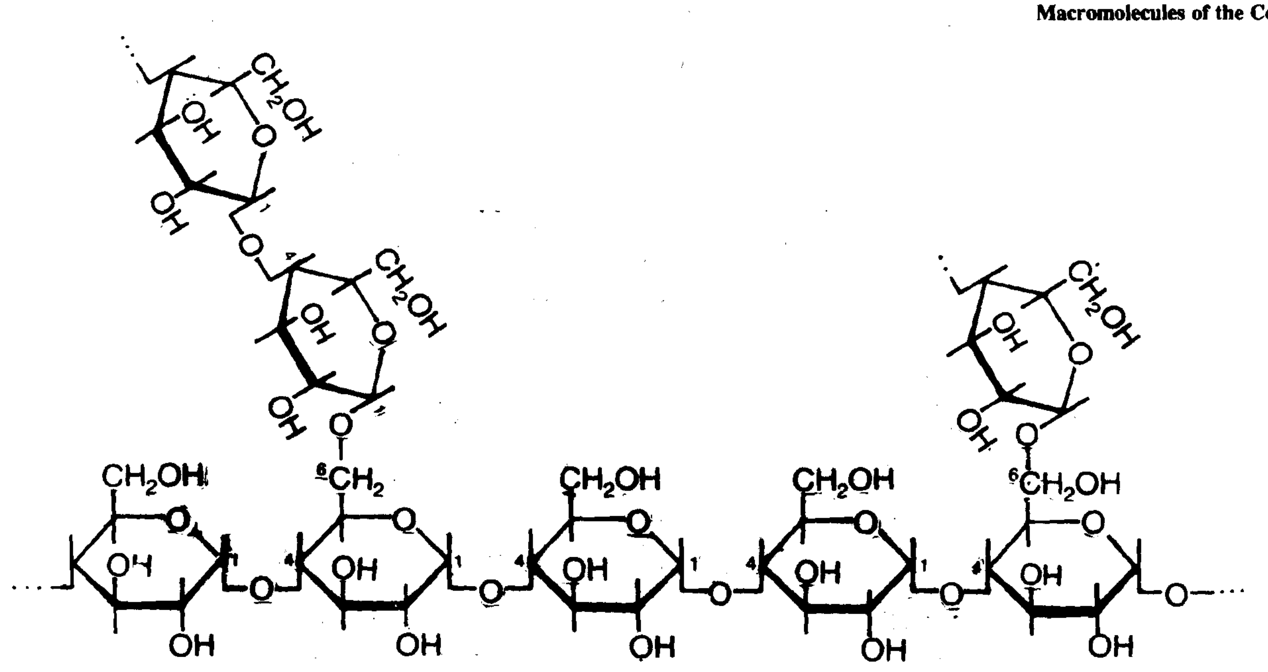

Fig. 5.6 : a) The 1-4 glycosidic bond between two glucose molecules showing a part of amylose molecule. b) The 1-4 glycosidic bond between two glucose molecules showing a part of a cellulose molecule. c) The 1-4 and 1-6 glycosidic bonds between glucose molecules which give rise to branched molecules of glycogen and amylopectin. Glycogen is highly branched, the ratio of 1,4 to 1,6 bonds being from 12 to 18, while amylopectin is less branched.

SAQ 5

Which carbon atoms of glucose are most commonly involved in glycosidic bond formation? Write your answer in 2-3 lines.

....

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Complex Polysaccharides

In some of the hexoses, the hydroxyl group is replaced by amino, acetylamino, carboxyl or sulphate groups to form derivatives of monosaccharides (Fig. 5.7). These derivatives of monosaccharides combine together to form complex polysaccharides. Complex polysaccharides are important in molecular organisation. They are often found in combination with proteins or lipids.

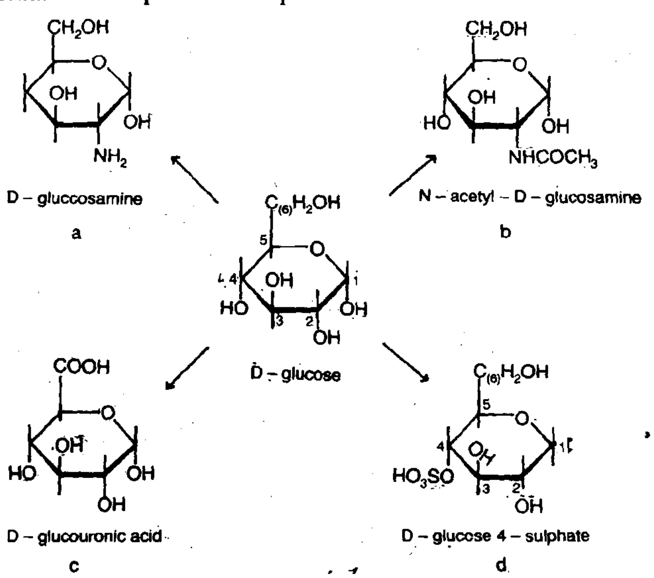


Fig. 5.7 : Derivatives of monosaccharides. The replacement of –OH group of D-glucose by $-NH_2$ (amino) group forms D-glucosamine (a); by $-NHCOCH_3$, (acetylamino) groups forms N-acetyle D-glucosamine (b); by-COOH (carboxyl)group forms D-glucouronic acid (c); and by OSO_3H sulphate group, forms D-glucose 4-sulphate (d).

Glycosaminoglycans, Proteoglycans and **glycoproteins** are examples of complex polysaccharides. Glycosaminoglycans are built up of repeating disaccharides units, generally composed of an amino sugar (either glucosamine or galactosamine) and a uronic acid (e.g. glucouronic acid). Glycosaminoglycans were formerly called mucopolysaccharides. Hyaluronic acid, chondroitin sulphate and heparin are a few examples of this class. Numerous glycosaminoglycan molecules in combination with small amounts of protein form proteoglycans, formerly known as mucoprotein.

The glycoproteins, on the other hand, are protein molecules with a few short or long carbohydrate side chains. It may be noted that proteoglycans are mainly glycans whereas glycoproteins are mainly proteins.

5.6 LIPIDS

Lipids are major structural components of the cells, and are a class of chemically diverse compounds with a common property. They are all insoluble in polar solvents such as water but are soluble in non-polar organic solvents such as ether and alcohol. This is because lipids contain hydrocarbon chains which are non-polar and hydrophobic. Since they contain fatty acids (about which you have studied in detail in Section 4.2 of Unit 4) with a free carboxyl end, they can undergo saponification (soap formation). Some of the commonly known lipids are classified in three groups (Table 5.6).

Table 5.6
Classification of Lipids

Lipid group	Class name	Cellular location of compounds
Fatty acids*	Fatty acids	Cytosol, mitochondria, glyoxysome of fatty seeds
Simple lipids (Esters of fatty acids with alchools)	Neutral fats (Triacylglycerols)	Fat storage in cytoplasm
Compound lipids (Simple lipids containing other group(s) in addition to fatty acids)	Phospholipids	Membranes
	Sphingolipids	Membranes
	Glycolipids	Membranes
Derived lipids	Steroids	Membranes
	Terpenes (Essential oils, caretenoinds)	Plant cytosol and chloroplast

* Fatty acids as such are not lipids but they are the essential components of lipids.

5.6.1 Simple Lipids

You have already studied the structure of fatty acids in Section 4.2 of Unit 4. Simple lipids are triacylglycerols, which are formed by the combination of three fatty acid molecules with a glycerol molecule (Fig. 5.8a). Triacylglycerols are non-polar, hydrophobic molecules and since they do not contain any charged groups, they are named as neutral fats. When oxidised, these fats produce energy more than twice of that given by carbohydrates or proteins.

In simple triacylglycerols such as tristearate glycerol or tripalmityl glycerol all the three fatty acid molecules (R_1, R_2, R_3) are of one type (Fig. 5.8 b). But in mixed triacylglycerols such as 1,2 distearopalmitin, more than one type of fatty acid molecules are joined to the same glycerol molecule (Fig. 5.8 c).

Most of the neutral fats, such as those in butter and olive oil are mixtures of simple and mixed triacylglycerols. Neutral fats containing only saturated fatty acids are solids at room temperature. Fats with largely unsaturated fatty acids like oleic and linoleic acid etc. remain liquid at room temperature and are known as oils. Oils are converted into fats by hydrogenation of the double bonds. That is how the vegetable ghee is produced. Oils, such as groundnut oil which contain unsaturated fatty acids are easily oxidised because of the presence of a large number of double bonds and hence they are spoiled easily. Saturated fats have better keeping quality.

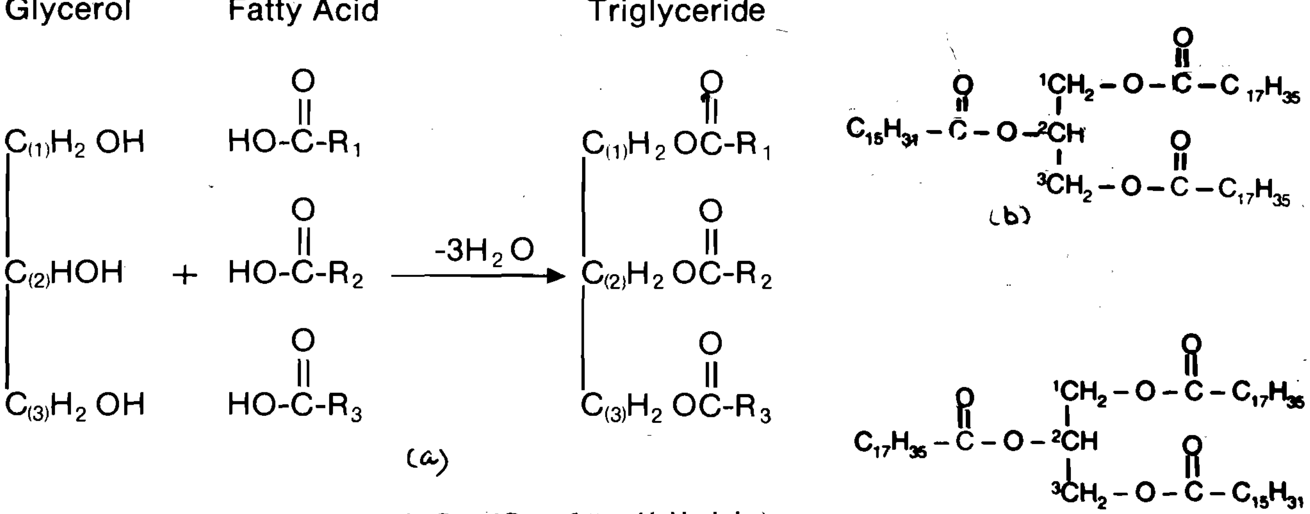
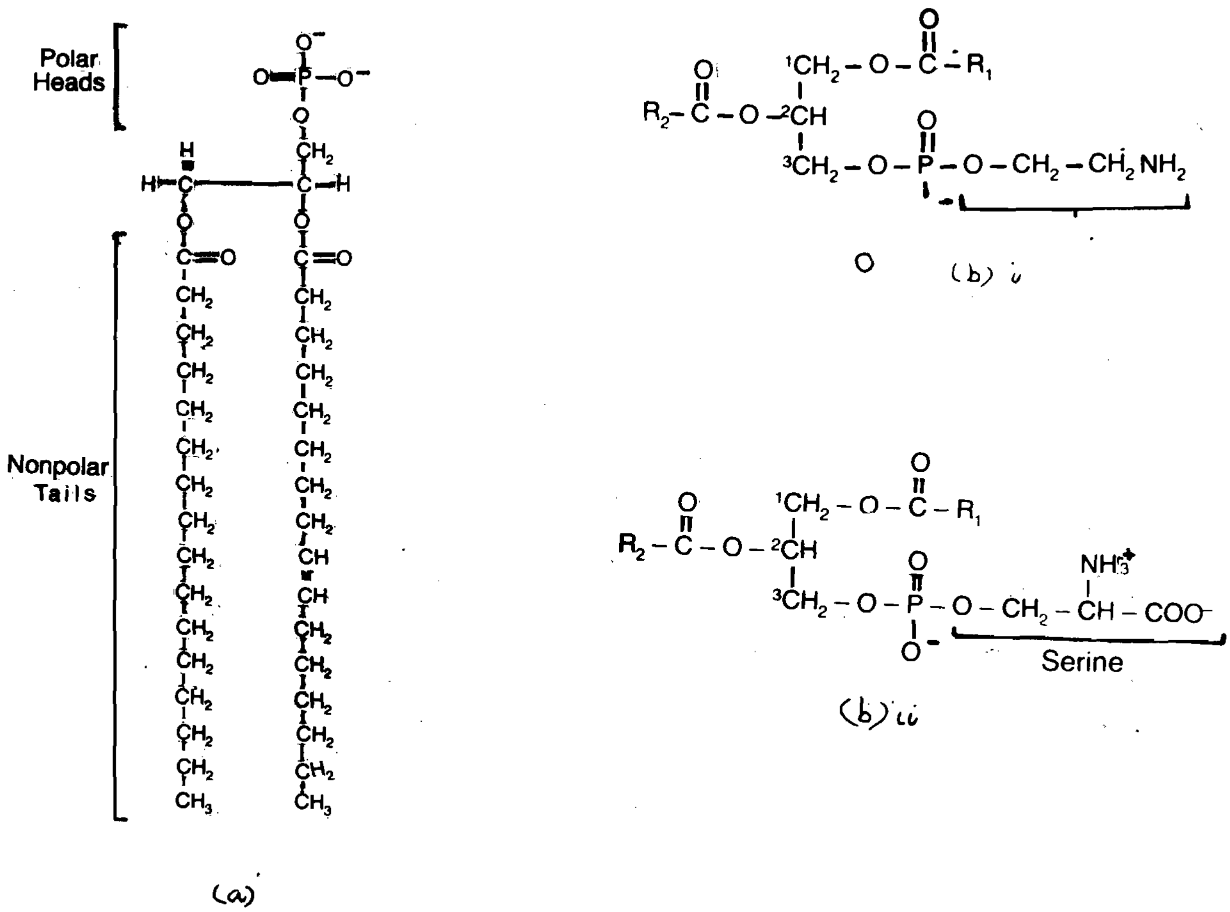


Fig. 5.8 : a) Structure of a triacylglycerol (R_1, R_2 and R_3 are fatty acid side chains).
b) Simple triacylglycerols (Tristearin).nitimluqi1 I bnd
c) Mixed triacylglycerol (1-2 distearopalmitin).

5.6.2 Compound Lipids

Amphipathic: Molecules that have both hydrophilic and hydrophobic groups.

These are the lipids which are composed of glycerol, fatty acids, phosphoric acid and a nitrogenous compound such as choline, serine, ethanolamine etc. Major types of compound lipids are phospholipids, glycolipids, and sphingolipids. In phospholipids, one fatty acid molecule in a triacylglycerol is substituted by a phosphoric acid molecule. Thus, all phospholipids have a hydrophobic tail consisting of two fatty acid chains and a hydrophilic head made up of negatively charged phosphoric acid residue (Fig. 5.9 a). Consequently, they are amphipathic in nature as they have both hydrophobic and hydrophilic region in the same molecule. They are the major constituents of the cell membrane.



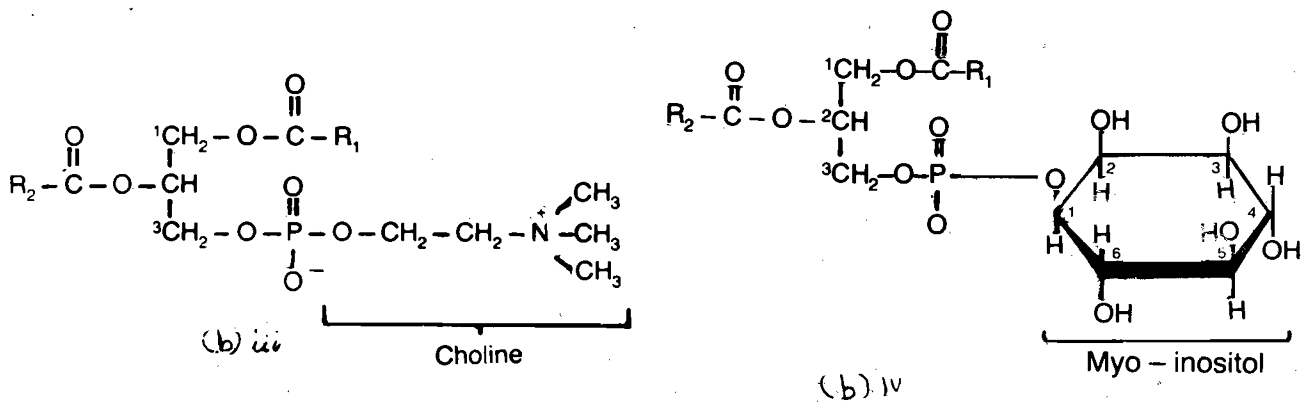


Fig. 5.9 : a) A phosphoglyceride. Two fatty acid molecules are esterified to the first and second hydroxyl groups of glycerol. Phosphoric acid is esterified to third hydroxyl group of glycerol.
b) Different types of phosphoglycerides.

The most abundant phospholipids are phosphatidylethanolamine (cephalin), phosphatidylcholine (lecithin), phosphatidylserine and phosphatidylinositol (Fig. 5.9 b). Sphingolipids and glycolipids are also amphipathic molecules and are main constituents of cell membranes. These are the main components of brain and nervous tissues.

5.6.3 Derived Lipids

Derived lipids contain no fatty acids. Therefore, they cannot be converted into soaps (non-saponifiable). These include steroids and terpenes.

All the steroids have parent nucleus called as **cyclopentanoperhydrophenantherene** ring (Fig. 5.10). This structure is composed of four rings A,B,C and D which are fused with each other. A, B and C rings constitute phenanthrene ring and to them the cyclopentane ring D is attached.

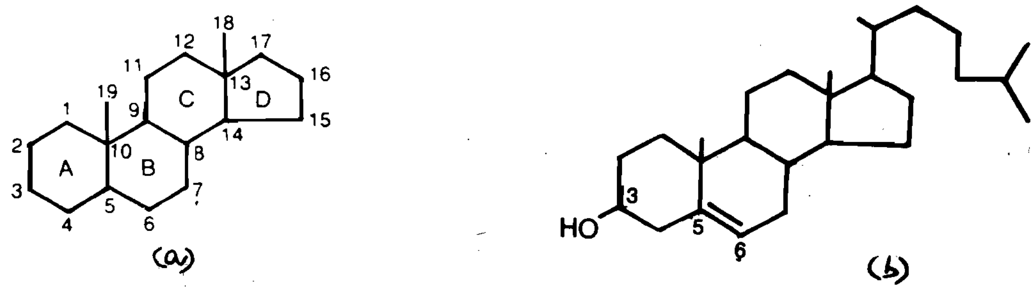


Fig. 5.10 : a) Cyclopentanoperhydrophenantherene nucleus with numbered carbon atoms. Three cyclohexane rings (A,B and C) and a terminal cyclopentane ring (D) form the basic structure of steroid.
b) Cholesterol. The hydroxyl group is polar and rest of the molecule is non-polar in nature.

The most important members of steroids are cholesterol, bile acids and sex hormones. Cholesterol is only found in animal tissues and is the parent compound which produces ergosterol, a precursor for the formation of vitamin D (Fig. 5.10).

Terpenes are synthesised by polymerisation of the five carbon unit called isoprene unit. These units are bound in head to tail organisation. Terpenes include certain fat soluble vitamins like Vitamin A, E, K, plant pigments like carotenoids, chlorophyll and certain co-enzymes (coenzyme Q, ubiquinone). Terpenes are major components of the essential oils.

5.7 SUMMARY

In this unit, you have studied:

- Types of chemical bonds and formation of macromolecules,
- Structure of proteins which are formed from amino acids bonded together by covalent peptide bonds. Proteins have four levels of structural organisation i.e. primary, secondary, tertiary and quarternary structures. Proteins are of major importance in the living system as they are the major cellular components and are involved in several vital functions such as enzyme formation and transport of substance etc.
- Nucleic acids, the genetic material, are the linear polymers of nucleotides.
- Deoxyribonucleic acid (DNA) consists of two complementary strands joined by hydrogen bonds and is coiled to form a double helical structure. Ribonucleic acid (RNA) is a single stranded structure having a ribose sugar and nitrogenous base uracil in place of thymine.
- Polysaccharides may be branched or unbranched chains formed by monosaccharides joined together by glycosidic linkages. The most important storage polysaccharides are starch in plants and glycogen in animals. Cellulose is the main component of plant cell wall. Chitin forms the exo-skeleton in most invertebrates.
- Lipids are water-insoluble components of cells. Neutral fats are simple lipids and serve as storage fats. Phospholipids, sphingolipids and glycolipids are structural elements of membranes and are amphipathic in nature.
- Sex hormones and cholesterol, are some examples of steroids, which are non-saponifiable lipids. Terpenes are major components of essential oil and chlorophyll.

5.8 TERMINAL QUESTIONS

1) Why is the tertiary structure of a protein lost on heating to 80° whereas the primary structure remains unchanged? Give your answer in 3-4 lines.

....

....

....

....

2) a) How many nucleosomes would be formed by 4×10^5 bp long DNA and why?

....

....

b) How many molecules each of histones H1,H2A, H2B, H3 and H4 would be required to form the nucleosomes for the above DNA?

....

....

3) In a fragment of DNA double helix there are 60 pyrimidine bases and 20 adenine bases. Calculate the number of each of the following in the fragment giving reasons.

a) Thymine bases

....

....

b) Total number of bases

....

....

c) Cytosine bases

....

....

d) Nucleotides

e) Complementary base pairs

4) Cellulose, amylose, amylopectin and glycogen are all polymers of only one monosaccharide, i.e. glucose. Then how do they differ from each other in their structure and properties? Give four reasons.

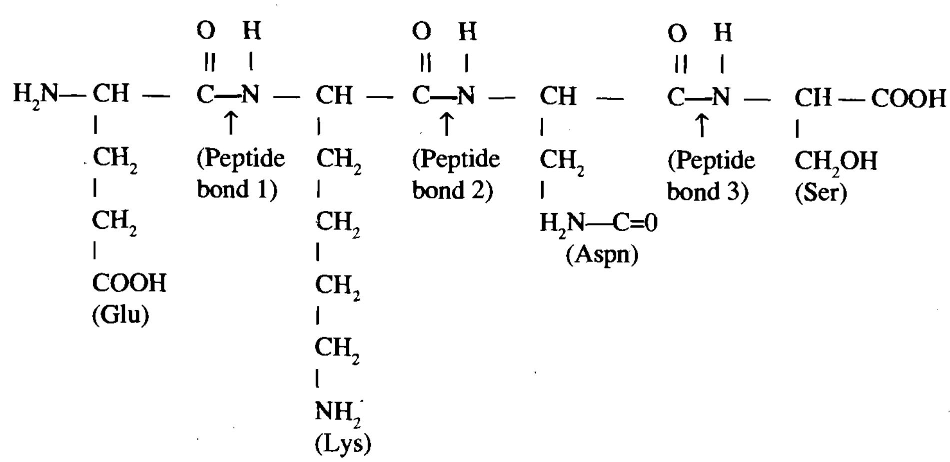
5) Write the structural formula of dipalmitinstearic glycerol in the given space. (**Hint**: See the structures of palmitic acid and stearic acid in Section 4.2 of Unit 4.)

5.9 ANSWERS

Self-assessment Questions

1) Ionic bonds become weak in the presence of water because water molecules prevent the interaction between ions by increasing the distance of separation between charged molecules.

2)



3) 3′–TAGCTTGCA-5′

4) i) a
ii) b
iii) a
iv) c

5) Carbon atom 1 and 4 or carbon atom 1 and 6 of glucose are most often involved in glycosidic bond formation.

Terminal Questions

1) The tertiary structure of proteins is stabilised by weak hydrogen bonds which break at 80°, whereas the primary structure is stabilised by covalent bonds which are too strong to be affected at this temperature.

2) a) 2×10^3, as 200 bp length of DNA comprises one nucleosome.

   b) 2×10^3 of H1 and 4×10^3 each of H2A, H2B, H3, and H4.

3) a) 20. By the base pair rule of A-T and G-C.

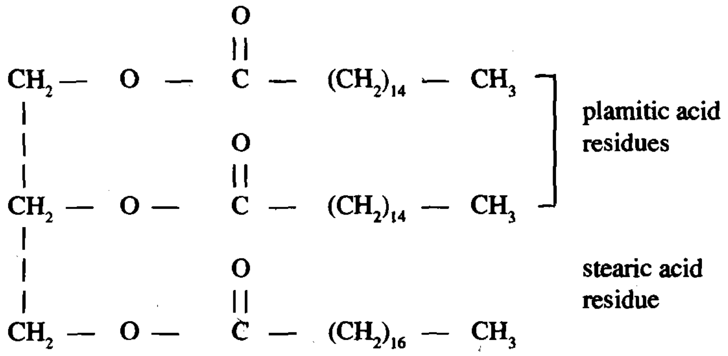
   b) 120. As there are 60 pyrimidine bases, there must be 60 purine bases that is 120 (60 +60) bases altogether.

   c) 40. As pyrimidine bases (T+C) are 60, and thymine bases are 20, so cytosine bases are 40 (60-20).

   d) 120. As the total number of bases is 120.

   e) 60. As total number of bases is 120, the number of base pair must be half.

4) This is due to (i) branched or unbranched structures, (ii) sequences of different lengths (iii) 1–4 or 1–6 glycosidic bond and (iv) different types (α or β) of glucose molecules.

5) 

(The order of fatty acid residues may differ.)

GLOSSARY

affinity chromatography: a technique for separating macromolecules based on the biological affinity of the molecule for a matrix bound ligand.

autophagy: digestion of cellular material by the cell's own enzymes; part of normal regeneration and turn over of eucaryotic cellular components.

autoradiography: determining the location of radioactive tracers introduced into cell by exposure of photographic emulsions placed in contact with the cells.

basal body: an organelle located at the base of cilia and believed to be involved in the organisation of ciliary microtubules.

cell culture: a population of cells grown *in vitro.*

centromere : the primary construction of a chromosome to which the spindle fibers remain attached.

chloroplasts: membranous organelles of plant cells containing chlorophyll wherein photosynthesis occurs.

cilia (sing: cilium): locomotor organelles located at the cell surface.

cisterna (pl. cisternae): a flattened membranous sac filled with fluid.

codon: a sequence of three nucleotides of messenger RNA that codes for an amino acid or for chain termination.

complementary base pairing : hydrogen bond formation between a particular purine and a particular pyrimidine in nucleic acids, for example, guanine and cytosine and adenine and thymine.

core particle: result of partial digestion of a nucleosome leaving the histone octamer and 146 base pair of DNA.

covalent bond : bond between atoms formed by sharing of electrons.

cristae: infoldings of the mitochondrial inner membrane and the site of enzymes of oxidative phosphorylation and electron transport.

cytoskeleton: an intracellular framework composed of filaments and microtubules.

cytosol: the fluid portion of the cytoplasm in which the organelles are suspended.

deoxyribonucleic acid (DNA) : the genetic material of all cells and many viruses.

dictyosome: a stack of cisternae that forms part of the Golgi apparatus. In plant cells, the term is often used for the entire Golgi apparatus.

endocytosis: intake of solutes or particles by a cell by enclosing them in an infolding of the plasma membrane.

exocytosis: a mode of transport of substances out of the cell by enclosure in a vesicle, fusion of the vesicle with the plasma membrane and subsequent expulsion of the vesicle's contents.

ferritin: an iron-rich protein found in the liver, spleen and bone-marrow.

flagella (sing flagellum): locomotor organelles ultra structurally similar to cilia but usually longer and present in smaller numbers per cell.

fluorescent antibody technique: detection of selected antigens in cells by staining with specific antibody that has been conjugated with a fluorescent dye.

GERL: Golgi associated endoplasmic reticulum involved in the production of lysosomes.

hairpin loops: a folded region of single-stranded DNA or RNA formed by the pairing of two neighbouring complementary stretches of bases.

helix : a spiral structure having a repeating pattern described by two simultaneous operations—rotation and translation. It is the natural conformation of many biological polymers.

heterophagy : the process of forming a heterophagic vacuole.

histone: a protein component of the chromosome having a high content of basic amino acids. Eight histones comprise the core of a nucleosome.

hydrophobic bond : the associations formed by hydrophobic groups when surrounded by water.

in vitro (Latin-"in glass") : experiments carried out with isolated cells, tissues or cell free extracts.

in vivo (Latin-"in life"): experiments carried out using the intact organism.

lipid: class of organic compounds that are poorly soluble or insoluble in water but soluble in nonaqueous solvents such as ether or acetone.

lysosomes: intracellular organelles that contain a large variety of hydrolytic enzymes.

macromolecules: molecules having molecular weights in the range of few thousand to hundreds of millions of molecular weight units.

microbody: a membrane bounded cytoplasmic organelle with varied enzyme content and functions e.g. peroxisomes and glyoxysomes.

neutral fats : glycerides, fatty acid esters of glycerol, a major storage form of fats.

nucleic acid : polymer of nucleotides in an unbranched chain, DNA and RNA.

nucleoid : a region in the cytosol of procaryotic cells that contains nuclear material but is not segregated by membranes.

nucleoside: molecule containing a purine or pyrimidine linked to a pentose sugar.

nucleosomes: spherical particles seen along decondensed chromatin, each nucleosome is composed of eight histones around which there are nearly two turns of DNA.

nucleotide: a phosphorylated nucleoside.

organelle: a subcellular component, a discrete structural differentiation of the cell containing particular enzymes and performing particular functions for the whole cell; e.g. mitochondria, ribosome, etc.

peptidoglycan: macromolecule formed from both protein and carbohydrate parts, abundant in the cell walls of bacteria.

phagocytosis: a form of endocytosis in which large amounts of particulate material, even whole cells are enclosed in endocytic vesicles.

phosphodiester linkage: a covalent linkage involving esterification to phosphoric acid.

phospholipids: lipids that contain charged, hydrophilic phosphate groups; primary components of cell membranes.

photorespiration: uptake of oxygen and release of carbon dioxide by photosynthetic cells or whole plants in the light.

pinocytosis: endocytosis of small molecules in an aqueous medium.

plastid : eucaryotic cell organelle that stores pigments or carbohydrates.

polynucleotide: a linear sequence of nucleotides in which the sugar of one nucleotide is linked through a phosphate group to the sugar on the adjacent nucleotide.

procaryotes: organisms such as bacteria, blue green algae and mycoplasmas in which the nucleus is not separated from the cytoplasm by membranes.

purine: parent compound of the nitrogen containing bases adenine and guanine

pyrimidine: parent compound of the nitrogen containing bases cytosine, thymine and uracil.

radioactive isotope: isotope with an unstable nucleus that emits electrons (undergo beta decay) and are used as labels or tracers in biology.

residual bodies: secondary lysosomes containing undigested residues, membrane fragments and whorls.

ribonucleic acid (RNA): nucleic acids that function in transcription and translation. The genetic material of certain viruses.

rough ER(RER): portion of the endoplasmic reticulum bearing ribosomes.

smooth ER(SER): portion of the endoplasmic reticulum devoid of ribosomes.

steroids: compounds that are derivatives of a tetracyclic structure composed of a cyclopentane ring fused to a substituted phenantherne nucleus.

stroma: unstructured matrix of the chloroplast in which the grana and stroma thylakoids are suspended.

template: a molecule which contains information from which other molecules can be synthesised.

thylakoid: a membranous sac present in chloroplasts that may be disc shaped (in the grana) or elongated, it is the site of reactions of the photosynthesis requiring light and CO_2.

ultracentrifuge: centrifuge capable of producing rotor speeds up to 100,00. rmp and able to rapidly sediment tiny particles and macromolecules.

van der Waals force: a weak, attractive force between atoms, particularly important in hydrophobic bonding of amino acids in proteins.

wobble: capability of the third base in the tRNA anticodon (5' end) to form a hydrogen bond with any two or three bases at 3' end of the mRNA codon.

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UNIT 6 ALGAL HABITATS AND DISTRIBUTION

Structure

6.1 INTRODUCTION

You are familiar with the general features of algae, and their position among the other groups. You have also learnt about the classification of algae into various divisions and the characteristic of each. By now it must have been clear to you that they are very diverse in their structure and characters, and are quite distinct from plants as a group.

Algae range from unicellular (microscopic) to large (macroscopic) thalloid forms growing in variety of habitats almost all over the surface of earth. A brief account of various habitats where algae grow in nature is included in this unit. This is to familiarise you so that you may recognise and identify some common algae if you happen to see them in their natural surroundings.

When we say algae are found everywhere it is no exaggeration. Wherever there is water, a little moisture or water vapours, and light, however feeble, they are sure to appear as green, yellow, or brown patches, which in course of time cover the whole surface. Their occurrence and growth is controlled by several factors and is the subject of science, ecology. When several types of algae grow together under similar natural conditions we call them as communities. The composition of a community is determined by the physical and chemical nature of the habitat. In many cases the algal community indicates to us about the nature of the habitat, whether it is rich or poor in nutrients or polluted etc., in other words it serves as an ecological indicator.

In this unit you will also learn how algae have adapted to the environment in which they are found growing by having special morphological and physiological features. We list below some important algal habitats found in nature.

Objectives

After studying this unit you should be able to:

- describe the various types of habitats of algae,
- give examples of algae that are of common occurrence in fresh water, marine and harsh habitats,
- recognise some classes of algae when you happen to come across them in their natural surrounding,

- describe algal association with plants and animals and
- give examples of algae that live in symbiotic association with other algae, other protists, plants and animals.

Study Guide

We have given several examples of algae in this unit but you are expected to remember at least two for each habitat.

6.2 AQUATIC ALGAE

Salt pan-a vessel, or a depression near the sea, used for getting salt by evaporation.

Most of the algae grow in water in the absence of which they quickly dry up and die; however, there are also subaerial algae, which are described in section 6.3.2 of this unit. Depending on the concentration of salts there are various kinds of water bodies, such as fresh water, brackish water, sea water, brine-salt lakes and salt pans. Further, these habitats nowadays may contain many types of pollutants, like excessive organic matter, heavy metals, pesticides, industrial effluents which are produced and dumped into them by man. This greatly affects algae and other organisms present in the water.

6.2.1 Fresh Water Habitats

Fresh water habitats comprise of rivers, mountain streams, lakes, ponds, tanks, and temporary rainwater puddles. In our country, rice fields where standing water is present for several months, are rich in nitrogen-fixing cyanobacteria such as *Aulosira, Rivularia, Gloeotrichia, Cylindrospermum, Nostoc, Anabaena, Aphanothece* and some green algae *Oedogonium, Draparnaldiopsis,, Chaetophora* and *Coleochaete*, and desmids and diatoms.

In slow flowing rivers with rocky shores one may find many filamentous algae like *Spirogyra, Oedogonium* and *Cladophora* as extensive floating mats generally attached to the under water rock boulders. The surface of submerged rocks also shows various types of attached epiphytic algae like diatoms, desmids and cyanobacteria. Algal flora also shows seasonal variation depending on the turbidity and rate of flow of water and other seasonal factors.

The algal flora in a lake shows different communities at different regions. Near the shores and at the bottom (benthos) thick mats of *Spirogyra, Oedogonium, Chara, Nitella* and a number of epiphytic algae like *Chaetophora, Coleochaete*, desmids, diatoms colonial cyanobacteria, *Cladophora* growing as tufts on the shells of animals are frequently found. Suspended in the upper layers of water, unicellular and colonial algae *Chlamydomonas, Volvox, Pandorina, Scenedesmus, Euglena,* diatoms, *Microcystis, Anabaena, Anabaenopsis* occur as - phytoplankton. These algae are generally small, phototactic - moving up and down depending on the light conditions - floating during the day and sinking at the night. At times, when the water is rich in nutrients with optimum temperature and sunshine, one particular algal type (*Microcystis, Euglena*) multiplies very rapidly to dominate the other algae, resulting in water blooms (flowering of water). Such blooms can be harmful to the fish and other animals that grow in the water because they may consume all the oxygen in the water during the night. While seasonal water blooms are more common in temperate countries, in India and other tropical countries. permanent blooms of colonial cyanobacterium *Microcystis* is most frequent. It forms thick. bluish-green suspension in many temple tanks and lakes making the water unfit for human needs.

6.2.2 Marine Habitats

Sea inhabits largest number of algae collectively known as seaweed. Although India has a very long shore line, it is only the rocky areas as found in Gujarat, Tamil Nadu, Andhra Pradesh, and in the islands of Andamans and Laksha Dweep that have rich marine flora.

Seacoast is periodically flooded and exposed to sun because of the tides. The area between the high tide and low tide level is known as intertidal zone. The seaweed that grow in the intertidal zone face alternate drying and wetting. They are also firmly attached to the underlying rocks by means of holdfasts. At times they may get detached and found floating in the open sea as in the case of Sargasso Sea. On the coasts of India, like Gulf of Mannar (Tamil Nadu) one can collect manually several seaweed such as *Gracilaria edulis* (red alga), *Gelidiella acerosa* (red alga), *G. folifera, G.crassa, Hypnea musciformis* (red alga) *H. valentiae, H. pannosa, Sargassum wightii* (brown algae) and *Turbinaria* (brown algae), which are of commercial importance.

Sargasso Sea

A sea in North Atlantic, named because of huge accumulation of *Sargassum* fronds found floating in island like masses.

Benthic algae constitute the seaweed that are attached to the bottom away from the shore in deeper waters and are never out of water. Their distribution depends on the depth of the sea to which enough light can penetrate. Beds of seaweed may be found in very deep waters, 100-200 meters, mostly containing red algae because only these algae can utilise the blue wavelengths of light that can be absorbed by the red pigment, phycoerythrin.

Table 6.1: Some Important Littoral Seaweed Found on Indian Coast.

East Coast	
Chlorophyta (green algae)	*Ulva, Cladophora, Bryopsis, Acetabularia, Neomeris, Udotea Halimeda, Boodlea, Dictyosphaeria.*
Phaeophyta (brown algae)	*Ectocarpus, Pedina, Dictyopteris, Dictyota, Turbinaria, Zonaria, Hormophysa, Sargassum.*
Rhodophyta (red algae)	*Acrochaetium, Laurencia, Chondria, Polysiphonia, Gelidiopsis, Grateloupia, Rhodymenia, Liagora, Porphyra, Gelidiella, Gracilaria, Ceramium.*
West Coast	
Chlorophyta (green algae)	*Chamaedoris, Enteromorpha, Ulva, Bryopsis, Acetabularia, Struvea, Pseudobryopsis.*
Phaeophyta (brown algae)	*Dictyopteris, Dictyota, Nemacystis.*
Rhodophyta (red algae)	*Scinaia, Halymenia, Caloglossa, Rhodymenia, Dasya, Laurencia, Helminthocladia.*

The intertidal zone also known as littoral zone can be differentiated sometimes into three belts, supralittoral, middle littoral and infralittoral belts, each consisting of associations of different but characteristic algae. The algae found in different zones vary according to the geographical location, nature of the substratum and other factors. Important seaweed found in the littoral zones of coastal India are listed in the table 6.1(for reference).

Open sea away from the coast is rich in planktonic algae. Marine phytoplankton is rich in variety and its composition depends on the geographical location and seasons. Diatoms form the main bulk of phytoplankton, Dinophyta, Cyanophyta, silicoflagellates and other groups also occur but in less quantities. Sometimes, the sea water becomes coloured due to thick pink blooms of *Noctiluca* and some other algae. A cyanobacterial bloom of *Trichodesmium* may cover large area of the sea giving a red colour as in Red Sea. Occasionally, some dinoflagellates (toxic) multiply very fast and form blooms generally known as **red tides**. Phytoplanktons of the sea play an important role in the primary production of organic matter, photosynthetic carbon fixation and serves as food for crustaceans, fingerlings of many fishes and even whales. All marine living organisms are directly or indirectly dependent on the growth and activities of the phytoplankton.

In recent years very minute organisms collectively known as **picoplankton** including *Chlorella nana, Micromonas, Nannochloris, Dolichomastix* and *Hilba* have been found to play a very important role in the biological productivity of oceans.

6.2.3 Special Habitats

Algae are also found in special habitats where environmental conditions are in extreme.

Brines and Salt Lakes

Inland lakes like Sambhar Salt Lake in Rajasthan contain sodium chloride and other salts in saturating concentrations (brines). One can see in them thick floating blue-green scums of permanently growing cyanobacteria *Anabaena, Anabaenopsis* and unicellular green alga *Dunaliella*. The metabolism of these halophilic organisms is active only at high salt concentration.

Thermal Regions

Among the lower Himalayas and other mountains (Himachal Pradesh, Bihar, Orissa and Maharastra) are found hot water thermal springs with temperatures ranging from 40° to 70°C which inhabit quite a number of algae, mainly cyanobacteria, *Mastigocladus laminosus, Synechococcus lividus, Oscillatoria* and *Phormidium*. Unlike in other algae, the growth and metabolism of the thermal algae are most active only at high temperatures.

Polar Regions

Algae can also grow under extremely cold climate conditions that prevail at Arctic and Antarctic regions. Among cyanobacteria-*Nostoc* is most common, besides *Schizothrix, Oscillatoria, Lyngbya, Phormidium* and *Stigonema*. Lichens with algal symbionts (*Collema*) are of common occurrence. Cyanobacteria and lichens grow and fix nitrogen under polar conditions. Indian expeditions to Antarctic have collected several types of algae mostly diatoms and cyanobacteria.

On permanent snow fields where the surface is stable atleast for a few weeks, abundant growth of algae is found giving red, brown or yellow colour to the snow. Red snow is caused by green algae *Chlamydomonas nivalis* and *C. flavo-virens*.

SAQ 6.1

a) Tick mark the correct answer in the following:

i) Most of the fresh water algae belong to the Division

1) Cyanophyta
2) Chlorophyta
3) Phaeophyta
4) Rhodophyta

ii) Which of the following algae is found in the rice fields?

1) *Sargassum*
2) *Porphyra*
3) *Aulosira*
4) *Ulva*

b) Which group of algae are found in deep sea waters and why?

....

....

....

....

....

....

c) Name the two seaweed that can be collected from Gulf of Manner in India.

....

....

d) In the following sentences fill in the blank spaces with appropriate words.

i) The algae that cause permanent blooms in temple tanks and lakes belong to the Division ....

ii) .... form the main bulk of marine phytoplanktons.

iii) The colour of Red Sea water is due to ....

iv) The name of Sargasso Sea is due to floating of huge islands of ....

v) The most common algae of arctic and antarctic region is ....

vi) The species of *Chlamydomans* that give red colour to the snow are ....

vii) The algae that inhabit sea are called ....

6.3 SOIL AND SUBAERIAL ALGAE

6.3.1 Soil Algae

Surface layers of soils all over the world provide a favourable substratum when wet for the growth of several types of algae. Terrestrial algae play a major role as primary colonizers on newly exposed areas and help in the establishment of other plants in the accumulation of humus. After the destruction of all life by the eruption of a volcano on the island of Krakatoa in 1883, the first organisms that appeared were cyanobacteria like *Anabaena, Tolypothrix, Symploca* and *Lyngbya.*

Soil algae grow profusely on damp or moist soil, although many of them can withstand prolonged and severe dry conditions. Many cyanobacteria (*Nostoc, Cylindrospermum, Porphyrosiphon, Scytonema, Tolypothrix, Stigonema, Aphanocapsa, Lyngbya, Phormidium)* green algae (*Oedogonium, Oedocladium, Uronema,* and other algae (*Botrydium, Vaucheria,* diatoms) grow on the surface of the soil, which is temporarily moist at least for brief time during the seasons. They form a crust over the surface of the soil, particularly cyanobacteria which have mucilagenous sheaths and prevent erosion of the top soil.

6.3.2 Subaerial Algae

Subaerial algae obtain their water from the moisture in air and grow if moisture is available. They are capable of enduring drought like the soil algae. In our country one can see dark brown patches, sometimes with a velvety carpet like cushions covering extensively the exposed surfaces of buildings, walls, terraces, asbestos roofs, rock surfaces,and also tree trunks. Ancient archeological monuments, temples and in fact, any lime coated or lime plastered surfaces form excellent habitat for the growth of cyanobacterial cushions on which seeds of higher plants colonize and ultimately bring out ruin and destruction of the structures. The algal growth is mainly cyanobacterial in nature consisting of *Chroococcus, Myxosarcina, Scytonema, Tolypothrix, Lyngbya, Porphyrosiphon, Synechococcus.* All forms show thick layers of mucilagenous sheath deep brown in colour. Bark of many tree trunks also harbours not only the above algae but also a few green algae like *Trentepohlia, Physolinum* (orange tufts) and *Chlorococcum.*

6.4 ALGAL ASSOCIATIONS

Algae live associated with other plants and inside animals as described below.

6.4.1 Algal -Plant Associations

Algae are known to be associated with other plants, some as epiphytes attached to the outer surface and some inside the tissues as endophytes. Epiphytes are common in all the groups of aquatic algae. One interesting case is a green endophytic alga *Cephaleuros* which grows just below the cuticle of leaves of tea (red rust disease of tea) coffee, mango, guava and other fruit bearing trees, as rusty red coloured patches.

Another endophytic alga *Chlorochytrium* is found in the intercellular spaces of water plants *Lemna, Ceratophyllum* and *Elodea. Coleochaete nitellarum* occurs inside the cuticle of another alga *Nitella.* Several species of brown algae *Ectocarpus* and *Sphacelaria* grow as endophytes in larger kelps - *Laminaria* and *Cystoseira.*

6.4.2 Algal-Animal Associations

There are number of instances where algae are found growing inside the animals (endozoic). Green alga *Chlorella* is found inside the unicellular *Paramaecium,* in the tentacles of *Hydra* and in sponges. In marine habitats, sea anemones, and some corals contain unicellular algae-zooxanthellae (Cryptophyta) and also some Dinophyta members. *Platymonas* (green alga) is found inside a marine worm *Convoluta.* In unit 1 you learnt that recently discovered prokaryotic alga *Prochloron didemni* (which contains chlorophyll *b* also) exists as a symbiont in the gut of sea squirts.

6.4.3 Algal -Symbiotic Associations

When an alga lives in close association with a non-photosynthetic organism (fungus or an animal), because of its ability to fix carbon photosynthetically some of the carbon fixation products like sugars may be absorbed by the nonphotosynthetic host, while the alga in turn may get some sort of protection. This kind of mutually beneficial association is known as **symbiosis**. Where the alga is also a nitrogen-fixer as in some cyanobacteria, nitrogenous compounds are also available to the host organism along with carbon compounds.

Several cyanobacteria and also some green algae occur in symbiotic association with fungi as distinct group known as lichens (refer to Block 2, Unit 12, for more information on lichens). Nitrogen-fixing cyanobacteria are found in symbiotic association with photosynthetically active plants, bryophytes, pteridophytes, gymnosperms and angiosperms (see table 6.2).

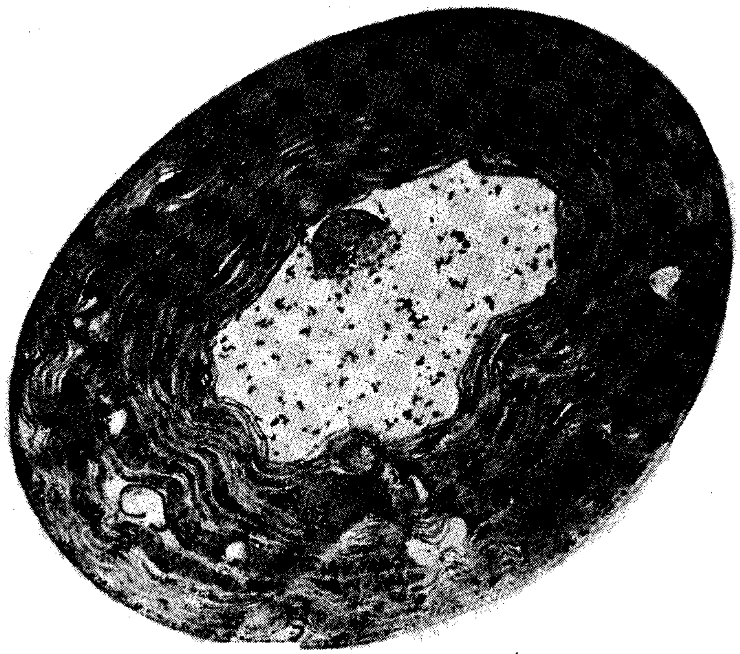

Fig. 6.1 : Detailed structure of *Prochloron.*

They are mostly found in intercellular spaces forming coralloid (calcarious) nodules as in *Cycas. Azolla*, a water fern has packets of *Anabaena* in the leaf cavities. In the case of a marine diatom –*Rhizosolenia* (unicellular), a single filament of cyanobacterium *Richelia intracellularis*, probably a nitrogen-fixer is found. Such intracellular existance has been observed also in unicellular flagellate *Paulinia* and *Oocystis*, where cyanobacteria-like bodies have been discovered. *Cyanophora* (cryptophyte) also shows such cyanobacteria-like intracellular inclusions. These are known as cyanelles and under electron microscope they appear to have prokaryotic structure but without proper cell walls.

Table 6.2 : Symbiotic Associations of Cyanobacteria with Plants and Animals.

Partner Organism	Cyanobacteria
Fungi	
ascomycetes in lichens	*Calothrix, Nostoc, Scytonema, Stigonema*
Bryophytes	
Anthoceros	*Nostoc, Anabaena*
Blasia	
Ferns	
Azolla	*Anabaena-azollae*
Gymnosperms	
Cycas, Macrozamia	*Nostoc*
Angiosperms	
Gunnera	*Nostoc*
Protozoa	
Cyanophora paradoxa, Glaucocystis, Paulinella	various "cyanelles"

As has been mentioned earlier that a prokaryotic alga *Prochloron didemni* exists as a symbiont in the gut of sea squirts. (This alga as well as another

Prochlorothrix hollandica show prokaryotic structure like cyanobacteria in all respects except that they contain chlorophyll *b* also but no phycobilins).
In some phytoflagellates (green alga or cryptomonad) cyanobacterial cells exist in symbiotic association. "The host cell is called **cyanomes,** the cyanobacterial cell **cyanelles** and the association is called **syncyanosis.**

Intracellular existance of one alga inside another is also found in Dinophyta. The unicellular, colourless alga *Peridinium balticum* and *Glenodinium* contain in their cytoplasm a unicellular chrysophyte as an endosymbiont. In all the above cases it is to be noted that the host cell being colourless depends on the photosynthetic endosymbiont for organic carbon compounds.

An extreme case of symbiotic state is the presence of chloroplasts (not complete cells) in tissues of marine animals. A marine slug -*Saccoglossa* feeds on marine green algae like *Codium.* The chloroplasts of the alga instead of being digested are incorporated into the epithelial cells of the digestive tract of the animal. The animal appears green in colour and the chloroplasts actively photosynthesize in light like normal cells.

The existance today of such diverse symbiotic associations, specially those instances where a colourless eukaryotic cell is inhabited by a prokaryotic cyanobacteria-like organism, strongly supports the assumption that the chloroplasts of higher plants evolved from the ancestral cyanobacteria- like endosymbionts (ref. unit 1, section 1.6, p 18; unit 2 section 2.2, p 36).

SAQ 6.2

In the following statements fill in the blank spaces with appropriate words.

i) The algae that are primary colonizers on volcanic soils belong to the Division ....

ii) Thick layers of cyanobacteria on the soil prevent soil erosion because of the presence of ....

iii) The alga .... lives inside *Paramecium.*

iv) The existence of functional chloroplasts is observed in a marine ....

v) The cyanobacterial cells found in some phytoflagellates are called ....

vi) The red rust of tea is due to an alga of Division ....

vii) *Prochloron didemni* exists as an endosymbiont in the gut of.........................

6.5 SUMMARY

In this unit you have learnt that

- Algae are distributed in all habitats on the surface of the earth wherever water or water vapours and sunlight are reasonably available. They show astounding ability to adapt themselves to the environmental conditions where they grow.

- Green algae are found in fresh water bodies, polluted water, flowing rivers and mountain streams. The flora varies according to seasons.

- Different regions of the sea show characteristic algal flora.

- Cyanobacteria and some algae can be found under extremely cold and hot conditions.

- Cyanobacteria, green algae, diatoms and some other algae grow on damp soil if sunshine is available. Many of them can withstand prolonged desiccation. Cyanobacteria play a major role as primary colonizer on newly exposed area. Blue green and green algae are subaerial in habitat also.

- Certain algae live associated with plants as epiphytes or endophytes. Some of them are parasitic in nature also,

- Algae are found growing inside animals, for example in *Paramecium,* sponges, *Hydra*, sea anemone, corals and marine worms.

- Cyanelles of cyanobacteria are observed in animals, plants and protists. This observation along with the presence of functional chloroplasts in marine animals support the endosymbiont theory of evolution of chloroplasts.

6.6 TERMINAL QUESTIONS

1. Choose the correct answers:

a) Common algae found in thermal springs belong to
   i) Cyanophyta
   ii) Phaeophyta
   iii) Dinophyta
   iv) Rhodophyta

b) Algae found in salt lakes belong to
   i) Dinophyta
   ii) Cyanophyta
   iii) Rhodophyta

c) *Ectocarpus*, a brown alga is found in
   i) open sea
   ii) fresh water;
   iii) littoral areas of sea.

2. Which of the following statements are true and which are false? Write T for true and F for false in the given boxes.

   a) Kelps like *Laminaria* are found in west coast of India. ☐

   b) Cyanelles are symbiotic, eukaryotic algae. ☐

   c) *Prochloron* is a prokaryotic alga which contains -chlorophyll *b*, also. ☐

   d) *Microcystis* forms water-blooms in the sea. ☐

3. Prepare a list of fresh water and marine algae.

....

....

....

....

....

6.7 ANSWERS

Self-assessment Questions

6.1 a) i) 1 and 2
ii) 3•
b) Mostly red-algae because they contain red pigment-phycoerythrin that absorbs blue wavelength of light available in deep waters of the sea.
c) *Gelidiella*
Gracilaria
d) i) Cyanophyta
ii) Diatoms
iii) *Trichodesmium*
iv) *Sargassum*
v) *Nostoc*
vi) *C.nivalis* and *C. flavo-virens*
vii) seaweed

6.2 a) i) Cyanophyta
ii) mucilagenous sheath
iii) *Chlorella*
iv) slug
v) cyanelle
vi) Chlorophyta
vii) sea squirts

Terminal Questions

1. (a) Cyanophyta, (b) Cyanophyta, (c) in littoral areas of sea.

2. (a) F (b) F (c) T (d) F

UNIT 7 ALGAE AND HUMAN WELFARE

Structure

7.1 INTRODUCTION

Some of you may wonder about the relevance of the previous four units. Why study the structure and reproduction of different algae in detail? Biologists explore nature out of curiosity to obtain fundamental knowledge about different types of organisms. However, this knowledge is often applied to satisfy human needs.

In India algae, a fascinating group of organisms have not received much attention, perhaps on account of the rich diversity of higher plants from which one can obtain useful and interesting products in plenty. While in the maritime countries – Japan, Taiwan, China and Hong Kong, some algae are part of the daily meal. There are large industries in these countries for farming algae on commercial scale. These countries also export various algal products.

The purpose of this unit is to introduce you to the vast potential of algae as a source of human food, animal feed, biofertilisers and energy, and for various pharmaceutical and other useful products. It is high time that Indian industrialists take interest in algae and produce various useful products for home and export purposes. We wish and hope that some of you would take active interest in exploring algae of your region and grow it on commercial scale.

Objectives

After going through this unit you should be able to:

- give examples to show that algae are economically important,
- list main edible algae and discuss their nutritional value,
- discuss the commercial production and consumption of algal foods in various countries,
- suggest the use of algae in waste water treatment,
- suggest the use of algae as biofertiliser,
- give reasons for considering algae as a source of energy,

- describe important algal products and their uses and
- discuss the negative role of algae.

Study Guide

You should consider this unit as important as others. Several generic and specific names of cyanobacteria (blue-green algae) and algae are cited only for reference. You are expected to remember only a few important ones, which we have discussed in detail.

The economic importance of cyanobacteria, which have traditionally been grouped with algae, is also included here. Please note that they are referred to as algae instead of cyanobacteria. The following genera are cyanobacteria.

Spirulina	*Scenedesmus*
Anabaena	*Calothrix*
Nostoc	*Haplosiphon*
Oscillatoria	*Westiella*
Tolypothrix	*Westielopsis*
Aulosira	*Anabaenopsis*
Cylindrospermum	
Mastigocladus	

7.2 ALGAE - A NUTRITIONAL FOOD SOURCE

Kelps (brown algae) can accumulate iodine in concentrations 10,000 times greater than those found in sea water.

In order to fulfil the demand of growing global population, there is constant search for new food sources. About 90% of the food is obtained from land. Though aquaculture or farming of fresh water, brackish and seawater is almost as ancient as agriculture, its potential has not been fully explored. Among marine organisms - algae appear to be one of the promising food resources. Many of the edible forms are quite rich in proteins, vitamins and minerals including iodine. Algae synthesise some essential polyunsaturated fatty acids which are rarely synthesised in higher plants or animals. Algae grow rapidly and their farming can be carried out in fresh water, brackish water, and shallow coastal areas and also in the open sea. Therefore, it is worthwhile to explore algae and algal products that have potential food value.

The idea of including algae in human diet is relatively new in India but in maritime countries algae and algal products are daily consumed along with other food items. The consumption of seaweed by coastal Japanese people dates back to 600 B.C. and by Chinese sixth century A.D. About 160 species of algae are used as commercially important food sources. Some of the major edible ones are given in table 7.1.

Spirulina (Fig. 7.1) contains about 65% proteins and is also rich in carotenes. It can be grown in wastewater.It is mass cultured in Mexico, Taiwan and India. Because of its high nutritive value it has been identified as a source of single cell protein (SCP), as a suitable supplement to a vegetarian meal. It can be supplemented in the diet of children to curb malnutrition prevalent in developing countries. The natives of Mexico and Africa have long used it. So far, attempts to popularise it in India are not successful due to different food habits and tastes. However, it can be cultured and exported as health food to earn foreign currency. At present, a few private and government agencies are engaged in its commercial farming. The Central Food Technological Research Institute, Mysore has developed technology to grow *Spirulina* on large scale.

Processed *Chlorella vulgaris* E-25, is sold as Momotaro E-25 in Japan. This is the only cell wall permeable *Chlorella*. It is sold in the form of granules in packets each containing 5g.

Another single cell, rapidly growing alga is *Chlorella* (Fig. 7.1). It has a potential food value as it is rich in proteins, lipids and contains many vitamins in high concentration. Its nutritive value is almost equivalent to that of soybean and spinach. In Japan, Taiwan and other South East Asian countries it is grown as

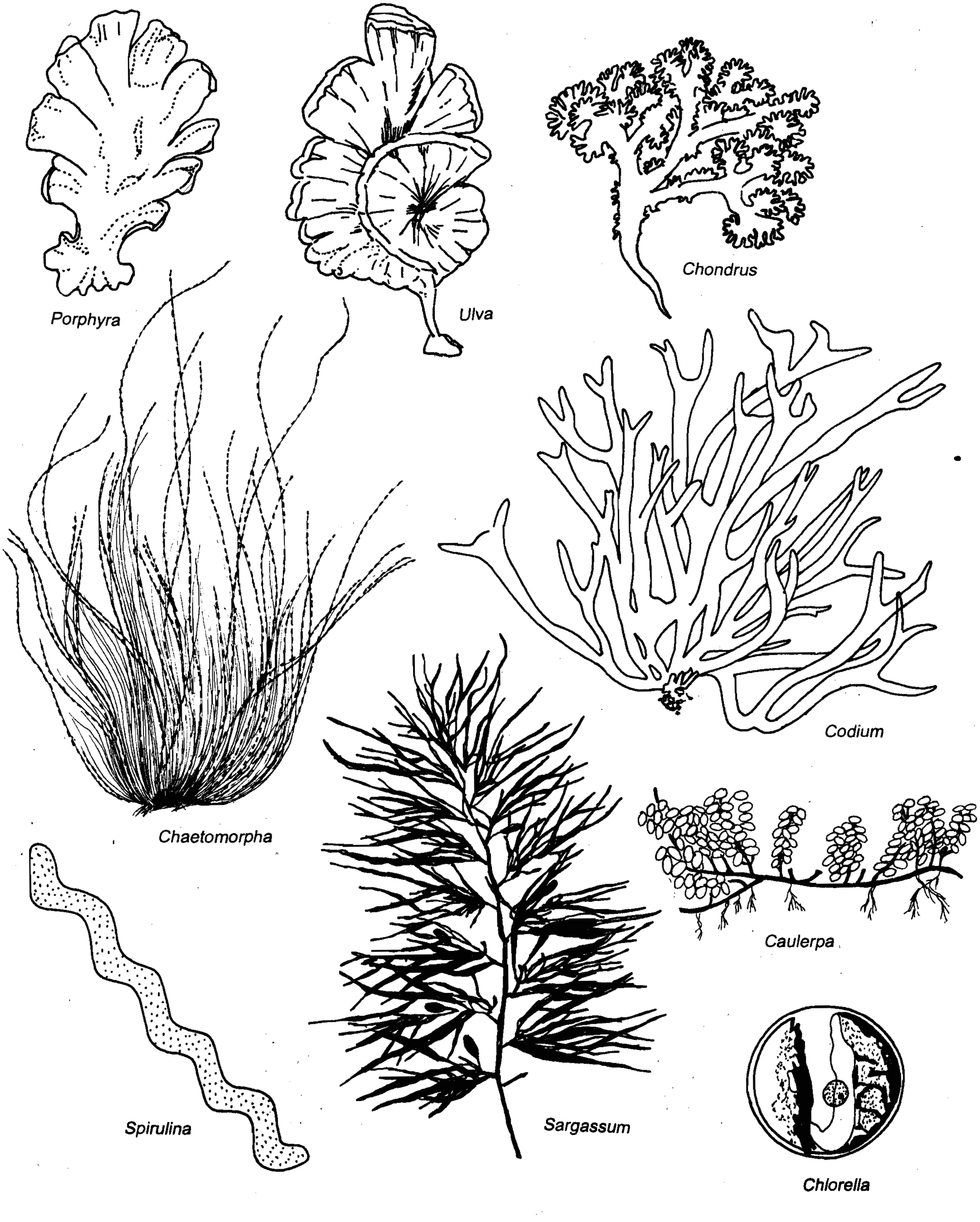

Fig. 7.1 : Some edible algae.

Undularia (brown alga) is used in Japan for extracting an edible product called *Wakame*.

Ulva lactuca (green alga) known as sea lettuce is eaten as salad mainly in Scotland.

The edible seaweed of Indian Coasts are:

Green Algae

Chaetomorpha
Caulerpa
Codium
Enteromorpha
Ulva

Red Algae

Rhodymenia
Laurencia
Scanthophora

Brown algae

Padina
Turbinaria
Chnoospora
Hydroclathrus
Sargassum

health food having 'cure-all' properties, Taiwan alone produces 1500 tons (dry weight) annually. After harvesting the cells are washed and pigments are extracted. The dried algal mass is ground and stored in powdered form. Efforts to introduce *Chlorella* as a food supplement have not been fruitful in India as its colour and taste are not quite acceptable.

Marine algal foods are both conventional and a delicacy in Japan, Korea, China, Philippines and Thailand. Many species of algae such as *Enteromorpha, Caulerpa, Ulva lactuca, Gelidiella, Laurencia* and *Gracilaria* are eaten raw as salad. *Gracilaria* is used in preparing a tasty dessert. *Ulva lactuca* and *Gelidiella acerosa* are cooked with other vegetables like spinach is cooked in India.

Among seaweed, one of the most important is *Porphyra*. It contains 30-35% proteins, 40-45% carbohydrates and is rich in vitamins. The mature *Porphyra* is harvested, dried and pressed into sheets. The sheets are toasted and cut into pieces and eaten with rice, raw fish or some vegetables. They are also used for flavouring soups and in 'sushi'. In Japan *Porphyra* (called **nori**) farming is carried out over 60,000 hectare area in sea by either placing concrete blocks on the sea floor to enhance seaweed growth or on bamboo-cum-rope network or raft like network of bamboos. In North Atlantic coast *Palmaria* called **dulse** and *Porphyra* called **laver** are most widely used seaweed. In the Pacific countries and Asia a great variety of seaweed are harvested while foraging the shore and are consumed as food.

Undularia is used in Japan for extracting an edible product called *Wakame*.

Table 7.1: Some examples of edible algae and the countries where they are consumed.

Examples	Countries
Seaweed	
Porphyra	Japan (as nori), China (as tsatsai & zicai) Korea (as kim and laver), Philippines, Britain
Laminaria	Japan (as kombu), China (taidaine), Korea, Philippines
Undularia	Japan, China, Philippines
Lemanea	Manipur, India (as nughee)
Enteromorpha	Philippines
Palmaria	Canada, U.K.
Chondrus crispus	Canada, U.K.
Microalgae	
Spirulina	Central America, Mexico, W. Africa (as duhee) US, Israel, Taiwan, Thailand
Phormidium	Mexico
Chroococcus	Mexico
Nostoc commue	Mexico, Mongolia, China, Fiji, Ecuador
N.edule	Mongolia, China, Peruvian Andes
N.verrucosum	Thailand
Chlorella	Japan, Mexico, U.S., Taiwan, Germany
Prasiola	China, Japan
Spirogyra	Burma, Thailand, India
Oedogonium	Burma, Thailand, India

SAQ 7.1

a) Fill in the blank spaces with appropriate words.

i) Edible algae are important nutritional food source because they are rich in ...., ... and .... including ....

ii) *Spirulina* contains ....% proteins.

iii) Algal farming can be done in fresh water, ...water, in shallow and .... sea.

iv) Single cell alga .... is sold as health food in Japan with .... properties.

v) *Spirulina* can be grown on .... water.

vi) The dried pressed sheets of .... are toasted and eaten with rice, raw fish or vegetables.

vii) Algae synthesize some .... polyunsaturated fatty acids.

b) Name three nutritionally important algae that are commercially cultured.

....

....

....

7.3 ALGAE - A SOURCE OF ANIMAL FEED

As we have mentioned above *Spirulina, Chlorella* and many seaweed are commercially cultured for human consumption because of their high nutritive value. These can also be used directly as fodder for livestock or supplemented with regular feed. During World War I when fodder was in short supply, seaweed were

Seeweeds used for fodder

Rhodomenia
Laminaria
Alaria
Fucus
Ascophyllum
Macrocystis
Sargassum

Microalgae used in poultry, fish, oyster, prawn, mollusc raising industries

Chlorella
Scenedesmus
Spirulina

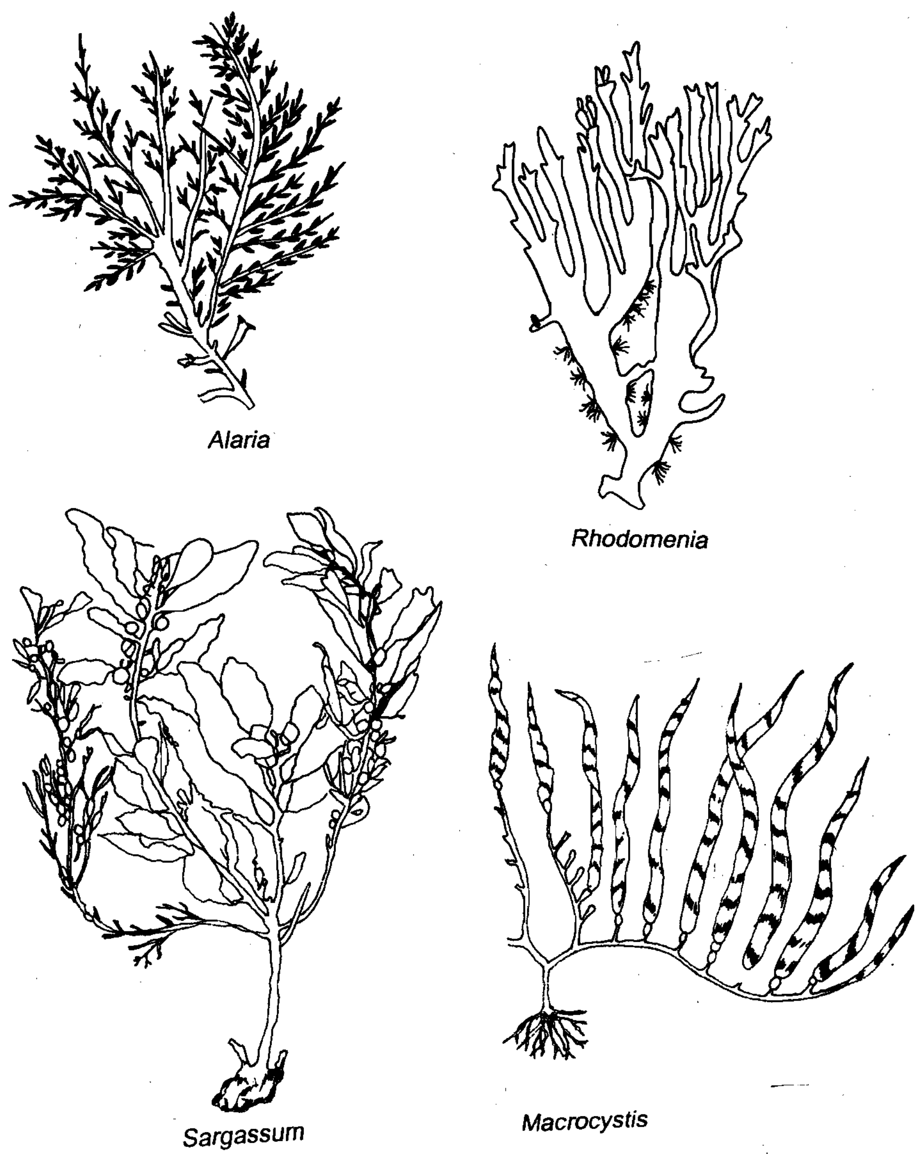

Fig. 7.2 : Algae used as fodder.

tried as cattle feed and the quality of milk was found to be unaffected. Thereafter, seaweed based stock feed factories were set up in France, Norway, Denmark, Germany and USA. According to some reports the milk of cows fed with seaweed is rich in fat content than those fed on conventional fodder. The seaweed are used either directly as fodder for livestock or added in powdered form to the regular feed of cattle, pigs, sheep, fish and poultry. In India *Spirulina* has been grown on wastewater in Lucknow, Nagpur and Varanasi. It is fed to fish, poultry and cattle. The aim is to improve health and productivity of the animals.

SAQ 7.2

Indicate whether the following statements are true or false. Write the letter **T** for true and **F** for false in the given boxes.

i) Seaweed cannot be used for animal feed. ☐

ii) Microalgae are used to feed fish and poultry. ☐

iii) Milk of cows fed with seaweed is rich in fat content. ☐

iv) In India *Spirulina* is grown on waste water. ☐

7.4 USE OF ALGAE FOR WASTE WATER TREATMENT

Waste water from lavatories, bathrooms and kitchens of the houses contains large amount of organic material and is generally known as sewage. Sewage is foul smelling but rich in nutrients. If it is discharged into ponds, lakes or rivers the growth of various types of bacteria and viruses is encouraged resulting in epidemics of diseases like cholera, gastro-enteritis, typhoid, viral jaundice etc. In cities the amount of sewage produced is indeed very large. It needs to be treated in order to get rid of most of the organic matter and nutrients before the water is reused or disposed of into a river or lake.

Sewage treatment involves broadly the following two stages:

In the first stage, diluted sewage is allowed to decompose in the absence of air (anaerobic digestion) by anaerobic micro-organisms. When it gets partially digested and methane gas (biogas) is produced.

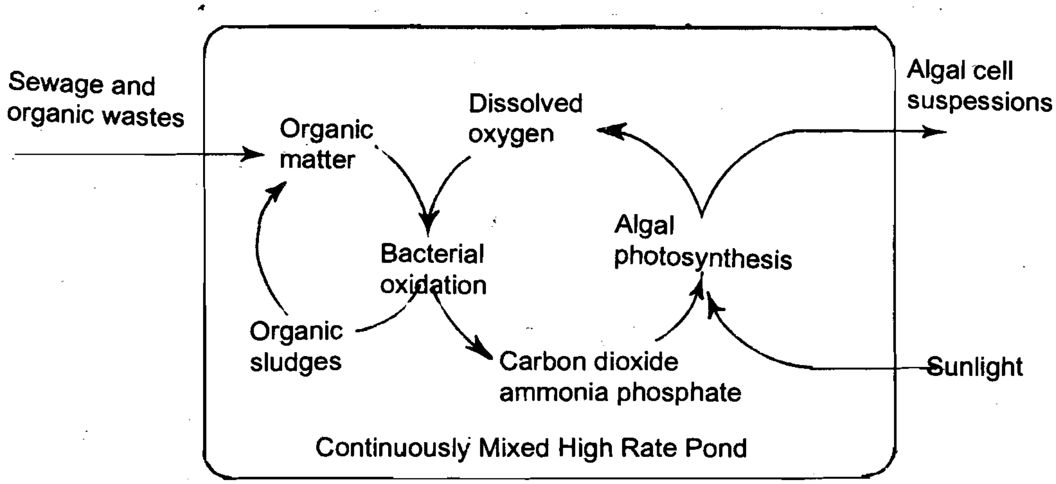

Fig. 7.3: The cycle for photosynthetic oxygenation of waste water.

Algae used for waste water treatment

Chlorella
Spirulina
Scenedesmus
Chlamydomonas
Oscillatoria

In the second stage the sludge is vigorously aerated with air or oxygen so that complete oxidation may take place. This process can best be done economically and profitably by using algae. Some of the algae used are *Chlorella, Scenedesmus, Chlamydomonas, Oscillatoria*. In shallow ponds, exposed to bright sunlight algae grow profusely. During photosynthesis they produce oxygen that helps aerobic microorganisms to breakdown organic matter completely. The water of oxidation ponds can be safely used for horticultural or agricultural purposes. The algal biomass produced can be profitably used for other purposes like feed for cattle or poultry.

Algae as Bioaccumulator of Toxic Pollutants.

It has been observed that algae can accumulate as much as several thousand folds of pesticides and toxic metals such as Zn, Hg, Cd, Cu, Pb prevalent in industrial effluents. Hence algae can be used for the treatment of industrial effluents to remove toxic pollutants. The algal biomass thus obtained can be used for biogas production instead of feeding to the animals.

SAQ 7.3

In the following statements fill in the blank spaces with appropriate words.

i) The main requirement of sewage digestion is a good supply of ....

ii) Algae can be used for waste water treatment to replenish .... used by the aerobic decomposers.

iii) Contamination of drinking water with sewage can cause ....

iv) The algal biomass recovered after the treatment of waste water can be fed to ....

v) The algal biomass produced after treatment of industrial effluents can be used for ....production.

7.5 USE OF ALGAE AS BIOFERTILISER

With increase in population, it has become necessary to increase the yield of crop plants and this has resulted in large scale use of chemical fertilisers. It is only recently that people have realised the harmful effects of such fertilisers on environment particularly on the soil. Chemical fertilisers are produced in factories from non-renewable sources like crude oil and natural gas, which may not be available after some time when exhausted. Being soluble in water much of the fertiliser added to the crop is literally washed down by irrigation water or rain and reaches the water resources like ponds, lakes and rivers. This brings about the growth of algae and bacteria leading to severe water pollution. Besides, such undesirable side effects, chemical fertilisers affect the chemical and physical properties of the soil so as to make it soon unfit for growing crops. Traditionally, farmers use farmyard manure (FYM), produced from agricultural wastes. Although they are good as soil conditioner but are poor in nutrients. In recent years, a number of organic, nutrient-rich fertilisers of biological origin termed as biofertilisers have become popular. Some of the algal biofertilisers that are being developed and used successfully in India and abroad are given below:

Seaweed

In coastal areas where seaweed are washed ashore, they are collected and composted like farmyard manure. Seaweed compost is rich in minerals like potassium, phosphate, sulphate and trace elements. Several vegetable crops like bhindi, brinjal, tapioca, cucurbits; fruits like lemon; trees such as palm and papaya are found to be benefited by this manure.

Extracts of seaweed (seaweed boiled in water) have been found stimulatory for the germination and seedling growth of red gram, tomato and other plants by Indian workers. Such extracts are commercially available in some countries under the name of Algifert (Norway) and SM3 (England). Similar water extracts of common cyanobacteria like *Cylindrospermum, Calothrix, Anabaena, Aulosira* are also found beneficial for the growth and yield of crop and vegetable plants. In India palm trees are fertilised with *Turbinaria*.

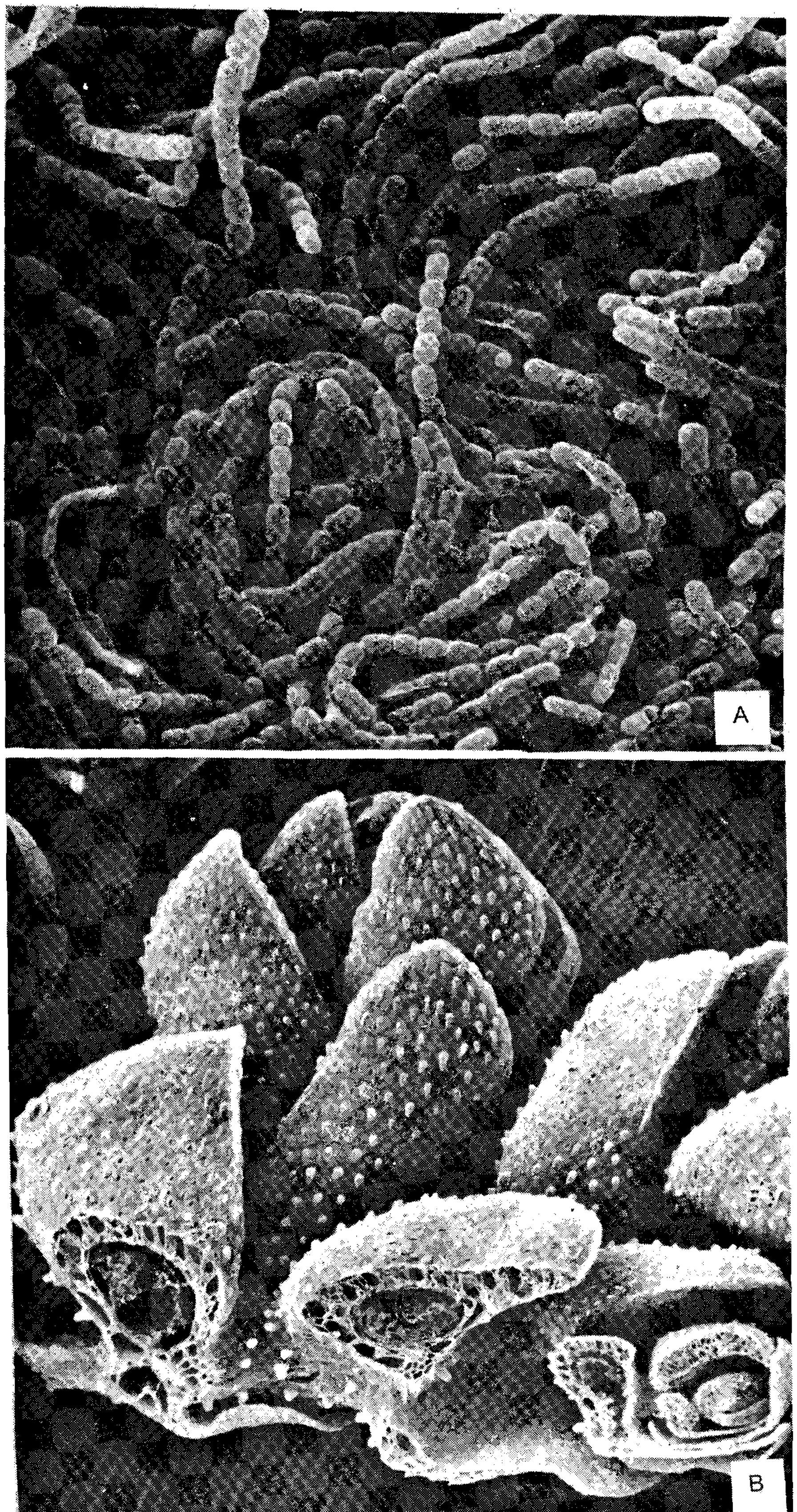

Fig. 7.4: Scanning electron micrograph of *Nostoc muscorum* (A) and water-fern *Azolla* (B), some leaves are partly cut open to reveal the cavities containing nitrogen-fixing *Anabaena* colonies.

Blue-green Algal Biofertilisers

Wherever sunlight and water are available, nitrogen-fixing cyanobacteria can be grown in summer in shallow puddles or metal pans. The thick mats that develop within a week or so are dried and kept in bags. This is literally growing ones own fertiliser during the summer season when the field is empty without the crop. Such dry algal material is a rich source of nitrogen and phosphorus besides several other important elements. Agricultural departments supply kits to the farmers to grow their fertiliser. This is very popular in the rice growing areas of South India.

Nitrogen-fixing cyanobacteria are also directly added to the rice field paddies immediately after the transplantation of rice seedlings. They multiply rapidly and supply directly or by decay nitrogen and other nutrients to the rice plants.

Azolla

Azolla is a water fern, very common in ponds all over India. In China, Vietnam and other South East Asian countries, it is grown and used as fertiliser and also as feed for cattle and poultry.

Azolla contains symbiotic nitrogen-fixing cyanobacteria -*Anabaena* in the leaf pockets and grows rapidly when inoculated in the rice fields. It can also be grown separately and composted, stored and added to crops when needed.

Reclamation of Usar Lands by Blue-green Algae

In our country large tracts of land is not fit for cultivation because of its high alkaline condition (usar soils). The only organisms that can grow there profusely are blue-green algae. During the rainy season bunds are constructed to retain the rain water and inoculated with nitrogen-fixing algae. The algae rapidly grow and form thick mats adding a lot of organic matter and also lower the alkalinity. By repeating this process for two or three seasons the quality of the soil improves and one can grow crops like rice, wheat and sugar-cane.

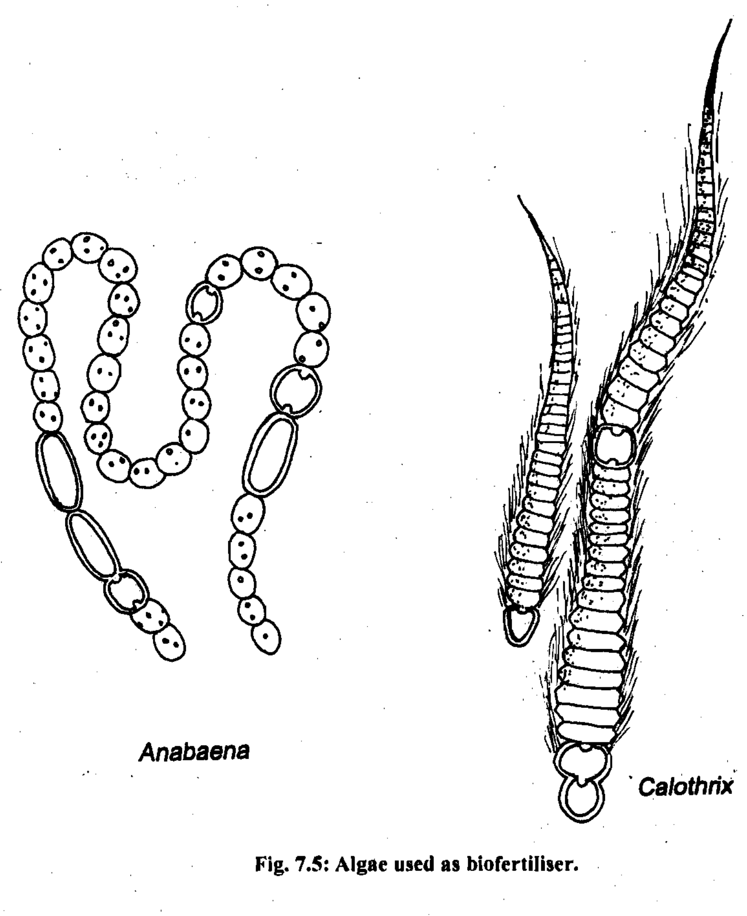

Fig. 7.5: Algae used as biofertiliser.

Indian Agricultural Research Institute, New Delhi has developed simple method for Indian farmers to grow their algal biofertilizers.

Some of the important Nitrogen -fixing cyanobacteria.

Anabaena oryzae,
Nostoc commune,
Tolypothrix tenuis,
Aulosira fertilissima,
Anabaenopsis arnoldii,
Calothrix confervicola
Haplosiphon,
Fritschiella,
Mastigocladus,
Westiella,
Westiellopsis

***Azolla* in Rice fields**

The length of the time required for the development of Azolla depends upon various factors such as soil chemistry, ploughing, temperature, irradiance, water availability, nature of inoculant environmental and climatic conditions. After the decay of Azolla, the fixed nitrogen becomes available to the crop. Successive *Azolla* farming in the same field results in an increased soil conditioning.

In India *Azolla* technology suitable for small scale farmers has been perfected at Indian Rice Research Institute, Cuttack (Orissa).

SAQ 7.4

Name the algae involved in the following.

i) The algal-fern association used to enrich rice fields with nitrogen.

ii) A blue-green alga used as biofertiliser.

iii) The seaweed used to fertilise palm trees in India.

iv) The type of algae used for enriching the soil with minerals.

v) The algae grown to reduce the alkalinity of usar lands.

7.6 ALGAE - A SOURCE OF ENERGY

Algae that can be considered for the production of energy:

Spirulina
Botryococcus braunii
Sargassum tenerrimum
Astromonas gracilis
Chlamydomonas
Dunaliella.
Anabaena (for hydrogen)

Glycerol is the major photosynthate in *Dunaliella*. This unicellular wall-less halophytic alga is an ideal organism for the production of glycerol. It can be grown in the arid zones of Rajasthan and elsewhere, where highly saline water is readily available. It's biomass is rich in protein and β-carotene and can be used as animal feed.

In Australia and Israel glycerol is commercially produced from *Dunaliella*.

The strains of algae considered for hydrogen production

Chlorella
Scenedesmus
Synechococcus
Microcystis
Oscillatoria

The fossil fuel reserves like coal, peat, crude oil products (hydrocarbons) and natural gas on the earth are limited. At present, they are consumed at much faster rate than before due to the rapid increase in industrialisation. Unfortunately, they are non-renewable and it is estimated that they will soon be depleted. Therefore, serious efforts are being made to find alternate renewable sources of energy. Algae are identified as one such potential source.

Algal biomass is found quite suitable for use in biogas plants for producing methane gas. It can be fermented in anaerobic digesters as sole substrate or along with sewage sludge. It has been shown that *Spirulina* when added to sewage sludge doubles the production of methane. In Bhavnagar *Sargassum tenerrimum* has been successfully used in biogas plants.

Algae synthesise the energy-rich molecules like long chain hydrocarbons, glycerol and lipids. When some algae are grown without nitrogen and silicon, there is an increase in the synthesis of lipids. These energy rich chemicals can be converted into petrol and diesel. Glycerol required in pharmaceutical industry is produced by *Astromonas gracilis, Chlamydomonas* and *Dunaliella*.

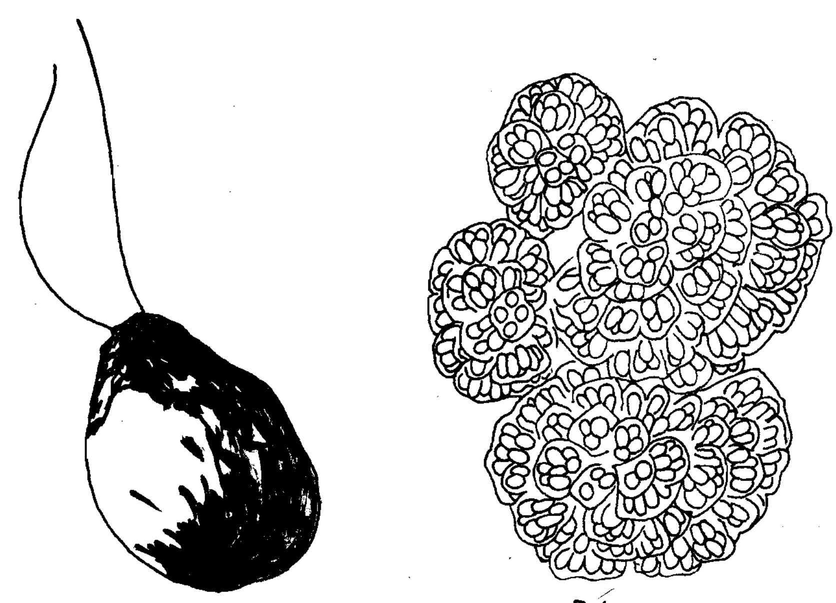

Fig. 7.6: ***Dunaliella salina*** **and** ***Botryococcus braunii.***

Although, glycerol is not a good liquid fuel as it is highly oxygenated, but it can be converted to other liquid fuels like ethanol, butanol and propane-diol that can be used as a substitute for petrol. In Brazil ethanol is used in place of petrol and in USA it is added to gasoline and sold as **gasohol**.

Another potential alga is *Botryococcus braunii* which under saline conditions produces long chain hydrocarbons including fatty acids. In Sumatra oil is extracted from this alga.

The possibility of hydrogen production by cyanobacteria has drawn much attention, because they can produce hydrogen in the presence of light exclusively in a nitrogen free atmosphere. (ref. to LSE-05, Block 4, Unit 15, P. 12) Hydrogen along with air is used in fuel cells to produce electricity without polluting the atmosphere.

Another interesting possibility that has been successfully explored is the sustained photo-production of ammonia from nitrate by cyanobacteria. This requires inhibition of enzyme glutamate synthetase. Consequently, the alga produces ammonia at high rates with fairly high efficiency.

SAQ 7.5

Indicate whether the following statements are true or false. Write the letter **T** for true and **F** false in the given boxes.

i) Long chain hydrocarbons and fatty acids are energy rich molecules. ☐

ii) Certain algae synthesise glycerol molecules. ☐

iii) Algal mass cannot be used in biogas plants. ☐

iv) Blue-green algae are being explored for the production of hydrogen fuel. ☐

7.7 INDUSTRIAL APPLICATIONS OF ALGAE

A large number of algal products have proved to be of great commercial use. The variety of compounds obtained from seaweed are discussed below:

7.7.1 Phycocolloids

Alginic acid, agar and carrageenans are high molecular weight polysaccharides and possess colloidal properties.They are the constituents of cell wall of mostly red and brown seaweed. They are used as viscofers, emulsifiers and lubricants in food, paper, textile, drug and caustic industries. Since there are no synthetic substitutes or non-algal sources to obtain them seaweed are of great value.

Phycocolloids

The colloids obtained from algae are called phycocolloids.

In cells polysaccharides are of three types: structural (cell wall), exocellular mucilages and intracellular reserves (starch). The exocellular mucilages are made of monosaccharide units which may be sulphated. They are rich in ribose and arabinose. Animals also contain sulphated polysaccharides. The presence of sulphate makes these polysaccharides a good thickening or gelling agents.

Alginic Acid

In the cell wall of algae, alginic acid is present in the form of alginates- Na, K, Ca, NH_4 salts of alginic acid. Since the sodium salt is soluble in water, the extraction is done with sodium hydroxide. Alginates are used for wide variety of purposes (Table 7.2). They are also used for making flame-proof fabrics and plastic articles. This polymer can absorb large quantities of water, therefore, it is used as highly absorbant gauze in internal operations to stop bleeding effectively. Owing to its non-toxic and colloidal property it is used for making antibiotic capsules.

Coasts of North and South America, Australia, New Zealand are rich in *Macrocystis* which commercially harvested for alginic and in North Atlantic, *Ascophyllum* is a source of alginates.

The uses of alginates are summarised below:

Seaweed utilisation has got a boost since the establishment of Marine Algal Research Station at Mandapam, near Rameswaram and also due to keen interest taken by some of the coastal Universities. Most of the natural seaweed growing areas are located in Tamil Nadu coast, Ramnad district, where villagers found it profitable to collect and sell seaweed to the local industries. In the Gulf of Mannar there are a number of Islands bearing rich growth of seaweed and today these places are used for large scale cultivation. Agar and Alginate are two important products.

a) Agar production - *Gracilaria edulis* and *Gelidiella acerosa.*

b) Alginate production - *Sargassum, Turbinaria.*

Due to indiscriminate harvesting year after year, there is tremendous depletion of naturally growing seaweed and so it is now necessary to resort to cultivation to provide constant supply of seaweed in quantity and quality. Methods are now available for marine cultivation of *Gracilaria* and *Gelidiella* and village women are being trained to undertake this work for extra income.

Economically important seaweed in India:

Red algae

Gelidiella acerosa
Gracilaria edulis
G.corticata
G.foliifera
G.crassa
Hypnea musciformis
H. valentiae
H. pannosa
Sargassum wightii.

Algae commonly used for the extraction of alginic acid:

Macrocystis (giant kelp)
Ascophyllum
Laminaria
Sargassum
Turbinaria.

These are abundant in coastal Japan, Chile, Mexico and U.S. *Gelidiella acerosa* is the principal agar yielding alga in India.

Gracilaria and *Gelidium* are abundant in coastal Japan, Chile, Mexico and US. *Gelidiella acerosa* is the principal agar yielding alga in India.

Table 7.2:Uses of Alginates.

Purpose	Items
Thickening Agents	Jams, jellies and sauces, cosmetics, textile and pharmaceutical industries
Stabilisers	Ice creams, milk shakes and squashes
Emulsifiers	For the preparation of paints and polishes
Surface coating agents	For flame proof fabrics, plastics
Absorbent	In surgical operations

Agar

The gelatinous substance agar, is well known for the solidification of culture media in microbiology and tissue culture. It is a mixture of agarose and agaropectin and is extracted from about 80 algal species of seaweed. The commonly used algae are *Gracilaria* and *Gelidium.* Like alginic acid it is also used in the manufacture of puddings, ice creams, jellys and soups. As stabilizer or emulsifier it is used in cosmetics, leather and pharmaceutical industries. Because of its laxative property it is used for the treatment of constipation.

Carrageenan

The main sources of carrageenan are *Chondrus crispus* (commonly known as 'Irish Moss') and *Eucheuma* spp. The polysaccharides in carrageenan are sulphated. Like alginic acid and agar, it is used in dairy industry and in cosmetics, textile, pharmaceutical, leather and brewing industries.

7.7.2 Diatomite

Diatoms have rigid silicified cell walls. The entire cell wall of a diatom is known as frustule. The fossilised frustules of diatoms are commonly known as diatomite or diatomaceous earth. They form sedimentary rocks and serve as biogenic silica sources. Due to low density, high porosity, large surface area, low abrasion capacity and chemically inert nature, diatomite are used in industry. The uses of diatomite are listed in the table below :

Table 7.3 : Uses of Diatomite.

Purpose	Uses
Filter	For clearing lubricating oils and aviation fuels, for refining sugar.
Insulator	In boilers, furnaces, refrigerators, for making soundproof rooms.
Abrasive	In scouring and polishing powders like tooth powder, bleaching powder, glass cleaners, paints and varnishes.
Filler	In battery boxes.
Inert substances	Controller of burn and friction in match heads and cigars, for packing explosive materials.
Absorptive	In handling and packaging of hazardous materials.
Anticake	In fertilisers

7.7.3 Pigments

You know that one of the criteria for classifying algae is the presence of photosynthetic pigments - chlorophylls, carotenes, xanthophyll and fucoxanthin that impart distinct colours - red, blue, green, yellow, golden, brown etc., to them. These pigments are extracted on commercial scale and are used for various purposes. *Dunaliella* and *Spirulina* are rich sources of β-carotene, the precursor of vitamin A. In comparison to other sources of β-carotene microalgae offer several advantages. They require a short generation time for growth and can be grown in sewage water. The amount of β-carotene in them is in high concentration. We would like to tell you that β-carotene has been identified as an anticancer drug.

β-carotene and other pigments (like xanthophylls, cantaxanthin and zeaxanthin) are used as food colourant. For example β-carotene is used for colouring soft drinks and margarine and cantaxanthin is used for colouring chicken skin, gold fish skin and egg yolk.

Fig. 7.7 : Scanning electron micrograph of a fragment of diatomaceous earth showing the remnants of silicified cell walls of fossil diatoms (Courtesy P. Dayanandan).

7.8 MEDICINAL USES OF ALGAE

Some algae show antibacterial, antiviral and antipyretic properties. They are used for wound healing, treatment of heart diseases, gout, goitre, hypertension, gall stone, bowel movement, skin diseases and as vermifuge. The beneficial uses of algae in medicine are summarised in the table below:

Table 7.4 : Medicinal Uses of Algae

Used as	Active Compound
antibiotic	Chlorellin (*Chlorella*)
vermifuge	Kainic Acid (*Digenea*)
cough syrup	Carrageenan
anticoagulant	Agar
diagnostic tool in understanding the nature of seizure in epilepsy.	Kainic Acid
anticancer	Decoction of some Seaweed
binding agent for medicinal tablets	Fucoidin and agar.

7.9 ALGAL COMPANIES

The companies that have set up large scale industries to exploit algal potential for a range of products are: Dupont and Sohio (USA), Kirin Brewery and Dainipa (Japan), Thapar Corporation (India), Wester Biotechnology Ltd. (Australia), Siam Algae Company (Bangkok). The market value of algae is also given in the table. (This in included in this unit in order to give you an idea of the algal products and the market size. you are not expected to memorise it).

Table 7.5: Variety of Products Obtained from Algae, Their Approximate Value and Market Size.

Algal products	Uses and examples	Approx. value, $/Kg.	Approx market*
Radioactive Isotopic labelled compounds	Biochemical and medical Research	> 1,000	Small
Phycobiliproteins	Diagnostics Food colours	> 10,000 > 100	Small Medium
Pharmaceuticals	Anticancer Antibiotics	Unknown (very high)	Large Large
β- Carotene	Food supplement Food colour	500 300	Small Medium
Xanthophylls	Chicken feeds Fish feeds	200-500 1000	Medium Medium
Vitamins C and E	Natural vitamins	10-50	Medium
Health foods	Supplements	10-20	Medium to large
Polysaccharides	Viscofers, gums Ion exchangers	5-10	Medium to large
Bivalve feeds	Aquaculture	20-100 1-10	Small Large
Soil inocula	Conditioner, Fertilisers	> 100	Unknown Unknown
Amino acids	Proline, Arginine Aspartate	5-50 5-50	Small Small
Single cell Protein	Animal feeds	0.3-0.5	Large
Vegetable oils	Foods Feeds	0.3-0.6	Large
Marine oils	Supplements	1-30	Small
Waste treatment	Municipal, Industrial	1	perkg algae Large
Methane, H_2, liquid fuels	General uses	0.1-0.2	Large

* Market sizes ($ million): Small <$10; Medium $10-100; Large >$100.

7.10 HARMFUL EFFECTS OF ALGAE

Some important algae which impart odour and taste to water:

Microcystis
Anacystis
Chlamydomonas
Ceratium
Synedra
Synura.

From the previous sections you have become aware of several uses of algae. In this last section we want to draw your attention to the adverse effects of algae. You know that rapid growth of algae in water reservoirs (algal blooms) leads to eutrophication. The water reservoir is no more suitable for recreational – swimming, boating or fishing activities. During cloudy weather algae deplete oxygen of the water and suffocate the fish and other aquatic animals. Fish also die because they get choked in mouth and gills when entangled in large masses of algal filaments.

Sometimes, you may have experienced strange odour and taste in your drinkinng water supply. This could be due to certain algae which impart grassy, fishy, musty or some other odour, and sweet or bitter taste to the water. The odour and taste are because of metabolic and/or decomposition products of algae. Only a few cells of alga (of Division Chrysophyta) are sufficient to give bad taste and foul smell to water. Similarly, if *Synura*, diatoms or blue-green algae get into the filters of water supply, the filters get clogged and serious economic losses occur.

Some algae produce toxins which enter humans and animals directly or through food chains. For example, a person can get poisoned on consumption of oysters or fish that feed on toxic dinoflagellates. This algal toxin inhibits nerve transmission and thus results in paralysis and even may cause death.

Ingestion of toxic algae with drinking water or during swimming may cause gastric problems, skin infections or respiratory disorders. The alga *Prototheca* causes disease, protothecosis which manifests in the form of skin lesions, inflamination around joints and defective leucocytes in humans. Persons working with diatomaceous earth suffer from algal silicosis. Arsenic poisoning is caused by the excessive consumption of seaweed. Affected persons suffer from skin rashes, blistering and inflammation. Fresh water blue-green algae produce alkaloids which are neurotoxins.

In Table 7.6 we have listed some medical problems and the causative algae for reference.

Some algae mostly belonging to genera *Chlorella* and *Zoochlorella* and some others are parasitic to aquatic invertebrates such as *Hydra*,snails, sponges and mussels.

Algae are responsible for some plant diseases also. For example the green alga *Cephaleuros* causes red rust of tea resulting in reduced yields.

Table 7.6: Some Medical Problems and Causative Algae

Medical problem	Causative Algae
Dermatitis (skin inflammation)	*Lyngbya mjuscula* *Chlorella*
Gastric problem	*Anabaena* *Oscillatoria*
Respiratory disorders	*Chlorella* *Oscillatoria* *Anabaena* *Gymnodinium spp.*
Neurological disorders	*Pyrodinium, Protogonyaulax*
Algal silicosis	Diatomaceous earth
Arsenic poisoning	Excessive consumption of seaweed
Allergens	*Lyngbya major* *Chlorella* *Oscillatoria* *Anabaena*

Control of Algal Nuisance

Chemical and biological methods can be used to control undesirable growth of algae. Several algicides are known such as copper sulphate, quinones, phenols and others that selectively kill algae. Algal growth can also be controlled by introducing suitable crustaceans or fish fingerlings in the affected reservoir. Certain viruses which kill blue-green and green algae are also useful for control.

SAQ 7.6

a) In the following statement fill in the blank spaces with appropriate words.

i) Alginates are present in the .... of seaweed. They are extracted by using .... because sodium alginate is soluble in water.

ii) The colloids present in seaweed are called ....

iii) Alginates are used for making .... proof fabric and .... articles.

iv) Alginic acid is highly .... therefore it is used in surgical operations to stop .... effectively.

v) Agar is used as .... medium for micro-organisms.

vi) The cell wall of diatoms is rigid because it is ....

vii) Diatomite is used as abrasive in .... and polishing powders.

viii) β-carotene is identified for having .... properties.

ix) *Gelidiella acerosa* is the principle .... yielding alga in India.

x) Irish moss is the main source of ....

b) List medicinal uses of algae.

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c) List the negative effects of algae.

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7.11 SUMMARY

In this unit you have learnt that:

- Algae are important and potential source of food and fodder, biofertilisers, energy and various medicinal and industrial products.

- Microalgae and seaweed are nutritionally rich. The commonly edible species are *Porphyra, Ulva, Chondrus, Palmaria, Gracilaria, Gelidiella, Caulerpa, Laminaria, Spirulina* and *Chlorella*. Some of these are cultured commercially on mass scale.

- Algae are used as fodder for cattle and as feed for poultry, fish, oyster, molluscs and caterpillars of silkworms.

- Microalgae *Spirulina, Chlorella, Scenedesmus, Oscillatoria* are used for the treatment of waste water.

- Blue-green algae enrich the soil with nitrogen, and seaweed with potassium and soil binding polysaccharides.

- The possibility of the production of H_2O, NH_3 and hydrocarbons by algae is being explored. The algal biomass is used for the production of biogas.

- Several compounds such as alginic acid, carrageenan, agar, diatomite amd pigments are extracted from algae. They have various applications.

- Algae are also used for medicinal purposes.

- Algae are a great nuisance also because they dominate our water resources and often affect aquatic animals adversely. They foul our drinking water supply and may cause epidemics.

7.12 TERMINAL QUESTIONS

1. List various uses of algae.

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2. List three major edible algae popular in maritime countries. How are they consumed?

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3. What are the advantages of using algae as biofertilisers?

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4. List four uses of alginic acid.

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7.13 ANSWERS

Self-assessment Questions

7.1 a) i) proteins, vitamins, minerals, iodine

ii) 65

iii) brackish, open

iv) *Chlorella,* cure-all

v) waste

vi) *Porphyra*

vii) essential

b) i) *Spirulina*

ii) *Chlorella*

iii) *Porphyra.*

7.2 i) F, ii) T, iii) T, iv) T.

7.3 a) i) oxygen

ii) oxygen

iii) water-born diseases

iv) cattle

v) biogas

7.4 a) i) *Anabaena - Azolla*

ii) *Nostoc/Anabaena,* also see the list given in the margin

iii) *Turbinaria*

iv) Seaweed

v) Blue-green algae.

7.5 i) T, ii) T, iii) F, iv) T.

7.6 a) i) cells wall, NaOH

ii) phycocolloids

iii) flame, plastic

iv) absorbant, bleeding

v) culture

vi) silicified

vii) scouring

viii) anticancer

ix) agar

x) carrageenan.

b) i) Vermifuge, ii) antibiotic, iii) cough remedy, iv) wound healing,

vi) heart diseases, vi) hypertension, vii) gall stone,
viii) bowel movement, ix) skin diseases, x) goitre,
xi) anticoagulant and xii) binding agent for medicinal tablets.

c) Elaborate the following points:

i) Colonisation of water bodies

ii) Change in the odour and taste of drinking water

iii) Diseases due to intake of toxic algae

iv) How algal toxins move into human and other animals

v) Parasitic algae

vi) Plant diseases.

Terminal Questions

1. Hint: See the headlines of various sections and subsections.

2. Refer to section 7.2. The most important are - *Chlorella, Porphyra, Ulva* or *Spirulina*. You may mention some other algae familiar to you.

3. Refer to section 7.5

   Hint: i) Enrich soil with nitrogen and potassium (blue-green algae and seaweed)

   ii) Soil reclamation (blue-green algae).

4. Refer to subsection 7.7.1.

GLOSSARY

Acronematic : flagella with slender and smooth surface and ending in thin hair.

Agar : a gelatinous substance derived from certain red algae that is used in preparing solid media for growing cells, tissues, or micro-organisms under sterile conditions.

Akinete : a vegetative cell that becomes converted into thick-walled non-motile resting spore; wall of the cell becomes wall of spore.

Algin : a polysaccharide present in the intercelluar spaces of some members of Phaeophyta made of d-mannuronic and L - guluronic acids.

Alginate : general term for salts of alginic acid.

Allophycocyanin : photosynthetically active biliprotein pigment of Division Cyanophyta, Rhodophyta and Cryptophyta blue in colour,

Antheridium : sex organ that produces male gametes, consisting of single cell in algae and fungi and many cells with a sterile jacket in bryophytes and vascular plants.

Antherozoid : motile (flagellated) male gamete.

Aplanospore : a non-flagellated spore in which spore wall is not derived from wall of its parent cell.

Benthic : living on or attached to the bottom substrates in aquatic ecosystem, especially marine environment.

Bloom : a dense growth of microscopic algae producing a noticeable discolouration of the water.

Calcareous : algae impregnated with lime.

Carboxysome : polygonal granule composed of ribulose bisphosphate carboxylase enzyme, generally observed in cyanobacteria.

Carrageenan : a mucopolysaccharide in the wall of some red algae, sulphated polymer of galactose.

Carpogonium : a cell containing the egg in red algae (equivalent to an oogonium).

Chemotaxis : motile response of a cell to chemical stimulus.

Chromatophore : plastid containing chlorophyll *a* and other pigments but not chlorophyll *b*.

Chromatoplasm : the area in the cytoplasm containing chromatophore.

Chrysolaminarin : a reserve polysaccharide composed of β-1, 3 - linked polymer of glucose.

Clone : a population of genetically identical cells, produced by asexual reproduction.

Coccolith : a body composed of calcified scale, made up of calcium carbonate in algal organisms called prymnesiophytes (relatives of the golden- brown algae)

Coenobium : a colony of algal cells in which the number of cells is fixed at the time of formation and no further addition of cells occurs; usually the cells are also in a distinctive arrangement.

Coenocyte : a multinucleate cell.

Conceptacle : a cavity containing reproductive structures (in *Fucus*).

Coralline : frequently used to refer to calcareous algae.

Cyanophycean granules : proteinaceous food reserve occurring in granular form in cells of blue- green algae.

Cyanelle : an endosymbiotic cyanobacterium functioning as a chloroplast in a eukaryotic cell.

Diatomaceous earth : deposits composed largely of walls of fossil diatoms.

Dichotomously branched : repeated bifurcating pattern of branching.

Diplobiontic : having two free living morphological phases (gametophytic and sporophytic) in an alternation of generations.

Diplont : vegetative body is diploid, haploid phase is represented by gametes.

Encrusting : growing appressed to the substrate.

Endophyte : an alga growing inside another alga or plant.

Endosymbiont : a symbiont living within the cells of its host.

Endozoic : living within tissues of animal but not necessarily parasitic.

Epiphyte : an alga or a plant growing on other alga or plant.

Epizoic : growing attached to outer surface of animals.

Eyespot : red-coloured spot (stigma) sensitive to light.

Frond : leaf of a fern, also used for large algal thallus that appears like leaf of a fern.

Fucoidin: a derivative of carbohydrate.

Fucoxanthin: a kind of carotenoid present in some algae

Gamone: chemical involved in affecting sexual union.

Gonidia: asexual reproductive cells in *Volvox* which produce daughter colonies.

Glaucophyte: a eukaryotic cell containing endosymbiotic cyanobacteria (cyanelle).

Hair: elongate, non-pigmented cell or cells often tapering to a point.

Haplobiontic : having only one vegetative phase (either haploid or diploid).

Haplont: vegetative body of the alga is haploid, diploid phase is represented by zygote only.

Hemicellulose : a complex polysaccharide component of plant cell walls.

Heterocyst : a highly differentiated cell in some filamentous blue-green algae that is a site of nitrogen fixation.

Heteromorphic generation : vegetative phases in alternation of generations which are distinctly different in form.

Heterothallic : of the sexual reproduction of certain algae and fungi in which reproduction can only take place between two genetically different thalli, they are either male (+) or female (–).

Heterotrichous habit : a filamentous thallus showing differentiation into prostrate branches (growing on the substrate) and erect branches.

Holdfast : a modified basal region of the body of an organism for attachment to the substrate, may be multicellular or unicellular.

Homothallic : the sexual reproduction of certain algae and fungi in which a single thallus produces different mating types on the same thallus to perform the sexual functions so that the species is, in effect hermophrodite. Also called monoecious.

Intertidal region : part of a shore exposed to the air during low-tide and submerged during high tide.

Isogamy : sexual fusion between flagellated gametes which are morphologically similar, usually of same size.

Isomorphic generation : vegetative phases in alternation of generations which are similar in morphology.

Kelp: the common name for any of the large brown algae.

Laminarin : a reserve polysaccharide found in brown algae composed of β-1, 3-linked polymers of glucose.

Leucosin (Chrysolaminarin) : a reserve polysaccharide composed of β-1, 3-linked polymers of glucose.

Lichen : symbiotic association of a fungus and an alga.

Littoral : the zone of a fresh water environment between the water's edge and a depth of about six metres. Zone of sea coast between the high and low tides. A littoral species is the one which lives primarily in the littoral zone.

Mannan : polymer of mannose (a monosaccharide).

Mannitol : a sugar alcohol found in brown algae.

Mastigoneme : a stiff, tubular hair found on some flagellates.

Medulla : the inner layer of a multicellular thallus composed of non- pigmented cells which usually function in storage.

Mitospore : spore formed after mitosis; may be haploid or diploid.

Mucopeptides : compounds made of carbohydrates and amino acids; carbohydrates are N- acetyl glucosamine and N- acetyl muramic acid; amino acids are glutamic acid, alanine, glycine, aspartic acid, lysine and diaminopimelic acid.

Muramic acid : glucosamine derivative containing carboxyethyl group.

Oogamy : sexual fusion between a flagellated gamete (sperm, antherozoid) and a non-flagellated gamete (egg).

Ostiole : opening or pore of conceptacle.

Palmella Stage : temporarily non-motile sedentary stage in the life history of certain motile algae; cells remain passive and embedded in gelatinous matrix.

Paramylon : the polysaccharide storage product that occurs in euglenoids, made up of β-1,3-linked glucose units, and is similar to laminarin.

Paraphysis : sterile filament borne near reproductive structure; paraphysis is hair-like and may be branched or unbranched.

Parasexual : organism showing genetic recombination not involving regular alternation between karyogamy and meiosis.

Parietal : positioned against inner wall of cell.

Pelagic: in the open sea. Floating or partially submerged in waters beyond the continental shelf region, e.g. *Sargassum*.

Parthenogenesis : pertaining to mode of development in which female gamete germinates without undergoing fertilization.

Pectin : a cell wall polymer made of β-1,4 linked galacturonic acid residues with carboxyl groups esterified with methanol rhamnogalacturonan (rhamnose and galactose) and arabinogalactan (arabinose and galactose).

Pellicle : outer boundary membrane found in cells lacking cell wall; resembles but is not equivalent to firm cell wall.

Periplast : delicate protective covering of flagellates that lack cell wall.

Periphysis : sterile, branched or unbranched hair-like cells growing from conceptacle.

Phycobilin : water soluble pigment found in cyanobacteria, red algae and cryptomonads, covalently linked to a protein to form a phycobiliprotein : Phycocyanin (blue) Phycoerythrin (red).

Phycobilisome : granular structures on the outer surface of thylakoids of cyanobacteria and red algae composed of phycobiliproteins.

Phylogeny : evolutionary development of species.

Pit connection : cytoplasmic strand connecting two adjoining cells through pit in their respective cell walls, as in red algae.

Plasmogamy : fusion of cytoplasmic materials of two cells usually associated with fusion of nuclear materials as in the formation of zygote.

Plurilocular sporangia : multicellular reproductive structure formed in brown algae.

Polyphosphate granules : polymers of inorganic phosphate stored in algal cells, occur in granular form.

Pyrenoid: a distinct structure in chloroplasts composed of ribulose bisphosphate carboxylase, may be embedded in the chloroplast or protrudes from it, with starch accumulated on the surface.

Red Tide: a bloom and/or dense concentration of phytoplankton, usually dinoflagellates, yellow to red or brown in colour, often associated with toxins that can kill fish and can cause illness or death in humans.

Rubisco : ribulose 1, 6, bisphosphate carboxylase, the enzyme responsible for the fixation of carbon dioxide.

Seta :a rigid extension from a cell.

Spermatium : a non-motile male gamete of red algae.

Stellate : star shaped.

Statospore: a resistant stage, formed by the members of Chrysophyta which is surrounded by a siliceous wall.

Thalloid: plant or alga that is not differentiated into roots, stem and leaves.

Thallus : the body of an alga lacking true root, stem and leaves.

Trichoblast : a series of non-pigmented cells forming a tapering branch or hair in red algae.

Trichogyne : the extension of a carpogonium to which spermatia attach in red algae.

Trichome : in cyanobacteria a row of cells composing a filament, without a mucilaginous sheath.

Unilocular sporangia : a unicellular sporangium in which meiosis occurs, in brown algae.

Uniseriate : having cells arranged in a single row or series.

Upwelling : movement of deeper water, often rich in nutrient, to the surface.

Xylan : polymer of xylose (monosaccharide).

Zoospore : a flagellated spore (for asexual reproduction).

Zooxanthella : symbiotic dinoflagellate found in the cells of cnidarians and other invertebrates.

Zygospore : a thick-walled zygote.

UNIT 13 MORPHOLOGY AND ANATOMY OF BRYOPHYTES

Structure

13.1 INTRODUCTION

In Block IB you studied about algal habitats and morphology. You have learnt that algae are aquatic in habitat. In the course of evolution the first land plants appeared about 400 million years ago. It is presumed that they have evolved from green algae. In this unit we will discuss why algae are thought to be the ancestors of land plants.

Bryophytes are considered to be the first land plants among embryophytes. Exactly how this happened is not clear because the fossil records are not complete. When there was a shift from aquatic mode of life to land habit the species had to face many challenges. How could water and minerals be taken from the soil and transported to parts that are not in contact with soil? How could the soft bodies keep from drying out? To meet these challenges there was a need to develop certain structural modifications. The land plants belonging to various groups have continued to exist approximately from the Devonian period. This demonstrates that they are well adapted to their particular niche on land. It is the nature of these adaptations that is of interest to us in this unit.

In Block IA you have studied the classification of bryophytes into liverworts (Hepaticopsida), hornworts (Anthocerotopsida) and mosses (Bryopsida). In this unit we will deal with the characteristic features of each group and describe a few genera belonging to these groups. You will study how these genera differ from each other and also from the majority of flowering plants which are so commonly growing around you.

Objectives

After studying this unit, you should be able to :

- describe the general characteristics of bryophytes,
- give reasons why algae are considered to be ancestors of the first land plants,
- list the competitive advantages and challenges of terrestrial environment for plants,
- describe the adaptations acquired during move from water to land, and
- describe and compare the morphology and anatomy of the following representative genera belonging to various classes - *Riccia, Marchantia* and *Pellia* (Hepaticopsida), *Anthoceros* (Anthocerotopsida), *Sphagnum* and *Funaria* (Bryopsida).

Study Guide

Before studying this unit, read chapter 17, Plant Kingdom (Biology Class XI, Part II, 1990, NCERT).

13.2 GENERAL CHARACTERISTICS AND LIFE CYCLE

The Division Bryophyta includes the simplest and the most primitive members of land plants that lack roots, and do not have a vascular system. There are some mosses that have a primitive system of tubes that conduct-water and food. The water-conducting tubes are called **hydroids.** They have elongated, thick, dead cells and contain polyphenolic compounds. But they are not lignified like tracheids and vessels (ref. box item 2, Block 4, Unit 17, P 18). The food-conducting tubes are called **leptoids**, and they are connected through plasmodesmata.

A single plant is very small, hardly a few cm in size. It seldom grows large because of lack of supporting tissues. Thousands of tiny moss plants often grow together and give a thick, green carpet-like appearance. The morphology of some common bryophytes is given in Fig. 13.1. Have a good look at them. Can you recall seeing any in their natural habitats?

....

Bryophytes show two distinct and well defined phases of life cycle, sexual and asexual, which follow each other. The **gametophyte** is haploid and produces gametes. The **sporophyte** is diploid and produces spores. The haploid generation alternates with diploid generation (look at Fig. 4.15 and box item 1, Unit 4, to recall alternation of generations in algae). Both the gametophyte and sporophyte may be several centimetres in length but the gametophyte is the long-lived phase of life cycle. You may note that in other land plants the sporophyte is the dominant generation.

The gametophyte may be thalloid (Fig. 13.1 A, B and D) or has an axis differentiated into stem-like and leaf-like structures (Fig. 13.1 C, E and F) which lack xylem and phloem. You may note that these leaf-like structures are part of gametophyte, whereas in vascular plants the leaves strictly develop on sporophyte. The gametophyte is green, photosynthetic and nutritionally independent, and anchors to the soil by unicellular or multicellular filaments called **rhizoids**. Rhizoids appear like roots but unlike roots they lack vascular tissues and are much simpler in structure.

Now try to list a few points that distinguish bryophytes from algae.

Let us begin

1. All bryophytes are multicellular plants.
2. ....
3. ....
4. ....
5. ....
6. ....

Bryophytes are most abundant in moist tropical areas. But they also grow in deserts, mountains and are observed in parts of Antarctica. In dry areas their growth and activity is restricted to wet seasons only. Some mosses grow in fresh water streams but they are not found in sea flora.

Life cycle

We are illustrating here the life cycle of bryophytes taking *Funaria* as an example. The gametophyte of *Funaria* (Fig. 13.2 A) bears two types of specialised multicellular reproductive organs (Fig.13.2 B and C) called the **gametangia** (gamete holders) which protect egg and sperm during the development.

The male gametangia, called **antheridia** (sing, antheridium, Fig. 13.2 B), produce sperms. The female gametangia, called **archegonia** (sing, archegonium, Fig. 13.2 C), produce eggs. The gametangia have outer **sterile layer of cells** forming a protective jacket.

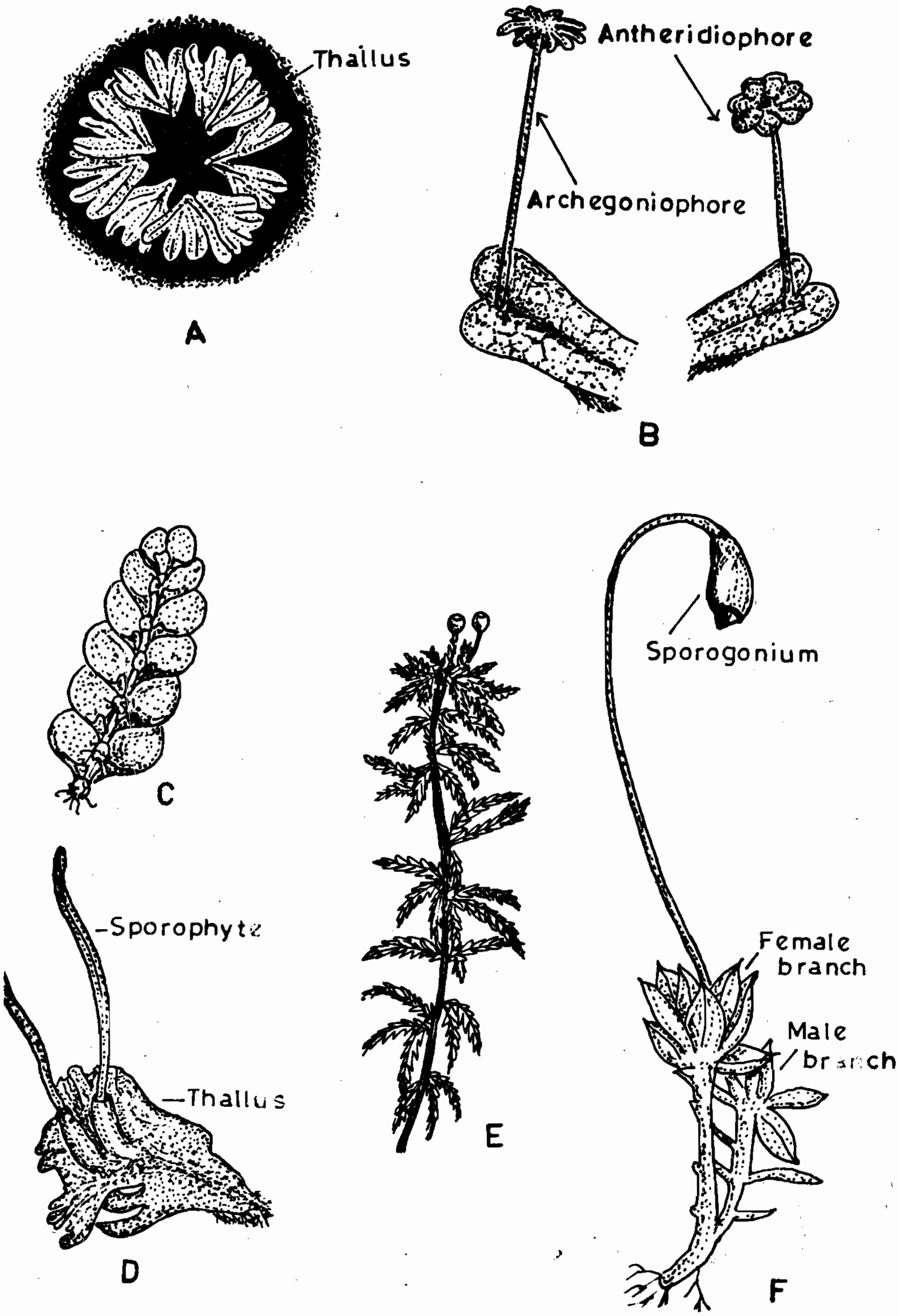


Fig. 13.1 : Morphology of bryophytes : A and B) thalloid liverworts - *Riccia and Marchantia,* C) a leafy liverwort - *Porella,*, D) a hornwort - *Anthoceros,* E and F) mosses - *Sphagnum* and *Funaria.*

Can you recall whether the gametangia in algae also have an outer protective sterile jacket of cells?

....

Bryophytes are oogamous i.e. the egg is larger, nonflagellated and non-motile, and the sperm is smaller and motile.

What types of sexual reproduction occurs in algae?

....

You may recall that besides oogamy some algae show isogamy and anisogamy.

After fertilisation (Fig. 13.2 D), the sporophyte starts developing inside the archegonium (Fig. 13.2 E). It may grow several centimetres in length, become photosynthetically sufficient but it draws minerals and water from gametophyte. However, in contrast to the sporophyte of all other land plants it never becomes independent of gametophyte. It remains permanently attached to it, until maturity and senescence. It is wholly or partially dependent on it for nutrition. Mature sporophyte is differentiated into a haustorial foot, a stem-like **seta** and a terminal spore producing **capsule** (Fig. 13.2 F). In *Riccia* both foot and seta are absent, while in others like *Sphagnum* seta is absent. Within the capsule spores are produced by reduction division of **spore mother cells.**

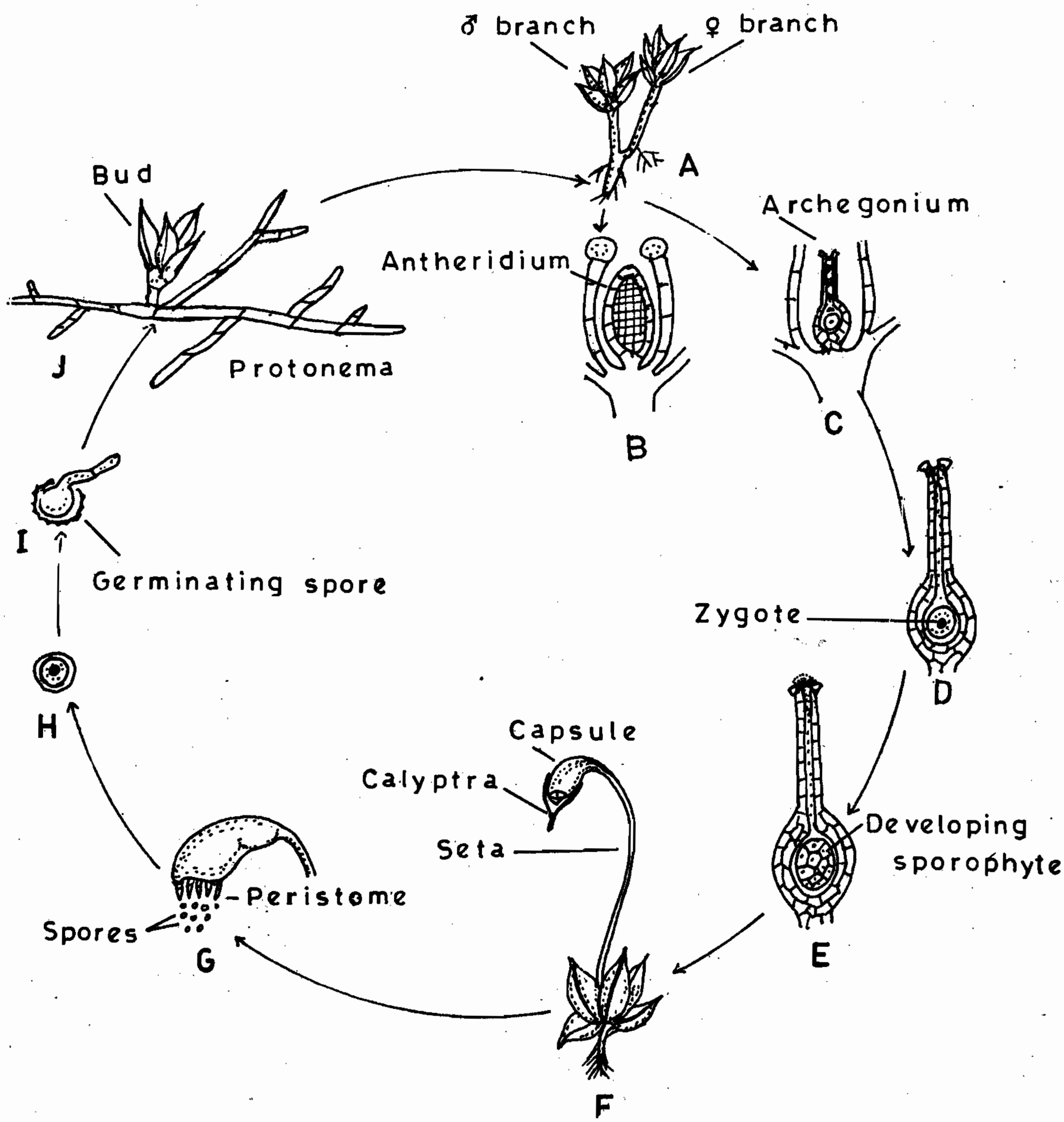


Fig. 13.2: Life cycle of bryophytes : A) a moss plant, B) enlarged antheridium, C) enlarged archegonium, D) formation of zygote in the archegonium, E) developing sporophyte, F) sporophyte growing on gametophyte, G) a capsule, H) a spore, I) germinating spore, J) growing protonema.

The bryophytes are homosporous i.e. spores of any given species are all alike. While some pteridophytes are heterosporous (they produce two types of spores - microspores and megaspores). In the next Block on pteridophytes, in Unit 18, you will learn about evolution of heterospory and seed habit.

A spore represents the first stage of gametophytic generation (Fig. 13.2 H). It is unicellular, haploid and germinates (Fig. 13.2 H,I) to produce a short-lived green **protonema** (Fig. 13.2 J).

The adult gametophore develops on this protonema. Protonema may be thalloid, globular or filamentous. The protonema and the adult gametophore are strikingly different from each other.

An adult gametophyte bears gametangia which produce haploid male and female gametes. The gametes represent the last stage of gametophytic generation and the zygote represents the first stage of sporophytic generation,whereas the spore mother cells (diploid) represent the last. The spore mother cells undergo reduction division to form haploid spores. So, any stage in the life cycle which is haploid, belongs to gametophytic generation, whereas the diploid stages belong to sporophytic generation.

Now let us sum up the distinguishing features of bryophytes.

1. They lack vascular system. In some of the mosses a primitive conducting system is present that transports food and water.
2. The gametophyte is dominant generation and sporophyte remains attached to it. In other land plants the sporophyte is dominant and independent.

SAQ 13.1

a) In the following statements choose the alternative correct word given in the parentheses. In bryophytes

   (i) the dominant phase of life cycle is (gametophyte/sporophyte).

   (ii) (roots/rhizoids) anchor the plant to the soil.

   (iii) the protonema is (haploid/diploid).

   (iv) the sporophyte is (dependent/not dependent) on gametophyte.

b) Which of the following statements are **true** and which are **false** about bryophytes? Write **T** for true and **F** for false in the given boxes.

   i) Some mosses have hydroids and leptoids for the conduction of water and food, respectively. ☐

   ii) The gametophyte is an independent plant. ☐

   iii) They produce two types of spores. ☐

   iv) Protonema is the transitional stage between spore and adult gametophyte. ☐

13.3 ADAPTATIONS TO LAND HABIT

You have learnt that most algae are aquatic in habitat. Some algae have adapted to terrestrial mode of living. Let us now learn about bryophytes which are the most primitive of land plants. The move from water to land is not absolute because their male gametes are still motile and have to swim through a film of water to fertilize the eggs. Hence, in this aspect they are amphibians like those of the animal kingdom.

In Unit 2 (Block 1 A) you have learnt that some scientists believe that land plants might have originated from fresh water green algal ancestors of the group related to modern algae such as stoneworts and coleochaetes. Although there are no fossil records available to substantiate this belief, bryophytes share the following structural and biochemical characteristics with algae that support this view.

(i) The chloroplasts of bryophytes have chlorophylls and carotenoid pigments closely similar to that of green algae.

(ii) The food reserves of both the groups consist mainly of amylose and amylopectin.

(iii) They produce flagellated motile spermatozoids.

(iv) The flagella are of the whiplash type (i.e. they are naked structures; lateral appendages do not occur (see Unit 2, Block 1B, Fig. 2.6).

(v) Their cell wall contains pectin and cellulose.

(vi) The glycolytic pathway is quite similar in the two groups.

So, there are strong reasons to believe that green algae served as ancestors of bryophytes.

The move from water to land offers an organism some distinct competitive advantages as well as challanges. What could be the advantages of the terrestrial habitat over the aquatic? Some of the advantages are as follows:

i) greater availability of sunlight for photosynthesis,

ii) increased level of carbon dioxide, and

iii) decreased vulnerability to predation.

If some more points cross your mind, add to this list.

....

....

Can you now think what are the challenges of land environment? Try to list them below.

....

....

....

Compare your points with the following:

1. Plants on land are exposed to direct sunlight and air. Hence there is danger of drying out or desiccation because of evaporation. Gametes and zygotes are also susceptible to desiccation.

2. The aquatic plants are supported by the buoyancy of water, but on land, plants need some anchor to fix to the ground and also require support to stand erect.

3. Absorption of minerals and water, and their transportation to the parts which are not in contact with soil. In other words, land plants need supply lines for the distribution of water and nutrients.

4. Effective dispersal of spores at right time and at right place for the survival of progeny, with the help of hygroscopic structures like **elaters** and **peristome teeth.**

You may recall from Unit 2 that plants developed several adaptations that enabled them to survive on a terrestrial habitat. What are these adaptations? Write them down below.

....

....

....

The adaptations of land plants in general are epidermis with cuticle, stomata, vascular system, lignified thickening which provide support, sporopollenin, gametes protected by sterile layer of cells and the nourishment of embryo by the maternal tissues.

We will now discuss these adaptations in detail. Bryophytes are fixed to the soil by thread-like, small structures called rhizoids. They are unicellular and unbranched in liverworts but multicellular and branched in mossess. They fix the plant to the soil and absorb water and minerals from it. You will recall that aquatic algae are totally immersed in water and therefore do not face this problem. The development of conducting system was an early innovation during land adaptation. But the conducting system that developed in mosses is of very primitive type. Even this primitive type is present only in a few mosses like *Pogonatum* and *Polytrichum*. The hydroids transfer water from rhizoids to the leaves at the apex and the food conducting leptoids transport sucrose. In most other bryophytes external capillary system takes care of the distribution of water to all parts of the plant body.

As we have already mentioned, mosses are very small plants, most of them being only a few cm. in length. Can you think why is it so? It is because they possess only a primitive conducting system which cannot fulfil the need of taller plants.

Now, let us see what type of structural modifications developed to overcome the problem of desiccation and aeration of the internal tissue. In all land plants the outer wall of epidermis is covered with a water proof waxy cuticle. This layer is important as it protects the moisture-laden internal cells from direct contact with the atmosphere and slows down the evaporation of water. Moreover, multicellularity offers an advantage as it leads to an increase in the volume-to-surface area ratio. In such a body the inner cells are not in direct contact with the atmosphere, so they are better protected against desiccation.

To ensure the aeration of the interior tissue, stomata developed which provided a direct connection between the air spaces in the interior tissue and the external atmosphere and also the route for the diffusion of gases such as CO_2 and O_2 in and out of the tissue. Stomata are one of the most primitive features of the land plants. They are present in the sporophytes of all bryophytes except liverworts.

So, epidermis, cuticle and multicellular plant body are adaptations to protect the vegetative body from desiccation. To protect the gametes, the sex organs in bryophytes - antheridium and archegonium are multicellular and each is covered with a sterile layer of cells which forms a jacket around the gametes. Fertilisation and subsequent development of embryo (embryogenesis) occurs within the archegonium. The retention of zygote within the archegonium is considered an adaptation for life under terrestrial conditions. The multicellular maternal tissue called calyptra protects the egg, zygote and the embryo against the unfavourable conditions of the external environment, especially against desiccation. Similarly, the jacket cells of the antheridium provide a more uniform environment for the development of the antherozoids and protect them until the conditions are suitable for their discharge.

The embryo ultimately develops into the sporophyte, which normally consists of foot, seta and capsule (sporangium). Although in primitive bryophytes like *Riccia* the sporophyte is represented just by a capsule. The capsule contains diploid spore mother cells which undergo meiosis to produce haploid spores. The sporangium is a multicellular structure and is considered as one of the basic organs of land plants.

The spores are protected within the capsule until they are ready for discharge. There was also the need to develop some mechanism, for the dispersal of spores. A mechanism where all the spores were not released at a time and did not fall at the same place so as to avoid competition and to ensure that at least a few of them survived for the continuity of generation.

Different genera of bryophytes possess some sort of special mechanism for the dispersal of spores. But there are a few genera for example *Riccia* which do not have any special mechanism. Since we will study representative genera of almost all classes of bryophytes, we will also consider how spore dispersal takes place in each of them.

SAQ 13.2

a) List the main challenges faced by plants when there was transition from aquatic to terrestrial mode of life.

....

....

....

....

b) In the following statements fill in the blanks with appropriate words.

i) The sex organs in bryophytes are multicellular and the gametes are protected by a.. of cells.

ii) The water conducting cells present in some mosses are called .... and the food conducting cells are known as ....

iii) Hydroids are functional counter part of ....but they are...

iv) The substance that provides resistance to a spore and delays degradation is called ....

13.4 MORPHOLOGY AND ANATOMY OF BRYOPHYTES

So far you have studied the general characteristics of bryophytes. You may recall from Unit 2 (Block 1A) that the Division Bryophyta is divided into three classes (a) Hepaticopsida (liverworts) (b) Anthocerotopsida (hornworts) and (c) Bryopsida (mosses). Let us now study the representative genera from each class.

13.4.1 Hepaticopsida

The gametophyte of liverworts usually lies close to the ground. There are two forms of liverworts. In some the gametophyte is dorsi-ventral, thalloid in form with obvious upper and lower surfaces. These are thalloid liverworts. While in others it is differentiated into leaf-like and stem-like structures like those of mosses. The latter are known as leafy liverworts. The leaves of leafy liverworts are without midrib, whereas midrib is present in the leaves of mosses. Internally, the gametophytes of liverworts may be homogenous or composed of different types of tissues. Liverworts grow on moist ground or rocks that are always wet. They can be found in muddy areas near streams. In greenhouses you may find them growing in flower pots.

The term moss is sometimes also used for other group of plants.e.g. reindeer moss is a lichen, spanish moss is an angiosperm and Irish moss is a red alga.

In this course you will study two representatives of the order Marchantiales (*Riccia* and *Marchantia*) and one of the order Jungermanniales (*Pellia*).

The gametophytes of Marchantiales are exclusively thalloid. The order Marchantiales consists of about 35 genera and approximately 420 species.

We will first study in detail the genus *Riccia* and then *Marchantia*.

Riccia

Riccia

Division - Bryophyta
Class - Hepaticopsida
Order - Marchantiales
Family - Ricciaceae

Riccia belongs to the family Ricciaceae which is the most primitive and the simplest family of the order Marchantiales. *Riccia* has more than 130 species and is very widely distributed. Most of the species are terrestrial and grow mainly on moist soil and rocks. *Riccia fluitans* is an aquatic species.

In structure *Riccia* represents the simplest of the bryophytes. Its gametophyte is small green fleshy, thalloid. It grows prostrate on the ground and branches freely by dichotomy. Several *Riccia* plants grow together and take the form of circular patches, which are typically resette-like (Fig. 13.3 A). The thallus bearing female and male sex organs are shown in Fig. 13.3 B and C.

Some of the common Indian species of *Riccia* are

Riccia discolor
R. gangetica
R. crystallina
R. frostii

The two former species are found from July to August i.e. in rainy season, whereas latter two grow during November-December.

The branches of the thallus are called thallus-lobes. According to the species, thallus lobes are linear to wedge-shaped. The dorsal surface of the thallus has a prominent midrib, represented by a shallow groove called the dorsal groove. At its apex there is a depression termed as apical-notch. The sporophytes are sunk deeply, in the dorsal groove, each in a separate cavity. Both male and female sex organs may develop on the same thallus (monoecious) or on different thalli (dioecious) (Fig. 13.3 B and C). On its ventral surface (Fig. 13.3 D) there are a number of slender, colourless, unicellular, unbranched processes called rhizoids that help to attach the thallus to the substratum. The rhizoids are of two types: (a) smooth walled - these have smooth walls (Fig. 13.3 E) and (b) tuberculate - these have peg-like ingrowths of wall projecting into the lumen (Fig. 13.3 F). On the ventral surface towards the apex and along the margins of thallus small plate like structures are also present (Fig. 13.3 D). These are scales which are arranged in a single row and are single cell in thickness. These scales project forward and overlap the growing point to protect it from desiccation. The growing point is located in the notch and consists of a transverse row of 3 to 5 cells. The growth of the thallus occurs in length as well as in width by the divisions of these cells. Each thallus branches dichotomously and several dichotomies lie close to one another forming a typical rosette.

Internal structure

If we cut a transverse vertical section of the thallus (Fig. 13.3 G, H) we will find that *Riccia* thallus shows two distinct zones corresponding to the two surfaces of the thallus. a) The upper, green, photosynthetic zone corresponding to the dorsal surface and (b) the lower, colourless storage zone, corresponding to the ventral surface. The upper photosynthetic zone consists of columns of chlorophyllous cells separated by the narrow air channels. Each column consists of 6-8 cells, the terminal cell of each column is bigger and does not contain chloroplasts.

In the top view of the thallus we would see only the terminal colourless cells and spaces i.e. the pores. In vertical cross section we would see only a few vertical columns of cells arranged in a row, but in fact, there are a number of such columns which could be seen only in three dimensional view. The air channels are enclosed by 4 or 8 vertical column of cells. The terminal end of a channel opens to the external atmosphere through a pore which is surrounded by 4 to 8 colourless epidermal cells (Fig. 13.3 I). Pores, though rudimentary, allow exchange of gases between internal and external environment.

The lower storage zone consists of compactly arranged colourless, parenchymatous cells. The lowermost layer of this zone bears rhizoids and scales. The rhizoids are colourless, unicellular extensions of some superficial cells of mid-rib. The scales are multicellular, but one cell in thickness. In xerophytic species scales are better developed, longer lived and contain anthocyanin.

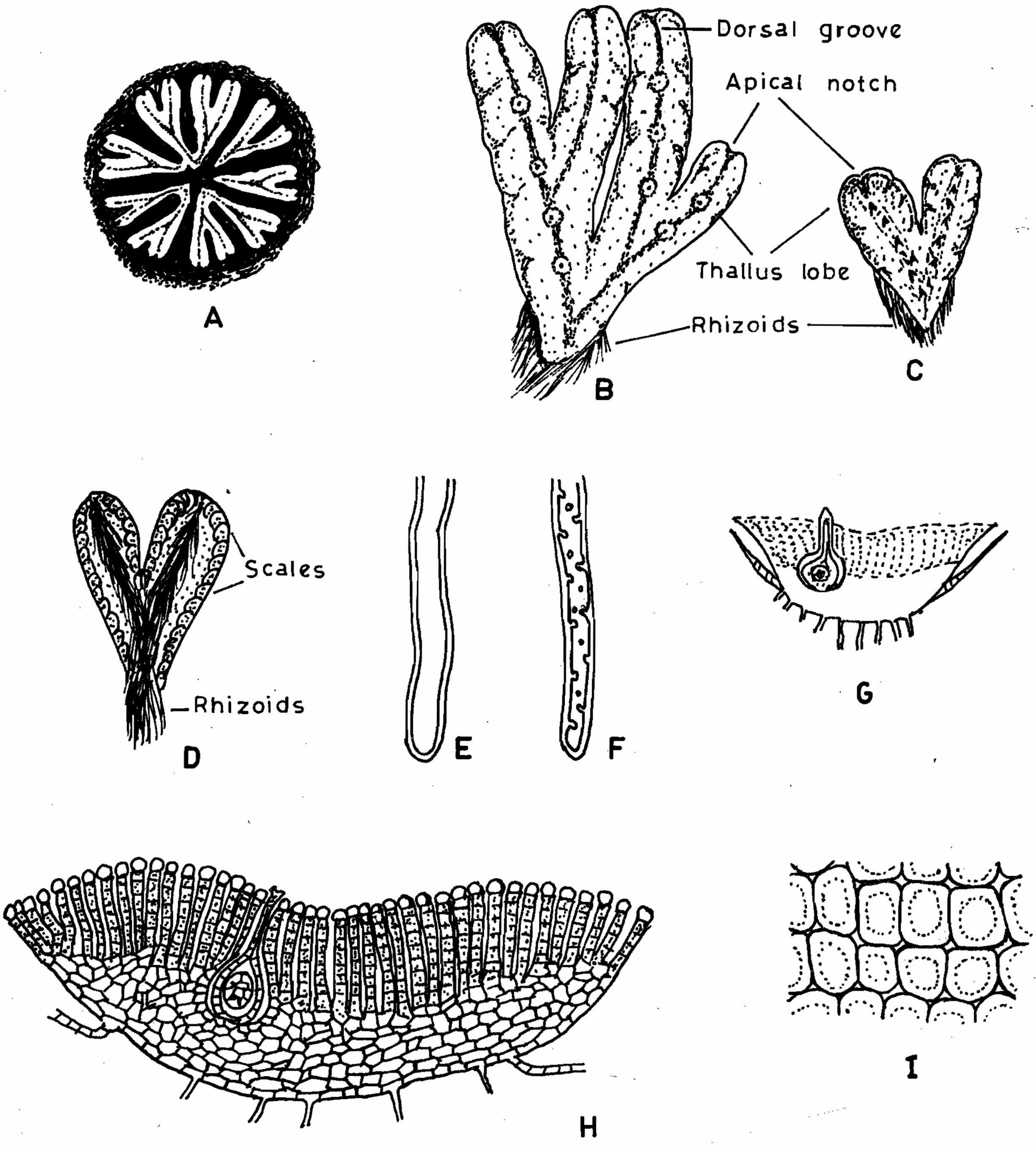


Fig. 13.3: Morphology and internal structure of *Riccia* : A) a rosette of *Riccia trichocarpa*, B) a female thallus of *R. discolor*, C) a male thallus of *R. discolor*, D) ventral surface of the thallus, E) a smooth walled rhizoid, F) a tuberculáte rhizoid, G) transverse vertical section of female thallus, H) G enlarged, I) epidermal cells in surface view from young portion of the thallus. Note that four cells enclose one air channel.

SAQ 13.3

In the following statements about *Riccia* fill in the blank spaces with appropriate words.

i) The gametophyte of *Riccia* grows in patches called ....

ii) The two types of rhizoids in *Riccia* are .... and ....

iii) Rhizoids are .... whereas scales are ....and arranged in single transverse row.

iv) Air-channels in the thallus communicate to the exterior by means of.........................

Marchantia

Division - Bryophyta
Class - Hepaticopsida
Order - Marchantiales
Family - Marchantiaceae

Marchantia

The family Marchantiaceae, to which *Marchantia* belongs, includes about 23 genera and approximately 200 species. The special feature of this family is that in all the genera the gametophyte bears archegonia on vertical stalked receptacles called archegoniophore

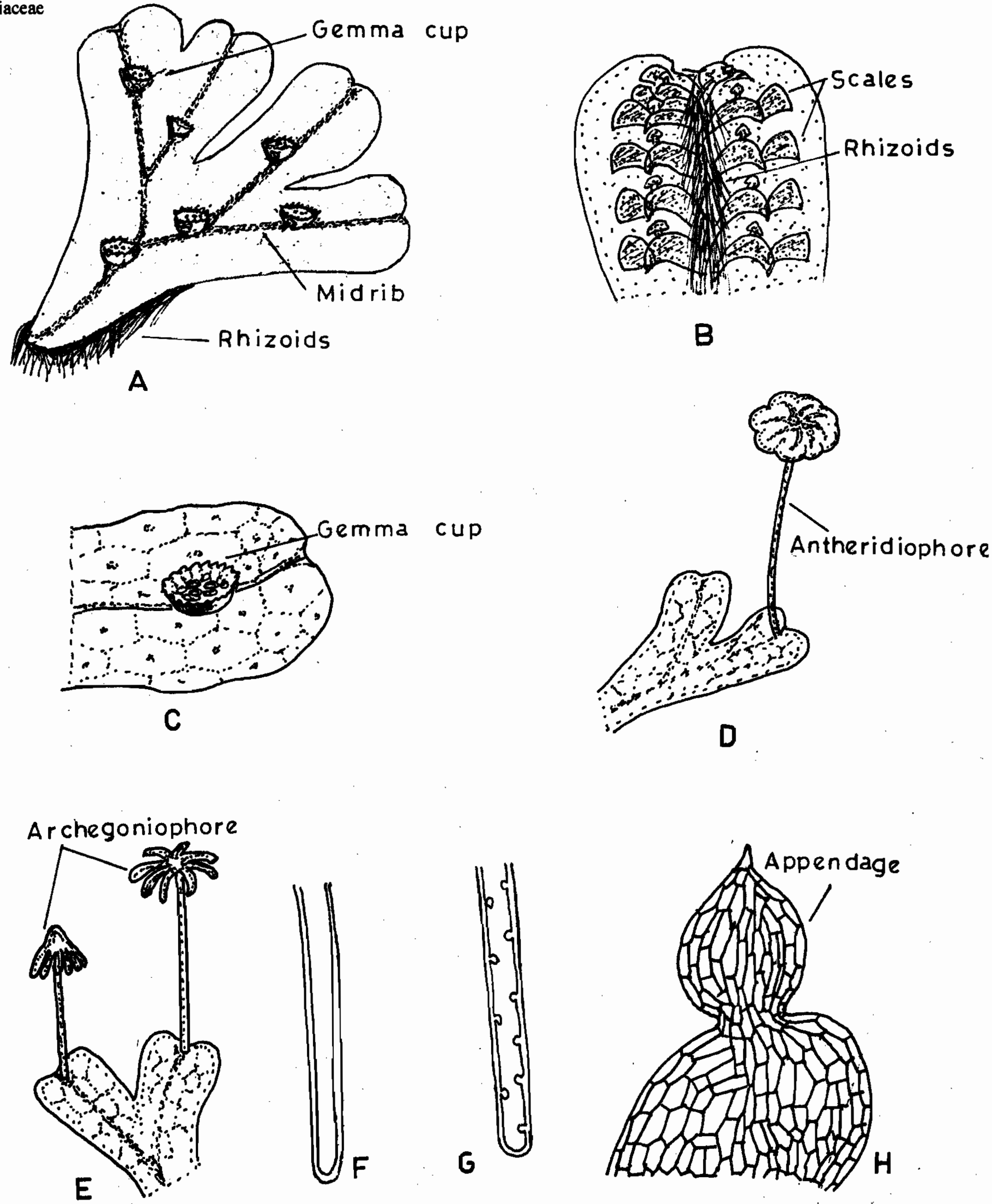


Fig. 13.4: A) Morphology of *Marchantia polymorpha*: A) thallus with gemma cups, B) ventral surface of the thallus, C) a portion of A enlarged, (note the hexagonal markings with a pore in the centre of each on the surface of the thallus), D) thallus with antheridiophore, E) thallus with archegoniophores, F) smooth walled rhizoids, G) tuberculate rhizoids, H) scale enlarged.

(carpocephala). In *Marchantia* antheridia are also produced in stalked receptacles known as antheridiophores. The type-genus *Marchantia* is placed among the most advanced members with about 65 species, of which *Marchantia polymorpha* is the most widely distributed.

In India there are about 11 species of *Marchantia* which grow mainly in Himalayas. The most commonly known are:

M. polymorpha
M. nepalensis
M. palmata (occurs in South India, Assam, Bengal and Punjab)

Marchantia usually grows in cool moist places along with mosses and in areas of burnt grounds. It is deep green in colour. Like *Riccia* its gametophyte is flat, prostrate, dorsi-ventral and dichotomously branched thallus (Fig. 13.4 A). There is a prominent midrib which is marked on the dorsal surface by a shallow groove and on the ventral surface by a low ridge covered with rhizoids (Fig. 13.4 B). Along the midrib there are a number of cup-like structures with frilled margins. These are called gemma cups (Fig. 13.4 C) which contain numerous vegetative reproductive bodies called gemmae (sing. gemma). In mature thalli antheridiophores and archegoniophores, which bear antheridia and archegonia (Fig. 13.4 D and E) respectively, are also present at the growing apices of certain branches. *Marchantia* is dioecious. Like *Riccia* the apex of each branch is notched and a growing point is situated in it. You will note that on dorsal surface the thallus is marked into hexagonal areas which are visible to the naked eye (Fig. 13.4 C). If we examine with a hand lens we can see a pore at the centre of each hexagon.

Like *Riccia* the thallus of *Marchantia* is anchored to the surface by rhizoids which are of smooth walled as well as tuberculate type (Fig. 13.4 F and G). Scales are also present on the ventral surface, but in *Marchantia* they are arranged on both side of the midrib (Fig. 13.4 B,H).

Internal structure

Look at Fig.13.5 A and B, showing the internal structure of the thallus. When examine under the light microscope, you will note a high degree of internal differentiation of tissues. The thallus is divided into two distinct zones :

a) The upper **photosynthetic zone** corresponding to the dorsal surface and

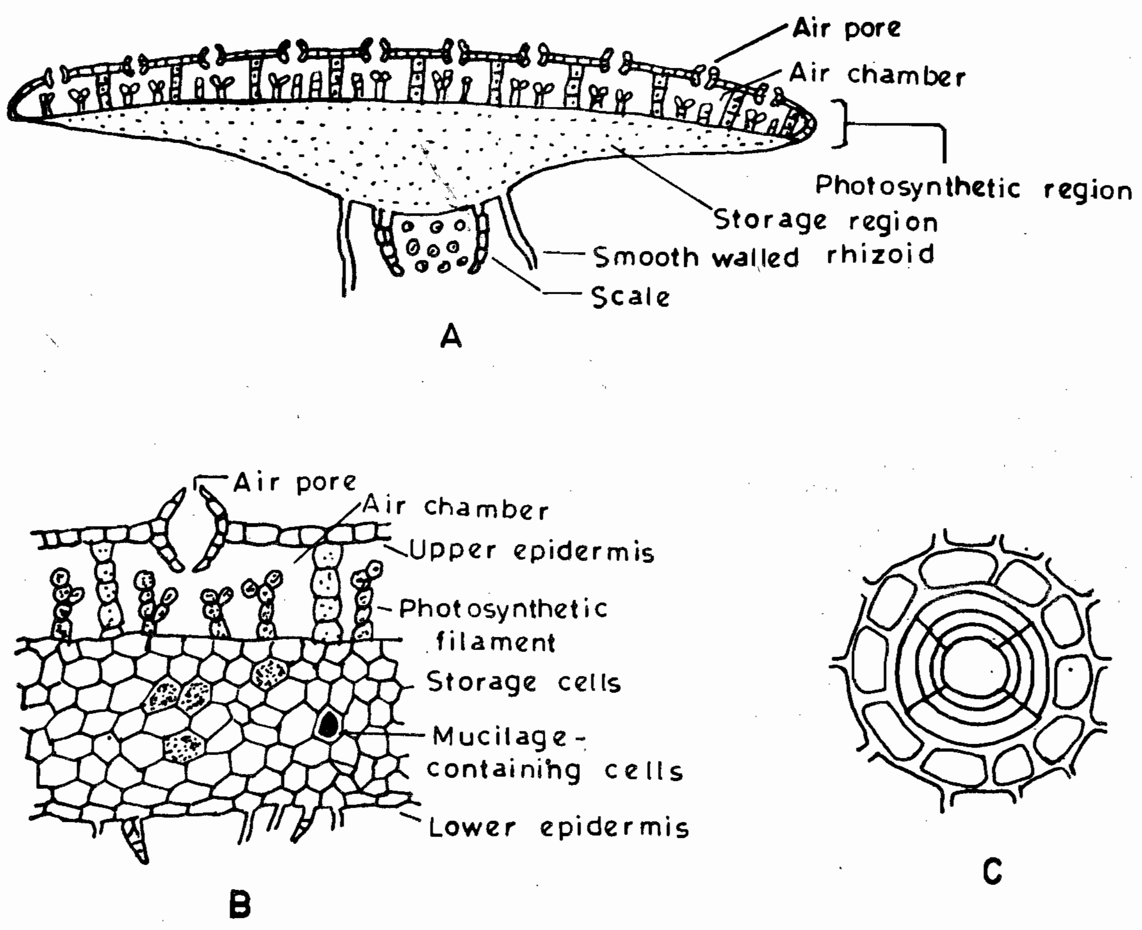


Fig. 13.5 : Internal structure of *Marchantia* : A) a vertical transverse section of a thallus, B) a portion of A - enlarged, C) a pore in the surface view.

b) the lower **storage zone** corresponding to the ventral surface.

The upper zone is covered by a single layer of thin walled cells which form the upper epidermis. These cells contain a few chloroplasts. This layer is interrupted by many barrel shaped pores (Fig. 13.5 A - C). Below the upper epidermis there are a number of air chambers in a single horizontal layer.

Do you find that pores are specailised in *Marchantia*?

....

Actually the pores are the opening of the air chambers. Compare these pores with that of *Riccia* (Fig. 13.3 I). What do you find? Are not the pores rudimentary in *Riccia*?

....

These air chambers are separated from one another by single layered partitions. The visible hexagonal markings seen on the dorsal surface are actually the outlines of these air chambers. Within each air chamber there are usually simple or branched photosynthetic filaments which arise from the base of the chamber (Fig. 13.5 A,B).

The ventral side of gametophyte is achlorophyllous, parenchymatous and several celled in thickness (Fig 13.5 B). A few cells of this region contain a single large oil body. Some cells are filled with mucilage. The lowermost layer forms a well defined lower epidermis. Two or more transverse rows of multicellular scales arise from it. You may recall that in *Riccia* there is a single row of scales along the margins. The scales protect the ventral surface and the growing regions. The smooth-walled and tuberculate rhizoids arise from the ventral surface between the scales.

SAQ 13.4

In the following statements about *Marchantia* fill in the blank spaces with appropriate words.

i) Marchantiaceae is characterised by the presence of .... female receptacles.

ii) The visible .... markings on the dorsal surface of the thallus are actually the outlines of .... below.

iii) ....filaments are at the base of each air chamber.

iv) A few cells on the ventral surface of the thallus are filled with .... or contain ....

Pellia

Pellia

Division - Bryophyta
Class - Hepaticopsida
Order - Jungermanniales
Sub-order - Metzgerineae
Family - Pelliaceae

Pellia belongs to the order Jungermanniales. This order is the largest of the Class Hepaticopsida and includes some 244 genera and 9000 species. The gametophytes of Jungermanniales may be a simple thallus or differentiated into stem-like and leaf-like structures. However, there is almost no internal differentiation of tissues.
Based upon the position of archegonia the Jungermanniales can be divided into two well defined groups (or sub orders) :

(a) In Jungermanniales Anacrogynae (also called as Metzgerineae) the archegonia are borne on the dorsal surface of prostrate thallus and the apical cells are not involved in the formation of archegonia. The sporophytes are dorsal in position.

(b) In Jungermanniales Acrogynae the archegonia are borne at the apex of the shoot and the apical cell participates in the formation of an archegonium. Further vegetative growth stops and the sporophytes are terminal in position.

Some common species of *Pellia* are

P. epiphylla,
P. endiviaefolia,
P. neesiana,

Pellia belongs to Family Pelliaceae (also called as *Haplolaenaceae*) of the Suborder Metzgerineae. *Pellia* usually grows in moist places especially by the side of ditches, streams or springs or even on moist rocks. The gametophyte is a thin, flat and dichotomously branched thallus and the margins of the thallus show several incisions (Fig. 13.6 A) so it appears irregular in outline. The middle portion of the thallus is thick, but the margins are very thin (Fig. 13.6 B). Like *Riccia* and *Marchantia* a growing point is situated at the anterior end in the notch. The ventral surface bears numerous unicellular rhizoids which are all smooth walled. Scales are absent.

Internal structure

Look at the internal structure of the thallus shown in Fig. 13.6 B, and try to describe it in a few lines. How is it different from the thallus of *Riccia* and *Marchantia*?

....

....

As you can see, internally the thallus is very simple and consists mainly of parenchymatous cells. The middle region of the thallus is very broad, 8 to 16 cells thick, but at the margins it is one celled thick. Cells of the wings and the upper layer of midrib contain abundant chloroplasts, whereas the lower cells of the midrib region contain a few or no chloroplasts. Starch grains are present in all the cells of the thallus. Some cells of the thallus also contain oil. Only smooth walled rhizoids are present.

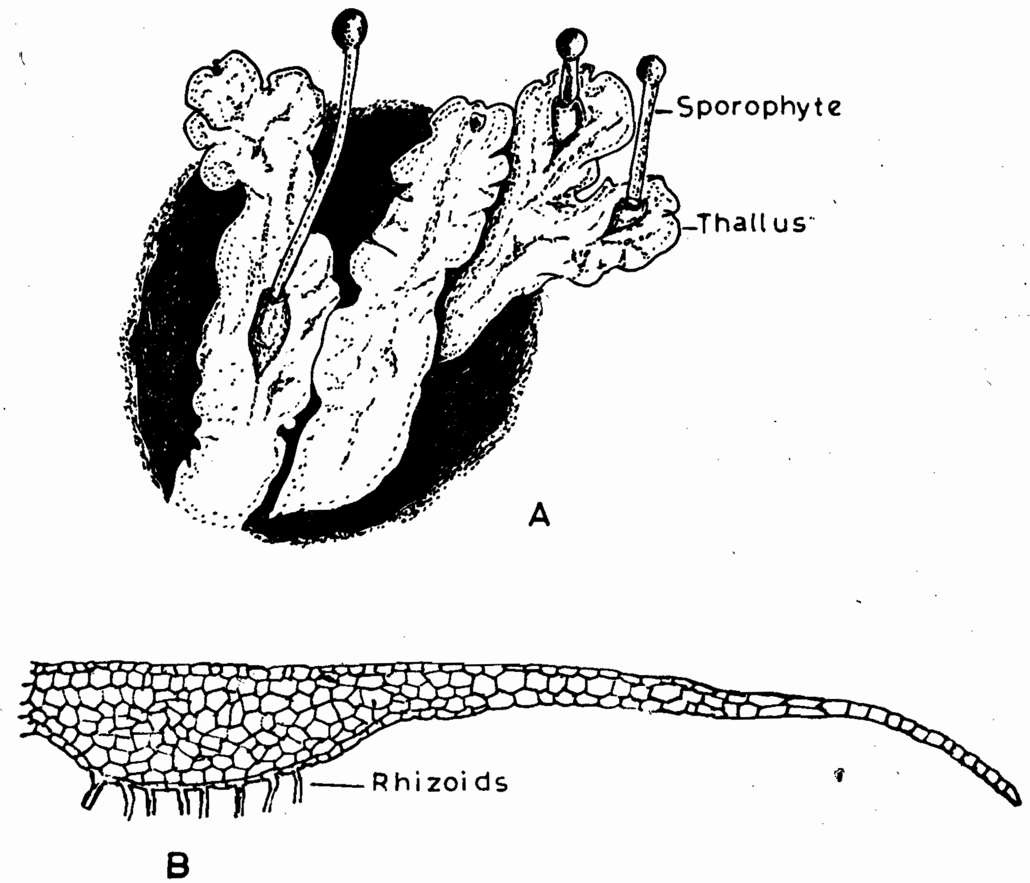


Fig. 13.6: *Pellia*: A) a mature gametophyte with attached sporophytes, B) transverse section of a thallus showing internal structure. Note that the thallus is many layered in the midrib region but single layered at margins.

SAQ 13.5

In the following statements choose the alternative correct word for *Pellia*.

i) It belongs to the order (Marchantiales/ Jungermanniales).

ii) There is (high degree of/no) differentiation in the gametophyte.

iii) (Smooth/Smooth and tuberculate) rhizoids are present.

iv) Starch grains are (absent/present) in all the cells of the thallus.

13.4.2 Anthocerotopsida

The class Anthocerotopsida contains the single order Anthocerotales. We will study *Anthoceros* as the representative of this class.

Anthoceros

Division - Bryophyta
Class - Anthocerotopsida
Order - Anthocerotales
Family - Anthocerotaceae

The genus *Anthoceros* has about 200 species. Some common Indian species are:

A. himalayensis, A. erectus, A. fusiformis, A. punctatus and A. laevis

Anthoceros

It grows principally in moist shady places on the sides of ditches, or in moist cracks of rocks. The gametophytes of *Anthoceros* are dorsi-ventral, thallose, somewhat lobed or dissected, and sometimes have a tendency toward dichotomous branching (Fig. 13.8 A).

The thallus of *Anthoceros* is dark green, velvety on the upper surface and variously lobed. Does it resemble *Pellia* in external morphology? Yes, except, that it is not regularly dichotomous. The midrib is either indistinct or absent. Like *Pellia,* it also lacks tuberculate rhizoids and scales. Only smooth walled rhizoids are present.

Internal Structure

Look at Fig. 13.7 B and note down the special features below.

....

....

The most noticeable feature is the presence of special mucilage cavities on the lower surface. These contain nitrogen fixing filamentous blue-green alga *Nostoc*. The cavities open to the outside through stomata-like pores termed as slime pore (13.7 C).

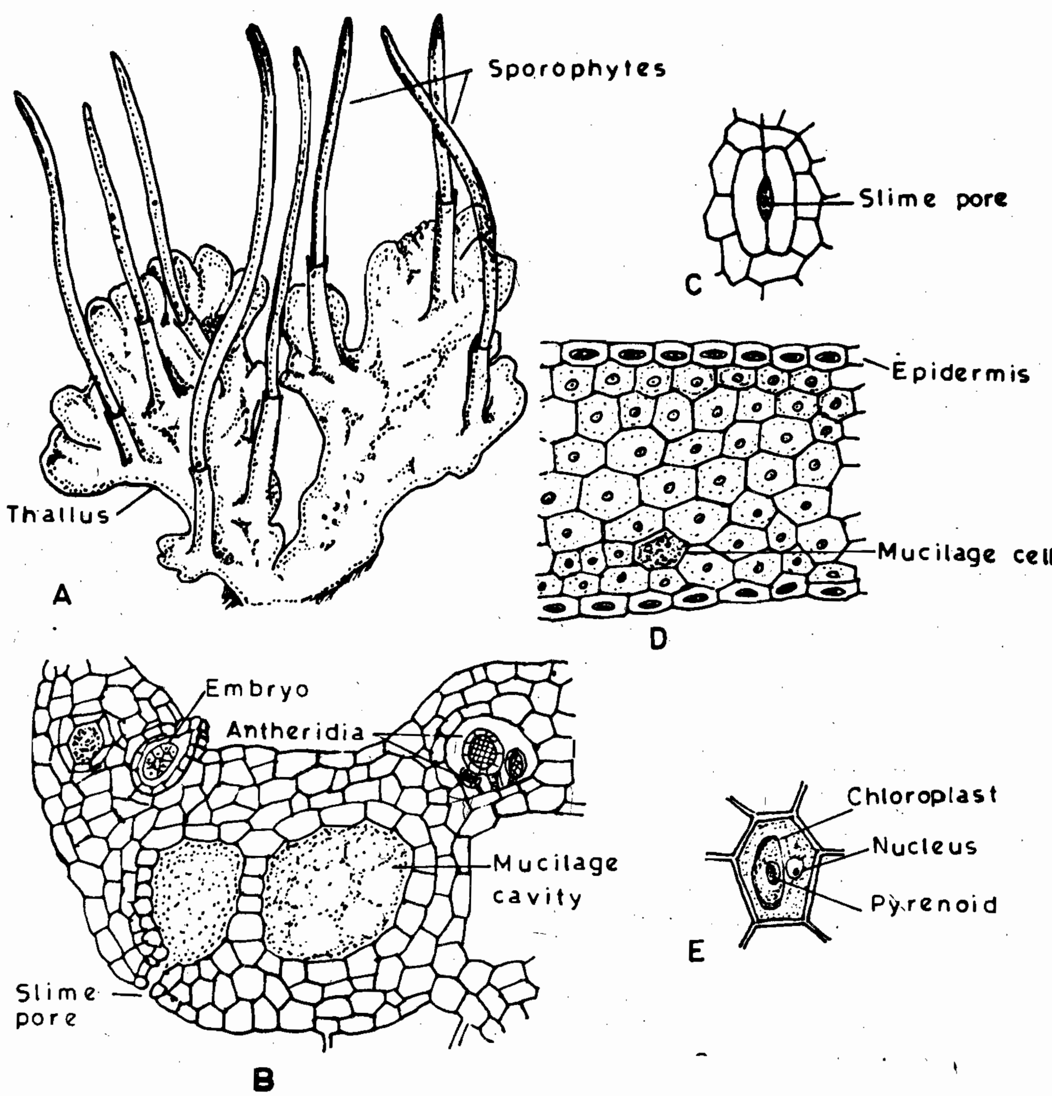


Fig. 13.7: ***Anthoceros*: A) mature thallose gametophyte with attached sporophytes. Note the sheath at the base of each sporophyte, B) portion of a vertical transverse section of thallus showing the enlarged mucilage cavities, antheridia and developing embryo, C) epidermal cells showing slime pore, D) a part of a section of thallus, E) a cell with a single large chloroplast and a single pyrenoid.**

What could be the significance of these pores?

....

Interestingly, you can see cavities even with a hand lens (Fig. 13.7 B).

Unlike *Marchantia*, in *Anthoceros* thallus there is no internal differentiation into photosynthetic and storage zone (Fig. 13.7 D). You can see that the entire thallus is uniformly made up of parenchymatous cells. The air chambers and air-pores are absent. In between the lower epidermal cells slime pores are present. Each cell of the thallus contains a single chloroplast, with a large pyrenoid (Fig. 13.7 E), a situation unknown elsewhere in the bryophytes or in higher plants, except in some species of *Selaginella*. Can you recall where you learnt about pyrenoids before?

....

Well, they are commonly found in algae. Does not this fact suggest that the family Anthocerotaceae is closer to an algal ancestor than are other bryophytes?

SAQ 13.6

Fill in the blank spaces with appropriate words.

i) In *Anthoceros*............................ rhizoids and ....are absent.

ii) Nitrogen fixation occurs in the thallus of *Anthoceros* because the filaments of .... are present in the mucilage cavities.

iii) The chloroplasts in *Anthoceros* resemble algae because they have ....

iv) The *Anthoceros* thallus is not differentiated into .... and .... zone.

13.4.3 Bryopsida

This is the largest class of bryophytes and includes about 660 genera and 14,500 species. Bryopsida is divided into three subclasses: Sphagnidae (peat mosses), Andreaeidae (rock mosses) and Bryidae (true mosses). Bryidae include about 14,000 species. You will study the genus *Funaria* as a representative of this order. Order Sphagnales is represented by a single genus *Sphagnum* which includes about 300 species. Let us first study *Sphagnum*.

Sphagnum

Sphagnum is confined to acidic, water-logged habitat. It is the principal component of peat bogs where it forms a more or less continuous spongy layer.

Sphagnum

Division - Bryophyta
Class - Bryopsida
Order - Sphagnales
Family - Sphagnaceae

The adult gametophyte develops as an upright leafy-shoot, called **gametophore** from a simple thallose, one cell thick protonema. The gametophore is differentiated into stem and leaves. The terminal growth of the stem is due to an apical cell. The axis is attached to the soil by means of multicellular, branched rhizoids with oblique cross walls. Rhizoids are present only in young gametophore and disappear when it matures. Afterwards, the gametophore absorbs water directly.

Look at Fig. 13.8 A, the mature gametophore consists of an upright stem bearing leaves. Every fourth leaf of the stem bears a group of three to eight lateral branches in its axil. These branches are of two types: (i) divergent and (ii) drooping lying next to the stem (Fig. 13.8 B). Sometimes, one of the branches in a tuft continues upward growth to the same height as the main axis and resembles it in structure. These strongly developed branches are called **innovations** and they ultimately get detached and become independent plants. The branches near the apex of a stem are short and densely crowded in a compact head called **coma**.

Sphagnum forms peat bogs in northern parts of the world. In some countries peat is burnt as fuel. *Sphagnum* is also used in plant nurseries as packing material. Mats of this moss hold moisture and help the seeds of other plants to germinate and grow.

The leaves lack midrib (Fig. 13.8 C and D). They are small and arranged in three vertical rows on the stem. In the surface view of a leaf one can observe two types of cells :
(i) narrow, living, chlorophyll containing cells and (ii) large dead, empty, rhomboidal, hyaline (glass-like, transparent) cells with pores and spiral as well as annular wall thickenings (Fig. 13.8 E). In transverse section, leaf shows beaded appearance, with large, dead hyaline cells regularly alternating with the small, green, chlorophyllous cells (Fig. 13.8 F). The spiral thickenings provide mechanical support and keep the hyaline cells from collapsing when they are empty.

The pores help in rapid intake of water and also in exchange of cations for H^+ ions which are the metabolic products of *Sphagnum*. Hence, they create acidic environment in their immediate surrounding. The hyaline cells take up and hold large quantities of water, sometimes as much as twenty times the weight of the plant. The narrow chloroplast containing cells carry on photosynthesis. In a mature leaf these two types of cells are arranged in a reticulate manner. This peculiar leaf structure accounts for the ability of the *Sphagnum* plant to absorb and retain large quantities of water and consequently for its outstanding bog-building properties. Because of their water absorbing quality they are used in gardening. You will learn more about its uses in unit 15 of this Block.

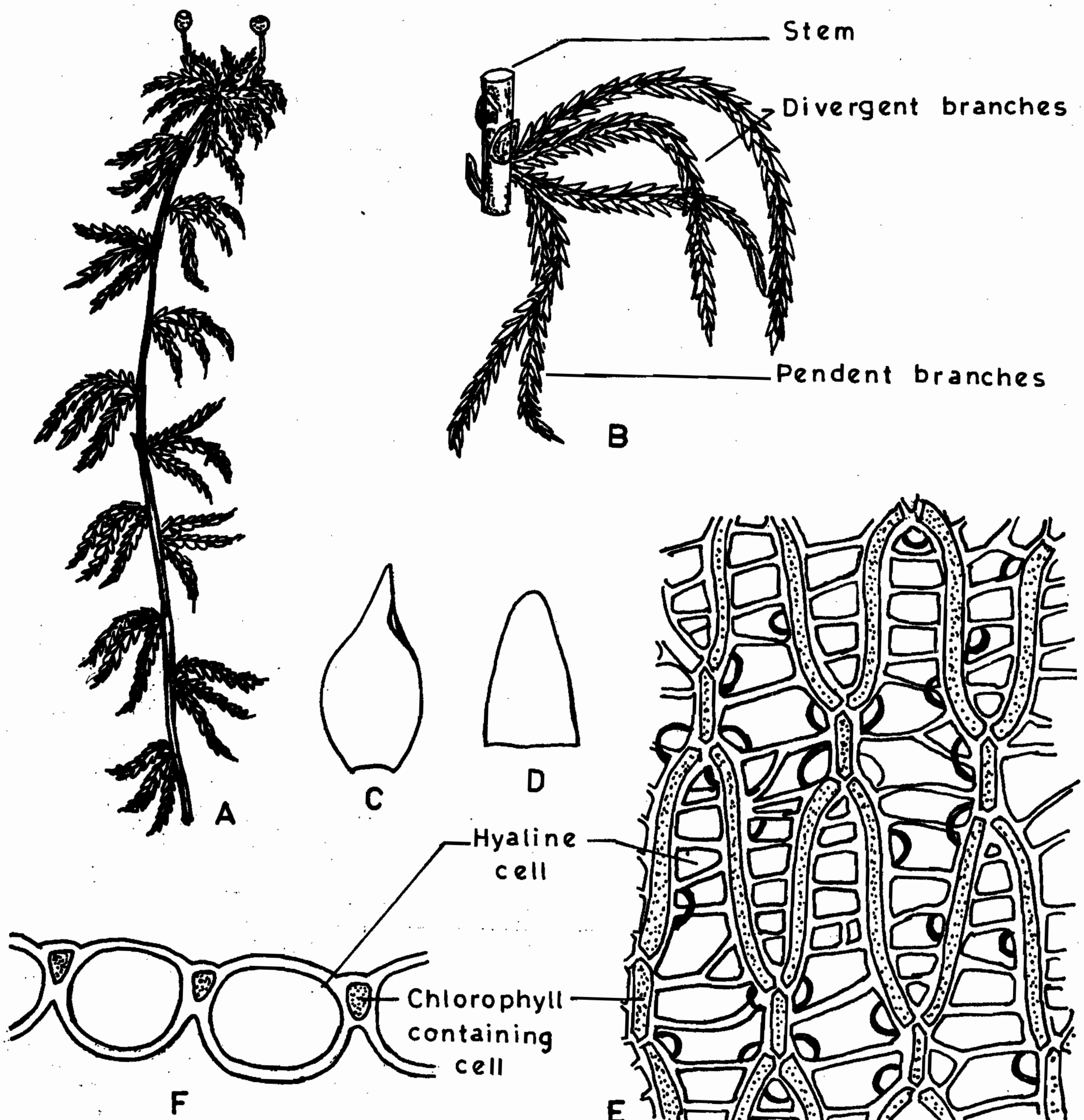


Fig. 13.8 : Structure and morphology of *Sphagnum* : A) a mature gametophyte with attached sporophyte at the apex, B) portion of a shoot showing divergent and drooping (pendent) branches, C) leaf of a divergent branch enlarged. Note the apex. The midrib is absent, D) leaf of the main stem without midrib, E) leaf cells in surface view. Note the network of chlorophyllous cells, surrounding porous hyaline cells; also the fibrillar thickenings of walls of hyaline cells, F) T.S. of a leaf.

Internal structure

Look at Fig. 13.9 A, the stem is internally differentiated into a central cylinder which can be distinguished into outer and inner regions. The layers ensheathing the cylinder form the cortex. When first formed, the cortex is one cell in thickness. Later, the cortex of the main axis becomes four to five cells in thickness and as these cells mature they may develop spirally thickened walls similar to those in hyaline leaf cells. The exterior cells of a central cylinder are thick walled, whereas the interior ones may be thin or thick-walled.

The cortex of the branches is never more than one cell in thickness (Fig. 13.9 B). It is composed of two types of cells : (i) the ordinary parenchymatous cells and (ii) retort cells (shaped like a retort, Figs.13.9 C and D). The retort cells are formed when some of the cells of cortex increase in size and their outer walls become perforated at the upper end forming a circular or oval hole. This end is slightly narrowed above into a neck which is curved away from axis giving them retort like appearance. They are dead, empty cells.

As we have mentioned before, the mature gametophore has no rhizoids and water is directly absorbed by the plant. Water in the stem moves upwards to the apex through cortex in those species in which cortical cells have pores and spirally thickened walls. In other species movement of absorbed water is by capillarity and by wick-like system of pendent branches clothing the stem.

The stems are individually weak but they aggregate and gain mutual support and thus can remain erect above the surface of the water. The stem may vary in size from a few to several centimetres.

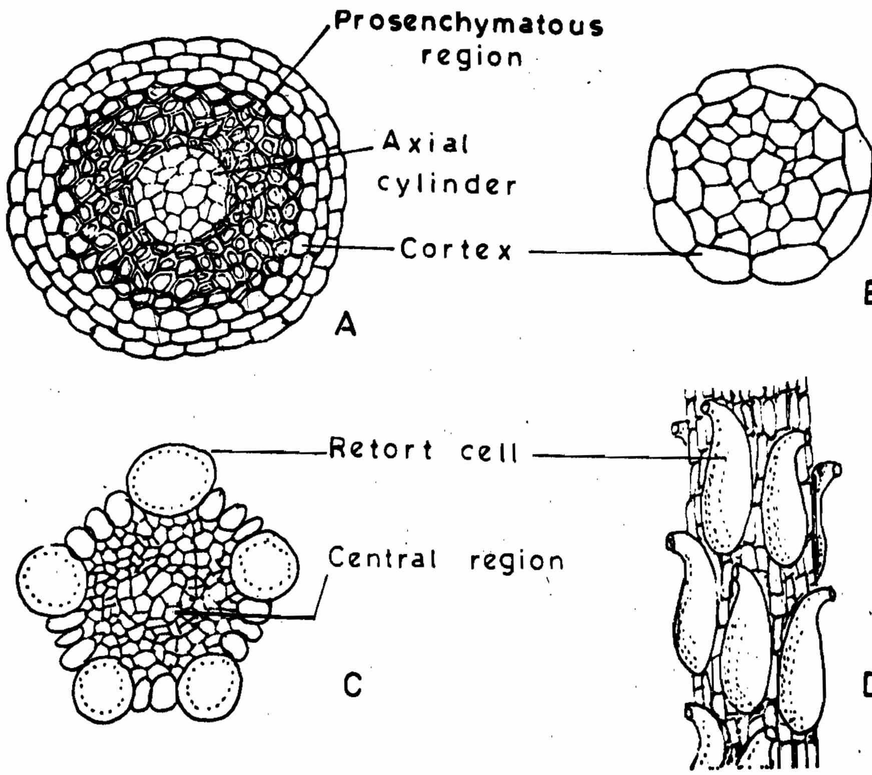


Fig. 13.9 : Internal structure of *Sphagnum* : A) T.S. of an old stem, B) T.S. of a brancn, C) T.S. of branch with retort cells, D) a portion of a branch showing retort cells, after leaves are removed.

SAQ 13.7

In the following statements fill in the blank spaces with appropriate words.

i) In *Sphagnum* the leaf lacks midrib and has two types of cells, ...and ....

ii) In Class Hepaticopsida the rhizoids are unicellular and unbranched,whereas in Class Bryopsida they are.. and ....

iii) Short compact branches at the apex of gametophore of *Sphagnum* are called ....

iv) The spiral thickenings of hyaline leaf cells provide...................................... support whereas intake of water is facilitated by ....

v) The cortex of branches show peculiar .... cells.

Funaria

Division	-	Bryophyta
Class	-	Bryopsida
Sub-class	-	Bryidae
Order	-	Funariales
Family	-	Funariaceae

Funaria

Funaria is a very common moss. It is very widely distributed throughout the world. One species, *Funaria hygrometrica* is cosmopolitan and is the best known of all the mosses.

Like other bryophytes that you have studied, the most conspicuous form of the moss plant is the adult gametophyte. This consists of a main erect axis bearing leaves which are arranged spirally (Fig. 13.10 A). This adult gametophyte is called gametophore. It is small, about

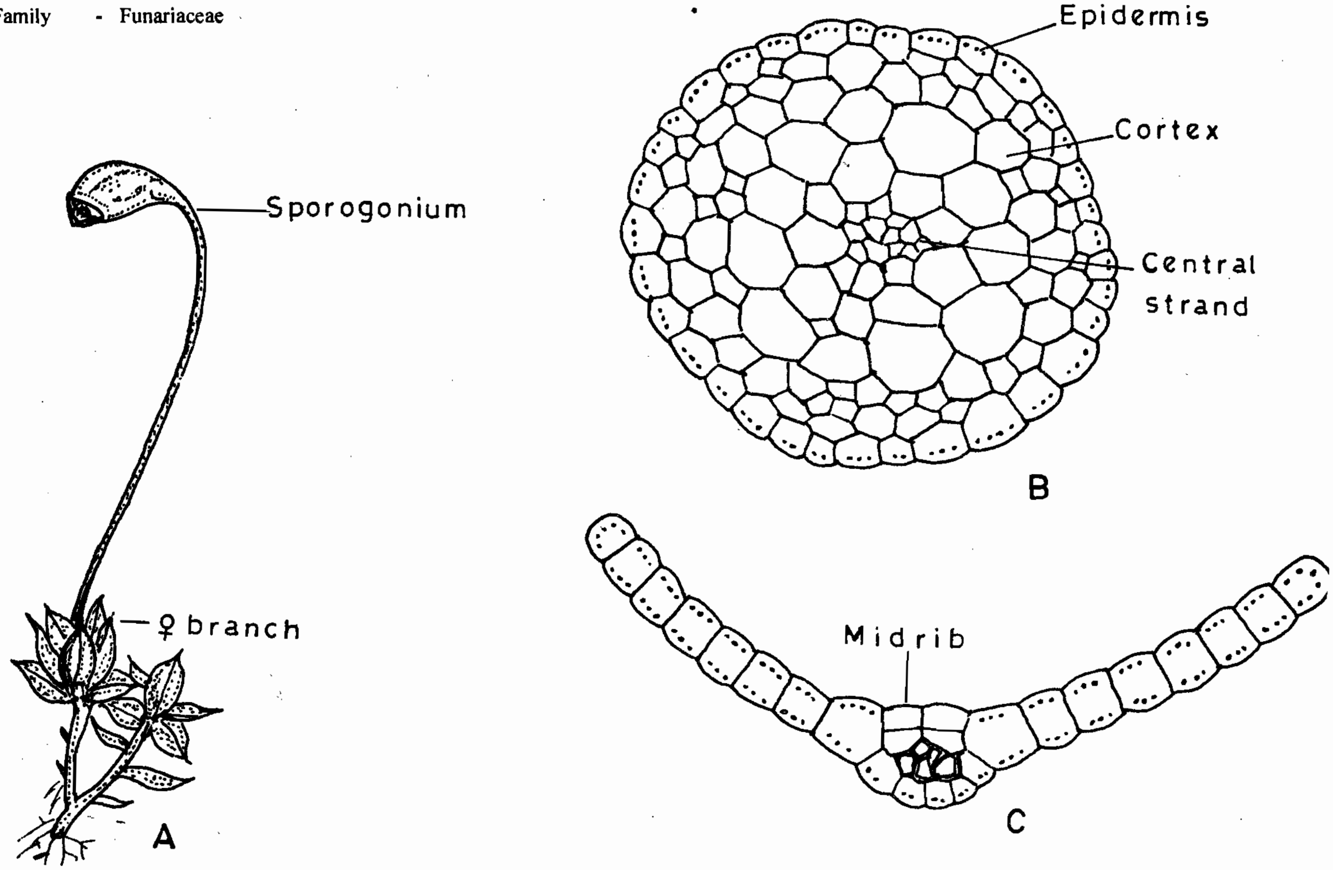


Fig. 13.10 : *Funaria:* A) mature gametophore with male and female branches and also a mature sporophyte (sporogonium), B) T.S. of stem, C) T.S. of leaf.

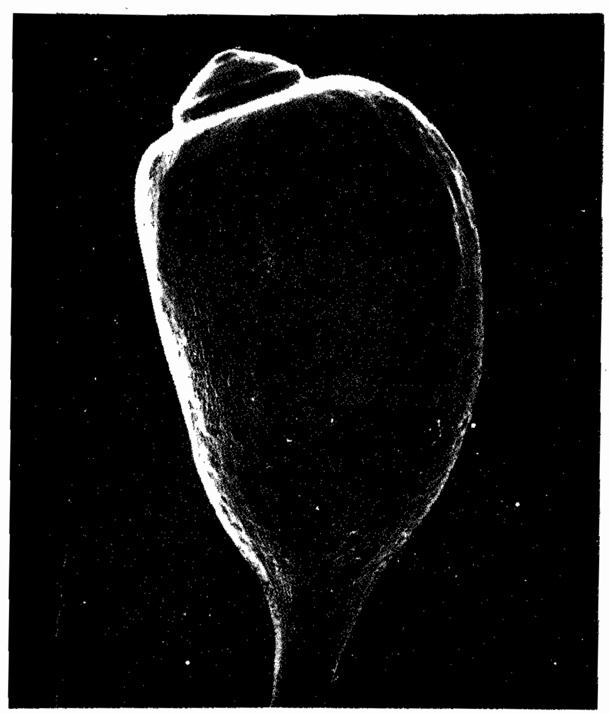


Fig. 13.11 : Scanning electron micrograph of moss capsule (courtsey of P. Dayanandan).

1-3 cm high. The leaves do not have a stalk but show a distinct midrib. The gametophore is attached to the substratum by means of rhizoids which are multicellular, branched and have oblique septae. The gametophyte bears sporophyte which has foot, seta and capsule (Fig. 13.11).

The gametophore develops from a filamentous, green short-lived protonema. The protonema produces buds at certain stage of development, which initiate the development of upright leafy green axis the gametophore.

Internal structure

Look at the T.S. of a mature stem in Fig. 13.10 B. It can be distinguished into three zones: the innermost central cylinder, the middle cortex and the outer epidermis. Cells of the central cylinder are vertically elongated, and smaller in diameter than those of the cortex. A fully mature cortex usually consists of thin walled cells near the central cylinder and thick walled cells at the exterior. The cortex contains "leaf traces" running diagonally from the leaves to the central cylinder. The cortical cells in the younger region of the stem usually contain chloroplasts.

Leaf trace - a bundle of vacular tissue that enters a leaf from the stem.

A mature leaf has a well developed midrib. The midrib is several cells in thickness, while the 'wings' on its either sides are formed by a single layer of cells (Fig. 13.10 C). The cells of leaves are elongated, thin-walled, rectangular or rhomboidal and contain chloroplasts. You may recall the details of leaves in higher plants. Is this leaf not much simpler? The centre of the midrib is occupied by a small central group of narrow cells which form a simple type of conducting strand. The stomata are absent.

SAQ 13.8

Which of the following statements are true or false for *Funaria*? Write **T** for true and **F** for false in the given boxes.

i) The adult gametophyte of *Funaria* is called gametangiophore. ☐

ii) The rhizoids in *Funaria* are different from *Marchantia* because in the latter they are multicellular and have oblique septae. ☐

iii) The wings of the leaf are formed by several layers of cells. ☐

iv) The leaves have prominent midrib. ☐

13.5 SUMMARY

In this unit you have learnt that

- Bryophytes are the simplest, primitive non-vascular land plants among embryophytes. Because of several common characteristics, it is believed that they evolved from green algae.
- There is alternation of generations between green independent gametophyte and sporophyte which is wholly or partially dependent on it. Sporophyte is generally a small capsule with or without foot and seta. The gametophyte develops from protonema and bears sex organs - archegonia and antheridia. Bryophytes are homosporous.
- The challenges of land environment for a plant are fixation to the ground, desiccation, conduction of water and dispersal of sperms and spores. These are taken care of by developing land adaptations such as epidermis, cuticle, stomata, airpores, rhizoids, multicellular jacket of cells for the protection of developing gametes, and retention of zygote in the archegonium. In some bryophytes the primitive conducting tissues - hydroids and leptoids have also developed.
- The gametophyte of liverworts - *Riccia* and *Marchantia* is dorsi-ventral, thalloid structure and is internally differentiated. The pores on the dorsal surface allow exchange of gases and are much advanced in *Marchantia*. While in *Pellia* the thallus is very simple internally. The leafy liverworts have leaf-like and stem-like appendages. * The gametophyte of *Anthoceros*, is also dorsi-ventral, but is not differentiated internally. Blue green algae *Nostoc* live in mucilage cavities of the thallus and fix atmospheric nitrogen.

- Mosses - *Sphagnum* and *Funaria* have erect axes and bear leaf-like structures. Midrib is not present in leafy structures of *Sphagnum*, while in *Funaria* leaves are with midrib. The main axis in both is internally differentiated into different regions.

13.6 TERMINAL QUESTIONS

1. Diagrammetically show the life cycle of a bryophyte, and highlight its special features.

2. List the characteristics common to green algae and bryophytes.

   ....

   ....

   ....

   ....

   ....

3. Match the genera given in Column 1 with their characteristics given in Column 2.

Column 1			Column 2
i)	*Riccia*	( )	a) barrel shaped pore
ii)	*Marchantia*	( )	b) rosette
iii)	*Anthoceros*	( )	c) leaves with midrib
iv)	*Sphagnum*	( )	d) innovation
v)	*Funaria*	( )	e) *Nostoc*

4) Indicate whether the following statements are **True** or **False** by placing letter T (True) and F (False) in the given boxes.

   i) The gametophyte of *Anthoceros* shows a high degree of internal differentiation. ☐

   ii) A protonema is diploid. ☐

   iii) Bryophytes do not require water for fertilization. ☐

   iv) Gametophytic stage is dominant in bryophytes. ☐

5) Differentiate between the following :

   i) Rhizoids of liverworts and mosses.

   ....

   ....

   ii) Arrangement of scales in *Riccia* and *Marchantia*.

   ....

   ....

   iii) Sporophytic and gametophytic generations of bryophytes.

   ....

   ....

13.7 ANSWERS

Self-assessment Questions

13.1 a) i) gametophyte, ii) rhizoids, iii) haploid, iv) dependent.

b) i) T, ii) T, iii) F, iv) T

13.2 a) Fixation to the soil, absorption and transport of water and minerals, desiccation of aerial parts and gametes, and dispersal of spores.

b) i) sterile layer

ii) hydroids, leptoids

iii) tracheids/vessels, non-lignified

iv) sporopollenin

13.3 i) rosettes

ii) smooth-walled, tuberculate

iii) unicellular, multicellular

iv) rudimentary pores

13.4 i) stalked

ii) hexagonal, air chambers

iii) Photosynthetic

iv) mucilage, oil body.

13.5 i) Jungermanniales

ii) no

iii) smooth

iv) present

13.6 i) tuberculate, scales

ii) *Nostoc*

iii) pyrenoids

iv) photosynthetic, storage

13.7 i) chlorophyllous, hyaline

ii) multicellular, branched

iii) coma

iv) mechanical, pores

v) retort

13.8 i) F, ii) F, iii) F, iv) T

Terminal Questions

1. See Fig. 13.2.
2. Chlorophyll, carotenoid, amylose, amylopectin, spermatozoids, whiplash flagella, cellulose,
3. i) (b), ii) (a), iii) (e), iv) (d),
   v) (c)
4. i) F, ii) F, iii) F, iv) T,
5. i) liverworts - unicellular, unbranched
   mosses - multicellular, branched
   ii) *Riccia* - in a single row
   Marchantia - in many rows
   iii) sporophytic - diploid (2n), reproduce asexually, dependent upon gametophyte
   Gametophytic - haploid (n), reproduce sexually, dominant, independent

Note : Elaborate the above points and supplement with figures

UNIT 5 CLASSIFICATION OF ALGAE

Structure

5.1 INTRODUCTION

From the previous two units it is evident that algae show a great diversity in structure and reproduction. In this unit you will learn classification of this diverse group. Classification means grouping of organisms according to the similarity in their characters. It is not far fetched but true that organisms showing similar morphology, life cycle, physiology and biochemistry are genetically related from the evolutionary point of view (phylogenetically related) and one is justified in grouping them together.

The position of algae as a group among the other groups of organisms has been discussed already in the previous Block 1A(Unit 2, Page 31). It was indicated that algae could be classified according to their common characters into 8 divisions of Kingdom Protista (Unit 1, p 18). The relationship among different groups was also discussed. You may recall that blue-green algae have been grouped as Division Cyanobacteria, and clubbed with bacteria under the Kingdom Monera.

In this unit you are introduced to the characteristics of different divisions of algae.

Objectives

After studying this unit you should be able to:

- list the various criteria used for the classification of algae,
- explain why algae are classified as protists instead of plants,
- list the various divisions of algae and describe the characteristics of each,
- classify the genera of algae studied in Unit 3 into division, order and family and
- give common examples of algae from each division.

Study Guide

In this unit we have given several examples of algae for each division but you are expected to remember at least three from each division.

5.2 CRITERIA FOR CLASSIFICATION OF ALGAE

The criteria used by phycologists are quite varied. Generally a number of characters are used together ranging from external morphology, ultrastructure, chromosome number and their morphology, pigment composition, nature of cellular storage products, enzymes, isoenzymes, DNA homology, and DNA banding etc. As new techniques are developed they are used to decide more precisely the relatedness (or absence of it) of organisms which seem otherwise related to each other.

Given below are the salient characters of each of the divisions of the algae. It is to be noted that each division is again divided into orders, families, genera and species. In section 5.5 you will find the classification of all the algae which are included in your study. Please note that they represent certain divisions, orders, and families only. Because of the restriction of time representatives of other divisions are not included in your course, not because they are any less important in the biological world.

Algae
- **Prokaryotic Algae** — Cyanophyta
- **Eukaryotic Algae**
  - Chlorophyta
  - Phaeophyta
  - Rhodophyta
  - Xanthophyta
  - Chrysophyta
  - Euglenophyta
  - Dinophyta
  - Bacillariophyta

5.3 PROKARYOTIC ALGAE

5.3.1 Division CYANOPHYTA (Cyanobacteria or Blue-green algae)

Prokaryotic algae are placed in Division Cyanophyta. Algae of this division may be unicellular, colonial, and filamentous, with or without branches, branching may be 'true' or 'false' type. Most forms are embedded in mucilaginous or gelatinous sheaths.

The composition of cell wall is similar to bacterial cell wall. It is, made up of distinctive mucopeptides and muramic acid.

The ultrastructure of the cell shows no organised nucleus, mitochondria or chloroplasts, Photosynthetic lamellae and ribosomes of 70s type are present in the cytoplasm of the cells. Some filamentous forms possess specialised cells termed as 'heterocysts' (ref. to Fig. 3.2), which are involved in nitrogen fixation.

The main photosynthetic pigments are chlorophyll *a* and phycobilins - (phycocyanin and phycoerythrin). A number of carotenoids including β-carotene are also present, some of which are specific to the division.

Carbon is reserved in the cells as glycogen granules and nitrogen as cyanophycean granules. Other granules like polyphosphate granules, some enzyme aggregates like carboxysomes may also be present.

Reproduction occurs by simple cell division. No motile cells are found in cyanobacteria and they do not have sexual method of reproduction. Thick walled cells called 'akinetes' or spores are present in some forms for perennation and asexual reproduction.

Cynobacteria are distributed all over the earth in diverse habitats, fresh water lakes, ponds, rivers, arctic, antarctic areas, hot water springs, brine salt pans, desert soils, subaerial surfaces like tree trunks, building terraces and rock surfaces.

Examples: *Anacystis, Microcystis, Nostoc, Anabaena, Oscillatoria, Spirulina, Calothrix, Tolypo thrix, Gleotrichia, Lyngbya, Scytonema, and Stigonema.*

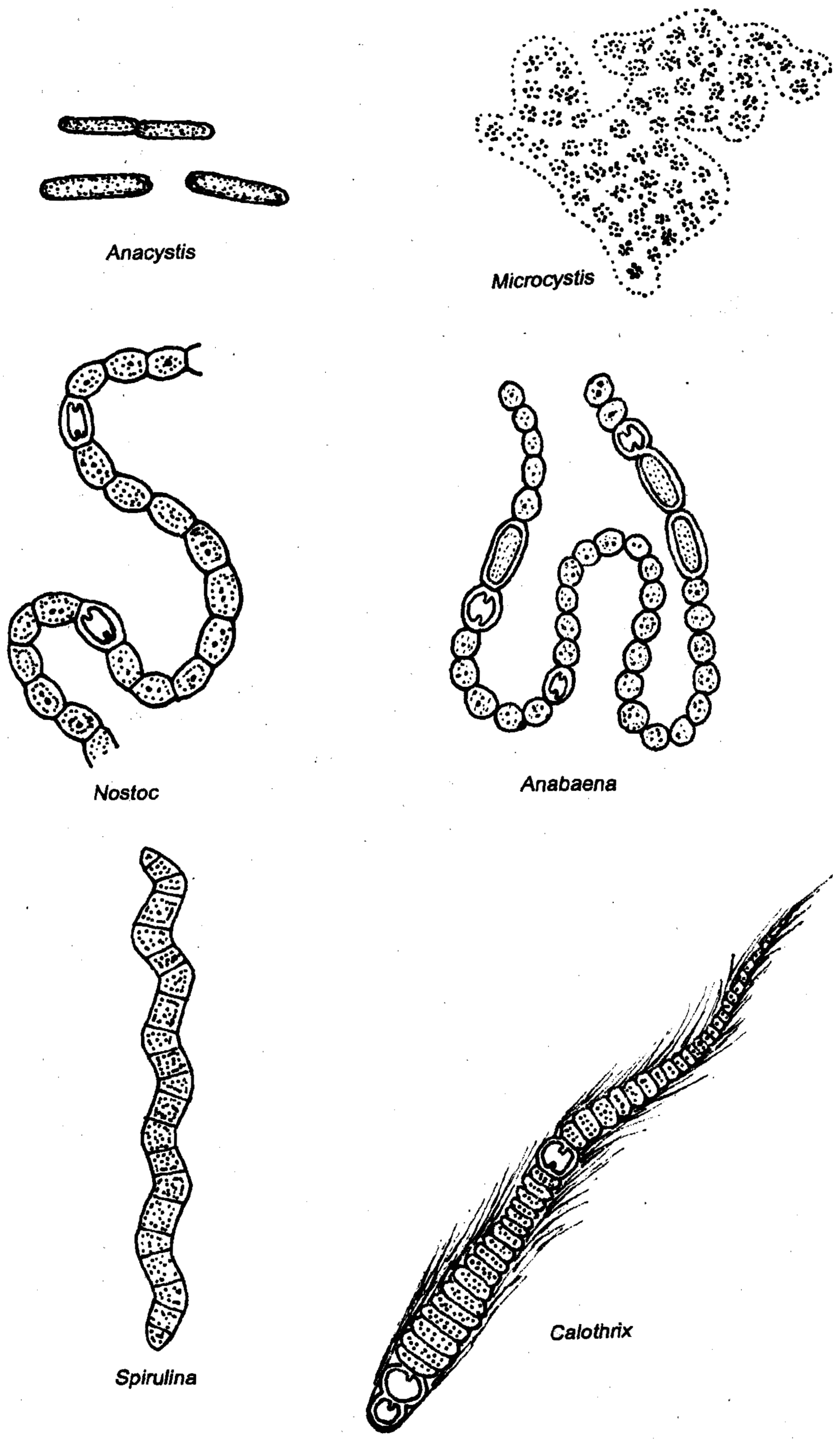


Fig. 5.1 : Some examples of blue-green algae.

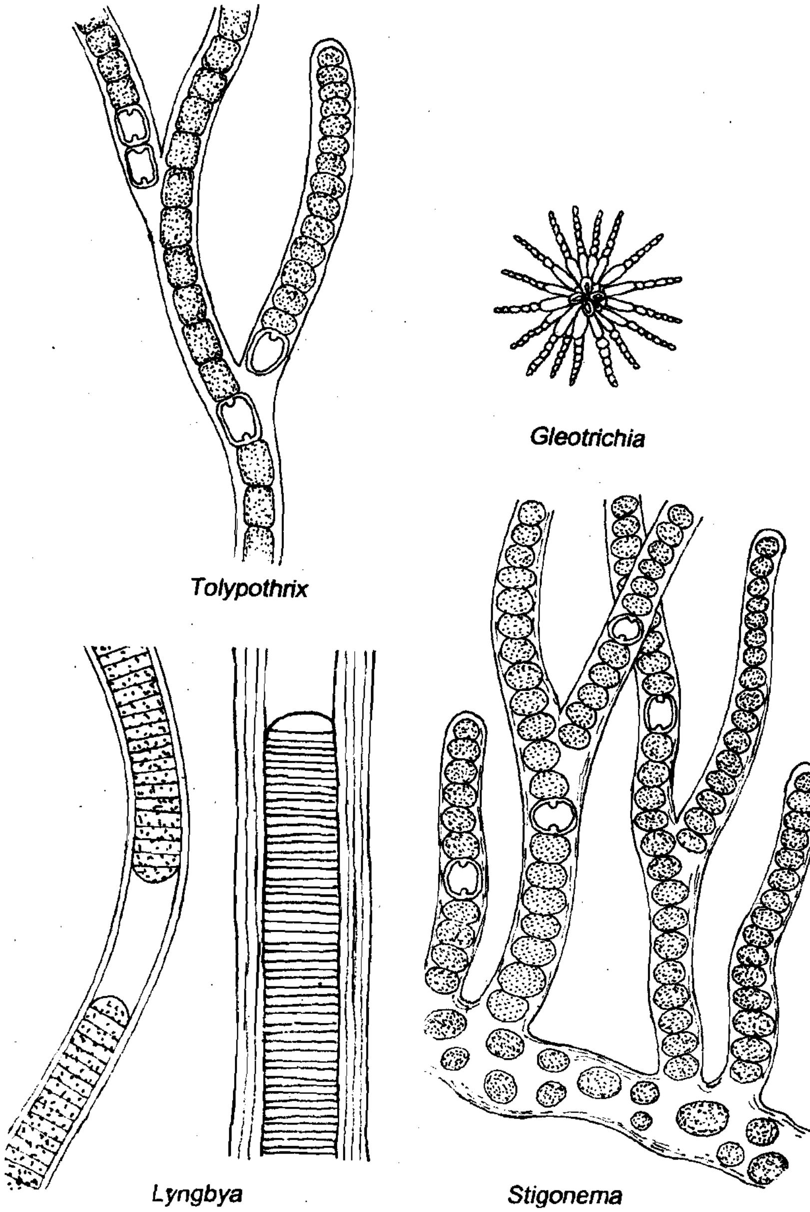


Fig. 5.2 : Thallus structure in blue-green algae.

5.4 EUKARYOTIC ALGAE

As you have learnt earlier, that Kingdom Protista includes eight divisions of algae. Some phycologists make nine divisions treating Bacillariophyta separate from Chrysophyta. You may note that we have also taken it as a separate division. In the following account they are described in detail below.

5.4.1 Division CHLOROPHYTA (Green algae)

This includes unicellular to multicellular forms of green algae. The multicellular forms may be in the form of filamentous, branched or unbranched, thalloid, tubular or sheet like arrangement of cells. Some of the green algae are colonial in form. The cell structure is eukaryotic type as in higher plants with membrane bound organelles-nucleus, plastids, mitochondria, and cytoplasmic ribosomes of 80s type.

The cell wall is generally made up of cellulose. Sometimes the cells are also covered with chitin.

The principal photosynthetic pigments are chlorophyll *a* and *b*, carotenes and xanthophylls located in the thylakoids.

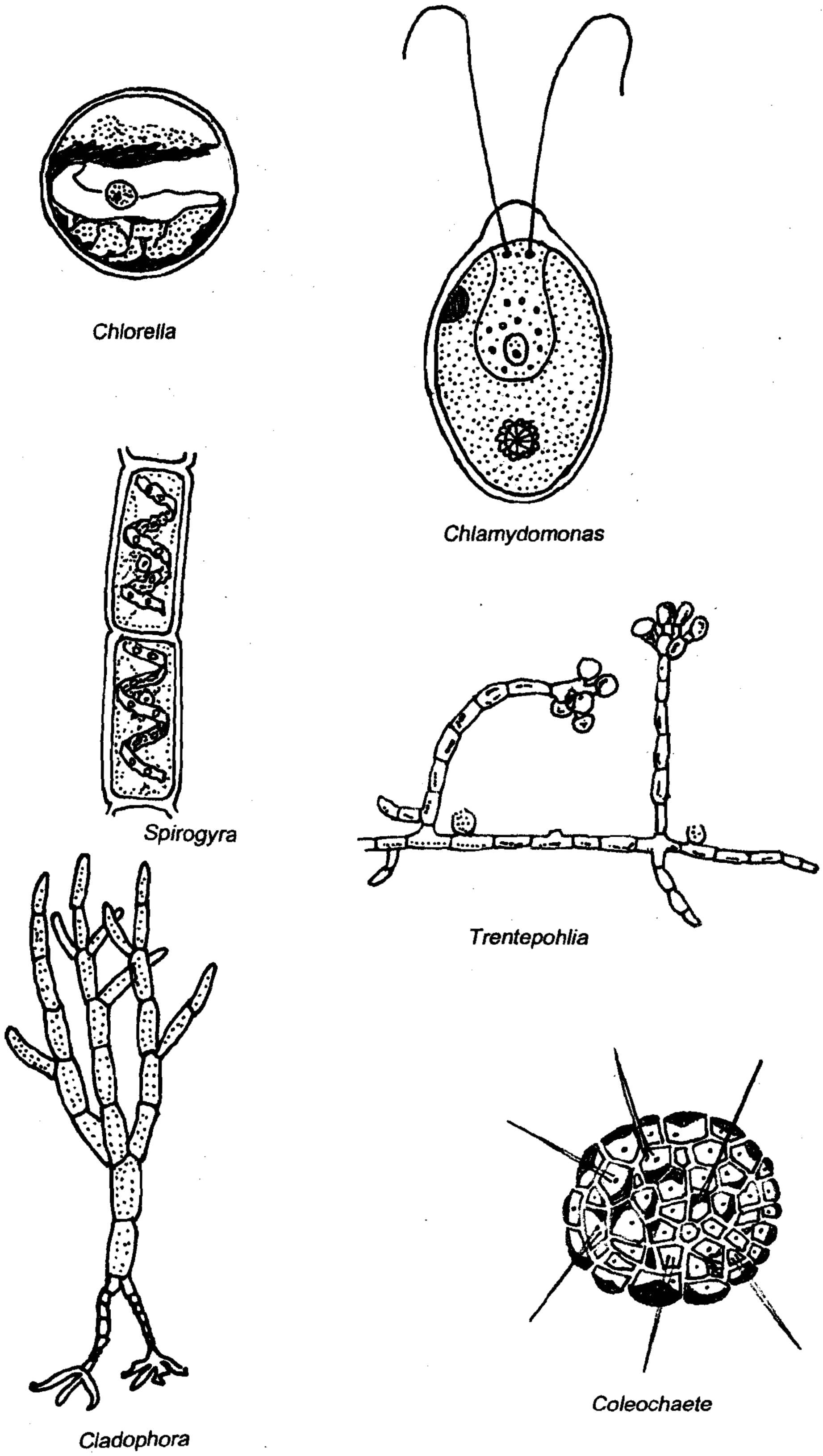
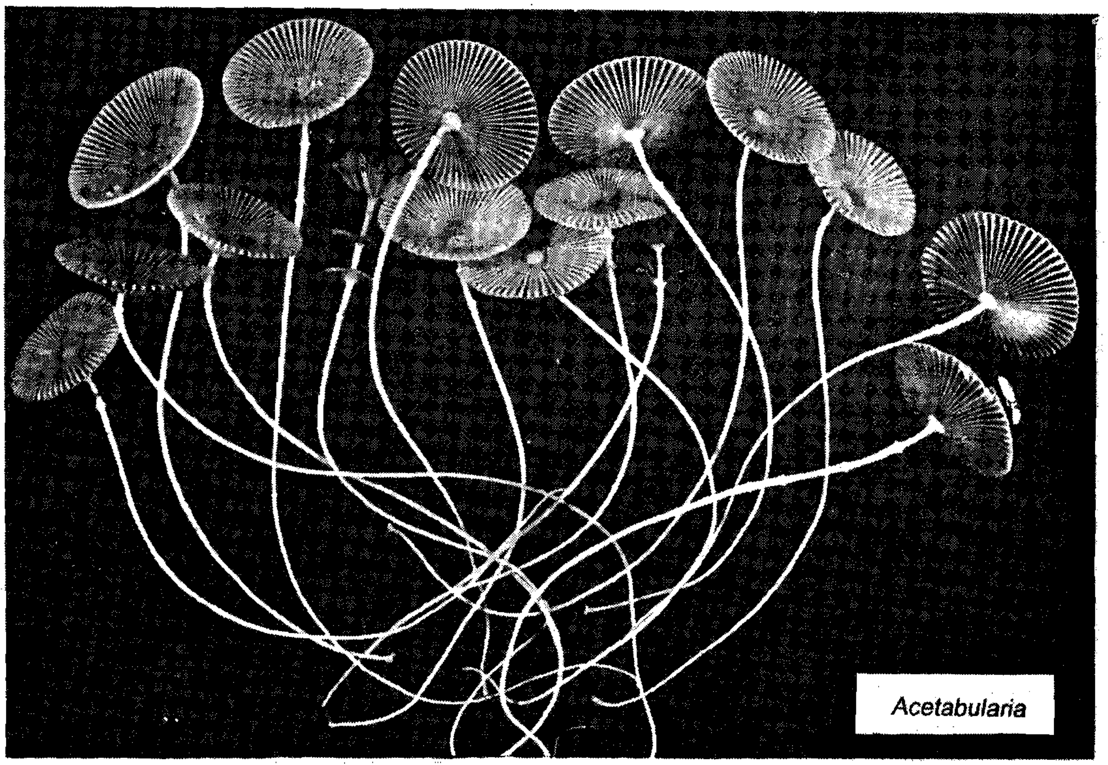


Fig. 5.3 : Some members of Division Chlorophyta.



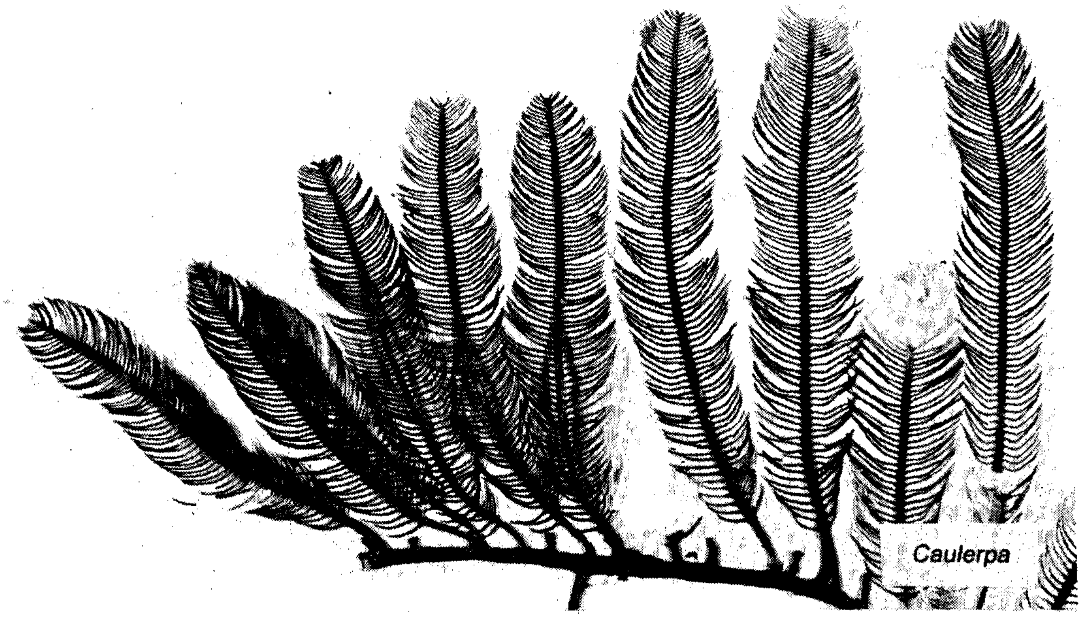


Fig. 5.4 : A) Several isolated thallus of *Acetabularia*, commonly called mermaid's wineglass, and B) *Caulerpa*, a coenocytic green algae (courtesy of P. Dayanandan).

The storage products of the cell are mostly starch, but in some algae lipids.

Reproduction occurs by asexual and sexual methods. Asexual reproduction is by biflagellate or quadri-flagellate zoospores whereas gametes (sexual reproduction) are biflagellate. The flagella are anterior and of whiplash type. Sexual reproduction includes isogamy, anisogamy, and oogamy.

Green algae are distributed in fresh water and marine habitats; some may be subaerial on wet soil or bark of trees.

Examples: *Chlorella, Chlamydomonas, Pediastrum, Spirogyra, Cladophora, Acetabularia, Trentephohlia, Micrasterias* and *Caulerpa.*

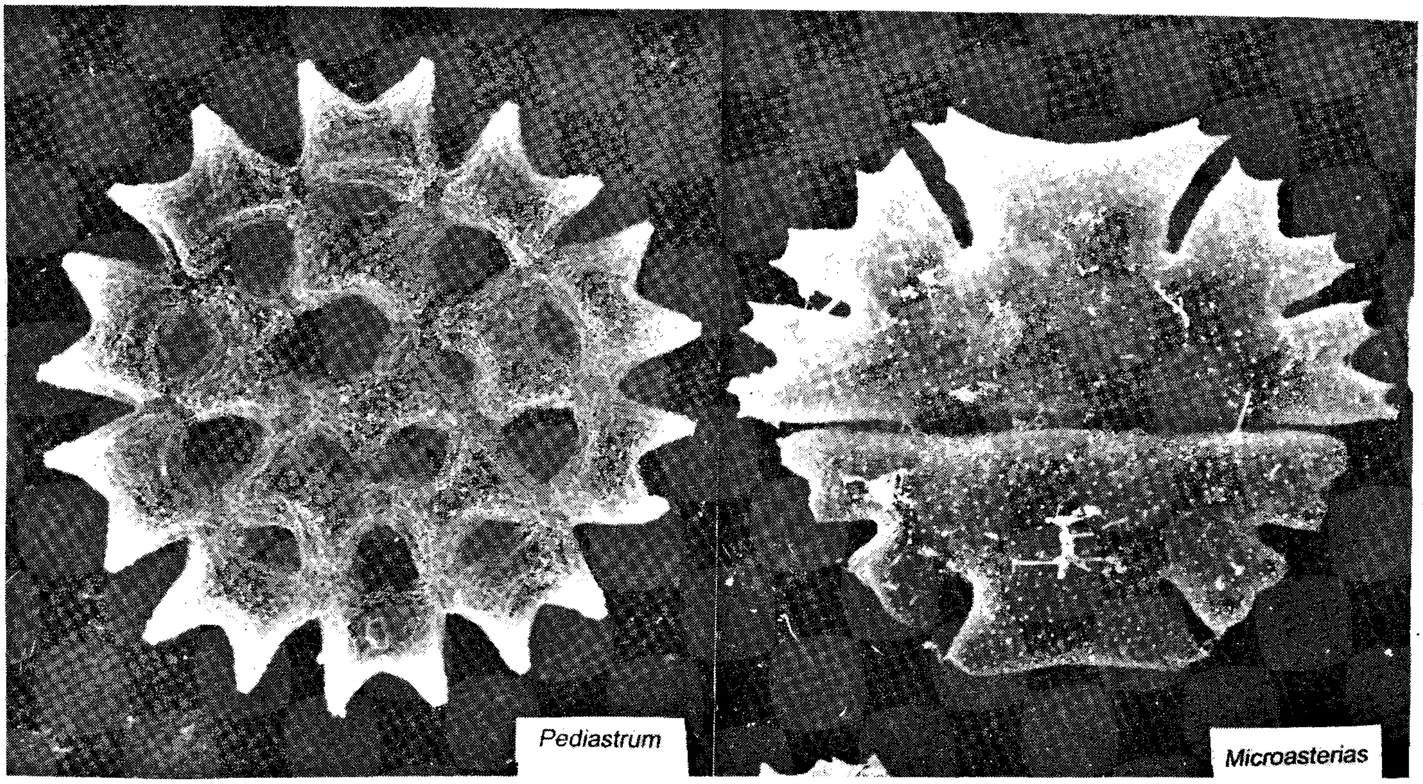


Fig. 5.5 : Scanning electron micrographs of A) *Pediastrum*, B) Micrasterias. (Courtesy of P. Dayanandan).

5.4.2 Division PHAEOPHYTA (Brown algae)

Structurally they are most complex in morphology. They range from simple branched filaments to massive bodies.

Cell wall composition is complex. Besides cellulose, it may contain algin, fucoidin

Principal photosynthetic pigments are chlorophyll *a* and c and carotenoids. Fucoxanthin (brown in colour) is present in large amount that gives alga brown colour by masking the green colour of chlorophyll.

Photosynthetic storage product is mannitol, some times laminarin. Rarely, lipid droplets may be found in the cells.

Sexual reproduction ranges from isogamy to oogamy. The motile swarmers have two unequal laterally inserted flagella, one of the flagella is larger and anterior and the other is smaller and posterior.

Most of the brown algae are seaweed, very large in size, commonly known as kelps. They are the main source of iodine, agar and related products.

Examples: *Ectocarpus, Fucus, Laminaria, Sargassum, Dictyota, Alaria, Macrocystis, Nereocystis* and *Padina.*

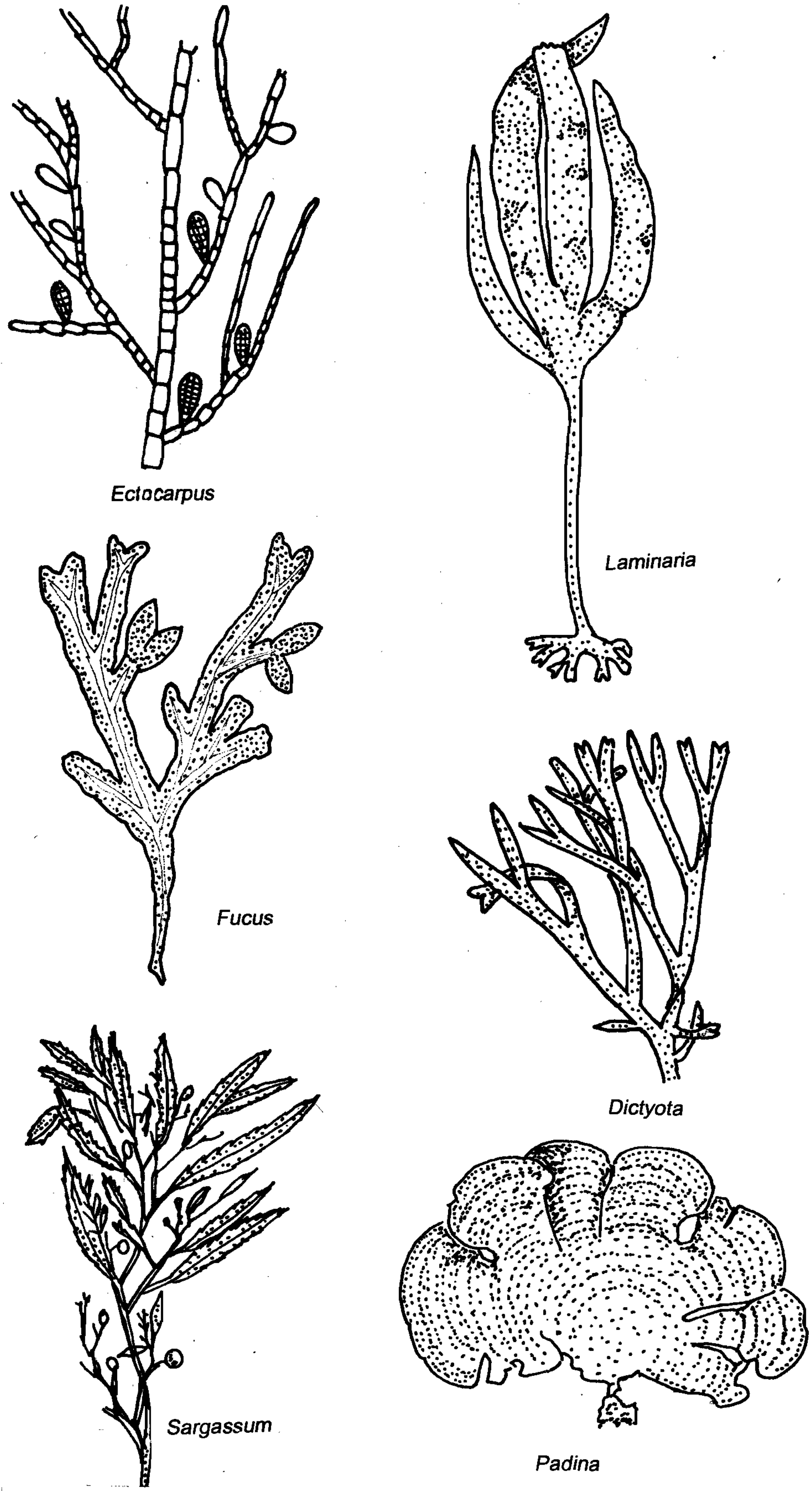


Fig. 5.6 : Some common brown-algae.

Macrocystis

Nereocystis

Fig. 5.7 : A) *Macrocystis*, B) Photograph of *Nereocystis* (Courtesy of P. Dayanandan).

Coralline algae are a group of red algae that secrete calcium carbonate around their cells and form stiff thalli .Coralline algae are important builders of coral reefs in tropical water, contrary to the believe that coral animals alone make up coral reefs.

5.4.3 Division RHODOPHYTA (Red algae)

Most forms are multicellular and highly branched, a few are thalloid and one alga *Porphyridium* is unicellular. The body may be covered with calcium carbonate incrustations.

Besides cellulose their cell wall contains pectin, polysulphate, esters and large amount of polysaccharides on the outside of their surface. These polysaccharides are the source of agar and carageenans. Certain red algae for example coralline algae secrete calcium carbonate around their cells and form stiff thalli.

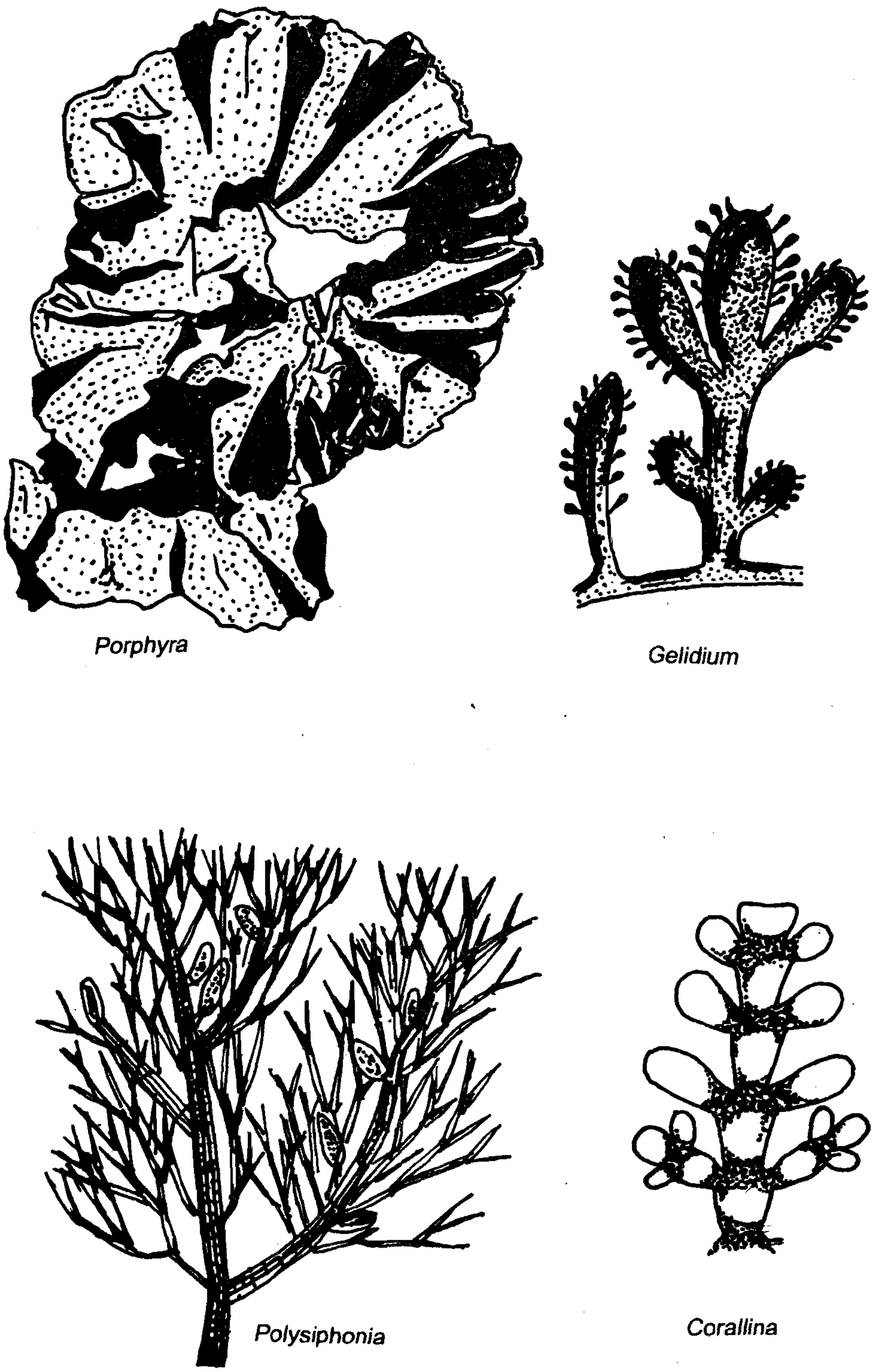


Fig. 5.8 : Some common Red algae.

The main photosynthetic pigments are chlorophyll a, *d* and phycoerythrin. Some red algae contain phycocyanin also. The algae appear red or pink in colour because of large amounts of phycoerythrin.

The food reserve in the cells is floridian starch.

No motile cells are found at any stage of reproduction. Sexual reproduction is advanced oogamous type. Male gametes – spermatia are passively transported by water movements to the tip of trichogyne of the female carpogonium. After fertilisation, special developmental changes occur, that are not found in any other division of the algae.

Most of the red algae are marine in habitat. A few are found in fresh water lakes, rivers, streams and ponds. Some are epiphytic or parasitic in nature.

Example: *Porphyridium (unicellular), Porphyra, Polysiphonia, Gracilaria, Gelidium, and Corallina.*

5.4.4 Division XANTHOPHYTA (Yellow-green algae)

Some forms are unicellular and motile while others are filamentous, with multinucleate cells.

Photosynthetic pigments are chlorophyll *a, c,* β-carotene which is present in large amount, and xanthophylls giving the cells greenish-yellow colour.

Food reserves include lipid and chrysolaminarin (β-1,3'- linked polymer of glucose, also known as leucosin).

Cell wall frequently consists of two overlapping halves, containing pectin, silica and small amount of cellulose.

Sexual reproduction is rare. The motile cells have two unequal flagella present on the anterior end; one is tinsel and the other whiplash type.

Yellow-green algae are widely distributed in aquatic, fresh water habitats. Some are sub-aerial and a few are marine in distribution.

Examples: *Vaucheria, Botrydium.*

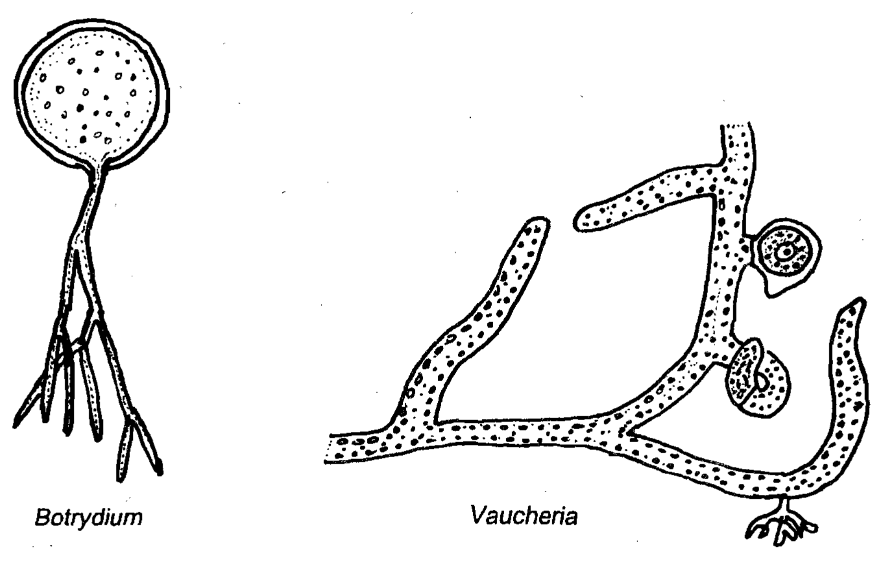


Fig. 5.9 : Two members of yellow-green algae.

SAQ 5.1

a) List the criteria for classification of algae.

....

....

....

....

b) In the following statements fill in the blank spaces with appropriate words.

i) In cyanobacteria carbon in reserved as ....

ii) The colour of red algae is due to ....

iii) The storage material in the algae of Divison Phaeophyta is ...., ...

iv) Sexual reproduction in Xanthophyta is ....

c) Which one of the following divisions of algae does not have motile cells?

i) Cyanophyta
ii) Rhodophyta
iii) Chlorophyta
iv) Phaeophyta

5.4.5 Division CHRYSOPHYTA (Golden brown algae)

Mostly unicellular or colonial, filamentous forms are rare.

Motile cells have two equal or unequal flagella present on the anterior end. The longer one has stiff hairs and the shorter is smooth. The cell wall is made of pectin and silica or scales of carbonate. The chloroplasts are deeply lobed.

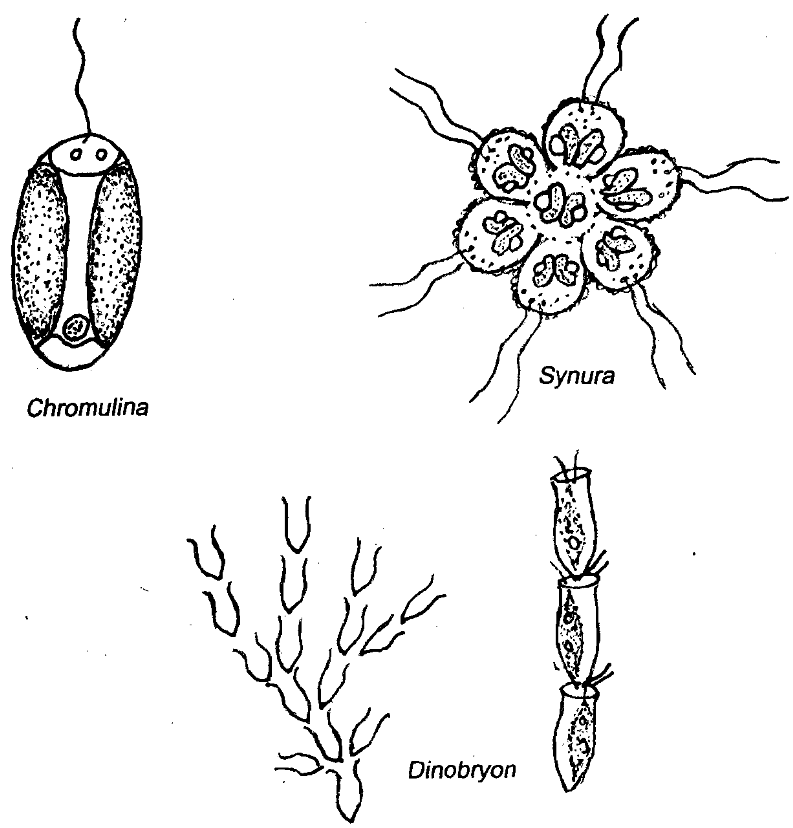


Fig. 5.10 : Some members of Chrysophyta.

Principal pigments are chlorophyll *a, c,* and carotenoids like β-carotene, fucoxanthin, diatoxanthin and neofucoxanthin.

Storage products are mostly oil droplets, and true starch is absent but glucan granules or leucosin are present.

Sexual reproduction is rare. Most common features are the formation of resting cysts, resting spore (statospores), with silica walls.The cysts are formed as a result of asexual or sexual reproduction.

Golden-brown algae are distributed in marine and fresh water habitats, and in fast flowing mountain streams. Marine coccolithophorides are responsible for the formation of chalk beds on the bottom of the sea.

Examples: *Synura, Chromulina, Ochromonas, Mallomonas, and Dinobryon.*

5.4.6 Division EUGLENOPHYTA (Euglenoids)

Most of the euglenoids are simple unicellular motile flagellates. They have no firm cell wall, and possess characteristics like protozoans. They have a contractile vacuole. Cell surface is pellicle (thin membrane) and has helical; knob like projections. Cell shape changes constantly (euglenoid-movements). Chloroplasts show variety of shapes such as discoid, ribbon like or stellate. Cells are biflagellate but only one flagellum emerges anteriorly.

Members of some algal divisions such as the euglenoids, cryptophytes, dinoflagellates, chrysophytes are predominantly unicellular. Some biologists consider these organisms to be more related to the animal kingdom and classify them under protozoa

The photosynthetic pigments located in the plastids include chlorophyll a, *b* and carotenoids including β-carotene. Some euglenoids are also colourless.

A form of starch-paramylon is present as distinct granules. Oil droplets and polyphosphate granules are also common in the cells.

Cells divide by binary fission. Many species produce cysts under adverse conditions. Sexual reproduction is absent.

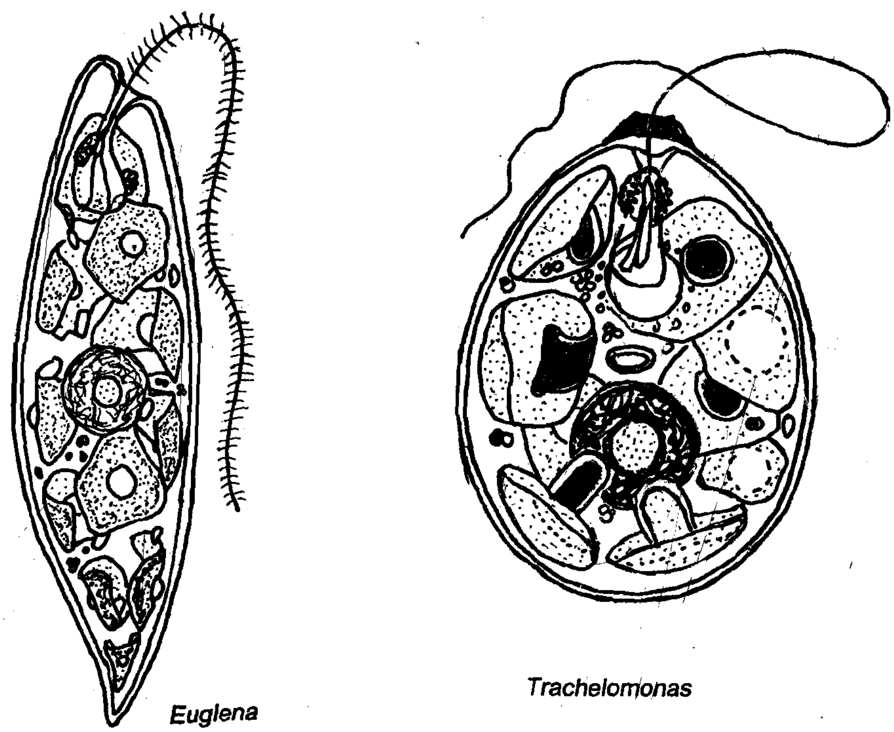


Fig. 5.11 : Euglenoids.

Euglenoids occur in fresh water and brackish water and very commonly in polluted ponds and temporary rain water pools.

Examples: *Euglena, Trachelomonas, Phacus.*

5.4.7 Division DINOPHYTA (Dinoflagellates)

Cell wall consists of cellulose plates which are inside the plasma membrane. A number of plates or body scales may be present on the cell wall. Cell structure is complex. Majority of forms are unicellular and motile. Many dinoflagellates such as *Noctiluca*, are luminescent. They glow in the dark when they are disturbed.

Most of these algae contain chlorophyll, *a* and *c* and distinctive carotenoid specific to dinoflagellates.

Reserve foods are mostly in the form of starch and oil.

Asexual method of reproduction is by cell division. Parent cell divides into a number of aplanospores or zoospores or non-motile cells. Sexual reproduction has been recently reported, gametes are smaller than the vegetative cells and the fusion is isogamous. Formation of cysts with or without gametic fusion is also found.

Gonyaulax produce nerve toxins that kill fish, shellfish are not killed by toxin but they accumulate as nerve toxins, when humans consume contaminated shell fish, they develop food poisoning.

Dinoflagellates are mostly found as marine phytoplankton, sometimes as 'red tide' blooms. Many occur as symbionts in marine animals like corals (zooxanthellae).

Examples: *Noctiluca, Gonyaulax, Peridinium, Ceratium.*

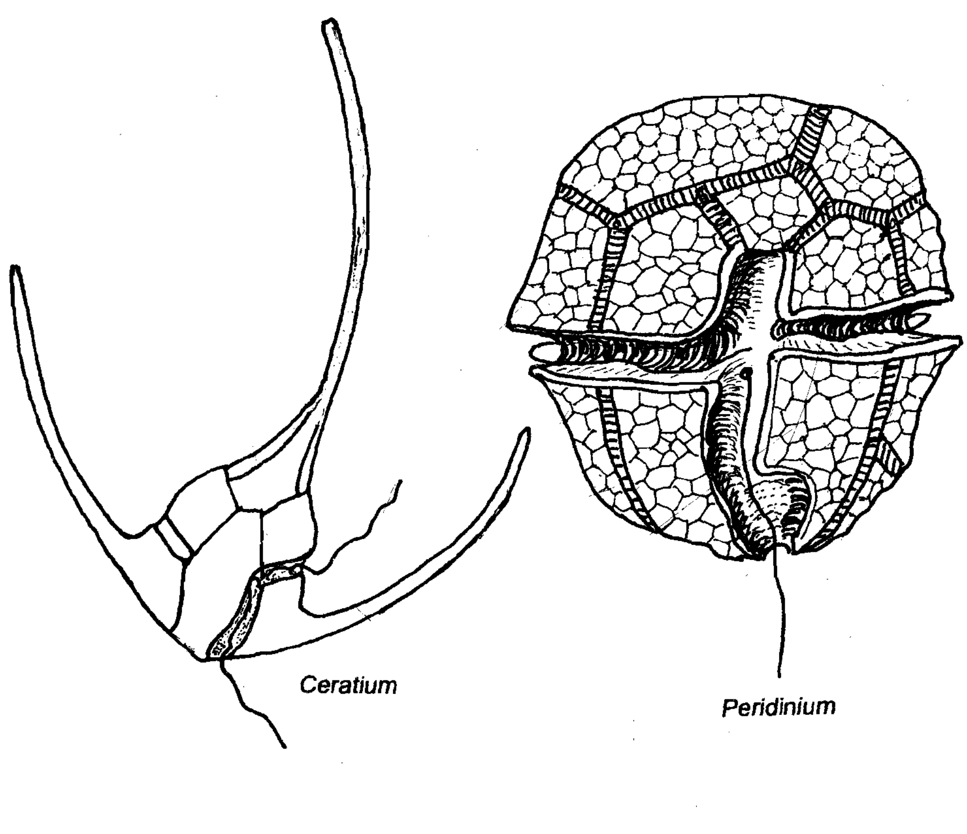


Fig. 5.12 : Members of Division Dinophyta.

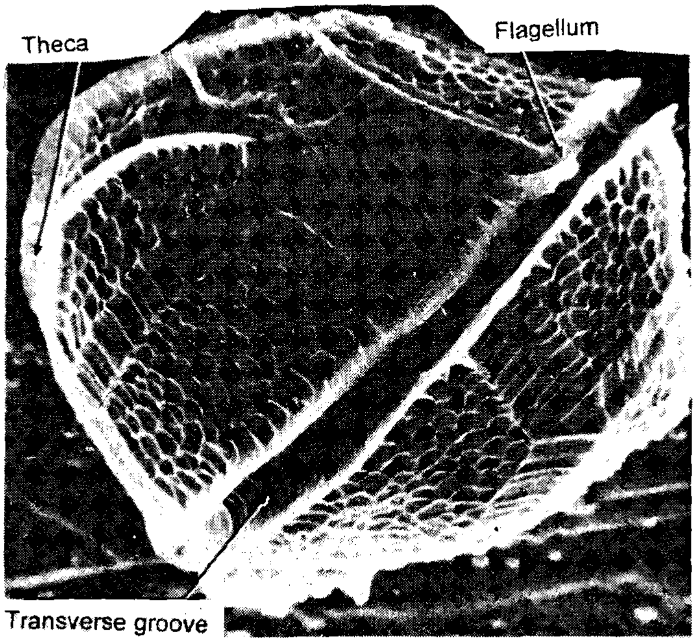


Fig. 5.13 : Scanning electron micrograph of a marine planktonic dinoflagellate (Courtesy of P. Dayanandan).

5.4.8 Division CRYPTOPHYTA (Crytomonads)

Unicellular motile organisms, when alive they are brown in colour. Several genera are animal like in morphology and mode of nutrition, some are colourless and saprophytic in nature.
Cells are without cell wall ovoid and dorsiventrally flattened. The two flagella are apical and unequal in length. The chloroplasts may be single or many in a cell. In some cryptomonads there are two, large parietal chloroplasts, or many disc like ones.

Pigments include chlorophyll *a*, *c*, phycocyanin, phycoerythrin,and diverse carotenoids.

Reserve photosynthate is starch.

Reproduction is by longitudinal division of the cell. Palmelloid forms may produce zoospores. Sexual reproduction has not been reported so far.

Examples : *Crytomonas, Chroomonas.*

5.4.9 Division BACILLARIOPHYTA (Diatoms)

Mostly unicellular forms, some are colonial and filamentous in structure. Cell wall is silicified, consisting of two perforated overlapping plates. It is highly ornamented on the surface. Chromatophores are brownish in colour due to large amounts of carotenoids.

Diatoms (cut in half) each cell is made up of two parts. The larger part fitting tighty over the slightly smaller part like a petridish.

Photosynthetic pigments are chlorophyll *a* and *c*, fucoxanthin, diatoxanthin and diadinoxanthin.

Common storage product is oil and chrysolaminarin.

Reproduction occurs by vegetative and sexual methods. Diatom cells unlike other algae are diploid in nature. Sexual fusion is homothallic, within the individuals of the same clone. Two amoeboid gametes fuse to form a zygote which develops into an auxospore. Fusion may be isogamous, anisogamous or oogamous type.

Diatoms are widely distributed in fresh water and sea as planktons, on mud surfaces, moist rocks, and sand. They may even be epiphytic, epizoid or endozoid.

Large deposits of fossil diatom shells known as diatomaceous earth are mined and used in various industries.

Examples : *Navicula, Cymbella, Coscinodiscus, Diatoma* and *Fragilaria.*

At the end we would like to point out that classification of algae is tentative and can be improved by using new and advanced techniques like DNA fingerprinting etc. which can clarify the genetic relatedness of organisms.

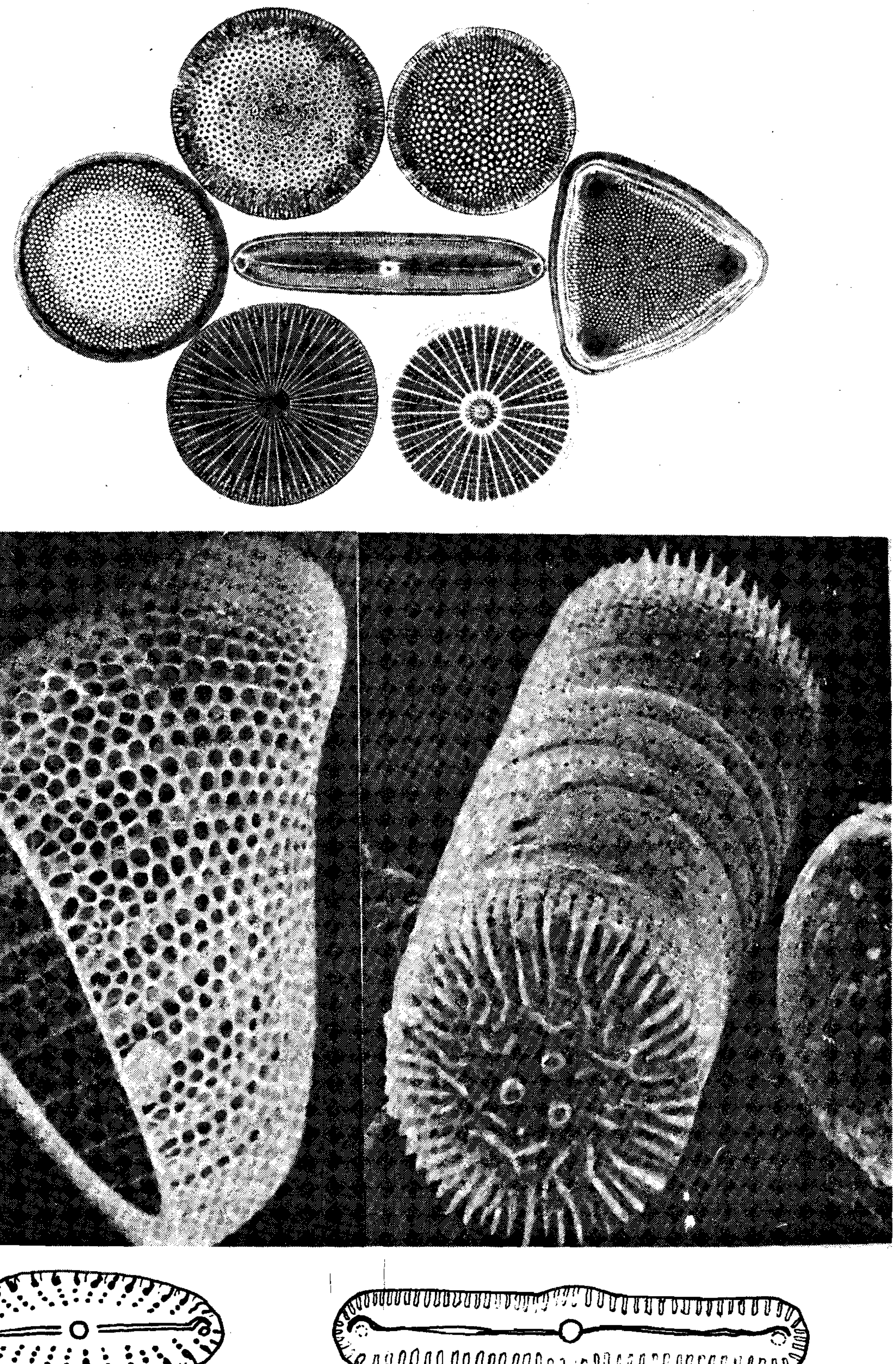


Fig. 5.14 : Members of Division Bacillariophyta, Some diatoms as seen under scanning electron microscope (Courtesy of P. Dayanandan).

SAQ 5.2

In the following statements choose the correct alternative word given in parentheses.

i) Cell wall is absent in (Phaeophyta/Euglenophyta).

ii) (Chrysophyta/Rhodophyta) are mostly unicellular.

iii) The storage material is paramylon in (Dinophyta/ Euglenophyta).

iv) The algae belonging to (Dinophyta/Bacillariophyta) are called diatoms.

v) The cell wall of (Dinophyta/Chrysophyta) is made of pectin, silica or carbonates.

vi) The algae of Division (Euglenophyta/Bacillariophyta) reproduce sexually.

vii) The cells of (diatoms/dinoflagellates) are diploid.

Table 5.1 : Selected characteristics of the Algal Divisions.

Divisions	Cell Types	Photosynthetic Pigments	Cell Wall Composition	Form of Food storage
Chlorophyta	Both unicellular and multicellular	Chlorophylls *a* and *b*. xanthophylls, carotenes	Polysaccharides or cellulose or cell wall absent	Starch
Phaeophyta	Mostly multicellular	Chlorophylls *a* and *c*. fucoxanthin	Cellulose with alginates	Laminarin (oil)
Rhodophyta	Mostly multicellular	Chlorophylls *a* and *d*, phycobilins	Cellulose or pectin, many with calcium carbonate	Floridian starch
Xanthophyta	Unicellular and multicellular	Chlorophylls *a* and *c*	Cellulose or cell wall absent	Chrysolami-narin
Chrysophyta	Mostly unicellular	Chlorophylls *a* and *c* and fucoxanthin	Cellulose or no cell wall some with silica or calcium carbonate	Chryolami-narin
Euglenophyta	Mostly unicellular	Chlorophylls *a* and *b*, carotenes in genera with chloroplasts	No cell wall; protein – rich pellicle	Paramylon (a starch)
Dinophyta	Mostly unicellular	Chlrophylls *a* and *b* and peridinin (a carotenoid)	Cellulose or cell wall absent	Starch Lipids
Cryptophyta	Unicellular	Chlorophylls *a* and *c*, phycobilins, alloxanthin	Cell wall absent	Starch
Bacillariphyta	Mostly unicellular	Chlorophylls *a* and *c* fucoxanthin	Cell wall silicified	Chrysolamin arin

5.5 SYSTEMATIC POSITION OF SOME GENERA.

Anacystis

Family - Chroococcaceae,
Order - Chroococcales,
Division - Cyanophyta

Microcystis

Family - Chroococcaceae,
Order - Chroococcales,
Division - Cyanophyta

Nostoc

Family - Nostocaceae,

Order - Nostocales
Division - Cyanophyta

Chlamydomonas

Family - Chlamydomonadaceae,
Order - Volvocales,
Division - Chlorophyta.

Volvox

Family - Chlamydomonadaceae
Order - Volvocales,
Division - Chlorophyta.

Ulothrix

Family - Ulotrichaceae,
Order - Ulotrichales,
Division - Chlorophyta.

Ulva

Family - Ulvaceae,
Order - Ulotrichales,
Division - Chlorophyta.

Oedogonium

Family - Oedogoniaceae,
Order - Oedogoniales,
Division - Chlorophyta.

Coleochaete

Family - Coleochaetaceae,
Order - Chaetophorales,
Division - Chlorophyta.

Draparnaldiopsis

Family - Chaetophoraceae,
Order - Chaetophorales,
Division - Chlorophyta.

Ectocarpus

Family - Ectocarpaceae,
Order - Ectocarpales,
Division - Phaeophyta.

Fucus

Family - Fucaceae,
Order - Fucales,
Division - Phaeophyta.

Laminaria

Family - Laminariaceae,
Order - Laminariales,
Division - Phaeophyta.

Polysiphonia

Family - Rhodomelaceae,
Order - Ceramiales,
Division - Rhodophyta.

5.6 SUMMARY

In this unit you have learnt:

- Algae have been grouped into two major types: prokaryotes and eukaryotes because of the basic differences in the ultrastructure of the cells.
- Cyanobacteria or blue-green algae although related to bacteria, are grouped with other algae because of the similarity in pigment composition and presence of oxygenic photosynthesis.
- Eukaryotic algae can be classified into 9 divisions each sharing a large number of common characters. All photosynthetic algae have chlorophyll *a* and β-carotene, but other pigments may vary.
- Three divisions Cyanophyta, Rhodophyta and Cryptophyta have similar phycobilin pigments - blue phycocyanin, and red phycoerythrin, otherwise they are unrelated in any of the other characters.
- Green algae (Division Chlorophyta) are unicellular, colonial and filamentous in forms, motile and free floating. The photosynthetic pigments are chlorophyll *a, b*, β-carotene and xanthophylls. Food is stored as starch. Though euglenoids also contain chlorophyll *a* and *b*, but they are different from green algae.
- Brown algae (Division Phaeophyta) are mostly marine, large, complex usually multicellular, and non -motile. The chlorophylls are masked by brown pigment fucoxanthin. Food is stored as oil and complex carbohydrate - laminarin. The zoospores and gametes are motile.
- Red algae (Division Rhodophyta) are marine, multicellular and filamentous. The chlorophyll is masked by phycobilins. Food is stored as floredian starch. There are no motile cells in the life cycle of the algae.
- Members of Xanthophyta, Chrysophyta, Dinophyta and Cryptophyta are mostly unicellular. They contain chlorophyll *a* and *c* and are collectively called chromophytes
- In Xanthophyta, Chrysophyta and Dinophyta the cell wall is made either of cellulose or is absent. In Euglenophyta and Cryptophyta cell wall is absent.

5.7 TERMINAL QUESTIONS

1. Match the divisions of algae given in column 1 with the colours of algae given below:

a) Rhodophyta	i) Blue - green algae
b) Phaeophyta	ii) Green algae
c) Xanthophyta	iii) Golden brown
d) Chlorophyta	iv) Red algae
e) Chrysophyta	v) Brown algae
f) Cyanophyta	vi) Yellow-green algae

2. List the major divisions of algae and briefly discribe their characteristics.

....

....

....

....

....

....

3. List the divisions of algae in which flagellated motile cells are absent.

....

5.8 ANSWERS

Self-assessment Questions

5.1 a) These include
i) External morphology, ii) ultrastructure, iii) chromosome no,
iv) photosynthetic pigments, v) storage material, vi) DNA homology,
vii) DNA banding, viii) enzymes and isoenzymes, ix) cell wall composition

b) i) glycogen
ii) phycoerythrin
iii) mannitol, laminarin, rarely lipid droplets
iv) absent

c) (i) and (ii)

5.2 i) Euglenophyta
ii) Chrysophyta
iii) Euglenophyta
iv) Bacillariophyta
v) Chrysophyta
vi) Bacillariophyta
vii) diatoms

Terminal Questions

1) a) iv, b) v, c) vi, d) ii
e) iii, f) i

2) Ref. to table 5.1.

3) Cyanophyta, Rhodophyta

UNIT 16 PTERIDOPHYTES : COMPARATIVE MORPHOLOGY AND ANATOMY

Structure

16.1 INTRODUCTION

Now we come to the last group of non-flowering plants, the pteridophytes, included in this course. The most familiar plants of this group are ferns which we commonly see as houseplants, in parks and also in house landscapes alongwith other ornamental plants. Ferns are rather small plants with graceful, often delicate compound leaves. Because of their beauty and difficulty in propagation, they are considered very precious plants.

We had mentioned in earlier course about the water fern *Azolla*. *Anabaena-Azolla* association (LSE-05, Block 4, Unit 15, P 6 and 7) is a source of nitrogen in wetland rice agriculture. There are also medium-sized tree ferns like *Cyathea*. Can you recall *Lycopodium, Selaginella and Equisetum*? These genera also belong to pteridophytes.

In this unit you will study the general characteristics and life cycle of pteridophytes and the structure and morphology of some representative genera.

Scientists got the idea about the early vascular land plants from fossils - the extinct members. *Rhynia* and *Cooksonia* were the simple and most primitive pteridophytes. One of the simplest living members of this group is *Psilotum*.

It is important that you know how fossils are formed. Therefore, we have discussed the formation of fossils and their types in one of the sections.

You know, pteridophytes are vascular plants and they possess root, stem and leaves. All vascular plants possess water- and food- conducting pipelines made up of xylem and phloem tissues, respectively. In different groups of plants, a great variation is found in the relative position and arrangement of xylem and phloem, other associated tissues and in the presence or absence of pith. In pteridophytes a natural gradation in vascular tissues from simple (primitive) to complex forms is observed. The organisation of vascular system observed in different groups is also discussed.

In this unit we have also described the anatomy of stem, root and leaf of various genera to give you an idea of how various forms of vascular organisations evolved.

Objectives

After studying this unit you will be able to:

- list characteristics of pteridophytes,
- outline the life cycle of a typical pteridophyte,
- compare the general features and life cycle of pteridophytes with bryophytes,
- differentiate between different types of fossils,
- give examples of fossil pteridophytes and describe them,
- describe morphology and anatomy of the genera included in this unit,
- distinguish different types of steles,
- distinguish among groups of pteridophytes on the basis of morphological and anatomical characteristics, and
- illustrate distribution of some common pteridophytes in India.

Study Guide

For an easier understanding of this unit our suggestions are listed below:

i) Learn new technical terms used in this unit. It is necessary that you master them for a thorough understanding of the text. A comprehensive glossary is provided at the end of the block, consult it often for the terms that you do not know or are in doubt.

ii) Revise the anatomy of root, stem and leaf.

iii) Read the text along with relevant figures.

iv) Try to draw and label the figures given in the text.

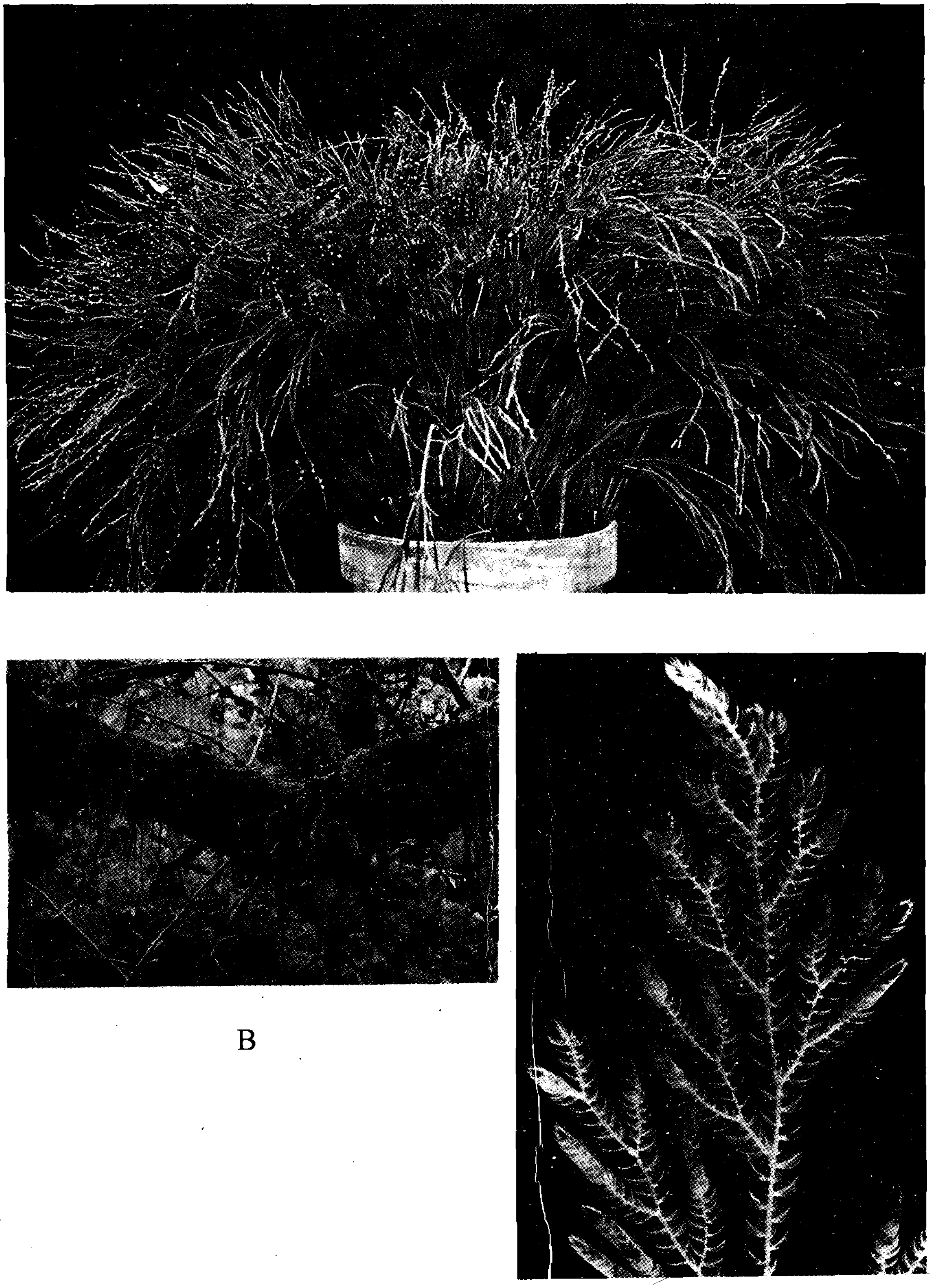
v) While studying the anatomy of various parts of pteridophytes, at times you may find it difficult to observe the described features in the line drawing. When you will do practicals on these genera [LSE-14 (L)], then it would be possible for you to distinguish various features by differential staining.

16.2 PTERIDOPHYTIC LIFE CYCLE

Have a good look at the pictures of some of the pteriodophytes included in Figs. 16.1 and 16.2. They are sporophytes of these plants. Their gametophytes are very small only a few millimetres in size, and are short-lived. Let us first learn about the life cycle of pteridophytes because then it would be easier for us to list their characteristics. Like bryophytes, pteridophytes also have two distinct phases in the life cycle: gametophyte and sporophyte (Fig. 16.3) that follow each other in regular succession. Since the two generations look different, they are termed **heteromorphic**. Under normal circumstances, gametophyte produces motile male gametes (sperms) and non-motile female gametes (eggs). Fusion between an egg cell and male gamete results in the formation of a zygote which is diploid. The zygote divides by mitotic divisions and forms the sporophyte. On sporophyte a number of haploid, non-motile spores are produced by meiosis. The life cycle is then completed when a spore germinates and produces a haploid gametophyte by mitotic divisions, (Fig. 16.3).

You have studied that in bryophytes, the dominant phase in the life cycle is the gametophyte, and the sporophyte is either partially or completely dependent on it for nutrition. But in pteridophytes the sporophyte very soon becomes independent of the gametophyte and is the dominant generation.

The sporophyte shows greater degree of complexity in structural organisation. It is organised into stem, root and leaves, except in the most ancient fossil pteridophytes and in the most primitive living members. The vascular tissues (xylem and phloem) are developed only in the sporophyte. Furthermore, the aerial parts are covered with a layer of cuticle. On the epidermis there are stomata for the exchange of gases. These anatomical complexities of the sporophyte helped in inhabiting a much wider range of environmental conditions than the gametophyte could.



A

B

C

Fig. 16.1: A) ***Psilotum nudum*** **growing in a pot. B)** ***Lycopodium*** **sp. growing as epiphyte on a moss covered tree trunk at 5000 ft elevation in a forest in South India. C)** ***Selaginella*** **sp. with characteristic arrangement of leaves and strobili (Courtsey of P. Dayanandan).**

Fig. 16.2: A) *Equisetum arvense* vegetative and fertile axes. B) *Marsilea* sp. C) Cultivated fern (courtsey of P. Dayanandan).

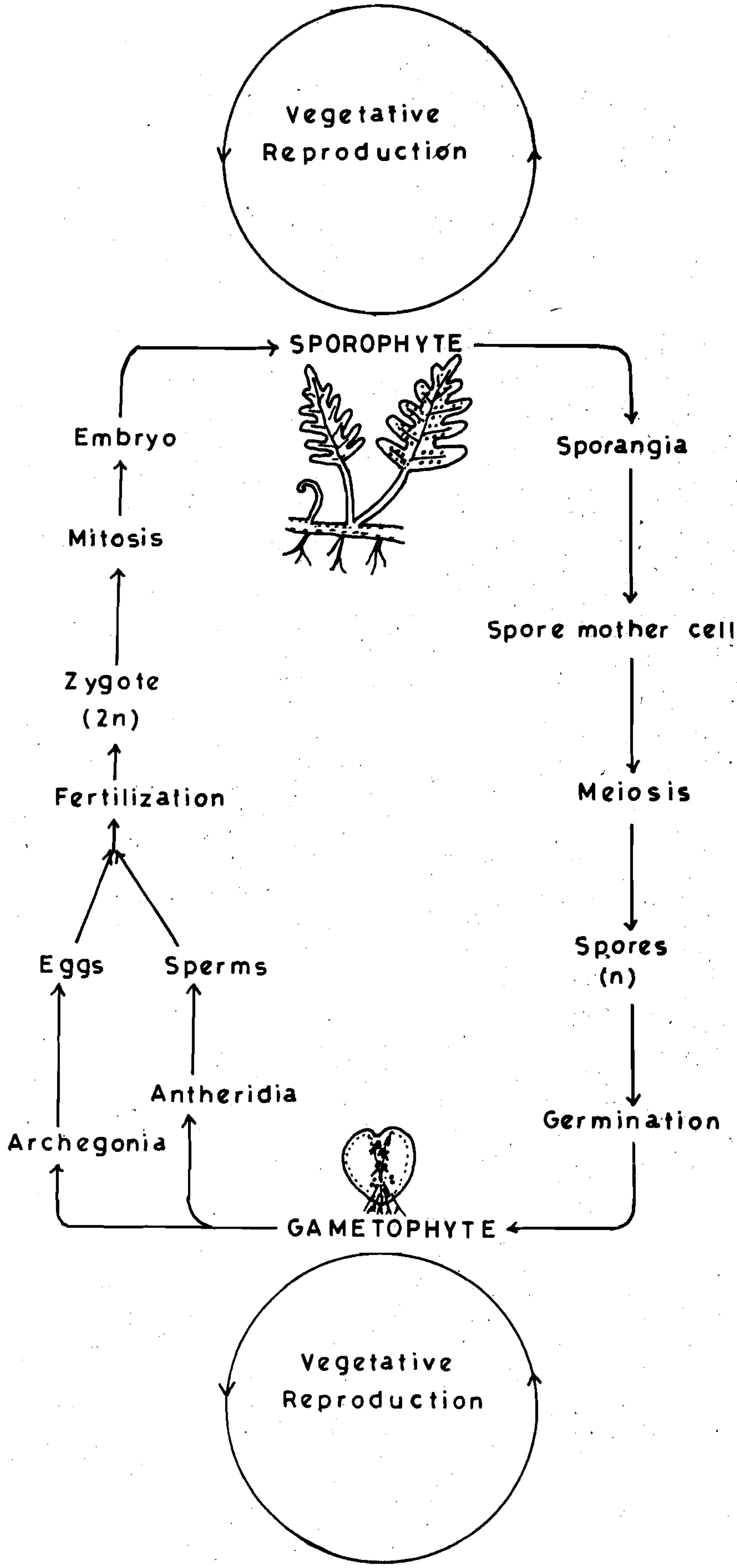


Fig. 16.3: Potential typical life cycle of pteridophytes.

SAQ 16.1

a) Which of the following statements are true or false about pteridophytes. Write (T) for true and (F) for false in the given boxes.

i) The sporophyte is differentiated into stem, roots and leaves. ☐

ii) The gametophyte and the sporophyte are independent at maturity. ☐

iii) Male and female gametes are non-motile. ☐

iv) Sporophyte lacks conducting system. ☐

v) Gametophyte is the dominant phase in the life cycle. ☐

16.3 GENERAL CHARACTERISTICS AND RELATIONSHIP WITH OTHER GROUPS

In the previous section you have learnt that in pteridophytes sporophyte is the dominant phase. It possesses a vascular system and is differentiated into true root, stem and leaves. Pteridophytes exhibit a great variation in form, size and structure.

Now look at Figs. 16.6 to 16.14 and study carefully the morphology of sporophytes and reproductive bodies of various genera before reading any further.

Most of the pteridophytes are herbaceous except a few woody tree ferns. They may be dorsi-ventral or radial in symmetry and have **dichotomously** or **laterally** branched stems that bear **microphyllous** (Fig. 16.1 A, B) or **megaphyllous leaves** (Fig. 16.2 B, C).

The organisation of vascular cylinder (also called **stele,** see box item 1) in the sporophyte varies from simple primitive type to more complex forms. Besides tracheids, vessels are also present in some members (you may like to go through box item 2 on vessels and tracheids).

The roots are generally adventitious, the primary embryonic root being short-lived.

The spores are produced in special structures called the **sporangia** that are invariably subtended by leaf-like appendages known as **sporophylls** (Figs. 17.5 C, 17.7 A, C, Unit 17). The sporangia may be scattered throughout the vegetative axis or may be restricted to a particular area. They are in many cases compacted to form distinct spore producing regions called the **cones** or the **strobili** (sing. strobulus, Figs. 16.8 A and 16.11 A). The sporangia in some cases, may be produced within specialised structures called the **sporocarp** (Fig.16.14 A). Distinct segregation of vegetative and reproductive shoots and leaves has also been observed in some other species. Have you ever noticed brown-black dots on the underside of a fern leaf? Each dot is a reproductive structure called sorus (plural, sori, Fig. 16.13 C). It is a cluster of sporangia that contain spores.

Pteridophytes, in general, are **homosporous** i.e. they produce only one type of spores (Fig. 17.5 B, C). However, a few species are **heterosporous** i.e. they produce two types of spores, **microspores** and **megaspores** (Fig. 17.7 A - D). A spore on germination produces gametophyte. Heterosporous species produce **microgametophyte** as well as **megagametophyte**.

In general, pteridophytes form green, dorsiventrally differentiated, thallose gametophytes with sex organs restricted to the ventral surface. The sex organs may be embedded or projecting. They resemble those of bryophytes in general plan. The female reproductive structure is archegonium and the male reproductive structure is an antheridium.

The archegonium has invariably four longitudinal rows of neck cells whose height varies in different genera. The antheridium consists of a single layer of sterile jacket of cells enclosing a mass of androcytes or antherozoid mother cells. Each androcyte gives rise to a single ciliated, motile antherozoid. The opening of the mature sex organs and the subsequent fertilization is still conditioned by the presence of water. Hence like bryophytes, they could also be called amphibians of plant kingdom.

The development of sporangia can be distinguished into two types: eusporangiate and leptosporangiate. You will learn about them in the next unit.

Now that you have studied the life cycle and the general characteristics of pteridophytes, can you compare them with bryophytes?

What similarities do you find between these two groups? Try to list them below.

1. ....

2. ....

3. ....

4, ...

5. ....

6. ....

Bryophytes resemble pteridophytes in the following features:

1. Thallose liverworts and pteridophytes show similarity in vegetative structure of gametophytes.

2. Their female and male reproductive structures are archegonium and antheridium, respectively.

3. The opening of the mature sexual reproductive organs and the subsequent fertilization are conditioned by the presence of water in liquid state, i.e., both require water for fertilization.

4. They usually show a distinct and clearly defined heteromorphic alternation of generations and the two generations follow each other in regular succession.

5. The spores arise in the same manner in both the groups. The spore mother cells are produced by the last division of the sporogenous tissue. Each of the spore mother cells undergoes meiotic division resulting in a tetrads of spores.

6. Development of embryo occurs in the archegonium.

7. The young sporophyte or embryo is partially parasitic upon the gametophyte.

Now try to list the characteristics which distinguish pteridophytes from bryophytes.

1. ....

2. ....

3. ....

4. ....

5. ....

Compare your points with the following:

1. Unlike bryophytes, in which sporophyte is dependent upon gametophyte physically and physiologically, the sporophyte is independent at maturity in pteridophytes, and is the dominant phase of life cycle instead of gametophyte.

2. In pteridophytes the sporophyte has true roots, stem, and leaves and well developed conducting tissues - xylem and phloem, which are absent in bryophytes.

3. Some of the pteridophytes are heterosporous but all the bryophytes are homosporous.

As mentioned earlier, pteridophytes form an important link between bryophytes and seed plants. This suggests that they also resemble in some respects with spermatophytes.

Pteridophytes resemble seed plants in the following respects:

1. The sporophyte is dominant, typically photosynthetic phase of life cycle.

2. It is organised into stem, root and leaves.

3. The roots and the leafy shoots are provided with a conducting system made of specialised cells.

4. Some pteridophytes do approach seed-habit and some fossil pteridophytes had seed-like structures.

Cryptogams
The plants that do not produce seeds

Phanerogams (flowering plants)
An old term which includes the Gymnosperms and Angiosperm. It is now replaced by the term spermatophyta.

Due to their affinities with bryophytes as well as with higher vascular plants, pteridophytes are also known as "Vascular Cryptogams".

In the above account you have learnt about the characteristics of pteridophytes and their relation to other plant groups. Now we will describe the formation of various types of fossils and how they reveal life forms that occurred millions of years ago.

16.4 FORMATION OF FOSSILS AND THEIR TYPES

You may raise a question as to how can one know "Where, when and from what ancestral group did the first vascular land plant and seed-like structure evolve?" To find the answer to these questions we have to depend on fossils. Let us first try to define a fossil and the ways in which fossils came to be formed. We will also try to know the extent to which they may be expected to provide information useful to the morphologists.

What are fossils?

Fossils are the remains and/or impressions of organisms that lived in the past. In its correct sense fossils include the remains of organisms or their parts and also anything connected with an organism proving its existence, i.e., anything which gives evidence that an organism once lived.

How are fossils formed?

The actual nature of fossilisation depends on the environmental conditions in which it takes place. Dead plant remains are liable to get disintegrated and it is only rarely that they get fossilised. Chances of fossilisation are better for organisms having stiff tissues/skeletons. The details of fossilisation process are discussed below.

Fossilisation Process

The process of formation of fossils is going on ever since the sedimentary rocks began to deposit and it is going on in nature even now.

In some cases plant parts may be deposited on the site where they grow (in situ), such as swamps and small inland lakes. Due to low oxygen content and presence of toxic substances in the water, microbial growth is inhibited, so the plants do not decay. This results in the preservation of the plant remains until they were covered by layers of sediments. European coal forests are the example of this type of fossilisation.

In other cases plant parts are carried down by flowing water and finally sink to the bottom of a lake or estuarine water where they are less susceptible to decay by microbes. Indian Gondwana coal deposits are example of this type of fossilisation.

During fossilisation the protoplasmic contents and softer parenchymatous cells disappear first, while the harder wood and other sclerenchymatous or cutinised tissues resist to the last. The growing pressure of the heavy sedimentary rocks above, first reduces the vacant spaces inside the cells and forces the liquid substances out. Some organic substances may also escape as marsh gas. Naturally, all fossils get highly compressed and the final result depends on how far the conditions were favourable for good fossilisation. In spite of all hazards sometimes fossils are formed, which retain their cellular structure beautifully and sometimes even some of the cell contents.

Types of fossils

According to the nature of fossilisation, fossils may be of the following types:

i) Petrifaction

It is the best type of fossilisation. In this type buried plant material gets decayed with the passage of time and gets replaced, molecule for molecule by mineral solutions. The impregnation of silica, calcium carbonate, magnesium carbonate, iron sulphide takes place within the tissues. Most of the plant material may get decayed but at least some original cell wall components remain. After fossilisation the whole structure becomes stone-like and it can be cut into fine sections (Fig. 16.4 A). The structure of the tissue may be observed by examining the section under the microscope (Fig. 16.4 B). Anatomical structures of ancient plants are beautifully obtained from such petrifactions. Silicified and calcified pieces of wood are quite common.

ii) Cast or incrustation

This type of fossilisation is also quite common. The plant part gets covered up by sand or mud. After sometime the plant material inside degenerates leaving a cavity known as mold. This cavity, again gets filled up by some rock-forming material which in course of time solidifies into an exact cast of the plant material, showing all its surface features (Fig. 16.4 C). A cast fossil does not actually contain any part of the original plant but it is of great use as the cast correctly shows the original features of plant part.

iii) Impression

These are formed when a leaf or any other part of the plant falls on and leaves an impression on the surface of semisolid clay. In course of time this impression becomes permanent when the clay turns into stone. Such impressions often very clearly show details of external features (Fig. 16.4 D), and structures like stomata are clearly seen in good preparations.

iv) Compression

In a compression the organic remains of the plant part actually remain in the fossils but in a highly compressed state. During fossilisation the great pressure of sediments above causes flattening of plant parts. In the fossil usually a carbonaceous film remains which represents the surface features. However, in good compressions it has been possible to swell out the organ by some chemical treatments so that some details become visible. A good type of compressed fossil is the "clay nodule". In this the plant material gets encased in a ball of clay, gets compressed and the clay ball turns into stone. On splitting open this nodule the organic remain is found very much intact, although not as perfectly as in a petrified fossil (Fig. 16.4 E).

Nomenclature of fossils

Mostly, fossils consist of fragments of plants. Sometimes it may take many years to find the fossil of a stem to which a particular kind of leaf belonged. Therefore, in the meantime each fragment of fossil plant is described under a separate generic name and such genera are known as "Form genera". In naming such form genera we usually add suffixes, signifying which part of the plant it came from. Following are a few examples:

	Plant part	Suffix used
a)	Leaf	-phyllum
b)	Fern-like or frond	-pteris
c)	Tree trunk	-dendron
d)	Woody part	-xylon

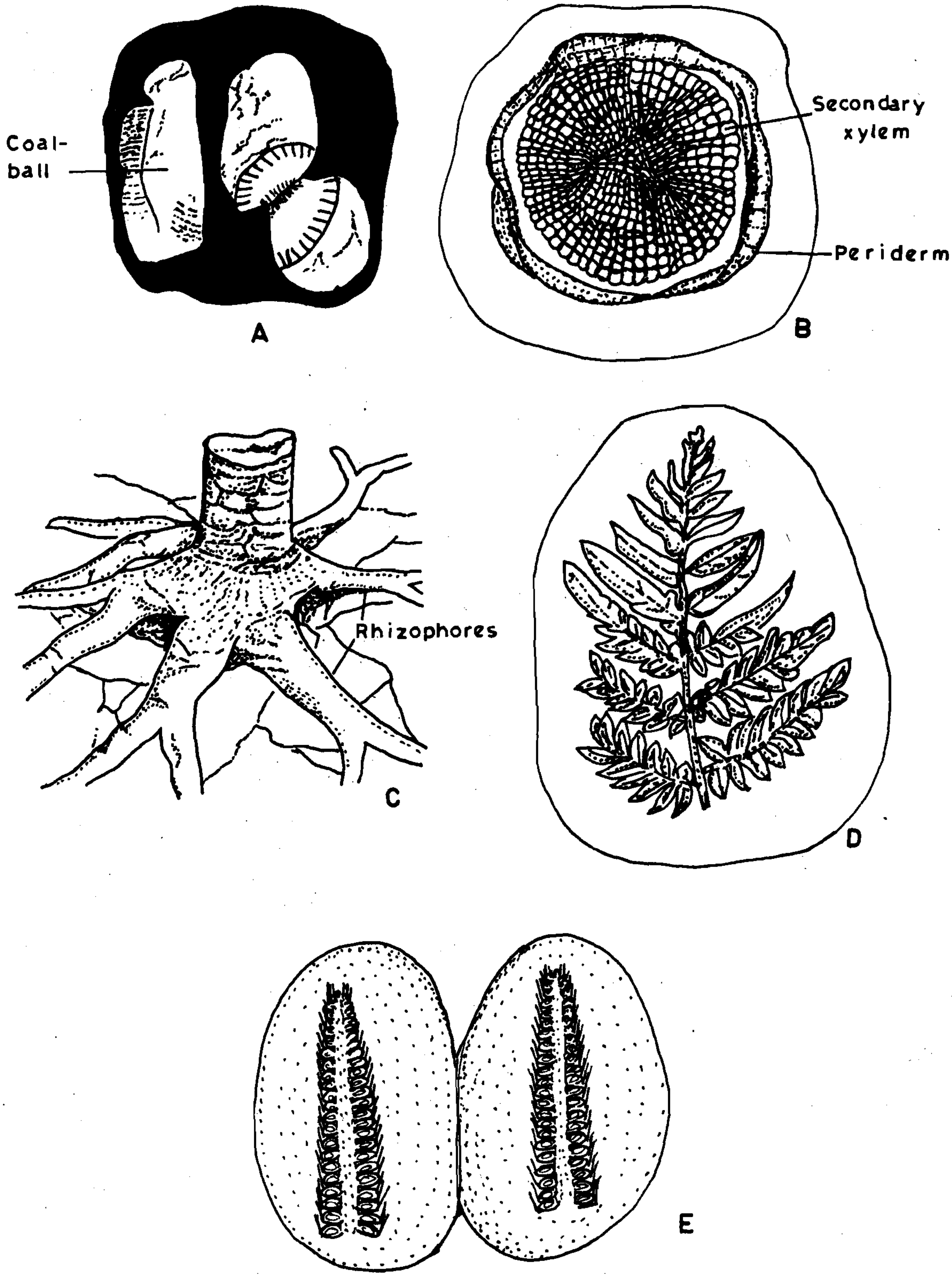


Fig. 16.4 Various types of fossils. A) Section of a coal ball showing petrified stem. B) Section of a coal ball showing T.S. of a petrified *Sphenophyllum* stem. C) Cast of *Stigmaria* (Stump of a Lepidodendroid). D) Impression of *Neuropteris* leaf. E) A clay nodule split open showing a Lepidostrobus cone compression inside.

e)	Seed-like structure	-spermum, -carpon, -carpus, -stoma
f)	Microsporangium	-theca
g)	Cone	-strobilus, -strobus.

It is the work of palaeobotanists to collect bits of such fossils, i.e, form genera, and to reconstruct the form, structure and mode of life of the plant from which they came. Success has been achieved in reconstructing a few fossil plants.

The age of the fossil is ascertained from geological time scale (Fig. 2.7, Block IA).

SAQ 16.2

a) In the following statements fill in the black spaces with appropriate words.

i) A good type of compressed fossil is -------------------- in which the organic materials is found very much intact.

ii) In impression ------------------------ features remain intact.

iii) ------------------------ are formed when plant material degenerates and in its place rock forming substances are deposited.

iv) In -------------------- impregnation of minerals takes place inside the tissue.

b) Match the fossil plant with the suffix used for its naming.

	Plant part	Suffix
i)	Woody part	-pteris
ii)	Microsporangium	-carpon
iii)	Cone	-theca
iv)	Fern-like	-strobilus
v)	Seed-like structure	-xylon.

16.5 MORPHOLOGY AND ANATOMY

As you have noticed in the earlier units on Algae, Fungi and Bryophytes, each of these major plant groups are classified into smaller groups on the basis of distinguishable characteristics. In units 1 and 2 (Page 1 and 37) you have also learnt about the classification of pteridophytes which include ferns and their allies. You may recall the following major divisions of extant and extinct pteridophytes.

Extinct Pteridophytes (known only from fossil records):

Rhyniophyta
Zosterophyllophyta
Trimerophyta

Living Pteridophytes

Psilotophyta
Lycopodiophyta
Equisetophyta
Pterophyta. (= polypodiophyta, Filicopsida)

In the following text we will learn in detail about representative types of some of these classes. As you know that during evolution, advanced, complex forms evolved from primitive simpler forms. So we will first study simple, primitive forms and subsequently the advanced, complex forms.

Before you study this section we advise you to read box item 1 given below. You must understand the following types of stele.

Box Item 1

The term stele is used for the vascular cylinder consisting of xylem, phloem and any associated adjacent parenchymatous tissue in shoot or root. The organisation of stele varies in different groups of plants. The botanists categorize protostele as primitive stele from which are derived other types of stele. Actually an evolutionary sequence of vascular plants is thought of on the basis of type of stele present. One can recognise the type of stele by looking at T.S. of shoot and root. The following are the main types of stele.

Protostele : It is the simplest type of stele. It consists of a central solid core of xylem surrounded by phloem. There is no pith. It occurs in Devonian vascular plants such as *Rhynia*. The variations of protostele are haplostele, actinostele and plectostele.

Haplostele : The xylem is solid in the centre and appears circular in a cross section (Fig. 16.5 A)
Actinostele : The central xylem tissue extends in the form of radiating ridges in a matrix of tissue (Fig. 16.5 B)
Plectostele : Xylem is dissected into many plate-like units (Fig. 16.5 C).
The other type of stele is siphonostele, that is also derived from protostele.

Siphonostele : Unlike protostele, instead of xylem a non-conducting tissue called pith occupies the centre.

On the basis of location of phloem with respect to xylem it is categorised as:

Ectophloic siphonostele : The phloem is on the outer surface of xylem only (Fig. 16.5 D).
Amphiphloic siphonostele : The phloem is on the both external and internal surface of xylem (Fig. 16.5 E). This type of stele is also called **solenostele.**

Dissected siphonostele or Dictyostele - The primary xylem and phloem are arranged in separate vascular bundles (Fig. 16.5 F). Each separate vascular bundle may be completely surrounded by phloemor phloem may be only on the outerside of xylem.

Let us now begin with the most primitive genera which are included in the division Rhyniophyta. You will learn in detail about the following two members of this division: *Rhynia* and *Cooksonia.*

16.5.1 *Rhynia*

The Rhynie chert depositsare thought to be of late lower Devonian age. This bed was discovered by geologist Mackie in 1913. The plants have been thoroughly worked out by Kidston and Lang. Some other plant fossils found in these deposits are *Horneo-phyton lignieri* and *Astero-xylon mackiei.*

Rhyniophytes were the simplest extinct vascular plants. *Rhynia* was discovered from the **Rhynie Chert Bed in Scotland.** These beds are thought to represent a peat bog adjacent to a live volcano. It is believed that 380 million years ago *Rhynia* and other plants grew in marshy environment. The periodic eruptions of the volcano flooded these plants with **silica-rich hot water** that instantly killed them and subsequently infiltrated them. In this way the plants remained preserved, some of them with great perfection. In the proceeding account you will study about the simplest, extinct vascular plant, *Rhynia* in detail. This genus was named after the locality and the two species identified are: *R.gwynne-vaughani* and *R.major*. *Rhynia major* is bigger than the former species (Fig. 16.6 A, B).

The following characteristics are revealed from the study of fossils.

Rhynia gwynne-vaughani, a small herbaceous plant of about 18 cm. height had cylindrical aerial stems and branches arising from a basal rhizome-like portion (Fig. 16.6 A,B). The basal portion was buried in the peat. Not much difference is observed in the structure of the rhizome and the aerial stem except that the rhizome bore at places tufts of rhizoids on its underside. They did not possess roots and the rhizoids performed the dual function - absorption and anchorage. The aerial dichotomously branched stem tapered gradually towards its apex and the aerial shoots ended in pointed tips or bore oval sporangia. Numerous spores can be seen in a L.S. of sporangium (Fig. 16.6 C). Stomata were present all over the surface of the aerial shoots as is shown in line drawing of T.S. of stem (Fig. 16.6 D). Adventitious branches also arose from the aerial shoots.

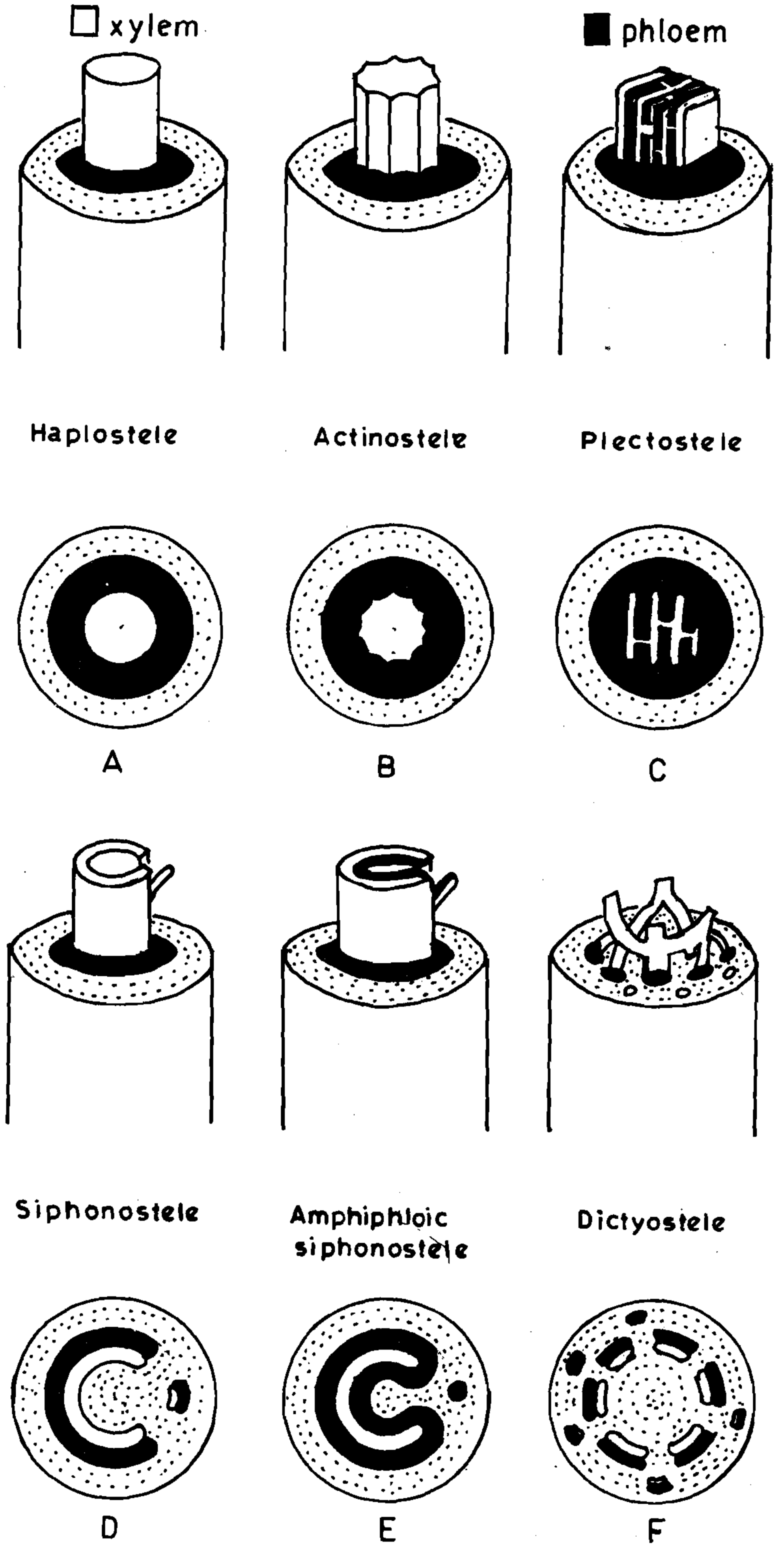
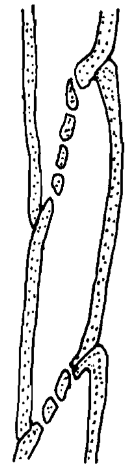


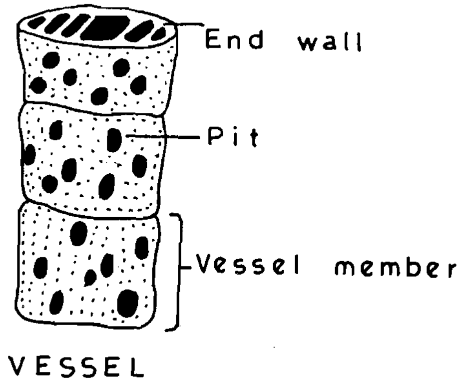
Fig. 16.5: Various types of steles.

Box Item 2

Vessels and Tracheids

The principle water conducting elements in plants are vessels and tracheids. Pteridophytes have mostly tracheids. A tracheid is a long cell with thick secondary walls and tapered ends. Water moves from tracheid to tracheid through pits which are thin, porous areas of the walls. Vessel elements are also elongated and have thick secondary walls. In addition to pits they have large perforations in their end walls. They are joined at their ends to form strong long tubes called vessels.





Internal Structure

Look at drawing of the transverse section of aerial stem in figures 16.6 D and 16.9 A, you will note the following regions.

i) Epidermis - It is the outermost layer and is covered by a thick cuticle. A number of stomata are also present.

ii) Cortex - It is differentiated into a single - layered outer and a multilayered inner cortex. The cells of the outer cortex are larger than those of the inner cortex. The cells of inner cortex have intercellular spaces between them. Note that the intercellular spaces are connected with stomata. The inner cortex was most probably the seat of photosynthesis.

iii) Stele - The centre of the stem is occupied by a very small, simple protostele (Ref. to box item 1) which has a thin cylindrical column of xylem surrounded by phloem. The xylem consisted of only tracheids (Ref. to Box item 2) which had annular and occasionally traces of spiral thickenings. Sometimes, but not always, the tracheids in the centre of the xylem strand were smaller in diameter than those in the periphery. The phloem was made up of elongated thin-walled cells with oblique end walls, but sieve plates have not been found.

16.5.2 *Cooksonia*

This plant had naked, straight and dichotomously branched stem (Fig. 16.6 E-G). Its lower regions are unknown. Five species have been described so far. The largest specimen discovered is about 7 cm long and 1.5 mm wide. The sporangia were terminal, short and wide. They varied in shape from reniform (kidney-shaped) through spherical to oval. Not much is known regarding the anatomy of the stem or the internal structure of the sporangium. Some specimens of *Cooksonia pertonii* from Upper Silurian of Wales show a thin vascular strand of tracheids within the delicate axes. The spores taken out from the sporangia possess tri-radiate marks. These features suggest that they were land plants. *Cooksonia* can be regarded as the earliest vascular plant so far discovered.

So far we have described primitive extinct land plants *Rhynia* and *Cooksonia*. Now we will describe another primitive, but living land plant. It is *Psilotum* of the class Psilotopsida. Before you learn about it, try SAQ 16.3.

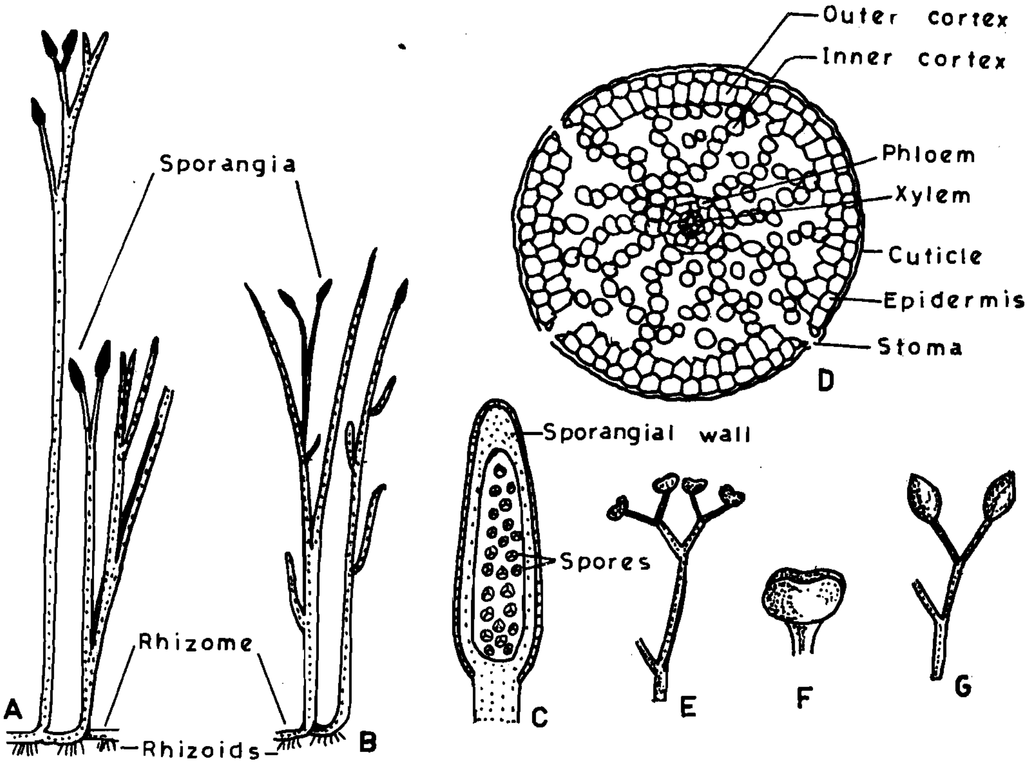


Fig. 16.6 A) ***Rhynia major*** **- note the dichotomous branching and sporangia. B)** ***Rhynia-gwynne-vaughani*****, C) L.S. of sporangium, D) Semidiagrammatic T.S. of an aerial branch of** ***Rhynia*****. E) Portion of plant of** ***Cooksonia caledonica*****, F) Sporangium of** ***C. caledonica*** **showing line of dehiscence, G) Portion of plant of** ***C. pertoni*****.**

SAQ 16.3

a) In the following sentences choose the **correct** word given in parentheses.

i) *Rhynia* was discovered from Rhynie Chert in (Scotland/Ireland).

ii) Rhynie Chert deposits are thought to be of (lower Devonian/ upper Silurian).

iii) The aerial stem in *Rhynia* is (dichotomously branched/ unbranched).

iv) Stele in *Rhynia* stem is (protostele/ siphonostele).

v) In *Rhynia* roots are (present/absent), whereas rhizoids are (present/absent).

b) In the following statements fill in the blank spaces with appropriate words.

i) In *Rhynia* the oval shaped sporangia were present on the ----------------- of the branches.

ii) The spores of *Cooksonia* show ------------- mark.

iii) In *Cooksonia* the lower regions of the plant are -----------------.

iv) Sporangia in *Cooksonia* are ------------------ in position.

c) List two features of *Cooksonia* that reveal it to be a land plant.

....

16.5.3 *Psilotum*

Psilotum

Division - Psilophyta
Class - Psilotopsida
Order - Psilotales
Family - Psilotaceae

Bifid sporophyll

A forked leaf that bears sporangia.

This plant is of great interest to morphologists because it exhibits a stage of organisation scarcely higher than that of some of the earliest, extinct land plants, despite the fact that it is living today. The plant is slender, green, densely tufted shrub about 15-100 cm in height. It grows in tropics and subtropics as an epiphyte on the tree trunks or on rock slopes, with its shoots hanging downwards. When growing on ground or bases of trees, it stands erect.

The plant consists of a subterranean (situated under the earth surface), colourless rhizome, and dichotomously branched, green aerial axes (shoots). True roots are absent. The function of absorption is performed by numerous, 1-3 celled long rhizoids present on the rhizome (Fig. 16.7 A). Associated with rhizome are the mycorrhizal fungal hyphae that reach the cortex.

The aerial axes bear minute scale-like appendages in spiral manner, and distal branches are triangular in outline. Scales are without any vascular trace or stomata. In more vigorously growing shoots the scale leaves in the upper region are replaced by fertile appendages (Fig. 16.7 B). The morphological nature of these fertile appendages has been the subject of much controversy. Some have regarded them as bifid sporophylls, each bearing a trilocular sporangium, but others regard them as very short lateral branches, each bearing two leaves and terminating in three fused sporangia. Apical growth takes place by the activity of a single tetrahedral apical cell.

Box Item 3

There are two species of *Psilotum: P.nudum (P. triquetrum)* and *P. flaccidum.*

P. nudum is found throughout the tropics and subtropics extending as far north as Florida (USA) and Hawaii (USA) and as far south as New Zealand. Most commonly it grows on ground or in crevices among rocks, but it may also grow as epiphyte on other plants. It has been brought in cultivation in green houses and is commonly known as "**Whisk fern**".

P. flaccidum is a much rare plant and occurs in Jamaica, Mexico as an epiphyte with penduous branches.

Internal Structure

Rhizome

The internal structure of rhizome varies with its diameter. Rhizome with a diameter less than 1 mm is composed of mainly parenchyma, while those with larger diameter possess a well developed stele. Look at the T.S. of large diametered rhizome in fig. 16.7 C and try to describe the various zones that can be distinguished.

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You will note the following:

i) In the centre is a solid rod of xylem. It is made of tracheids.

ii) Around the xylem is phloem.

iii) Surrounding phloem is a region of "pericycle" composed of parenchymatous cells.

iv) Next to pericycle is endodermis. It has casparian strips in the radial walls.

v) Epidermis encloses the cortex which has three distinct zones:

a) the innermost cortex (this is dark brown due to the presence of phlobaphene a substance formed by the oxidation and condensation of tannins),
b) the middle cortex consists of parenchymatous cells with abundant starch grains, and
c) the outer cortex contains, in addition, the hyphae of the mycorrhizal fungus.

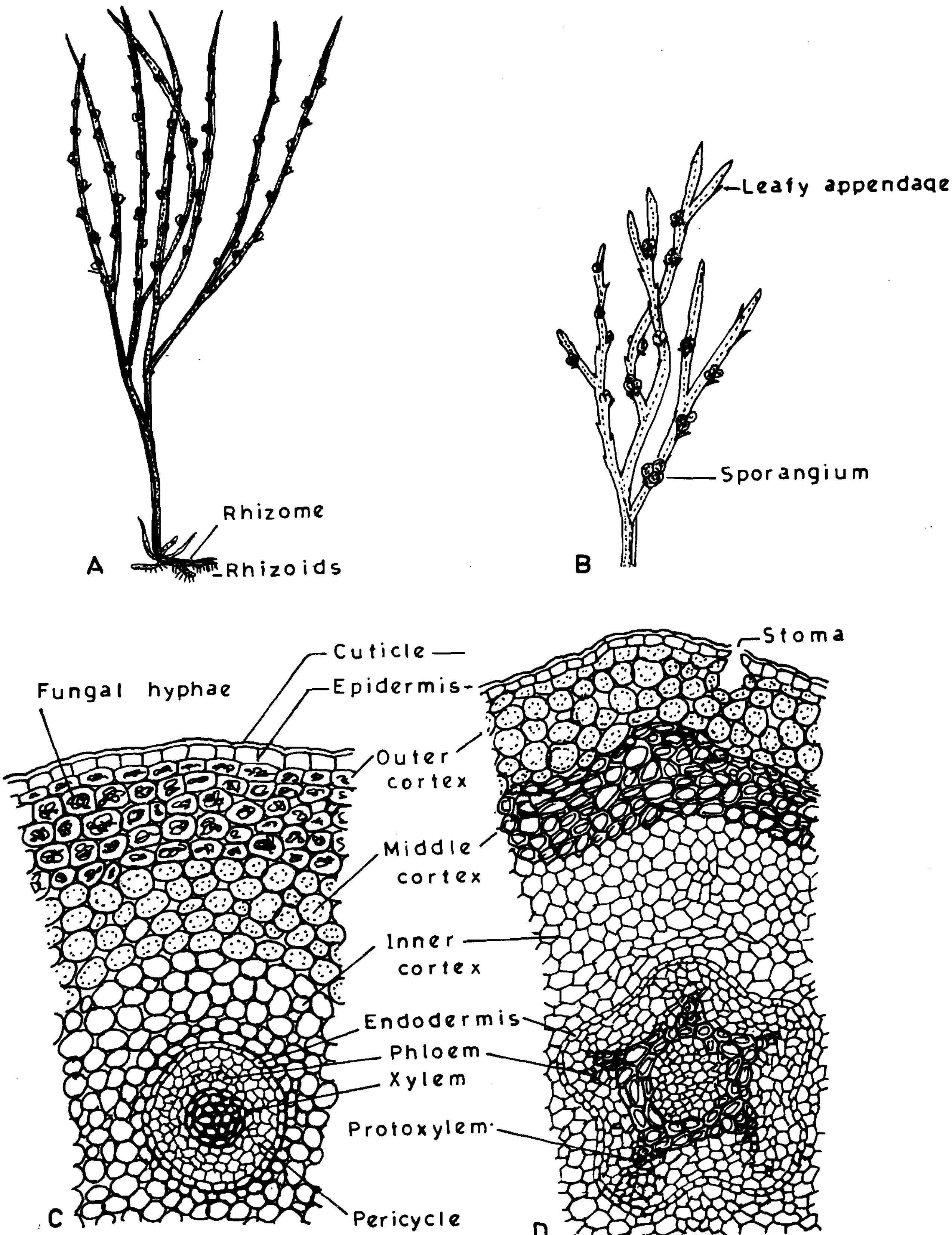

Fig. 16.7: ***Psilotum*: A) A plant of *Psilotum*. B) A portion of the plant enlarged showing leafy appendages and sporangia. C) T.S. of portion of rhizome. D) T.S. of aerial stem near the upper region showing actinostele.**

Aerial Axis

First try to study the T.S. of aerial axis of *Psilotum* (Fig. 16.7 D) and compare it with that of *Rhynia* (Fig. 16.6 D). Now indicate which of the characteristics listed in the table below are present (+ sign) or absent (-sign) in the two genera.

Features	*Rhynia*	*Psilotum*
Cuticle		
Epidermis		
Cortex		
Outer cortex		
Middle cortex		
Inner cortex		
Pericycle		
Endodermis		
Phloem		
Protoxylem		
Metaxylem		
Pith		

In aerial axis the internal structure of vascular cylinder varies all along its length. The basal part shows a **protostele.** In the upper portion stelar organisation becomes **siphonostelic** due to appearance of sclerenchymatic pith. Xylem is exarch and stellate or star-shaped (Fig. 16.7 D). It may be pentarch to octarch in the main axis and triarch or diarch in the distal region. (You may like to go through box item 4 before reading further).

According to the position of protoxylem with respect to metaxylem various arrangements are observed in the stele. Xylem is surrounded by poorly developed phloem which is enclosed by pericycle. As usual the endodermis is present outside the pericycle and the cells of the endodermis have casparian strips in radial walls.

Cortex may be differentiated into - outer, middle and inner cortex (Fig. 16.7 D). The cells of the innermost cortex contain phlobaphene. It is followed by a parenchymatous zone, without intercellular spaces, and the zone next to this is composed of sclerenchymatous cells. The outermost cortex comprises vertically elongated chlorophyllous cells. Small intercellular spaces present in this region are connected to the atmosphere through stomata in the cutinized epidermis. The stomata are slightly sunken, confined to furrows and are with small substomatal chambers. As the plants lack leaves this zone of cortex is photosynthetic in function.

SAQ 16.4

a) List the primitive characteristics of *Psilotum* that indicate its close affinity with *Rhynia* and *Cooksonia.*

....

....

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....

....

Box Item 4

Monarch: Stele in which there is only one xylem group and the protoxylem (the first formed elements of primary xylem) in situated towards the periphery.

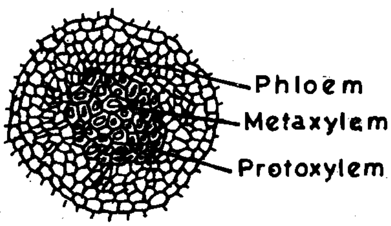
Diarch: Having two protoxylem groups.

Tetrarch: In this condition there is a large axial metaxylem (the later-formed xylem) element with four protoxylems equidistantly arranged around it.

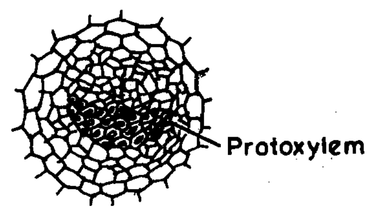
Endarch: In this condition protoxylem is directed towards the centre of the axis; the metaxylem therefore develops away from the centre (centrifugal xylem)

Mesarch: In this condition formation of both centripetal and centrifugal xylem takes place and the protoxylem lies in the centre.

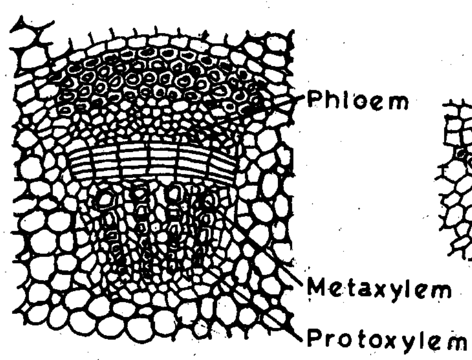
Exarch: In this type of xylem, protoxylem in directed away from the centre of axis, the later-formed xylem therefore develops towards the centre i.e. centripetal xylem is formed.



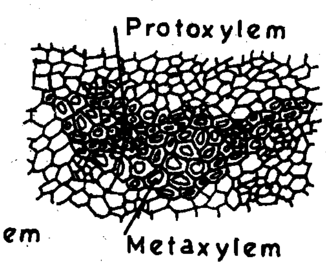
Monarch



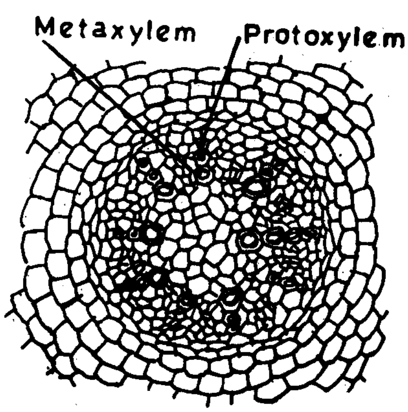
Diarch



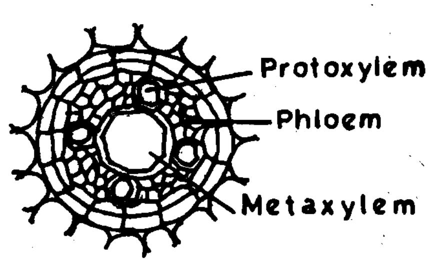
Endarch



Mesarch



Exarch



Tetrarch

b) Which of the following characteristics are true for *Psilotum*?

i) It is a fossil plant.

ii) It is a densely tufted shrub.

iii) The leaves perform photosynthesis.

iv) It possess true roots.

v) Mycorrhizal hyphae associated with rhizome help in absorption of water and nutrients.

vi) The stele in the upper region of aerial axis has pith.

vii) It is one of the earliest living land plants.

Now you will learn about another group of pteridophytes commonly known as "club mosses". Botanically, they are members of the genus *Lycopodium* belonging to the Division Lycopodiophyta.

16.5.4 *Lycopodium*

Lycopodium

Division - Lycopodiophyta
Class - Lycopsida
Order - Lycopodiales

Lycopodium, popularly known as **club moss,** is a large genus with about 180 species of which approximately 33 species are found in India. They are distributed world-wide in tropical, sub-tropical forests and in temperate regions. Some species are abundant in hills at comparatively high altitude. They grow in cool climate on moist humus-rich soil.

Decussate - x-shaped, with pair of opposite leaves each at right angles to the pair below.

The adult sporophyte is herbaceous and with a wide range of habits. Generally in tropics they are pendulous epiphytes, whereas in temperate regions they are prostrate or erect.(Fig. 16.8 A, B, C). They usually grow about 30 to 60 cm in length. The stem may be unbranched or dichotomously branched which later becomes monopodial. It is covered with microphylls which in most species are spirally arranged. However, in some species leaves are arranged in whorled or decussate manner (Fig. 16.8 D-G).

Apical growth occurs by means of an apical meristem i.e., a group of cells undergoing periclinal and anticlinal divisions.

Internal Structure

Aerial Axis

First try to study figure 16.8 I-K showing T.S. of stele, of *Lycopodium*. Can you identify the types of stele?

I. ....

J. ....

K. ....

Lycopodium

Terrestrial species
L. cernuum
L. clavatum
Epiphytes with pendent branches
L. squarrosum
L. phlegmaria
All are common in North-East India.

In all the species, during sporeling stage, stele is composed of a single rod of xylem with radiating arms, commonly four in number. However, stelar organisation varies at maturity in different species due to the xylem splitting up into separate plates or into irregular strands. However, species like *Lycopodium serratum* retain simple stellate four to six radiating arms of xylem (Fig. 16.8 I). Alternating with the xylem arms are the regions of phloem, which are separated from xylem by parenchyma, and this whole structure is surrounded by parenchymatous pericycle followed by endodermis. *Lycopodium clavatum* has a number of horizontal plates of xylem, alternating with plates of phloem (Figs. 16.8 J and 16.9 B,C). This process of elaboration has gone even further in *L. cernnum,* where xylem has become spongy with phloem and parenchyma filling the holes (Fig. 16.8 K). Throughout the genus, the stele is exarch. The endodermis is clearly recognisable in young stem only.

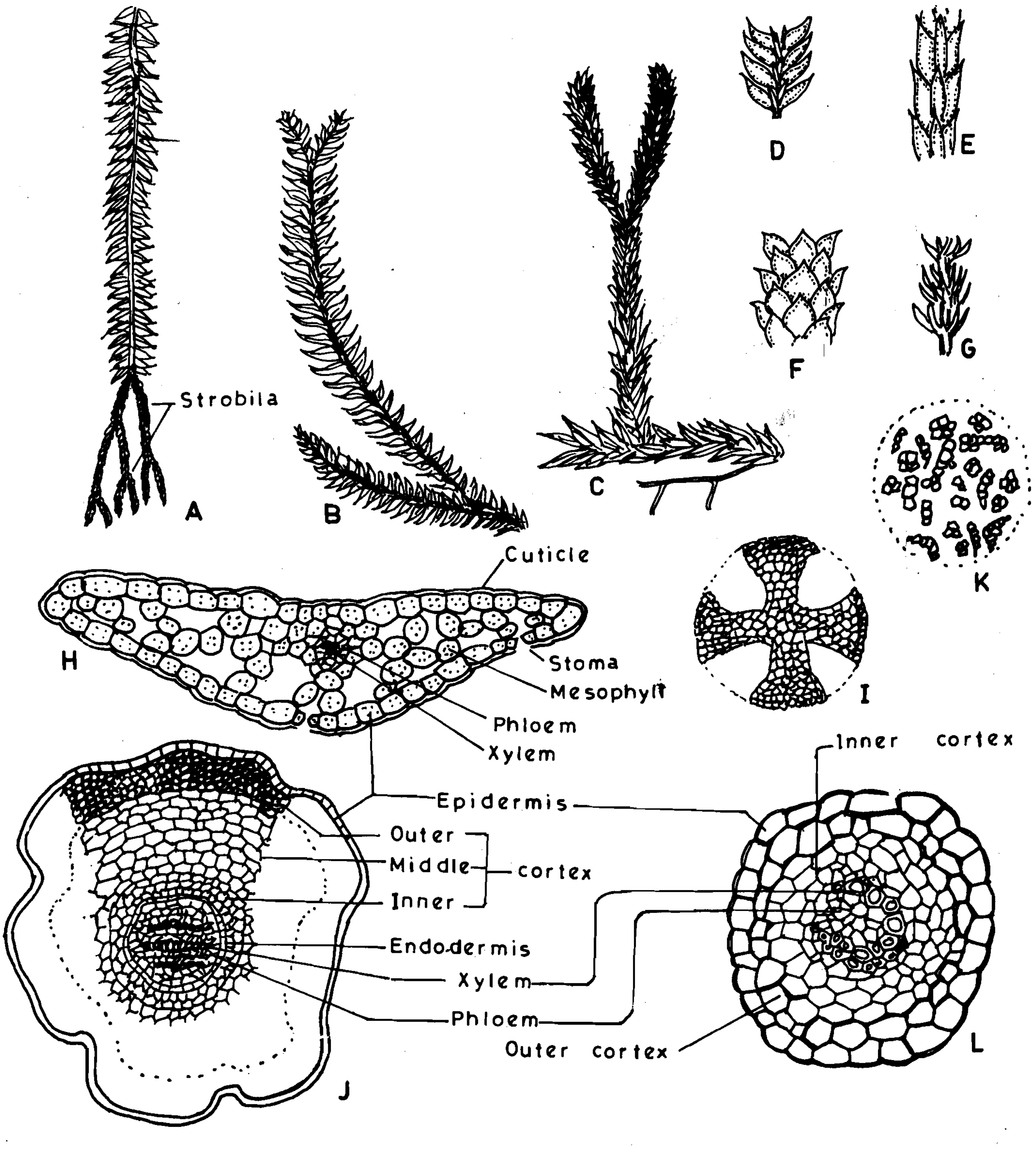


Fig. 16.8: ***Lycopodium*: A-C) Portion of plant of *Lycopodium phlegmaria, L. volubile* and *L. clavatum* respectively. D-G) Leaf form and arrangement in different species. H) T.S. of leaf. T.S. of stem of three species I) *L. serratum.* J) *L. clavatum.* K) *L. cernuum*. L) T.S. of root.**

Leaves

Look at figure 16.8 H. Each leaf receives a single trace, which continues into the leaf as a single unbranched vein composed entirely of spirally thickened tracheids. The epidermis is covered with a layer of cuticle. Most of the space of leaf is occupied by mesophyll cells. Stomata are present in the epidermis of the stem and in the leaves whereas, in some species, they are on both the surfaces (amphistomatic) and in others, only on the underside (hypostomatic).

Root

The roots are adventitious and show varying degrees of similarity to stems. They arise from the pericycle and branch dichotomously. They are provided with a root cap and bear paired hairs (a most peculiar arrangement). Look at xylem in figure 16.8 L. In majority of plants xylem is diarch crescent-shaped but in some species like *Lycopodium clavatum* the stele of the roots is very similar to that of the stem.

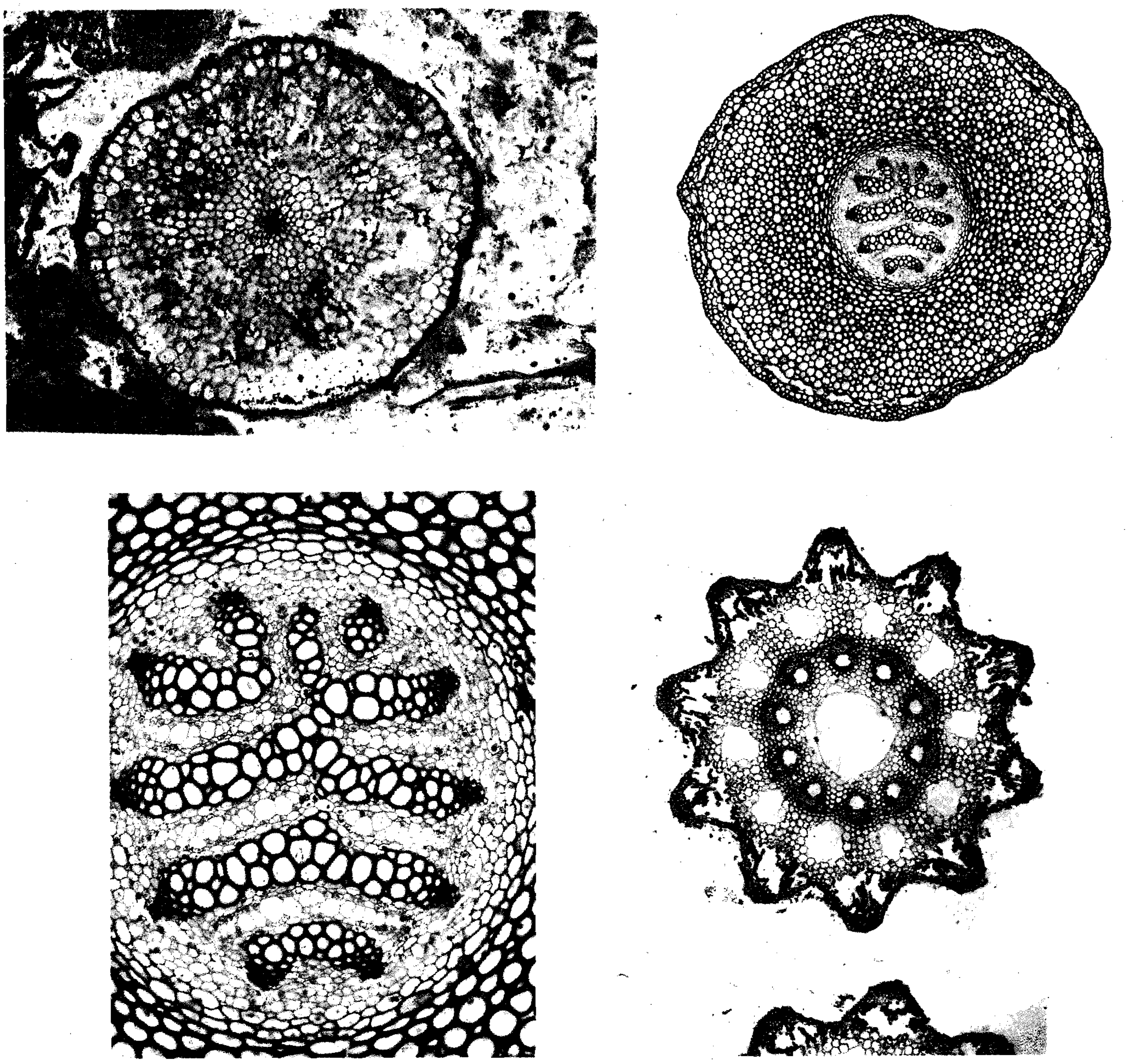


Fig. 16.9 Cross section of stem. A) *Rhynia*, B) *Lycopodium*, C) B enlarged, D) *Equisetum* (Courtsey of P. Dayanandan).

SAQ 16.5

a) Which of the following characteristics are true and which are false about *Lycopodium*?

i) The plant may be erect, semi-erect or epiphyte.

ii) It bears scales; true leaves are absent.

iii) Xylem in the root is tetrarch.

iv) It bears microphylls.

v) Root hairs are in pairs.

vi) In mature stem xylem may split into plate-like structures.

16.5.5 *Selaginella*

Selaginella

Division - Lycopodiophyta
Class - Isoetatae
Order - Selaginellales.

Most of the species of *Selaginella* are restricted to damp areas of the tropical and subtropical regions of the world. A few species are markedly xerophytic and inhabit desert regions. These are sometimes called "resurrection plants" because of their extra-ordinary power of recovery after prolonged drought. The plant may be prostrate, erect or sub-erect. Only a few are epiphytic. Some form delicate green mossy cushions, others are vine-like, with stems growing to a height of several metres, while many have creeping axes, from which arise leafy branch systems that bear a striking superficial resemblance to a frond of fern.

Branching in *Selaginella* is characteristic, terminal and unequal, forming weaker and stronger branches. At each dichotomy there are one or two meristems on either side. These angle-meristems develop into cylindrical outgrowths known as "rhizophores" (Fig. 16.10 A). In most species only the ventral angle-meristem develops into rhizophore, while the other remains as dormant papilla. The rhizophores grow downwards into ground and give rise to a small tuft of adventitious roots at their tips.

The morphological nature of rhizophore has been controversial. It has been held to be a (a) root, (b) a branch of stem, and (c) a structure *sui generis* (falling in neither of the categories). Earlier investigators reported a unique combination of characters of rhizophore:

i) exogenous origin from the stem at the time of branching,

ii) lack of root cap,

iii) production of roots endogenously behind the tip, and

iv) ability, in some instances, to be converted into leafy shoots. Since these features are not typical of root these outgrowths are called rhizophores.

The features suggestive of their root nature are:

Geotropism

The growth of part of a plant due to the influence of gravity.

(i) positive geotropism,

(ii) anatomical organisation (Fig.16.10.H), monarch xylem, and

(iii) in some species when these structures are less than 1 mm. the root cap develops , In *S. martensii* cap differentiates when it nears the soil.

Using labelled auxin (C^{14} IAA) it has been shown that auxin transport in rhizophores of *Selaginella* is acropetalous as in case of angiosperms root, whereas it is basipetalous in stems. Therefore, now the term "rhizophore" as well as the arguments regarding its nature are of historical significance.

In *Selaginella* the leaves are sessile with a single unbranched vein (Fig. 16.10 A). Leaves of *Selaginella* are **ligulate**. The ligule is present in or near the axil of each leaf as a laminate outgrowth (Fig. 16.10 B). It differentiates and matures very early in the ontogeny of leaf. A mature ligule is tongue-to fan-shaped. Its basal region is made up of tubular, hyaline cells forming the sheath. Below the sheath is a hemispherical region of thin and greatly vacuolate cells referred to as **glossopodium**. The remaining cells are isodiametric. The apical region is one cell thick and is made up of elongated cells with scanty contents.

The following are the functions of the ligule:

(i) conservation of water and thereby preventing shoot desiccation, and

(ii) upward movement of inorganic salts by compensating for smaller and less effective leaf primordia.

This genus is divided into two sections:

i) **Homophyllum section**-species included in this section are isophyllous and have spirally arranged leaves e.g. *Selaginella rupestris.*

ii) **Heterophyllum section** - species included in this section exhibit markedly dorsi-ventral symmetry and anisophylly. The leaves are arranged in four rows along the axis, two rows of small leaves attached to the upperside and two of the larger ones attached laterally. The fertile regions, however, are isophyllous and the cones are four-angled, which make them very clearly distinguishable from the vegetative regions.

Apical growth in *Selaginella* takes place by a single cell and its derivatives or by an apical meristem comprising a group of cells.

The primary root is short-lived and roots are adventitious. In most of the species, delicate and sparingly branched structures which develop at the distal ends of "rhizophores" are described as roots.

Internal Structure

Leaf

Look at the T.S. of leaf (Fig. 16.10 C) and try to describe the various zones.

....

....

....

....

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....

You will mark the following details,

i) Upper epidermis is one cell in thickness. In some species the upper epidermis consists of conical cells with very large chloroplasts, but there are no stomata.

ii) Lower epidermis is also one cell in thickness. Stomata are generally restricted to this layer.

iii) Mesophyll cells between upper and lower epidermis are usually composed of similar cells, more or less elongated, with intercellular spaces. All the cells of mesophyll contain chloroplasts (Fig. 16.9 D).

Chloroplasts vary in number and shape in different species. In the centre of each chloroplast there are many spindle- shaped, pyrenoid-like bodies, each of which may be transformed into a rudimentary starch grain.

iv) Note the single median vascular bundle in the middle. They are concentric, and leaf traces join the stele of the stem. The xylem consists of four to five tracheids, one of which is annular and 3 or 4 are spiral ones. Surrounding the xylem is a layer of phloem composed chiefly of elongated narrow parenchyma cells, and sieve cells. Outside the phloem is a single-layered bundle-sheath.

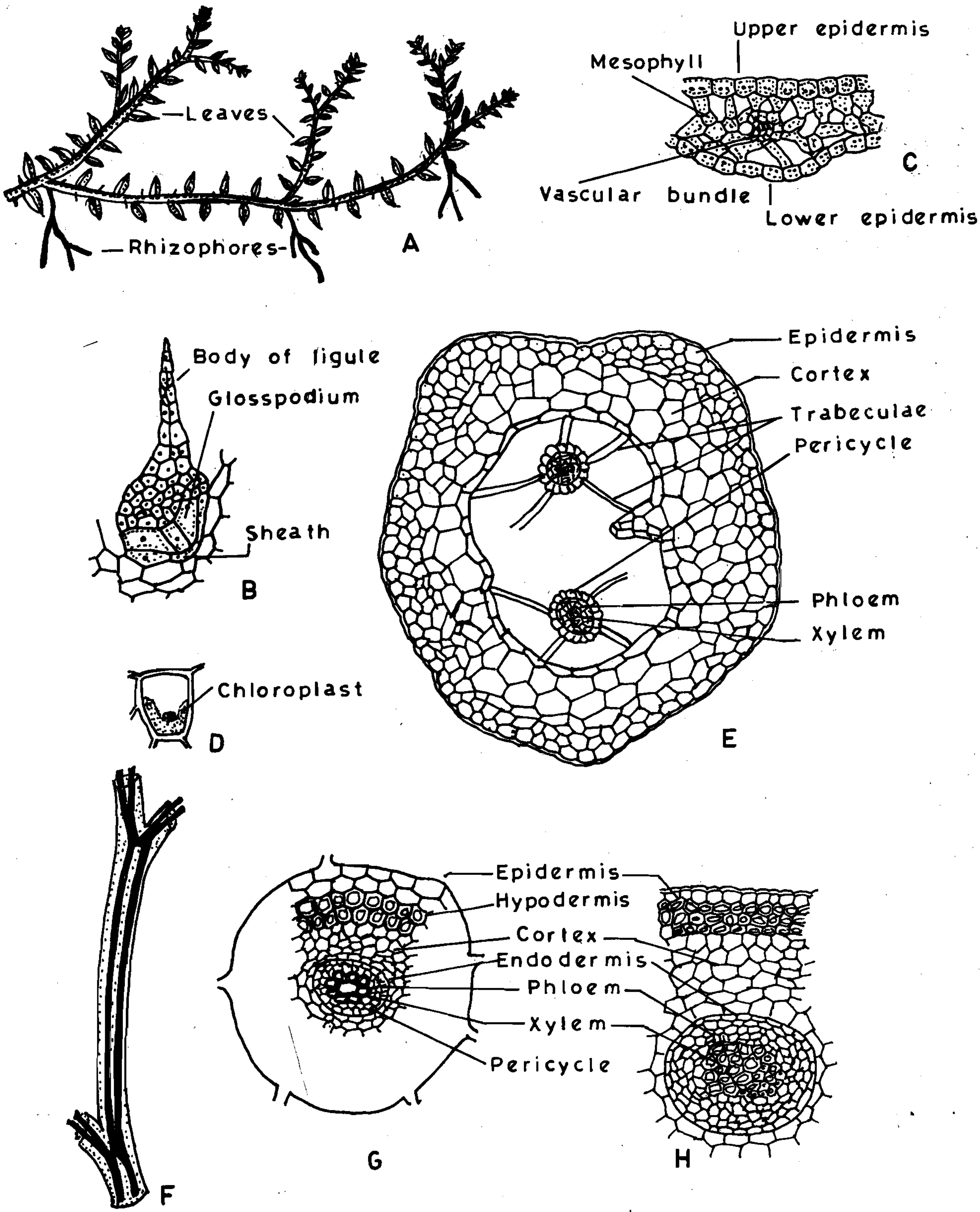

Fig.16.10: ***Selaginella*** **A) Portion of a plant. B) T.S. of a part of leaf. C) L.S. of mature ligule. D) A cell of mesophyll showing single chloroplast and nucleus. E) T.S. of stem F) A portion of stem cleared showing the vascular tissue. G) T.S. of root. H) T.S. of rhizophore.**

Stem

Look at fig. 16.10 E. Which of the zones can you distinguish in the transverse section of the stem? Write them below:

....

....

....

....

....

....

You can note the following:

i) **Epidermis** - thick-walled cells covered with cuticle.

ii) **Cortex** -composed of angular cells without inter-cellular spaces. In larger stems the cells of outer region are sclerenchymatous.

iii) **Stele** - It is separated from the cortex by a few radially elongated endodermal cells with casparian strips. These are termed as **trabeculae.**

Young plants invariably have single stele (monostelic). In adult forms the number of steles varies from two to sixteen (Fig. 16.10 F). Stele is circular or ribbon-shaped in outline, depending upon the species, it may be protostelic or siphonostelic with exarch protoxylem. It is bound by one-cell thick pericycle. Xylem is surrounded by two or three layers of parenchyma and outside this is a single layer of sieve tubes all around except the region radial to the protoxylem. In some isophyllous species true vessels occur. Large bundles in stems of *Selaginella* reveal both mesarch and exarch conditions. It depends on the level within the stem and the particular pole of maturation observed.

Root and Rhizophore

Now study the transverse section of the root and rhizophore of *Selaginella* (Fig.16.10, G, H). You can distinguish the following regions:

i) **Epidermis** - It is composed of large cells from which the root hairs arise.

ii) **Cortex** - It may either be wholly made up of thin-walled parenchyma, or there may be a hypodermis of three to five layers of sclerenchymatous cells and rest of the cortex may be thin-walled.

iii) **Endodermis** - This layer in most of the species is not well defined.

iv) **Pericycle** - It is composed of two to three layers.

v) **Stele** - It is monarch, exarch, i.e. there is only one phloem and one xylem group and the protoxylem is situated towards the periphery. The phloem more or less surrounds the xylem.

SAQ 16.6

(a) In the following sentences fill in the blanks with appropriate words:

i) *Selaginella* is called .... plant because it can recover after a prolonged period of drought.

ii) The function of ligule is to .... water and help in the upward movement of ....

iii) Tufts of adventitious roots develop from ....

iv) The cortex and central tissue of the stem is connected by elongated endodermal cells known as ....

(b) Define:

Microsporophyll, megasporophyll, ligule, sessile, rhizophore, trabeculae.

(c) Which of the following statements are true and which are false? Write **T** for true and **F** for false.

i) In stemof *Selaginella* trabeculae are formed by pericycle. ☐

ii) In *Selaginella* stem branching is dichotomous. ☐

iii) Roots are adventitious in *Selaginella.* ☐

iv) Rhizophores are found in *Lycopodium.* ☐

v) Leaves are ligulate in *Selaginella.* ☐

vi) Auxin transport in rhizophore of *Selaginella* is acropetalous. ☐

16.5.6 *Equisetum*

Equisetum

Division - Equisetophyta
Class - Equisetatae
Order - Equisetales

The genus *Equisetum* is popularly known as horsetails. This is the only representative genus of this class that is alive today. It is distributed throughout the world except Australia and New Zealand. All the species are herbaceous and perennials. In all species there is a horizontal, underground rhizome from which arise erect, aerial axes that branch profusely in some species, or remain quite unbranched in others (Fig. 16.11 A). The aerial shoots are usually annual but may be perennial. They range in height from only a few centimetres (15 cm) to several metres, but most of the species are not more than one metre in height. In *E.giganteum*, which grows in tropical America, the aerial branches may reach a maximum height of about 13 metres, but are relatively slender being less than 2.5 cm in diameter.

Leaves in *Equisetum* are very small, simple, uninerved, slender and scale-like. They are usually without chlorophyll, photosynthesis being carried out entirely by the green stems. They are arranged in whorls and are more or less fused laterally at their bases into a sheath, closely enveloping the base of the internode, with longer or shorter tooth-like free tips.

The stem is differentiated into nodes and internodes (Fig. 16.11 A) and is ridged. Each ridge corresponds to a leaf in the above internode and the ridges in successive internodes alternate with one another. At each node the branch primordia are equal in number to the leaves, and alternate with them. In some species all the branch primordia develop into branches with the result that there is a regular whorls of branches at the nodes.

Internal Structure

Stem

Look at Fig. 16.11 B, showing anatomy of stem of *Equisetum* and compare it with that of *Selaginella* in Fig. 16.9 E. Try to list below the special features of both the plants.

Equisetum	***Selaginella***

....

....

In a transverse section through an internode of an aerial branch the following zones can be distinguished (Figs. 16.9 D and 16.11 B,C):

i) **Epidermis** - This single layer is composed of elongated cells which have thick and undulated walls. These cells are heavily incrusted with silica which makes the surface rough. Stomata are restricted to the furrows between the ridges and are deeply sunken into pits whose openings may be partly covered by a layer of cuticle (Figs. 16.11 E, F). Characteristic rib-shaped silicious thickenings are present between the subsidiary and guard cells.

ii) **Cortex** - In fig. 16.11 B you may note that the cortex can be divided into outer and inner cortex. The outer cortex is differentiated into two types of cells.

Sclerenchymatous cells - These are present below the ridges. They occur in large and heavy groups. There is an equal number of smaller groups of sclerenchyma beneath the epidermis of the furrows but are absent beneath the stomata (Fig. 16.11 C).

Chlorenchymatous cells - These lie lateral and below the sclerenchyma forming a curved band and form the assimilatory region of the stem (Fig. 16.11 C).

The inner cortex consists of a few layers of larger parenchyma. In this region very large air spaces are present and these spaces are known as vallecular canals (Figs. 16.11 B, C). Each of these lies below the furrow of the external surface and is thus close beneath the photosynthetic tissue.

iii) **Vascular Bundles** - They lie beneath the ridges of the stem and have characteristic appearance (Fig. 16.11 C). Xylem is endarch and protoxylem is replaced by a **carinal canal**, formed by the dissolution of protoxylem elements. Phloem lies on the outerside of each carinal canal and on the same radius. On both sides phloem is surrounded by metaxylem. In some species each internodal bundle is surrounded by its own separate endodermis, in others there is a single endodermis running round the stem outside all the bundles, while in yet some other species there are two endodermis, one on the outer side the other inside all the bundles.

iv) **Pith** - A large pith cavity is present in the centre.

At the nodes xylem forms a continuous cylinder from which the leaf traces and branch traces arise. Vallecular canals occur in this region but carinal canals are absent.

This type of arrangement of air channels in addition to a very reduced vascular tissue, are features commonly found in aquatic plants. In contrast, thick cuticle, sunken stomata and reduced leaves are characteristics of **xerophytic** plants.

So you can see that the anatomy of the stem of *Equisetum* presents an interesting combination of xeromorphic and hydromorphic characters, together with a vascular system which is unique in the plant kingdom, and its correct morphological interpretation has long been the subject of controversy.

Root

Roots which are apparently borne on a horizontal rhizome, are in fact borne by the axillary buds hidden within its leaf sheaths. Now study the T.S. of root (Fig. 16.11 D), and write down the various zones you can recognise.

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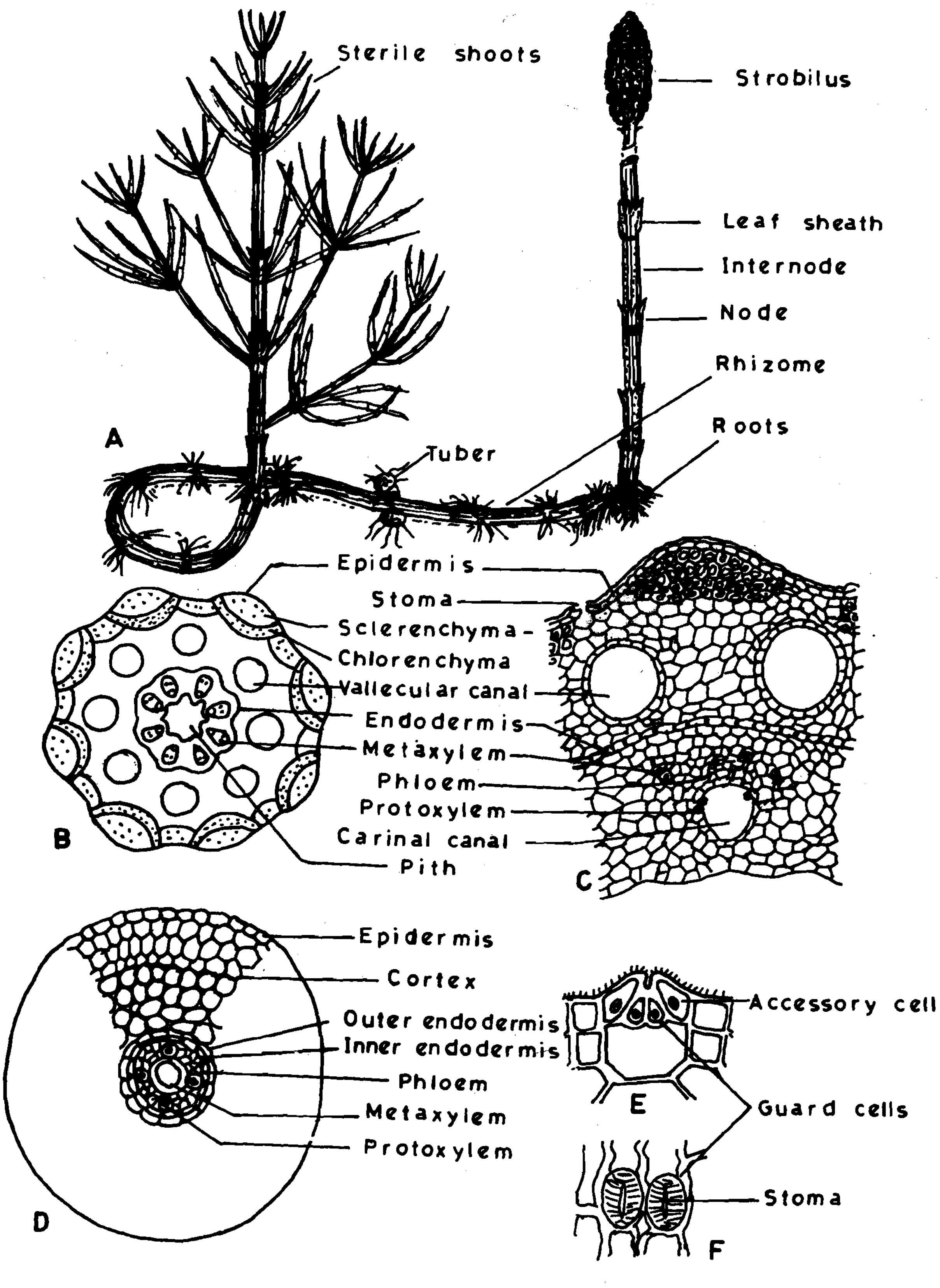


Fig. 16.11: ***Equisetum*** **: A) Portion of a plant. B) Semidiagrammatic T.S. through an internode of aerial sterile branch. C) Portion of B enlarged. D) T.S. of root. E) V.S. of stoma. F) Top view of leaf showing epidermis, stoma and thickenings.**

Epidermis - It is a single layer of cells.

Cortex - It is composed of several layers of parenchymatous cells. The cortical cells beneath the epidermis may be thick- walled and lignified. In some species the larger roots possess air spaces in the inner cortex.

Endodermis - It is one celled thick and the cells have casparian strips.

Stele - It is diarch, triarch or tetrarch and the xylem is exarch.

SAQ 16.7

a) Which of the following statements are True and which are False? Write **T** for true and **(F)** for false in the given boxes.

i)	Plants of *Equisetum* are annual.	☐
ii)	Leaves are alternatively arranged.	☐
iii)	Aerial system in *Equisetum* is differentiated into nodes and internodes.	☐
iv)	Stem shows ridges and furrows.	☐
v)	Stomata is *Equisetum* are not sunken.	☐
vi)	Vallecular canal is present below the ridge.	☐

b) Draw and label a T.S. of *Equisetum* stem and list its special features.

c) Explain the following terms:

Vallecular canal, carinal canal, endarch, xeromorphic, hydromorphic

The plants you have studied in the preceding account are known as Fern-allies. Now we will learn about "True ferns". They are included in the Division Pterophyta or Filicophyta. The ferns are the largest group of non seed-producing vascular plants. There are about 9,700 species of ferns. Most ferns are rather small plants and quite a few of them are grown indoors as house plants and in parks and house landscapes. A few ferns are medium- sized trees.

Ferns are adapted to a variety of habitats. They occur in Northern arctic region as well as in drier regions. Most of them are terrestrial but some grow as epiphytes on moist tree trunks. You are familiar with the aquatic fern *Azolla*. In this course you will learn in detail about three genera of ferns: *Pteris* - a small fern, *Cyathea* - a tree fern and *Marsilea* - a water fern.

16.5.7 *Pteris*

Pteris

Division - Pterophyta (=Filicophyta)
Class - Polypodiatae
Order - Filicales

Pteris is a widely distributed genus with about 250 species. It grows abundantly in cool, damp and shady places in tropical and subtropical regions of the world. In all there are 19 species recorded from India. *Pteris vitata* is a low level fern which brings out new leaves throughout the year. It is very common along mountain walls and grows up to 1200 metres above sea level. *Pteris quadriauriata* grows abundantly along roadsides and in the valley throughout North-Western Himalayas. Another species, *Pteris cretica* grows well from 1200 to 2400 metres above sea level.

All the species of *Pteris* are terrestrial, perennial herbs with either creeping or semi-erect rhizome covered by scales. Roots arise either from the lower surface or all over the surface of rhizome. You may have noticed that the most conspicuous part of a fern plant is its leaves which are called fronds. The leaves are compound in most species but a few have simple leaves, for example *Pteris cretica*. Look at figure 16.12 A, the stalk of leaf continues as rachis and bears leaflets called pinnae.

In *Pteris vittata* the pinnae present near the base and tip are smaller than those in the middle. The leaf apex is occupied by an odd pinna. Every pinna is transversed by a central mid rib which gives off lateral veins that bifurcate. The pinnae are sessile and broader at the base gradually decreasing

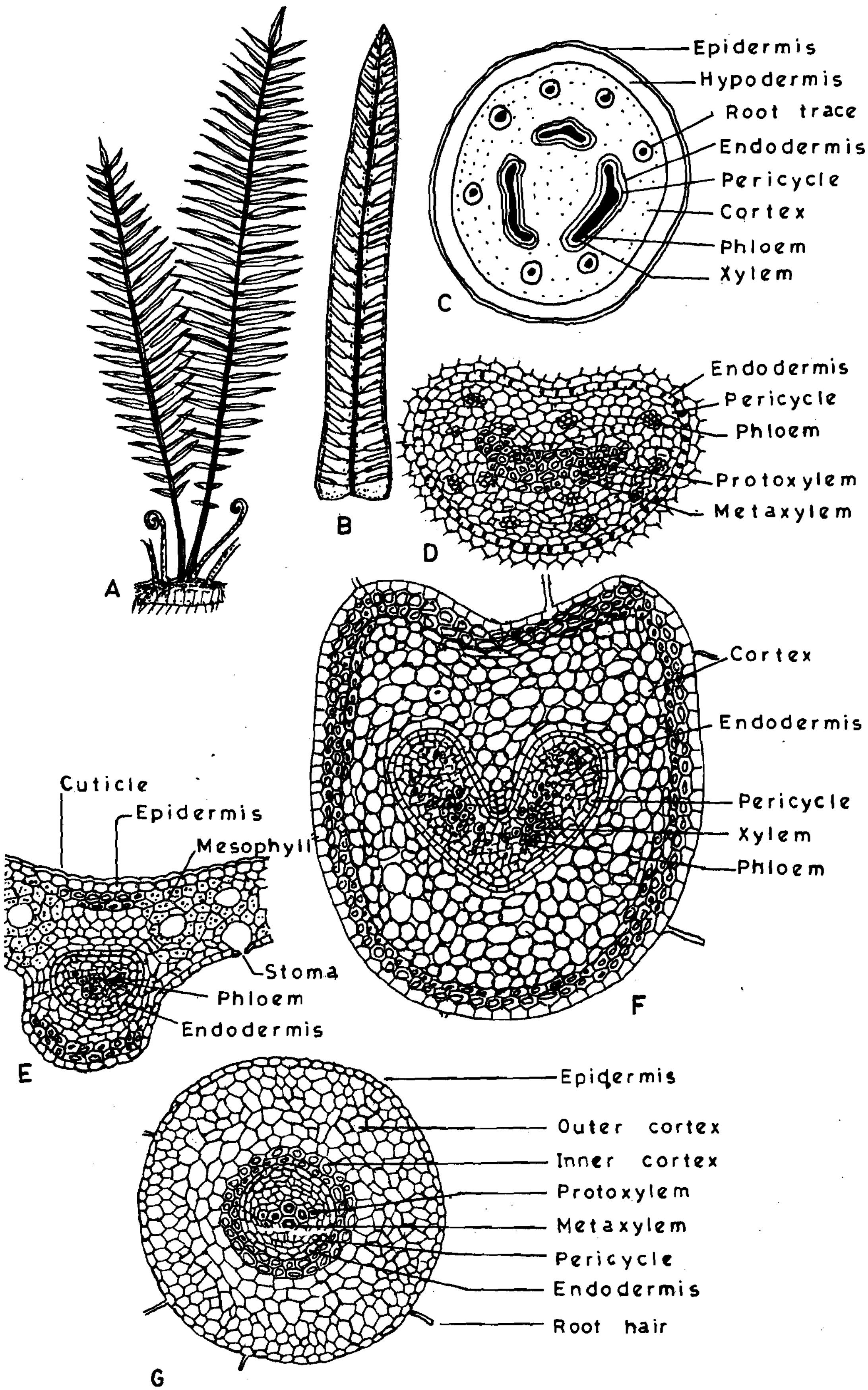


Fig. 16.12: ***Pteris*** **: A) A plant of *Pteris vittata.* B) A leaflet showing midrib and dichotomous vein. C) T.S. of rhizome showing meristele. D) A meristele in rhizome showing detailed internal structure. E) Portion of leaflet in T.S. F) T.S. of petiole. G) T.S. of root.**

in width towards the apex (Fig. 16.12 B). The leaves are bipinnate in *P. biauriata*. The pinnules are rough in texture. The young leaves show typical incurving known as **circinate vernation.** The leaves bear spore producing structures on the underside of the leaflets. They appear as rows of brown dots (sori, sing. sorus). Each sorus is a cluster of sporangia.

Internal Structure

Rhizome

The stelar organisation of rhizome of *Pteris* varies from protostele to dictyostele depending upon the species and sometimes in the same species. In the lower region of younger branches of the rhizome the stele is a mixed protostele. It becomes siphonostelic a little higher up and finally it becomes solenostelic near the apex. In the main rhizome dictyostelic condition is also found (Figs. 16.12 C,D). In case of *Pteris vittata* stele becomes a dicyclic dictyostele in the apical region of the rhizome.

Leaf

Look at the T.S. of pinnule (Fig. 16.12 E), you can distinguish the following zones:

i) The pinnule has upper and lower epidermis. In *Pteris cretica* the cells of upper epidermis are larger and have less sinuous walls. In this species stomata are restricted to lower epidermis which has smaller cells with more sinuous walls.

ii) Mesophyll consists of green parenchymatous cells.

iii) The midrib region has single vascular strand with distinct endodermis.

The petiole has a single U- or V- shaped leaf trace (Fig. 16.12 F), but in some species it is C-shaped. In the rachis, the petiole trace gives off strands into its pinnae. The rachis traces are marginal in origin and are usually flat U-shaped or shallow arc-like.

Root

Look at the T.S. of root (Figs. 16.12 G) and note the following regions:

i) **Epidermis** - Numerous root hairs arise from this layer.

ii) **Cortex** - It is differentiated into outer parenchymatous zone and inner zone having thick-walled cells.

iii) **Endodermis** - Inside the cortex there is a single-layered endodermis. The cells of endodermis have casparian strips on their radial walls.

iv) **Pericycle** - It follows the endodermis and consists of cells with thin walls.

v) **Stele** - It is diarch and exarch.

SAQ 16.8

In the following statements fill in the blank spaces with appropriate word(s).

i) The rhizome in *Pteris* is .... or ....

ii) Leaves of most species of fern are .... compound and are the most .... part of the plant.

iii) The stele in rhizome may be .... or ....

iv) The young leaves of fern show typical incurving which is termed as ....

v) The rhizome of fern is covered with ....

16.5.8 *Cyathea*

The genus *Cyathea* includes species which are commonly known as tree ferns due to their tree-like habit. They are largely restricted to tropical humid mountain forests from Mexico to Chile, Malaysia to Australasia, New Zealand and Africa. In India tree ferns are common in Eastern Himalayas.

Cyathea

Division - Pterophyta
Class - Polypodiatae
Order - Filicales

The plants of various species of *Cyathea* vary in height. The largest may attain a height upto 25 metres. Some species are comparatively smaller in size. The stem is aerial, erect and radial. It is generally unbranched, but sometimes forms lateral branches. In some species where stem is short and stumpy, bifurcation occurs near the apex and the two branches are equal. Scales and hairs form a dense covering on the stem. Much of the diameter of the trunk is composed of persistent leaf bases and matted adventitious roots. The actual stem within is of comparatively smaller diameter. The characteristic hexagonal scars of fallen leaves are quite distinct in the upper region of the stem (Figs. 16.13 A,B).

Leaves are present near the apex in the form of a crown. Young leaves are circinately coiled. In some species leaves are quite large and measure about 4 metre in length. Leaves are usually three to four times pinnate and are spirally arranged on the stem. However, in a few species they are simple. Venation in leaves is of open dichotomous type. In mature plants sori are present on abaxial leaf surface (Fig. 16.13 C). The surface of petiole is covered with chaffy scales similar to those present on the stem. The petiole receives a number of leaf traces which are also complex in most of the cases and are broken up into many strands.

Abaxial

The surface facing from the axis

Internal Structure

Stem

The internal structure is highly complicated (Fig. 16.13 D). Mature stem possesses a polycyclic dictyostele which is composed of a number of meristeles forming rings. Note that each meristele is enclosed by a plate of sclerenchyma and its ends are curved outwardly. Numerous leaf traces originate from the lower margins of leaf gaps and pass obliquely through the cortex. A number of accessory vascular strands are also present in the pith. These are known as accessory medullary strands. Structurally, medullary strands are similar to meristeles. Anastomosis of medullary strands with each other as well as with meristeles also occurs. In some species of *Cyathea* small meristeles are present in the cortex as well. These are known as accessory cortical strands. Due to the presence of accessory medullary and cortical strands a polycyclic dictyostelic condition occurs in *Cyathea* stem.

SAQ 16.9

In the following statements fill in the blanks with appropriate words:

i) *Cyathea* genus includes .... ferns.

ii) *Cyathea* leaves are .... arranged.

iii) Leaves are generally .... -pinnate and in some species reach a length of ....

iv) Venation in leaves is usually of .... type.

v) Trunk is covered with .... and ....

vi) Stele in the stem of *Cyathea* is ....

vii) The polycyclic dictyostele of *Cyathea* is composed of a number of meristeles which are enclosed with a plate of .... tissue.

viii) The accessary vascular strands present in pith are called accessory .... strands and those present in cortex are called accessory .... strands.

ix) The persistant .... give girth to the trunk.

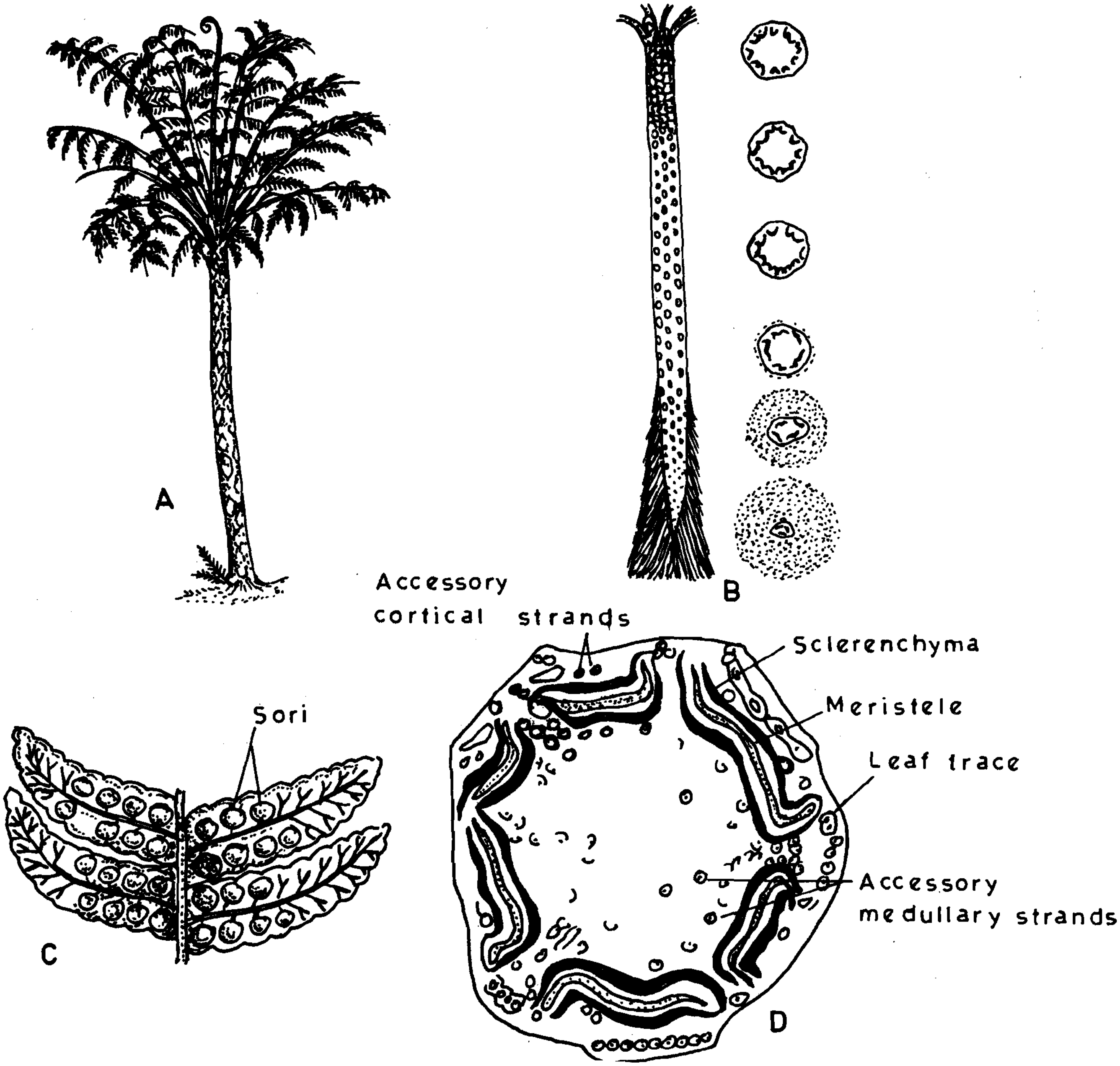


Fig. 16.13: A) Plant of *Cyathea*. B) Diagram of a stem showing persistent leaf bases and the vascular organisation at successive levels. C) A portion of leaf showing sori. D) T.S. of stem.

16.5.9 *Marsilea*

Marsilea is a very interesting genus of ferns as it shows heterospory and hydrophilous (love water) habitat. This genus is distributed worldwide in temperate and tropical regions of the world. They are either aquatic or amphibious in habitat and when they grow on land their roots are embedded in muddy soil.

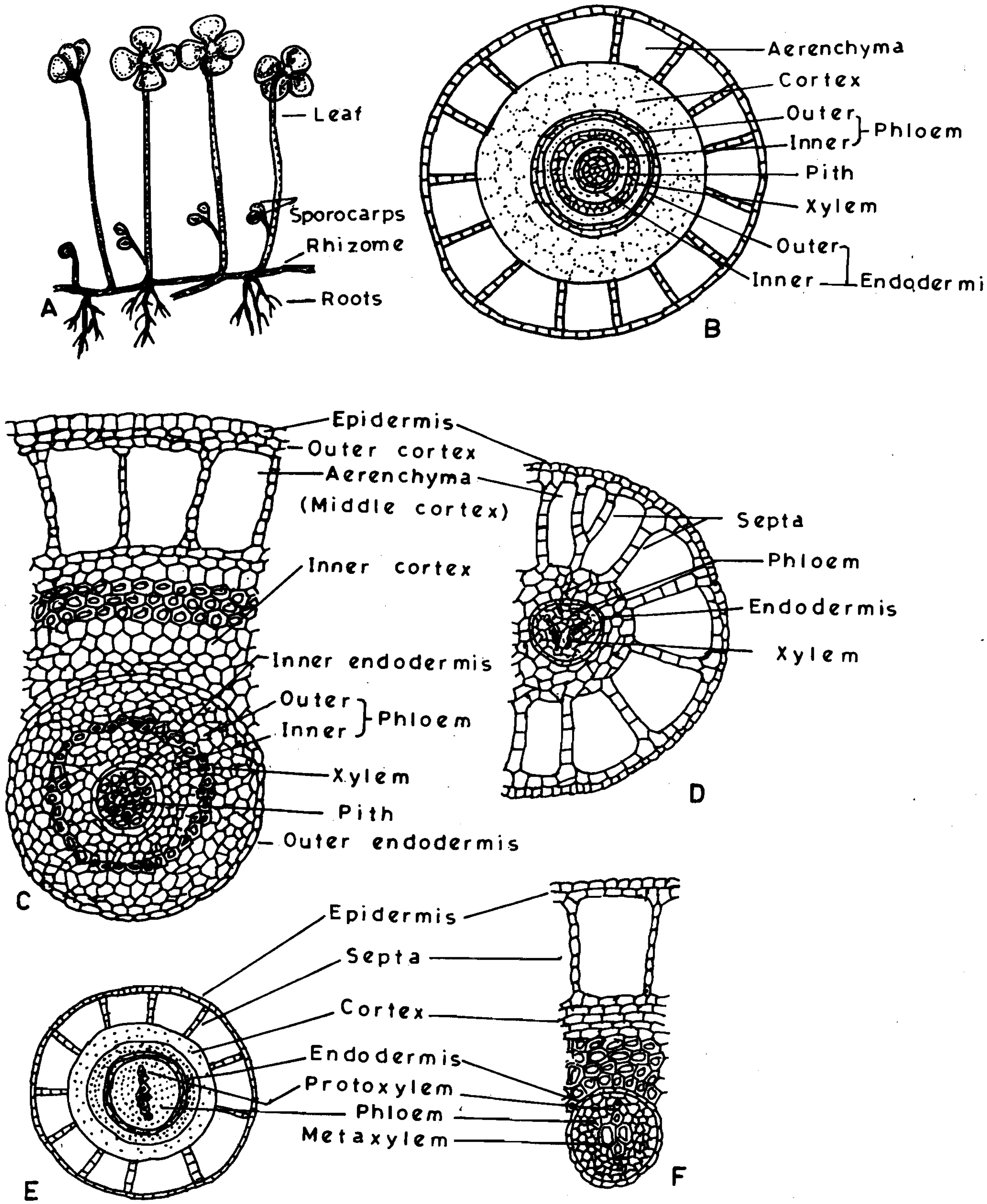


Fig. 16.14: *Marsilea:* **A) A plant of** ***Marsilea*** **showing sporocarps. B) Diagram of T.S. of rhizome. C) Part of B magnified. D) A portion of T.S. of petiole. E) Diagram of T.S. of root. F) A part of E magnified.**

Marsilia

Division - Pterophyta
Class - Polypodiatae
Order - Marsileales

Marsilea has a slender, creeping rhizome which is dichotomously branched and shows indefinite growth. It has distinct nodes and internodes. At each node leaves develop with a slender, flexible petiole and are arranged alternately in two rows along the upper side of rhizome. The lamina is divided into four leaflets. The leaf is circinate when young, and the leaflets are folded together upwards until nearly mature. At night also the leaflets are folded upward assuming a "sleeping position". At each node on the lower side one or two adventitious roots are produced (Fig. 16.14.A). The reproductive structures are sporocarps which contain micro and megasporangia. The sporocarps, as you can note in the figure are borne either singly or in a cluster on short lateral branch of petiole. The plants are adapted to grow in shallow water or wet places.. A few species are terrestrial. *Marsilea hirsuta, M. minuta* and *M. aegyptica* are xerophytic forms and are capable of surviving long periods of drought. In some species both land as well as water forms are known. These two forms can be distinguished from each other morphologically. Land forms possess short internodes, branched roots, a few air spaces and more sclerenchyma in vegetative organs. Leaves have long petioles, and stomata are distributed on both the surfaces of leaflets. In contrast, water forms have long internodes, unbranched roots and flexible petiole. Sclerenchyma is almost absent in vegetative organs, but there are extensive air spaces. Stomata are restricted largely to upper surface of leaflets.

Internal Structure

Rhizome

Look at the T.S. of mature stem or rhizome in figure 16.14 B, C and write below the special features that you have observed.

1. ....

2. ....

3 ....

4 ....

You will note the following regions:

i) **Epidermis** - It is composed of single layer of thick-walled compactly arranged cells.

ii) **Cortex** - In the cortex three regions can be differentiated:

a) outer cortex, b) middle cortex and c) inner cortex.

Outer cortex is composed of compactly arranged parenchymatous cells. A few tannin containing cells are also present in this region. Middle cortex is formed by a single layer of air chambers arranged in a ring. These chambers are separated from one another by one-celled thick partitions. The inner cortex is several-celled thick. Outer cell layers of the inner cortex are thick-walled whereas rest of the cells are parenchymatous and are arranged compactly.

iii) **Stele** - It is amphiphloic siphonostele. In this type xylem is in the form of a ring and phloem is present on both sides of xylem.

Petiole

The stele in petiole is somewhat triangular and is bound by single layer of endodermis. There are two arms of xylem which are curved away from each other (Fig. 16.14.D). Each xylem arm is composed of one or two metaxylem elements in the centre and a few protoxylem elements at both sides. The cortex is similar to that of stem and is variable in land and water forms.

Root

In a T.S. of root of *Marsilea* the following are distinguishable (Fig. 16.14 E,F):

i) **Epidermis** - It consists of compactly arranged biconvex cells with their outer walls thickened.

ii) **Cortex** - It shows distinction into outer and inner cortex. Like stem the outer cortex is composed of large air chambers arranged in the form of a ring and are separated from each other by longitudinal septa. Inner cortex is composed of compactly arranged round cells which contain starch.

iii) **Endodermis** - A distinct endodermis is formed by a single layer of cells.

iv) **Stele** - It is generally diarch and exarch.

SAQ 16.10

In the following statements fill in the blanks with appropriate words:

i) *Marsilea* is a .... fern but its few species are ....

ii) Some species can survive a long period of ....

iii) It has a .... rhizome, which is .... branched.

iv) Air chambers are present in the .... of stem.

v) In water ferns the sclerenchyma is almost .... in vegetative organs.

16.6 DISTRIBUTION OF PTERIDOPHYTES IN INDIA

Let us now learn breifly about the distribution of pteridc phytes in our country.In India, 191 genera, 10 fern allies and 181 ferns, belonging to 67 families are known to occur. The following six are the dominant families of ferns and the number of genera are given in brackets:

(i)	Polypodiaceae	(27)
(ii)	Thelypteridaceae	(21)
(iii)	Athyriaceae	(14)
(iv)	Hymenophyllaceae	(10)
(v)	Hemionitidaceae	(6)

Following are some common genera with localities in which they are found abundantly:

Psilotum: It is widespread in tropical and subtropical regions. It grows erect on humus or may by epiphytic. It is quite common in Pachmarhi (M.P.).

Lycopodium: It is found throughout India in tropical and temperate regions, but is more common in mountains.

Selaginella: Like *Lycopodium*, it is found in tropical and temperate areas, but it is more common in tropical rain forests where light is weak. It is also found in warmer plains of India.

Isoetes: It occurs all along the Indian coasts and also in the interior regions. *I. coromandeliana:* is the most common species. It grows in South India, Bengal, U.P. and M.P.

Equisetum: *E. debile* grows along the banks of rivers in sandy and swampy soil and is also found in the Gangetic plains.

Leaf trace -

In India species of *Pteris* are *Pteris vittata, P. cretica, P. biauriata, P. quadriauriata* and *P. wallichiana*. *P. vittata* is a low level fern and brings out new leaves throughout the year. It is very common along the mountain walls and grows up to 1200 metres above the sea level. *P. quadriauriata* grows abundantly along roadsides and the valley throughout North-Western Himalayas. *P. cretica* grows well from 1200 to 2400 meters above sea level.

Pteridium: It is distributed in India in the entire Himalayan tract and grows well at altitudes between 1000 and 3000 metre.

Pteris: It grows in tropical and subtropical regions up to 2400 metres. It is quite abundant in North-Western Himalayas.

Marsilea: This aquatic fern grows all over India. *M. minuta* is the most common species.

Cyathea: It is found abundantly in Eastern India, on hilly tracts in Darjeeling and Sikkim.

To get a better idea about the habitat, habit and actual size of plants you should see these plants in nature. Fortunately, pteridophytes are found in abundance in certain parts of our country.

SAQ 16.11

Match the names of pteridophytes given in the column A with the locality in which they grow described in column 2.

	Column A		Column B
(i)	*Cyathea*	(a)	Tropical and subtropical region, may be epiphytic.
(ii)	*Equisetum*	(b)	Tropical to temperate regions, but more common in mountains.
(iii)	*Isoetes*	(c)	Tropical to temperate regions, but more common in tropical rain forests.
(iv)	*Lycopodium*	(d)	All along Indian coasts.
(v)	*Selaginella*	(e)	Along riverbanks on sandy and swampy soil.
(vi)	*Psilotum*	(f)	Abundant in Eastern India, Darjeeling, Sikkim.

Box Item 5

The ferns can be propagated by the following means:

(i) spores,
(ii) division of crown,
(iii) cutting of rhizomes,
(iv) runners,
(v) adventitious suckers and
(vi) bulbils.

For raising ferns by means of spores, fertile fronds bearing sori are cut into pieces. These are allowed to ripen in paper bags in warm rooms. After sporangial dehiscence spores are collected and sown on pans with very moist, sterile peat or humus soil. After sowing they are not watered overhead. Instead they are covered with a pane of glass for 2 or 3 weeks until cultures begin to turn green. The temperature is maintained in the range 21 to 30° C. Higher temperature inhibits the development of sex organs on prothalli. The presence of thin film of water between prothallus and substratum is essential to effect fertilization. After 3 weeks a little air is admitted, care is taken to keep the cultures stay constantly moist, but never soaking wet. After the formation of the male and female reproductive organs and subsequent development of the characteristic plant (sporophyte) with first true leaves, watering is done over the surface. When the leaves are big enough, transplanting is done in clusters for mutual support.

16.7 SUMMARY

In this unit you have learnt that:

- Pteridophytes are primitive,vascular, non-flowering land plants,
- Like bryophytes they show distinct alternation of generations but instead of gametophyte, sporophyte is the dominant phase of life cycle,
- Fossils provide evidence for extinct plants. They are of four types: petrifaction, cast, impression and compression,
- The earliest land plants like *Rhynia* and *Cooksonia* were rootless. Their dichotomously branched aerial stem bore terminal sporangia. The underground rhizome had tufts of rhizoids, which performed the function of anchorage and absorption,
- One of the earliest living land plants is *Psilotum*, which shows primitive features. Its sporophyte is dichotomously branched, rootless, with scale-like leaves and terminal trilocular sporangia. The stele is protostelic.
- *Lycopodium* stem is densely covered with microphylls. It is also protostelic. Roots arise from pericycle and are diarch,
- In *Selaginella* the main stem may be prostrate, semi-erect or erect, branched or unbranched. It possesses microphylls which are spirally arranged on the stem and are ligulate. The stele in the stem is protostelic or siphonostelic with exarch protoxylem which is attached to the cortex with the help of trabeculae. Roots are monoarch.
- *Equisetum* is erect, herbaceous, perennial plant. The stem has nodes and internodes. Leaves at the nodes are fused laterally to form a sheath and are arranged in whorls. Adventitious roots develop from the base of stem. Stele is ectophloic, siphonostele with nodal rings. The anatomy of stem shows association of xeromorphic and hydromorphic characters. Vascular bundles are collateral and each with a carinal canal. Vallecular cavities are present in the cortex, each corresponding to a furrow. Cones or strobili are situated singly at the apices of fertile shoot,
- *Pteris* has a creeping rhizome which bears scales or branched hairs. The plant is characterised by prominent pinnately compound or digitate leaves. Stelar organization varies from protostele to dictyostele depending upon the species. The root is diarch. The sporangia are generally grouped together in sori,
- *Cyathea* is a tree fern. The stem is stout trunk with a crown of spirally arranged large pinnate leaves. Stem possesses polycyclic dictyostele,
- *Marsilea* is aquatic fern. Its stem is rhizomatous stolen with distinct nodes and internodes. Leaves borne on the nodes are long stalked and bear four leaflets. Adventitious roots are borne at the node on the underside of rhizome. Stele is amphiphloic siphonostele. Cortex has distinct air spaces. Spores are produced in specialised structures called sporocarps,
- Pteridophytes are found abundantly in our country and are more common in hilly areas.

16.8 TERMINAL QUESTIONS

1. Describe typical life cycle of pteridophytes and compare it with that of bryophytes.

....

....

....

....

....

....

2. List the characteristic features of pteridophytes.

....

....

....

....

....

....

3. Match the characteristics of stem listed in column 1 with genus listed in column 2.

	Column 1	**Column 2**	
1.	Protostele	a)	*Cyathea*
2.	Polycyclic dictyostele	b)	*Marsilea*
3.	Vallecular canals	c)	*Selaginella*
4.	Air cavities in the cortex	d)	*Equisetum*
5.	Trabeculae	e)	*Psilotum.*

4. Compare the morphological features of *Psilotum, Selaginella* and *Pteris*.

Psilotum	***Selaginella***	***Pteris***

16.9 ANSWERS

Self-assessment Questions

16.1 i) True

ii) True

iii) False (only female gamete is non-motile)

iv) False (vascular plants)

v) False (sporophyte is dominant phase).

16.2 a) i) clay nodule

ii) external

iii) Cast fossils

iv) pterifaction

b) i) Woody part - xylon

ii) Microsporangium -theca

iii) Cone - strobilus

iv) Fern like - pteris

v) Seed like structure - carpon.

16.3 a) i) Scotland

ii) lower Devonian

iii) dichotomously branched

iv) protostele

v) absent, present.

b) i) tips/apex

ii) triradiate

iii) unknown

iv) terminal

c) i) Vascular strands made of tracheids.

ii) Straight dichotomously branched stem.

16.4 a) i) True roots are absent.

ii) Rhizoids serve the purpose of anchorage and absorption.

iii) Aerial axis is covered with scale-like appendages, leaves are absent.

iv) Presence of protostele.

v) Fertile appendages present.

b) i) False

ii) False

iii) False

iv) False

v) True

vi) True

vii) True.

16.5 i) True

ii) False

iii) False

iv) True

v) True

vi) False

vii) True.

16.6 a) i) resurrection

ii) conserve, inorganic salts

iii) rhizophore

iv) trabeculae

b) Consult the text

c) i) False (endodermis)

ii) True

iii) True

iv) False

v) True

vi) True

16.7 a) i) False (perennial)

ii) False (form a sheath around nodes)

iii) True

iv) True

v) False

vi) False (below the furrow)

b) Hint:

Vallecular canal

Carinal canal

Vascular bundles.

c) Consult text and glossary

16.8 i) Creeping, semierect

ii) Pinnately, conspicuous

iii) Protostele, dictyostele

iv) Circinate vernation

v) Scales

16.9 i) tree

ii) spirally

iii) 3 to 4 times, 4 metres

iv) open dichotomous

v) scales and hairs

vi) polycyclic dictyostele

vii) sclerenchymatous

viii) medullary, cortical

ix) leaf bases.

16.10 i) water, terrestrial

ii) drought

iii) creeping, dichotomously

iv) middle cortex

v) absent

16.11 i) (f)

ii) (e)

iii) (d)

iv) (b)

v) (c)

vi) (a)

Terminal Questions

1. Refer to Section 16.2.
2. Refer to Section 16.3.
3. i) e, ii) a, iii) d, iv) b, v) c
4. Refer to Section 16.5

UNIT 17 COMPARATIVE STUDY OF REPRODUCTION IN PTERIDOPHYTES

Structure

17.1 INTRODUCTION

In the previous unit you have studied the morphology of various genera of pteridophytes. In this unit you will learn about the modes of reproduction in them. As you know, in plants there are two major methods of reproduction: asexual and sexual. In simple lower plants, every cell serves as reproductive cell. However, in higher plants reproductive cells are produced in highly complex, specialised structures which are exclusively set apart for reproduction. The morphology, position and development of these structures varies in different groups of plants and these serve as the basis for classification.

In the following account you will read about the structure of spore producing bodies, gametophytes, sex organs, male and female gametes as well as development of sporophyte in some selected genera of pteridophytes.

Objectives

After studying this unit you will be able to:

- list general characteristics of reproductive organs of pteridophytes,
- describe structure and development of spore producing organs in different groups of pteridophytes,
- compare the structure and development of sex organs in different groups of pteridophytes and
- enumerate methods of vegetative reproduction in different taxa.

17.2 REPRODUCTION IN PTERIDOPHYTES

In the following account you will learn about the structure of reproductive organs and details of the process of reproduction in some representative groups of pteridophytes. While going through the text try to note the similarities and differences in various groups.

17.2.1 *Rhynia* and *Psilotum*

In the previous unit you have read about the morphology of *Rhynia,* the fossil pteridophyte. You have also learnt that some of the fossil specimens indicate that the apices of aerial branches developed into oval or slightly cylindrical structures which had a diameter somewhat greater than that of subtending branch tip. As these structures contain spores they are termed sporangia (Fig. 17.1 A). They are somewhat pointed distally but at the base rather broadly attached to the branch tip. The sporangial wall is thick (Figs. 17.1 B, 17.2 A). It consists of three distinct layers: (a) a stout outermost layer composed of cuticularised cells; (b) a middle layer about three celled thick and composed of thin-walled cells; and (c) an innermost layer of small cells which provided nourishment to the developing spores. This layer is known as tapetum. Inside the sporangial cavity spores are present. All the spores are similar in structure. They are thick-walled and have the typical triradiate markings. In some specimens spores are united in tetrads (group of four spores) suggesting that they were formed by meiotic division and plant bearing them represents the sporophyte generation. There is no special device in the sporangium for dehiscence and dispersal of spores.

As you know that spores are haploid and on germination they produce gametophytes. Since we do not have fossils of gametophyte of *Rhynia* nothing can be predicted precisely about its structure. However, their germinating spores were also found in *Rhynie* Chert which seem very much similar to the spores of *Rhynia.* It is also reported that a multicellular structure is formed at the end of the germ tube in some of them.

In *Psilotum,* which is a living member of Psilotopsida, the sporangia are borne on leaf-like appendages (Figs. 17.1 C, Dand 17.2B). These fertile-leaves are borne on the distal part of more vigorously growing aerial shoots. The fertile appendages are forked. Each fructification has 3 lobes and represents a group of 3 fused sporangia called **synangium** (pl. synangia) (Figs. 17.1 C, D). They show distinct partition walls. Synangia are fairly large in size and measure 2 to 3 mm in diameter. Look at the cross section of synangium (Fig. 17.1 E). The partition or septum between sporangia of a synangium are composed of elongated cells.

In contrast to foliar, vegetative leafy appendages, synangia bearing appendages have a vascular strand. A single vascular trace from the stele of the aerial stem enters the fertile appendage (synangium-bearing leaf) and it divides into three parts which are directed towards one of the three sporangia.

The development of sporangia may be eusporangiate or leptosporangiate (Box Item 1). In all pteridophytes, formation of sporangium starts with a periclinal division in a superficial cell or group of cells. This results in the formation of an outer and inner daughter cell.

Development of sporangium in *Psilotum* is of eusporangiate type. In this type sporogenous tissue is derived from inner daughter cell, whereas sporagial wall and stalk are derived from adjacent cells. The spores are kidney-shaped. They are all similar in structure. The cell walls in the epidermal layer of the jacket are thick except in a small vertical row which is the future line of dehiscence of the mature sporangium. You may recall that in *Rhynia* there was no device for the dehiscence of sporangium for the dispersal of spores. The dehiscence of sporangium starts from the centre of the synangium and proceeds to the non-functional annulus, which is composed of a patch of thick-walled cells at the end of the line of dehiscence (Fig. 17.1 F). A spore germinates after 4 months and develops into a prothallus (Figs. 17.1 G-K). As you have already learnt that in pteridophytes spore on germination forms a plate of cells which is dorsi-ventral and bears the sex organs.

The prothallus is penetrated by an endophytic fungus. The mature prothallus is pale-yellow to dark-brown in colour, 0.5 to 2 mm in diameter and 1 to 18 mm in length, somewhat cylindrical subterranean and radially symmetrical structure (Fig. 17.3 A). In nature, prothalli are found growing in the crevices of rocks or the tree trunks. A prothallus grows by means of a pyramidal apical cell with three cutting faces and is densely covered with numerous dark-brown stiff hair-like rhizoids. The prothallus is mostly composed of colourless hexagonal cells which have strongly cutinised outer and radial walls.

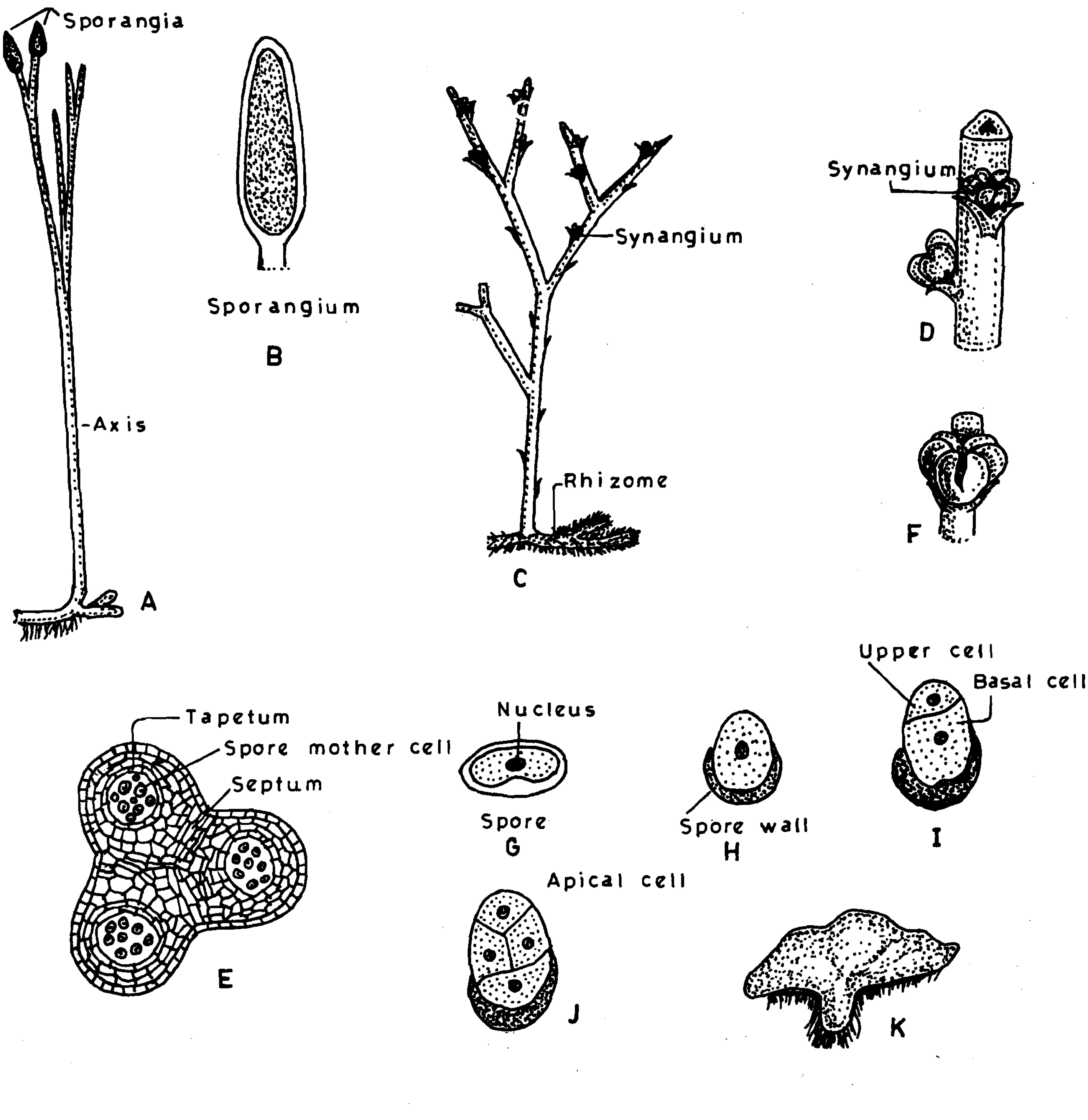


Fig. 17.1: A) *Rhynia* plant showing terminal sporangia. B) A single sporangium of *Rhynia*. C-K) *Psilotum*: C) Plant bearing synangia. D) Part of C enlarged. E) Cross section of synangium showing 3 lobes. F) Dehiscence of sporangium. H to K) Stages in the development of prothallus.

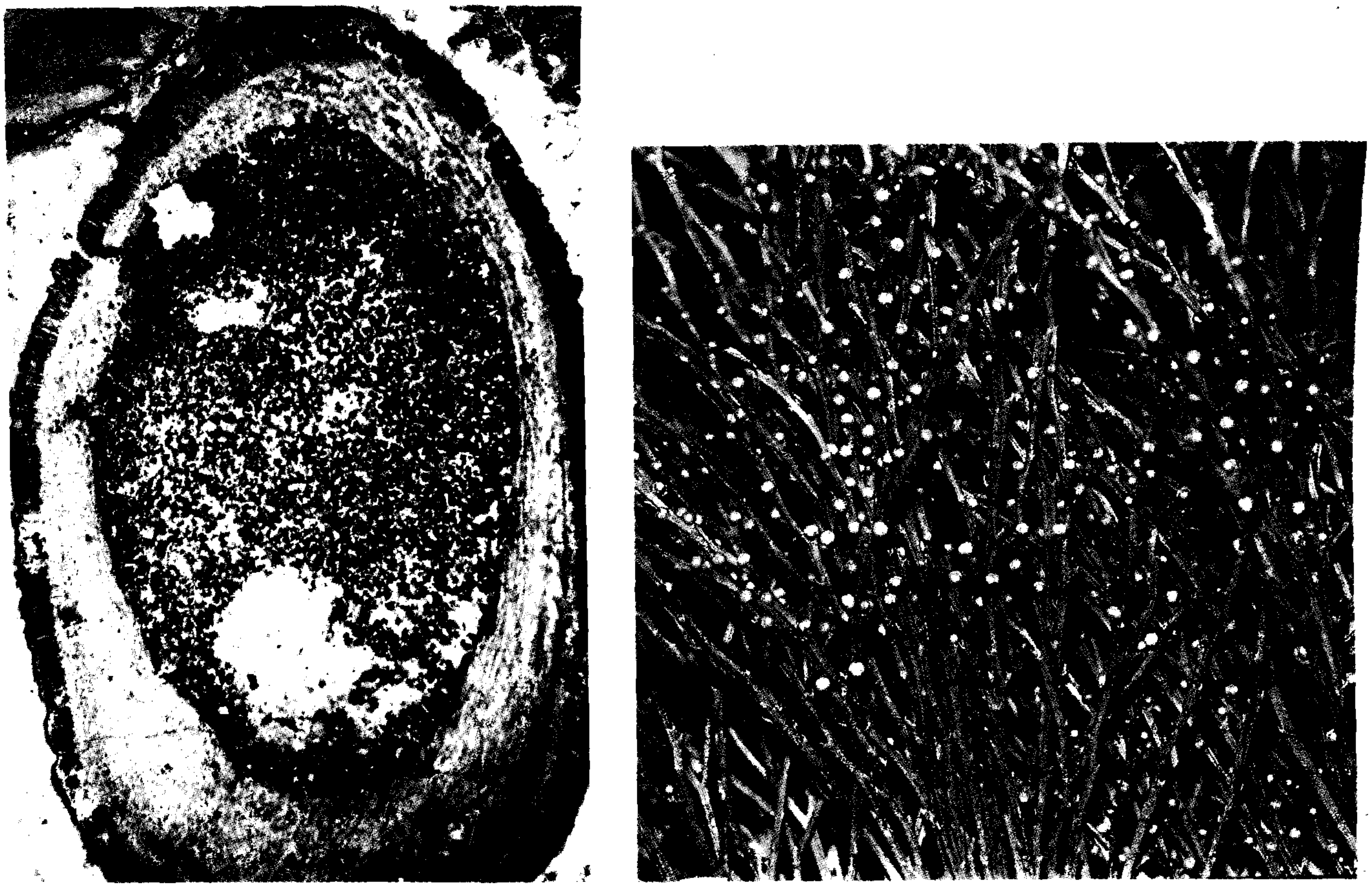


Fig. 17.2: A) Photograph of sporangium of *Rhynia* in cross section. B) *Psilotum nudum* with sporangia (courtsey of P. Dayanandan).

Box Item 1

The development of sporangia varies from species to species. It may be Eusporangiate type or leptosporangiate type

Following are the differences in these two types:

EUSPORANGIATE TYPE	LEPTOSPORANGIATE TYPE
a) Sporogenous tissue derived from inner daughter cell	a) Sporogenous tissue derived from outer daughter cell
b) In sporangial wall and stalk formation adjacent cells are involved	b) Sporangial wall, stalk and spores derive from outer daughter cell
c) Sporangium large, massive	c) Sporangium small
d) Sporangial wall multilayered	d) Sporangial wall one-celled thick
e) Large number of spores per sporangium are produced	e) Small number of spores per sporangium produced

The prothalli of tetraploid P. nudum are known to have a central vascular cylinder (Fig. 17.3 B). Occasionally, it is a complete stele with 1-3 tracheids surrounded by phloem and endodermis or is represented merely by a few elongated thick- walled cells.

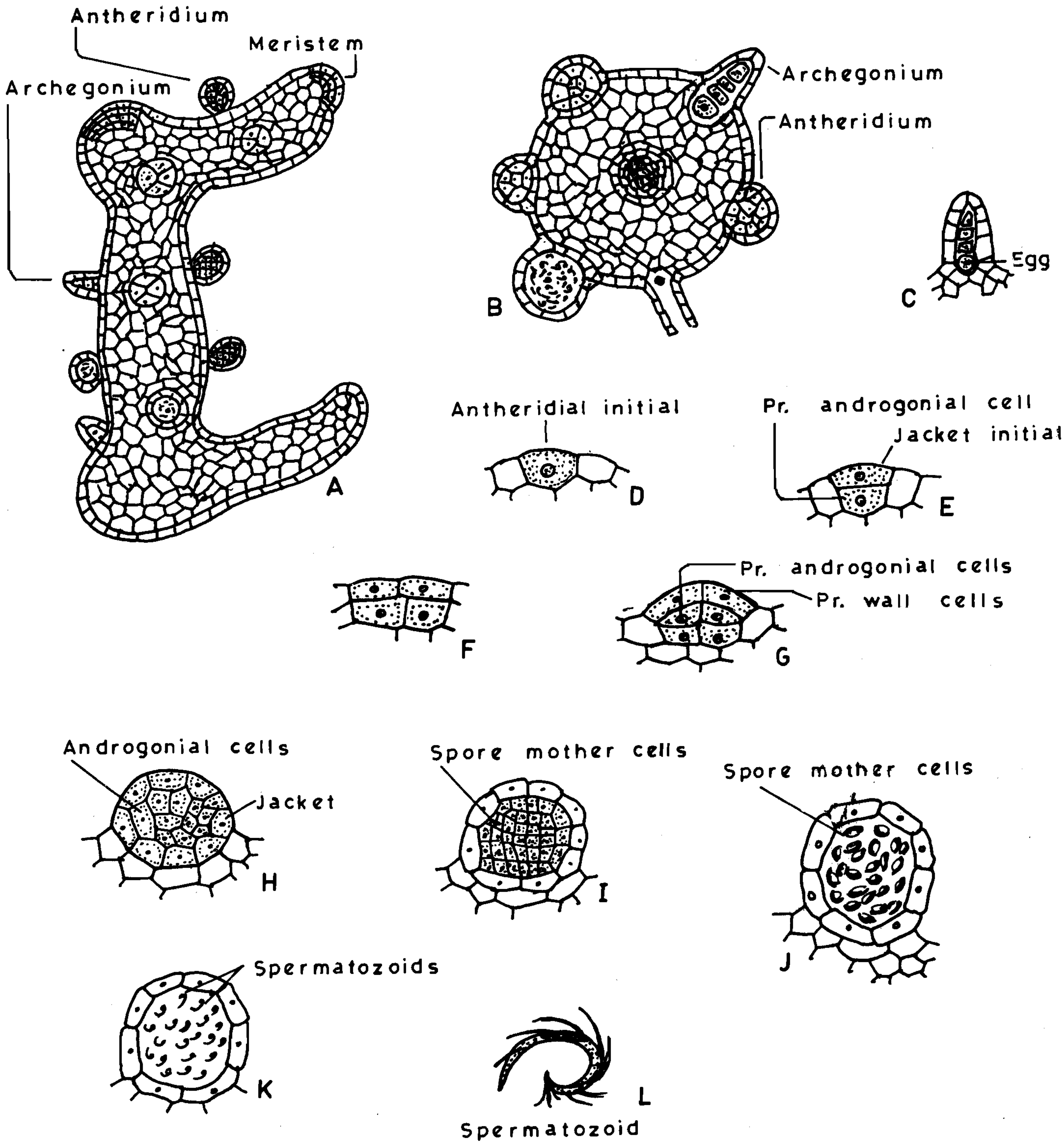


Fig. 17.3: A) Mature gametophyte of *Psilotum* with antheridia and archegonia. B) T.S. of mature gametophyte showing sex organs and central vascular strand. C) Mature archegonium. D-K) Different stages of antheridial development. L) A single antherozoid.

The gametophytes (prothalli) are monoecious i.e. both type of sex organs are present on the same prothallus. The gametangia, antheridia and archegonia, are scattered over the surface of gametophyte and occur intermingled (Fig. 17.3 A, B). They start appearing along the sides of apical portion of the prothallus. The venters of archegonia are embedded in the gametophyte and the necks are projecting above the surface of the prothallus. A mature archegonium consists of 4 longitudinal rows of neck cells, each row being 4 to 6 cells high (Fig. 17.3 C). The neck encloses the neck canal, with two neck canal cells. There is a single ventral canal cell and a single egg cell. The antheridium is a large superficial structure with one cell-thick jacket of cells. One can see stages of development of antheridium in Fig. 17.3 D-J. Each antheridium encloses numerous spirally coiled multiflagellate antherozoids (Fig. 17.3 K). A single antherozoid appears as given in Fig. 17.3 L.

As the archegonium matures the cell walls between upper tiers of neck cells become cutinised and the upper part of the neck breaks away. As a result of this, a passage is formed through which antherozoids enter the archegonial neck, reach the egg and fertilize it. Soon the zygote divides first by a transverse wall into an upper cell and a lower cell. The upper cell gives rise to the shoot system (both rhizome and aerial branches), whereas the lower cell by repeated divisions forms the bulbous foot which is haustorial in nature. It secures the sporophyte to the gametophyte and absorbs nutrition from it till the sporophyte becomes independent. The young sporophyte grows vertically by the activity of a three-sided apical cell. The young shoot soon develops vascular tissues and it acts as future rhizome. The rhizome continues to grow in length and branches repeatedly in a dichotomous manner. The tips of the ultimate branches turn upwards and develop into aerial branches that come out of the humus and grow erect.

SAQ 17.1

a) Which of the following statements are true and which are false about *Rhynia?* Write **T** for true and **F** for false in the given boxes.

   i) In *Rhynia* sporangia are lateral. ☐

   ii) Sporangial wall is three-layered. ☐

   iii) Sporangia possessed a special device for dehiscence. ☐

   iv) Sporangia in *Rhynia* occur in groups of three. ☐

b) Which of the following statements are true and which are false about *Psilotum?* Write **T** for true and **F** for false in the given boxes.

   i) In *Psilotum* sporangia are solitary and terminal ☐

   ii) Sporangia are 4 - lobed and are called synangium ☐

   iii) The development of sporangium is of eusporangiate type. ☐

   iv) An endophytic fungus is associated with prothallus of *Psilotum*. ☐

   v) Antherozoids are spirally coiled and multiflagellated. ☐

c) In the following statements fill in the blank spaces with appropriate words.

   i) In *Psilotum* a group of three sporangia is called ....

   ii) The prothallus of *P. nudum* has .... surrounded by phloem.

   iii) The gametophyte of *Psilotum* is .... as it possess both antheridia and archegonia.

   iv) The inner most layer of the wall of sporangium that provides nourishment to the developing spores is called....................................... .

   v) The spores of *Rhynia* have a .... mark.

17.2.2 *Lycopodium*

Let us now learn about reproduction in *Lycopodium.*

Formation of Reproductive bodies

In majority of *Lycopodium* species there is a gradual transition of vegetative leaves into sporangium-bearing leaves which are termed sporophylls. Look at Figs. 17.4 A and 17.5 A, the sporophylls are formed at the distal ends of the main axes or branches and bear cones or strobili.

A sporangium is borne on the upper (adaxial) surface of each sporophyll (Figs. 17.4 B, 17.5 B, C). All sporangia are homosporous i.e. they produce only one type of spores. The mature sporangia are yellowish in colour and measure 1-2.5 mm in diametre. They are reniform to subspherical and possess a short stalk or pad-like base (Fig. 17.5 C). The spores are liberated through a transverse slit in the wall of sporangium and this slit is composed of thin-walled cells transverse to sporophyll.

Adaxial surface

Surface of a lateral shoot organ that is toward the axis when the organ is placed vertically (parallel to the axis), e.g., the upper surface of a typical leaf.

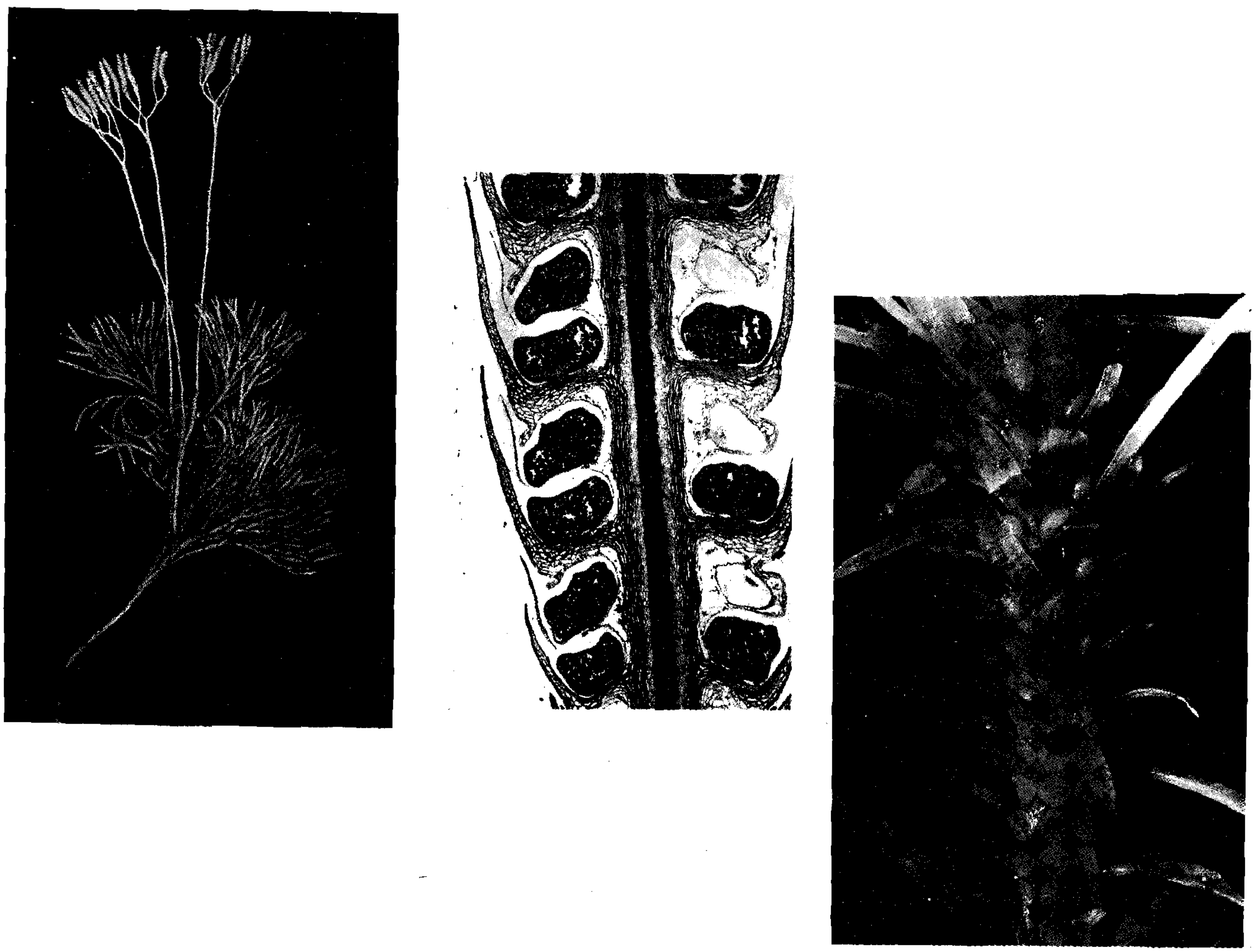


Fig. 17.4: ***Lycopodium:*** **A) Plant with strobili. B) Longitudinal section of strobilus. C) Sporangia in leaf axils (courtsey of P. Dayanandan).**

The development of sporangium is of eusporangiate type as in *Psilotum.* It starts with the appearance of a number of sporangial initials normally on the upper side of young sporophyll. One can see all the stages of development in a longitudinal section of strobilus (Fig. 17.5 B). The sporangial initials divide by periclinal division into inner and outer layer of cells (Figs. 17.5 D-G).

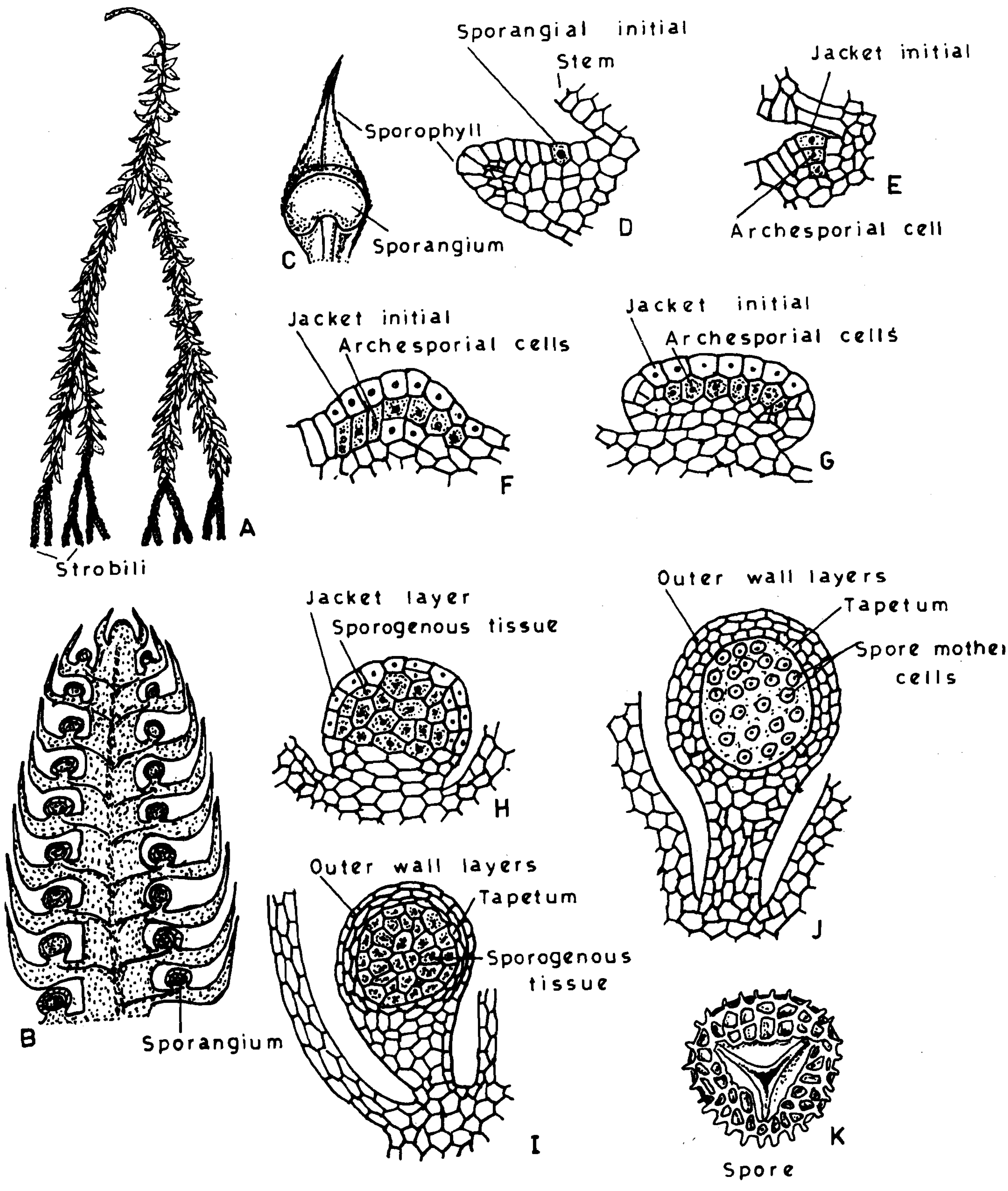


Fig. 17.5: *Lycopodium:* A) Plant showing strobili. B) A longitudinal section of strobilus. C) A sporophyll. D to J) Different stages in the development of sporangium. K) A single spore.

The inner layer forms sporogenous cells and the outer layer gives rise to the stalk of sporangiun and its wall (Fig. 17.5 H). Active divisions in the sporogenous tissue cause bulging and finally sporangium assumes a reniform shape. Further, periclinal divisions in surface layer result in the formation of many celled thick outer layer (Fig. 17.5 I, J). You know that the innermost layer surrounding sporogenous cells is called tapetum. It provides nutrition to the developing spores. This layer degenerates during maturation of spores. Each sporangium produces a large number of morphologically similar spores. Spores are small, light and have a smooth or ornamented wall. They exhibit a triradiate mark (Fig. 17.5 K).

Development of Gametophyte

The development of gametophyte starts with the transverse division in the germinating spore before exospore ruptures. As shown in figure 17.6 A, it results in the formation of two cells: a small biconvex lens-shaped rhizoidal cell at one side near the base, and a large cell. After this stage the spore increases in diameter and exspore ruptures along the triradiate mark. A vertical or oblique division takes place in the large cell and results in the formation of two cells (Fig. 17.6 B). The cell adjacent to the rhizoidal cell forms basal cell and undergoes no further division, whereas the other cell by two successive divisions forms an apical cell with two cutting faces. During early development the growth of the prothallus takes place at the expense of reserve food material present in mature spores. For further development association of a mycorrhizal fungus is necessary. The fungus enters the basal cell and forms endophytic mycorrhiza.

There are two types of prothalli: (i) surface living, green prothalli, and (ii) subterranean, non-chlorophyllous prothalli. The former type is more common in species of tropical regions, whereas the latter form is abundant in temperate regions. In the species with subterranean, colourless prothalli a long period of rest, about one year, intervenes between the 5-celled stage and mature prothallus. Figure 17.6 C shows a mature prothallus.

The prothalli are monoecious (Fig. 17.6 D). Each sex organ develops from a single superficial cell just behind the apical meristem. Distinct patches of antheridia and archegonia are formed in the crown or base of the lobes of subterranean prothalli. In elongated type of prothalli both sex organs are intermingled and are found on the central cushion. The mature antheridia produce large number of pear-shaped biflagellate antherozoids (Fig. 17.6 E,F) which are attracted chemotactically by the archegonial exudate. The venters of the archegonia are embedded in the prothallus and only the necks are projecting. Archegonia in subterranean prothalli have long necks, whereas necks are short in surface-living prothalli. Stages in the development of archegonium are shown in Fig. 17.6 G, H.

Fertilization takes place in the presence of water which is necessary for the movement of motile male gametes. After fertilization a wall develops around the fertilized egg. First division of the zygote is transverse to long axis of archegonium (Fig. 17.6 I). The outer cell normally does not undergo division and forms suspensor. The inner cell by further divisions forms a massive globose structure known as protocorm. It pushes its way through gametophyte. The protocorm bears rhizoids. From its upper surface many leaf-like vascular structures differentiate (Figs. 17.6 J, K). These structures are known as protophylls. Subsequently a shoot meristem is organised in the protocorm. The first root arises from the base of the stem.

Now that you have learnt about reproductive organs and development of gametophyte and sporophyte of *Lycopodium* let us sum up the main points.

1. In *Lycopodium* reproductive structures are cones i.e. strobili.

2. Each cone is made up of closely set sporophylls.

3. Each sporophyll bears adaxially a single large kidney-shaped sporangium which possesses a stalk.

4. Development of sporangium is of eusporangiate type.

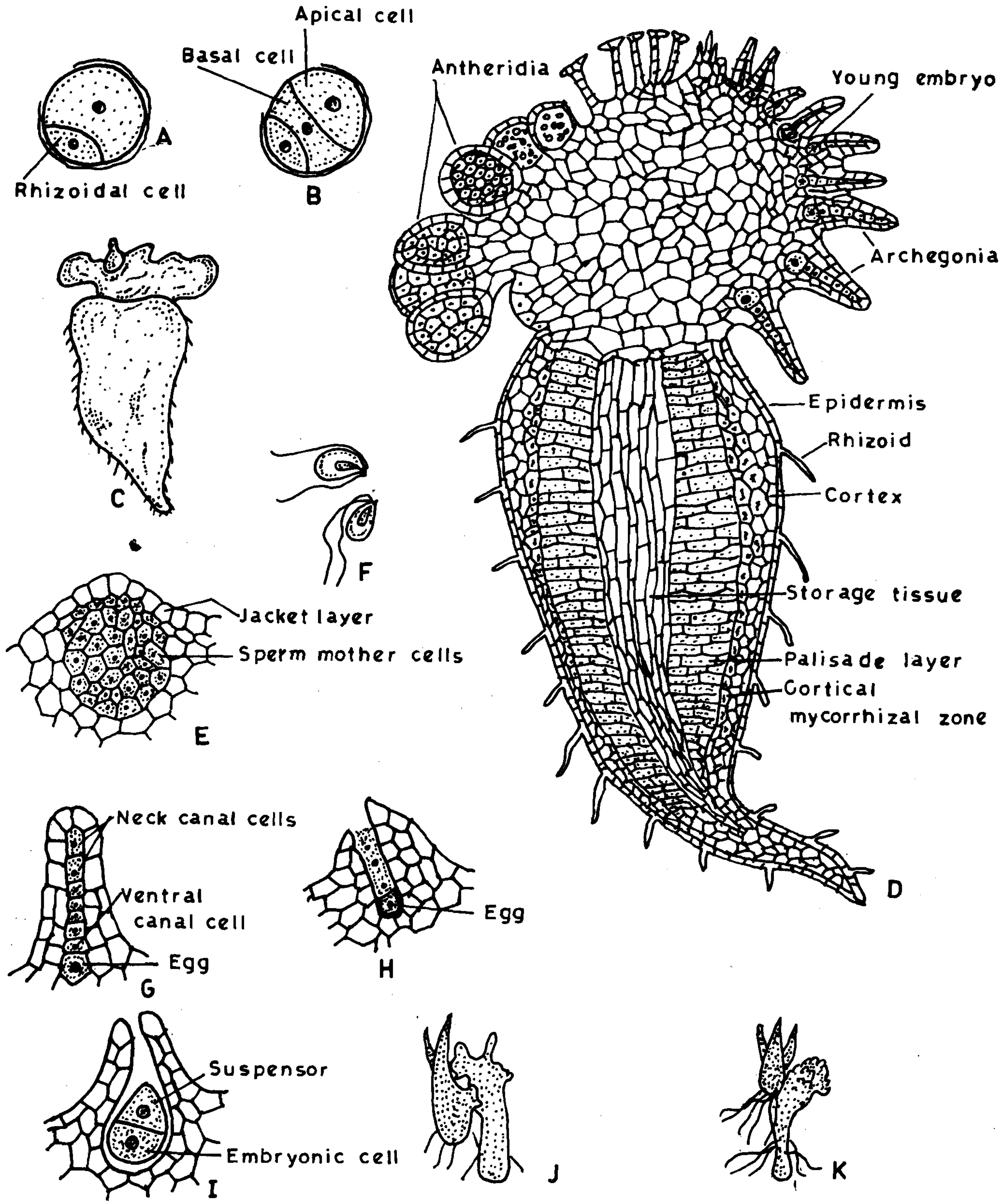


Fig. 17.6: Stages in the development of *Lycopodium*: A and B) Initial divisions in the spore. C) A mature prothallus. D) L.S. of mature prothallus showing antheridia and archegonia. E) Formation of antherozoids from mother cells. F) Antherozoids. G) An archegonium. H) Mature archegonium containing egg. I) First division of zygote. J,K) Protocorm showing leaf-like structures.

5. The sporangium has outer three or more layers of wall that form the jacket , The innermost layer-tapetum provides nutrition to the sporogenous tissue which differentiates into spore mother cells.

6. All the spores are alike, in tetrads, and have triradiate marking.

7. Spores on germination form prothallus i.e. gametophyte.

8. Both the sex organs develop on the same gametophyte.

9. Sperms are biflagellate.

10. After fertilization zygote is formed which develops into sporophyte.

SAQ 17.2

In the following statements fill in the blank spaces with appropriate words:

i) Sporangium bearing leaves are known as ....

ii) In *Lycopodium* sporophylls aggregate to form.................................. .

iii) Prothalli of *Lycopodium* bear .... and ....

iv) Sex organs develop from.................................. cells of prothallus.

17.2.3 *Selaginella*

You must have noticed that in pteridophytes described so far only one type of spores are produced in the sporangia i.e., these forms are **homosporous**. There are certain pteridophytes in which two distinct types of spores are produced. These are called **heterosporous.** *Selaginella* is an example of this type. In the following account you will learn about this genus which shows **heterospory**. In Unit 18 we will discuss the significance of heterospory and evolution of seed habit.

Reproductive Bodies

Selaginella produces two types of sporangia. The larger ones are known as **megasporangia** and contain large spores called **megaspores** (Fig. 17.7 A, B). Smaller ones are **microsporangia** and produce smaller spores, **microspores** (Fig. 17.7 C, D). According to the type of sporangium the sporophyll is called **megasporophyll** or **microsporophyll.** Like *Lycopodium* sporophylls form cones or strobili (Figs. 17.7 E and 17.8 A). These are terminal, either on the main stem or branches. The strobili are not very conspicuous and sporophylls are similar to vegetative leaves. In some forms due to continued meristematic activity vegetative leaves are produced above the strobilus. The sporophylls are always spirally arranged upon the strobilus axis, but the spiral is generally so condensed that sporophylls appear to lie opposite each other in pairs and in four distinct vertical rows. Normally megasporophylls and microsporophylls are borne on the same strobilus, the former at the base and the latter in the upper part. Sometimes, there may be two vertical rows of each type of sporophylls. In some species the strobili produce either megasporangia or microspo-ıangia but both occur on the same plant. In *Selaginella selaginoides* basal sporangia are non-functional.

In *Selaginella* sporangia are reniform (kidney-shaped) to ovoid and have a short stalk. They are borne on the adaxial face between ligule and base of the sporophyll. At maturity the sporangia are almost axillary in position. Generally, megasporangia are much larger than microsporangia. However, in some species they are of the same size. Microsporangia are slightly elongate. The growth of the strobilus is apical.

The development of sporangia is eusporangiate type. The various stages of development of sporangia can be seen in a longitudinal section of strobilus (Fig. 17.7 E).

The development of sporangium starts with a small group of epidermal cells of stem which act as sporangial initials (Fig. 17.7 F) and divide by periclinal division (Fig. 17.7 G). The outer cells produce wall layers and tapetum and inner ones by repeated divisions form the sporogenous tissue (Figs. 17.7

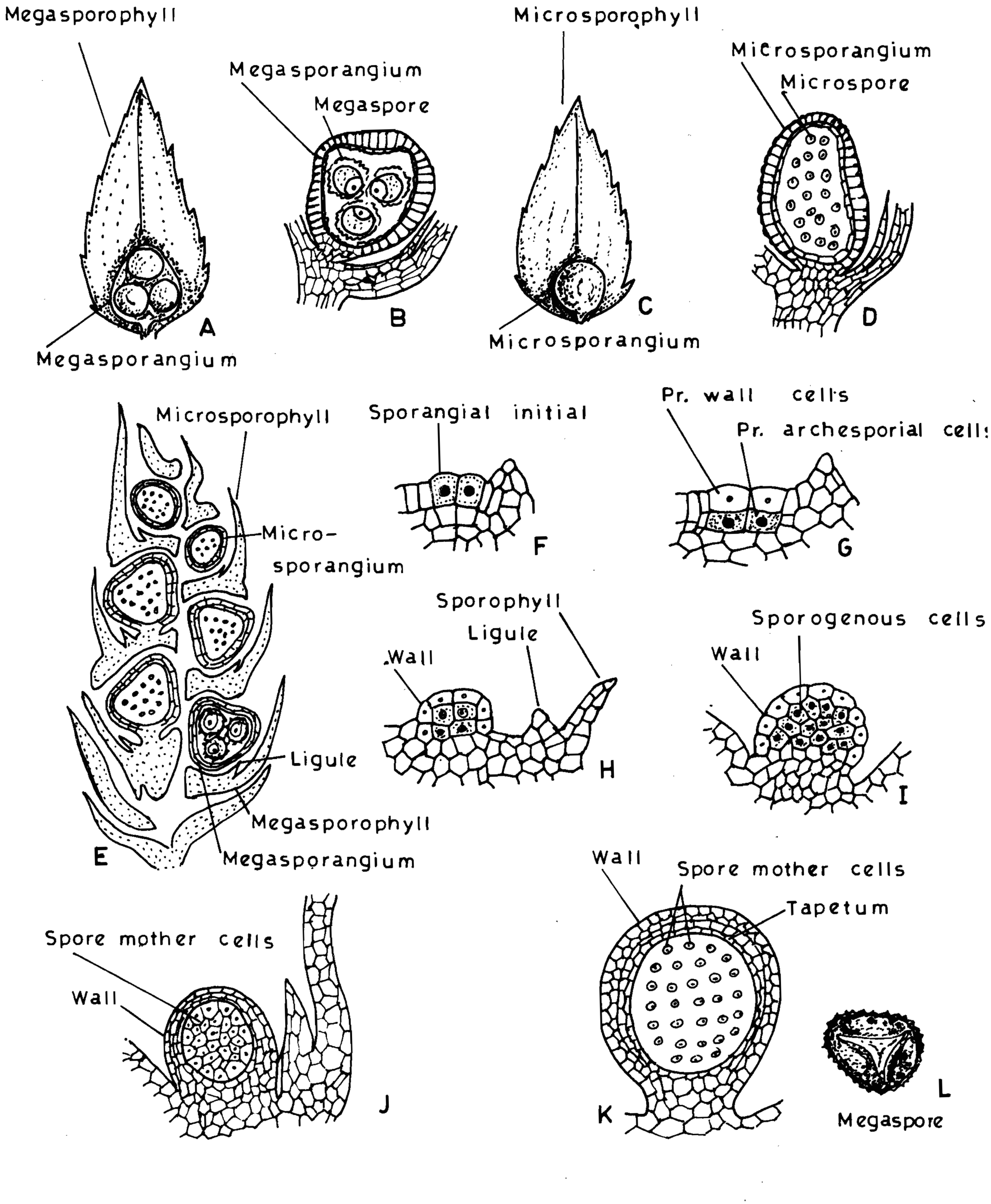


Fig. 17.7: ***Selaginella*****: A) A megasporophyll. B) V.S. of A. C) Microsporophyll. D) V.S. of microsporophyll, E) Vertical section of strobilus showing different stages of sporangial development. F to K) Different stages in sporangial development. L) A megaspore.**

H-K). All sporogenous cells of the last generation in the sporogenous tissue are potential sporocytes. In microsporangia most of the sporocytes form microspores and about 10-20% sporocytes degenerate and provide nourishment to the developing spores. In contrast, in a megasporangium all sporocytes degenerate except one. This surviving or functional sporocyte divides meiotically and forms four megaspores. Depending on their survival, varying number (1-4) of megaspores are formed in a megasporagium in different species. Only one megaspore per megasporangium is formed in *Selaginella sulcata.* In *S. rupestris* each megasporangium contains usually two megaspores. In some species there are more than one functional sporocytes so that up to twelve or rarely more megaspores result. Although both types of sporangia occur on the same plant, but in no instance one sporangium produces two types of spores. At maturity both microsporangia and megasporangia are stalked structures.

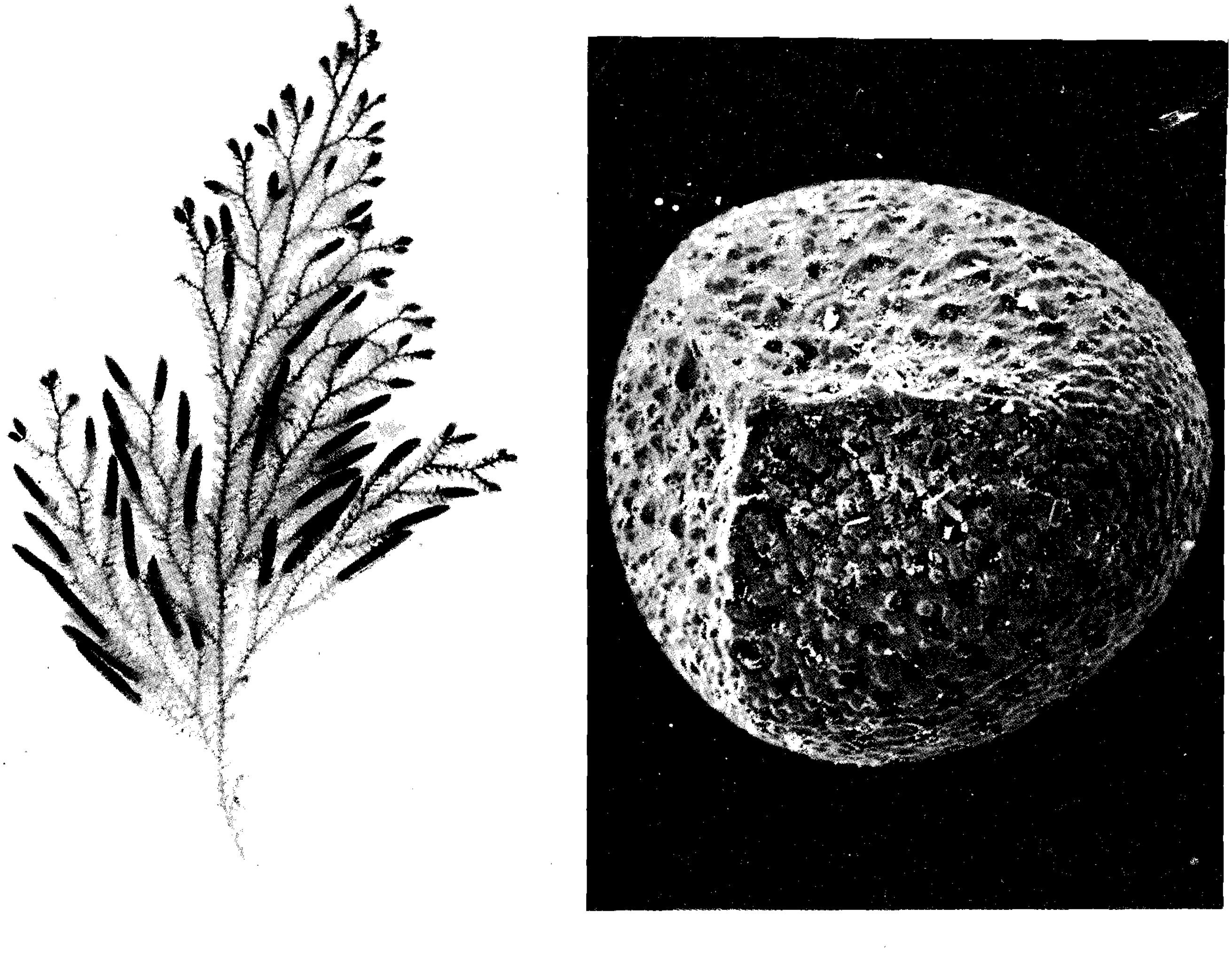


Fig. 17.8: ***Selaginella*****: A) Showing prominent strobili. B) SEM of megaspore (courtsey of P. Dayanandan).**

The wall in adult sporangium is 3-layered thick. The outer layer is composed of usually columnar cells which contain chlorophyll until after the spores are shed. The inner layer consists of flattened cells. The tapetum is the innermost layer. In a mature sporangium, only the outermost wall layer persists and rest decomposes before dehiscence. Spore dispersal takes place due to dehiscence of sporangium in the apical region. It is brought out by hygroscopic changes in the cells. In *Selaginella rupestris* though dehiscence of megasporangium takes place, but the megaspores are not shed. The spores (micro-and megaspores) are tetrahedral with a prominent tri-radiate mark and characteristic ornamentation (Fig. 17.7 L).

Development of Gametophyte

In *Selaginella* difference in the size of spores is associated with the difference in function. On germination these two types of spores produce two distinct types of prothalli; the microspore (Fig. 17.9 A) forms microgametophyte and the megaspore (Fig. 17.9 J) forms the megagametophyte also called macrogametophyte. With heterospory a new mode of gametophyte development is introduced in the life cycle. The gametophytes are formed within the spore wall i.e., development is *endosporic.* Nuclear divisions begin in spores before their dispersal. As a result of this gametophytes are in various stages of development at the time of dispersal of spore. At the time of liberation, the male gametophyte normally consists of 13 cells; one small prothallial cell, eight jacket cells and four androgonial cells. The various stages of development of male gametophyte are shown in figure 17.9 B-H.

By further divisions spermatogenous cells produce 128 or 256 antherozoids. Each antherozoid has two terminal flagella (Fig. 17.9 I). You have read in Unit 13 that bryophytes also produce such biflagellated antherozoids. In this respect *Selaginella* differs from other pteridophytes such as *Equisetum* and *Marsilea* that have multiflagellated sperms or antherozoids. The sperms are the smallest in *Selaginella* among vascular plants. Can you recall what type of sperms are produced in *Lycopodium*?

Generally, the development of megagametophyte in most species begins in *situ*, i.e., megagametophyte starts developing while the megaspore is still within the sporangium. Look at the developmental stages of megaspore shown in Fig. 17.9 J-L. Development of megagametophyte starts with considerable increase in the size of megaspore. Soon the megaspore nucleus divides repeatedly, but there is no cell wall formation. Megaspore develops a prominent central vacuole (Fig. 17.9 J). The multinucleate cytoplasm is restricted to a thin layer next to the spore wall. With the increase in number of nuclei, this cytoplasmic layer begins to thicken and the nuclei increase in size. After some time enlargement of multinucleate gametophyte slows down and cytoplasmic layer becomes thicker and thicker, eventually obliterating the central vacuole. The cytoplasmic layer is more thicker at apex, i.e. pyramidal end of the megagametophyte. In this region nuclei are arranged in a single layer and cell wall develops simultaneously (Fig. 17.9 K). The cells formed in the central region are regularly hexagonal and uninucleate, whereas cells present near the margins and below may contain 2 or more nuclei. For some time cell formation occurs in the apical region only and a lens-shaped cushion of tissue is formed which is 3-celled thick in the middle and only one cell in thickness at margins (Fig. 17.9 K). A very prominent diaphragm is formed by thickening of lower walls of lowermost layer which separates the apical cellular tissue from the (at first) non- cellular spore cavity (Fig. 17.9 L). The multinucleate layer of the spore cavity below the diaphragm rapidly becomes thicker and cellular. It is composed of large multinucleate cells of variable shape filled with reserve food materials like albuminous granules, oil and starch. These cells provide nutrition to the developing embryo until it becomes independent.

Eventually the exospore ruptures along the arms of tri- radiate ridge. The apical tissue projects above the tripartite cleft at its *apex* (Fig. 17.9 M). Most of the superficial cells of this tissue are potential archegonial initials, and many of these develop into archegonia (Fig. 17.9 N). Stages in the development of archegonium are shown in Fig. 17.9 O-S.

At maturity the neck cells of archegonia spread apart and a passage is formed for the entry of antherozoids.

Fertilization may take place while the megagametophyte is still within the sporangium or after it has fallen to the ground. The microgametophyte enclosed by the old microspore walls are brought to the megaspores by wind or gravity. The microspores drift among the megaspores with megagametophytes bearing archegonia. The antherozoids are set free and then they swim to the archegonia in a thin film of dew or rain water.

After fertilization the zygote secretes a protective wall and develops into an embryo. Further divisions in the embryo result in the differentiation of stem apex, cotyledons and a root-like structure-rhizophore (Fig. 17.9 T). The developing embryo eventually grows through the surrounding gametophytic tissue-the stem and its appendages growing upward and the rhizophore growing downward. This juvenile sporophyte is quite different from that of other pteridophytes in having the cotyledons borne directly on the stem and in having a conspicuous hypocotyledonary stem portion below the level of the cotyledons. Diagrammatic representation of life cycle of *Selaginella* is given in figure 17.10.

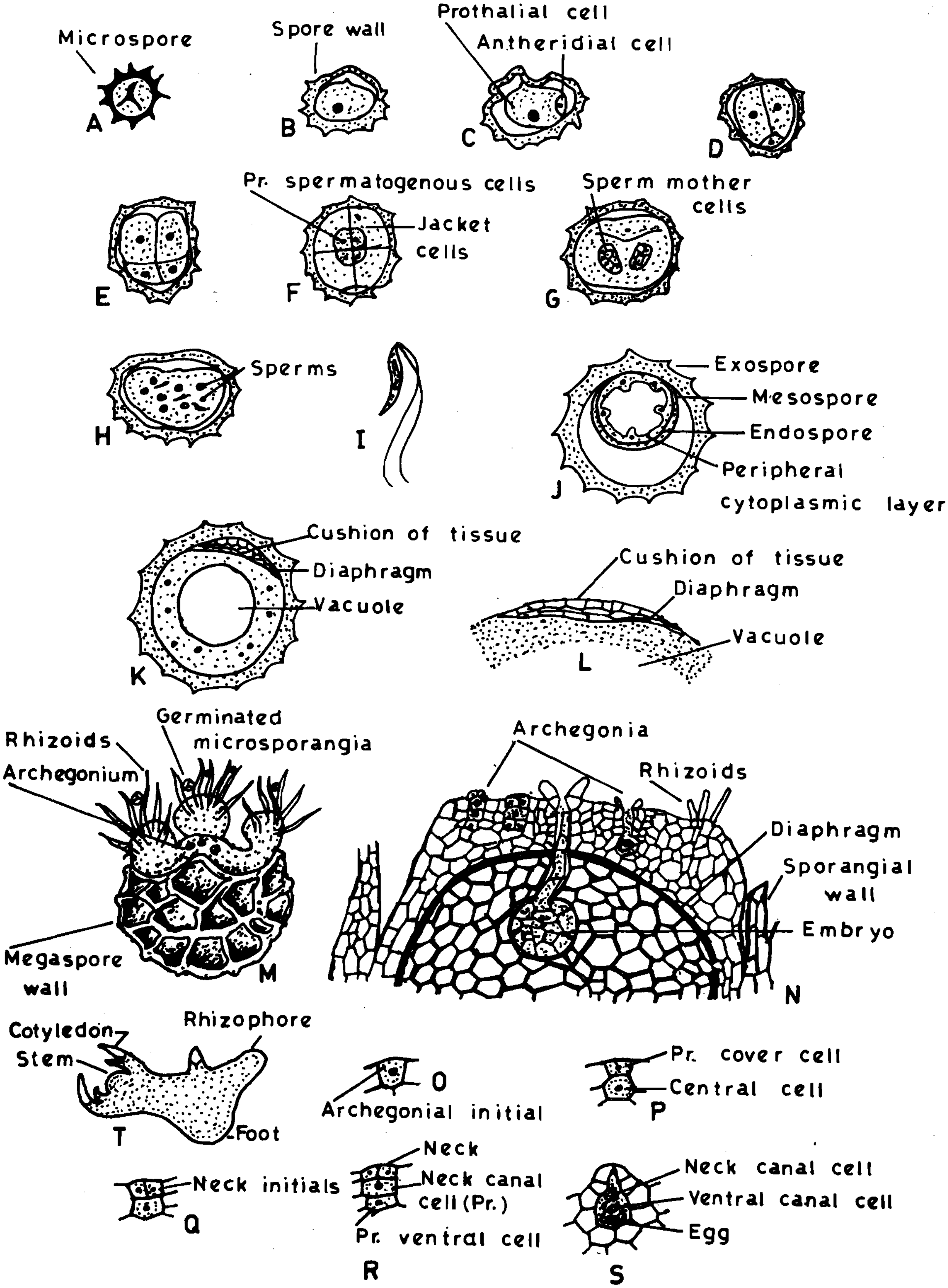


Fig. 17.9: ***Selaginella*****: A) A microspore. B to H) Different stages in the development of microgametophyte. I) Single antherozoid, J to L) Different stages in the development of megagametophyte. M) A mature megagametophyte. N) A portion of megagametophyte showing developmemt of archegonium in the cushion. O to S) Stages in the development of archegonium.**

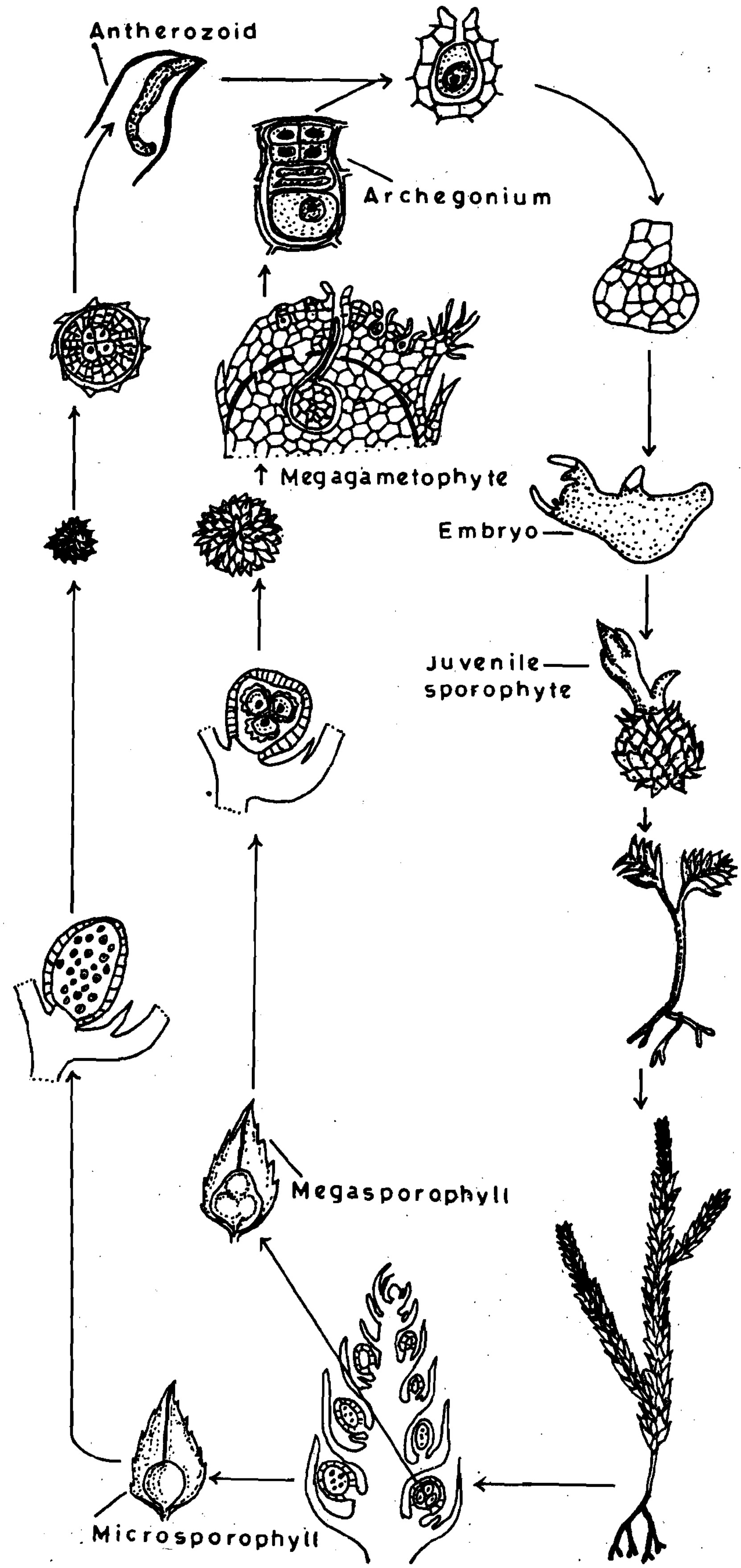


Fig. 17.10: ***Selaginella*, A diagrammetic representation of life cycle.**

Let us now sum up the main points.

1. Plants are heterosporous.
2. There are two kinds of sporophylls-microsporophylls and megasporophylls.
3. Both are situated spirally or in 4 ranked order on the cone axis. Both are ligulate.
4. A single large kidney-shaped stalked megasporangium is present on the adaxial surface near the base or in the axil of megasporophyll.
5. Similarly, microsporangia are present on microsporophylls.
6. Development of sporangium is of eusporangiate type.
7. Spores are of two kinds - larger megaspores on germination produce megagametophytes, small microspores on germination give rise to microgametophytes. Thus, gametophytes are dioecious.
8. Megagametophyte is much reduced in *Selaginella.* Its development starts within the sporangium while it remains in megaspore wall. Archegonia, from few to many, develop in the centre while it is in the megasporangium.
9. Fertilization may also occur while the gametophyte is still in the megaspore.

SAQ 17.3

a) Which of the following statements are true and which are false? Write **T** for true and **F** for false in the given boxes.

   i) Sporangia in *Selaginella* are of two types. ☐

   ii) Strobili in *Selaginella* are lateral. ☐

   iii) The development of female gametophyte and fertilization take place while megaspore is still within the sporangium. ☐

   iv) Some of the sporocytes degenerate to provide nourishment to the embryo. ☐

b) In the following statements choose the **correct** alternative word given in parentheses.

   i) Sporangial development is of (leptosporangiate/ eusporangiate) type. ( )

   ii) Megasporangia are (smaller/larger) than the microsporangia. ( )

   iii) Antherozoids are (multiflagellate/biflagellate). ( )

   iv) Female gametophyte develops (within/outside) megasporangium. ( )

c) Compare the development of gametophyte of *Selaginella* with that of *Lycopodium.*

....

....

....

17.2.4 *Equisetum*

Next to *Selaginella,* in evolution is *Equisetum.* You have already studied in the previous unit about morphological pecularities of vegetative parts of this genus. In the proceeding account you will learn details of reproductive structures and will compare with the genera you have studied so far.

Reproductive Bodies

Equisetum, unlike *Selaginella*, is homosporous. Spores are produced inside the sporangia as in *Selaginella* and *Lycopodium*, but sporangia of *Equisetum* are borne on stalked structure which are known as sporangiophores. These sporangiophores are quite different from the ordinary leaves and are grouped together forming a strobilus (Fig. 17.11). Strobili are terminal in position and solitary. In most of the species of *Equisetum* there is no segregation between fertile and sterile shoots. So in these species the aerial shoots perform dual function of photosynthesis and reproduction. Generally whorled branches of aerial shoots do not bear strobili.

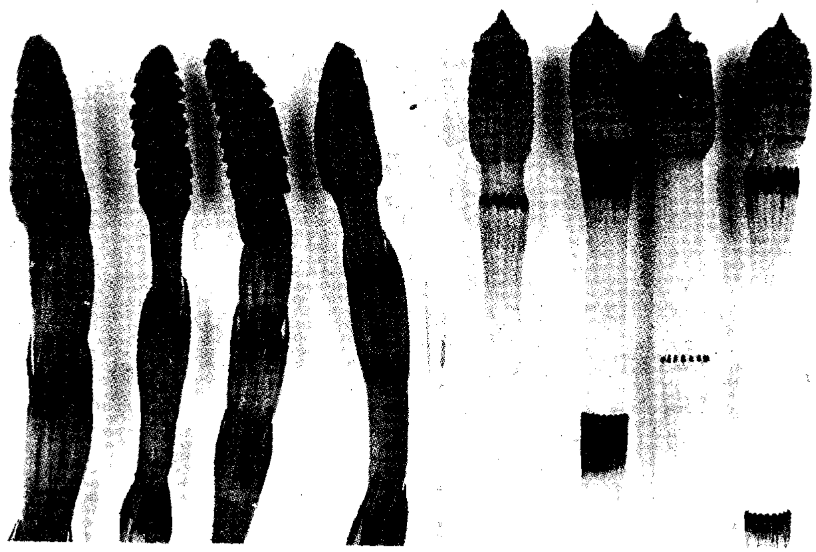


Fig. 17.11: *Equisetum*, arvense and *E.nyemale* Photograph showing strobili, (courtsey of P. Dayanandan).

Like vegetative structure, the strobilus of *Equisetum* is quite peculiar. It is composed of a central thick axis (Fig. 17.12 A). On this axis a number of T-shaped peltate sporangiophores are densely packed in successive whorls alternating with one another. The number of sporangiophores in each whorl varies from a few to many. A ring-like outgrowth also appears near the base of the strobilus and this is known as **annulus.** This is regarded as a protective structure by some botanists.

The sporangiophore can be divided into two regions (i) a small proximal cylindrical stalk-like portion attached at right angles to the axis of the strobilus (Figs. 17.12 B, C) and (ii) a shield-like peltate disc attached to the distal or outer end of the stalk. A number of sporangia (usually 5-10) are produced from the undersurface in the form of ring near the edge of this disc (Fig. 17.12 B). The peltate heads of sporangiophores are so packed that sporangia are concealed. The disc acquires a hexagonal shape due to mutual pressure.

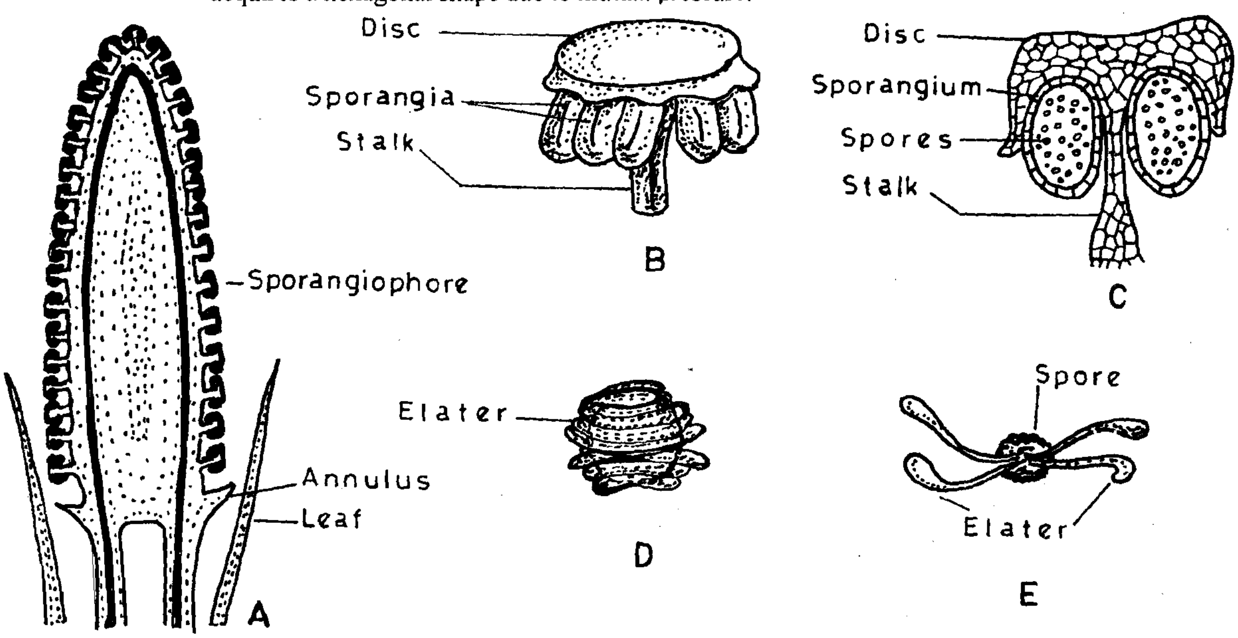


Fig. 17.12: *Equisetum*: A) V.S. of strobilus. B) Peltate sporangiophore. C) V.S. of sporangiophore. D and E) Spores showing elaters.

At maturity the axis of the strobilus elongates slightly and this results in the separation of the sporangiophores from each other. Later due to loss of water the sporangiophores shrink and fall apart exposing the sporangia. The sporangia dehisce by longitudinal slits, down the side next to the sporangiophore stalk and the spores are dispersed.

The spore wall is composed of four layers: outermost epispore, middle perispore, followed by exospore and the innermost is endospore. The epispore divides along several spiral lines into two long bands which until maturity remain closely wound around the spore (Fig. 17.12 D). These bands are detached from each other except at one point. The tips of the bands are slightly expanded or spoon-like (Fig. 17.12 E). They are known as elaters and are spirally wrapped around the spores. They are hygroscopic and remain coiled around the spores in moist air. During dry conditions the elaters stretch themselves out crosswise, remaining attached only in the middle of their length at one point so that they appear as four distinct appendages. In the previous units you have read about elaters in bryophytes. Compare the elaters of *Equisetum* with that of liverworts. You will find that in bryophytes elaters are formed from complete cells, not from the wall of spore. They are diploid and have spiral thickenings. But in *Equisetum* they are haploid and do not have spiral thickenings.

The elaters help in dehiscence of sporangium and in the dispersal of spores. At maturity when the sporangia lose water, elaters get uncoiled and exert pressure on the wall of the sporangium. This results in the opening of sporangium along the longitudinal slits and the spores are dispersed in masses.

Spores of *Equisetum* do not have triradiate mark.

Development of Gametophyte

Spores of *Equisetum* remain viable for 5-20 days. The spore is the first cell of gametophyte. It germinates within 2-3 days under suitable conditions such as sufficient oxygen and moisture. Before the initiation of spore germination, certain changes takes place inside the spore. The large vacuole is replaced by many smaller vacuoles and the chloroplasts surround the nucleus. The diameter of the spore increases by absorbing water and its wall ruptures. The elaters are cast off. It is followed by an unequal division of the spore into a smaller lenticular rhizoidal and a large prothallial cell. The stages involved in the development of gametophyte are shown in figure. 17.13 A-E. The prothallial cell is rich in chloroplasts and oil droplets. The rhizoidal cell elongates into primary rhizoid. The prothallial cell divides initially by transverse wall and forms a filament of green cells. The cells of this filament divide in all directions to form a flat green and leaf-like expanse of tissue or an elongated and branched thallus (Fig. 17.13 F). Any superficial cell of the thallus at this stage may divide unequally into a small secondary rhizoidal cell and larger cell. The smaller cell acts as secondary rhizoidal cell. By further anticlinal and periclinal divisions the prothallus increases in thickness. Ultimately a several cells thick, cushion-shaped massive thallus bearing numerous rhizoids on its lower surface is formed.

Further development results in the formation of prothallus in which three distinct regions can be recognised:

i) The upper erect, green, photosynthetic portion in the form of spongy, irregularly-shaped lobes.
ii) The middle basal prostrate region of light-yellow colour.
iii) The lowermost region of colourless cells that gives off rhizoids.

The mature prothallus ranges in size from 1-10 mm in diameter. The prothallus is generally attacked by a fungus in the upper cells of the lobes. Internally prothallus is differentiated into two zones: (i) lower compact rounded parenchymatous portion forming the disc, and (ii) an upper spongy portion. The disc is composed of non-chlorophyllous large cells which are compactly arranged and are full of starch grains.

The disc has outer marginal meristematic rim which increases the diameter of disc and forms new erect lobes as well as rhizoids. The spongy upper portion is composed of densely crowded green vertical lobes which completely cover the disc below. The lobes are irregular, plate-like expansions of chlorophyllous tissue several cells thick at the base but higher up becoming thinner and thinner, the ultimate part being only one cell in thickness. They are either spherical or more or less lobed. Sometimes lobes are arranged in a compact manner so that the spaces between them are narrow and the prothalli appear to be spongy.

Three types of prothalli may develop:

i) deep green female prothalli,
ii) light green male prothalli, and
iii) bisexual prothalli with thin male branches and thick and fleshy female branches.

Mature prothalli or gametophytes of *Equisetum* are dorsiventral, prostrate dull brownish-green thalloid structures generally found in abundance in shady places on the surface of clayey soil along the banks of streams and rivers.

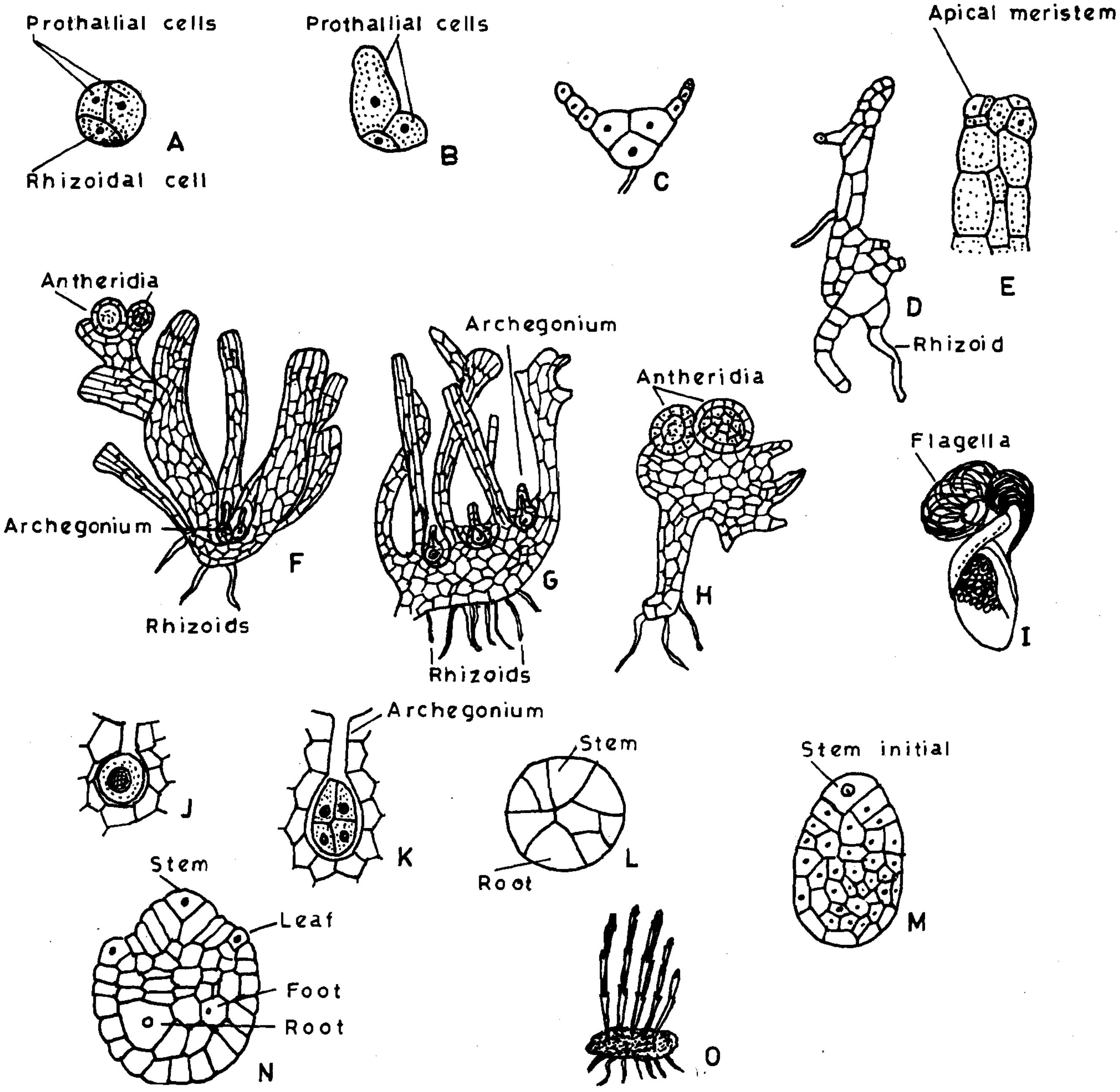


Fig. 17.13: ***Equisetum*****: A - E) Different stages in the development of prothallus. F - H) Dioecious and monoecious gametophytes. I) A multiflagellate antherozoid. J-O) Various stages of development of sporophyte.**

In most species the prothalli are monoecious i.e. both sex organs are produced on the same prothallus. Mature sex organs are present between the plates or the lobes (Fig. 17.13 F). It has been observed that generally the crowded and starved prothalli produce male sex organs, while those which get sufficient food produce female sex organs. So, prothalli of *Equisetum* are usually monoecious but show tendencies towards dioecism.

The archegonia are found near the base and between the lobes. The prothallus ceases to grow after fertilization of the first- formed archegonia. The mature archegonia have the sunken base in the prothallus tissue with only its neck protruding (Fig. 17.13 G). The neck is short consisting of four rows with usually 3 or 4 cells in each row. The neck cells of the upper most tier are divaricate (bent back) at maturity thus leaving a wide opening for the entry of the sperms. The axial row consists of the egg cell, the ventral canal cell, and one or two neck canal cells. At maturity there is the usual gelatinisation of all axial cells but the egg.

The antheridia develop later when the prothallus is several months old. They are produced in large numbers mainly in non- chlorophyllous part. They develop in an acropetalous succession and are of two types: embedded and projecting type. The embedded type develop on the lower massive and cushioned part of the prothallus. The projecting type usually develop in starved prothalli and are found at the apices of the margins of the erect lobes. Mature antheridium is a more or less globular sessile structure. The jacket of the antheridia is single layered (Fig. 17.13 H). It encloses a large number of multiflagellated spermatozoids (Fig. 17.13 I) and it dehisces by absorbing water. The wall of the antheridium forms a slit-like aperture through which antherozoids escape.

Water is also essential for fertilization. The spermatozoids are attracted by malic acid around the open archegonial necks. A number of spermatozoids enter the neck and reach the venter but only one is able to effect fertilization. The fusion of male gamete and female gamete (egg) results in the formation of zygote or the oospore. Many archegonia are fertilised on one prothallus.

Development of sporophyte:

The zygote divides by a transverse wall into an upper epibasal cell and a lower hypobasal cell. There is no suspensor. Next division is longitudinal which divides these cells into four cells forming quadrants. The upper cells are larger than lower ones. One more longitudinal division at right angles to the first longitudinal in the above quadrant results in the formation of octant (eight cells). Out of the epibasal octant the largest cell functions as the shoot apical cell. Various stages of development of sporophyte are shown in figure 17.13 J-O.

SAQ 17.4

(a) Which of the following statements are **TRUE** and which are **FALSE**? Write **(T)** for true and (F) for false.

i) Spores of *Equisetum* do not have triradiate marking. ☐

ii) Equisetum is heterosporous. ☐

iii) Prothalli of *Equisetum* are generally dioecious. ☐

iv) There is no suspensor in the embryo of *Equisetum*. ☐

(b) In the following statements fill in the blank spaces with appropriate words.

i) Sporangia of *Equisetum* are borne on stalked structures called ....

ii) Sporangiophores are .... in *Equisetum*.

iii) Spore wall is composed of .... layers.

iv) Spoon-shaped .... are present on spores.

v) Sporangia dehisce by .... slits.

vi) Growth of prothallus of *Equisetum* takes place by the activity of .... meristems.

17.2.5 *Pteris*

In the preceding account you have studied the structures associated with reproduction in fern-allies. Now you will study reproduction in true ferns.

Reproductive Bodies

As you have learned that in fern - allies the spores are produced within sporangia, which are arranged in the form of cones or strobili. In true ferns sporangia do not form cones or strobili instead they occur in small or large groups known as sori (sing, sorus, Fig. 17.14 A). The sori may be protected by a revolute margin or by a special outgrowth called the **indusium** (Figs. 17.14 B, C) or they may be unprotected or naked. Besides the sporangia, the sorus also includes the receptacle or placenta on which the sporangia arise. The indusium if present may also be regarded as a part of the sorus. A sorus may have from 2 to many sporangia. The sori are variously

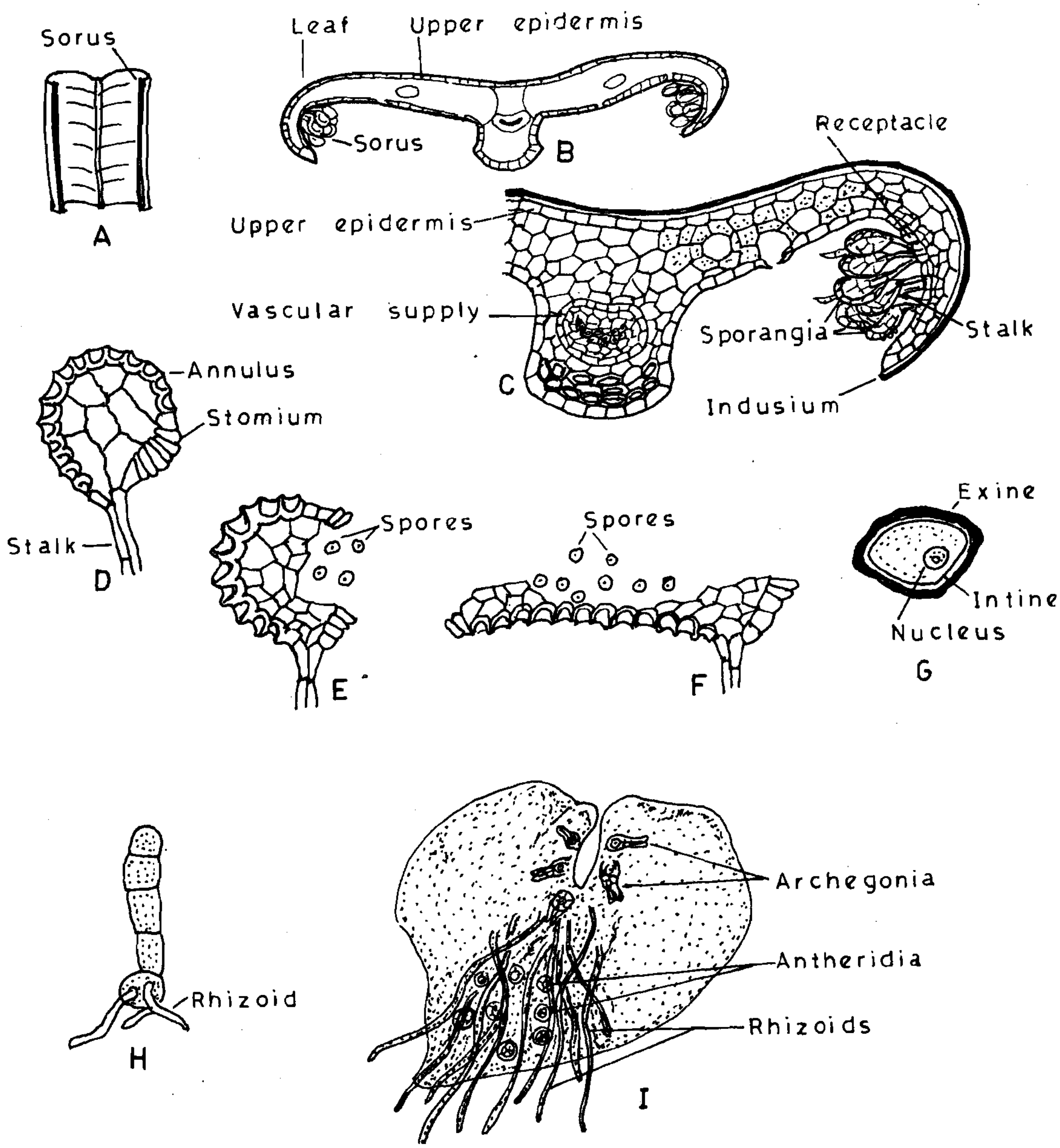


Fig. 17.14: ***Pteris:*** **A) A part of leaf of *Pteris* showing sorus. B, C) Sporangia protected with revolute leaf margins. D) A mature sporangium. E and F) Dispersal of spores from sporangium. G) A spore. H) Initial stage in prothallus development. I) A mature prothallus bearing sex organs.**

arranged on the margins or on the ventral surfaces of leaves or leaflets. The foliage leaves become sporangia bearing leaves and such fertile leaves are called sporophylls.

In *Pteris* any leaf or leaflet can bear sori on its under surface and there is no distinction between fertile and sterile leaves. The sori become confluent and appear as a single continuous linear sorus called coenosorus (Fig. 17.14 A). These sori are protected by the inwardly turned margins of the leaflets. Such a protective device is called false indusium (Fig. 17.14 B). In *Pteris* old and young sporangia occur together and show no regular arrangement in sorus. Each sporangium produces 48 spores. A sporangium has two parts: (i) stalk or the pedicle and (ii) capsule or the spore sac (Fig. 17.14 C). The stalk is formed by 3 rows of elongated cells. The capsule is more or less oval and appears like a biconvex lens. A mature sporangium possesses a single layered capsule wall surrounding the spores (Fig. 17.14 D). Capsule wall is composed of thin-walled, flattened polyhedral and transparent cells. These cells have wavy cell walls along the two flattened sides of the sporangium. Around the edge of the capsule a vertical row of about 16 cells, with specially thickened radial and inner tangential walls, forms the *annulus*. It stretches over about two- third of the circumference of the capsule connecting the sides and forms an incomplete ring. The remaining one-third portion has a small group of long, flat and thin-walled cells. It is known as *stomium*. In the stomium two cells are narrow and radially elongated. These form the lip cells. The annulus and stomium are associated with the dehiscence and dispersal of spores (Fig. 17.14 E-F). The development of sporangium is of leptosporangiate type.

Spores are somewhat triangular with a distinct tri-radiate mark. The size of spores also varies in different species. The spore wall is thick and composed of an outer exine and inner intine (Fig. 17.14 G). The exine is variously sculptured in different species.

Development of Gametophyte

Under favourable conditions germination of spore takes place. The exine ruptures and the uninucleate contents protrude out in the form of a small cylindrical structure (Fig. 17.14 H) which ultimately develops into prothallus.

The mature prothallus is thin, green in colour, heart-shaped with an apical notch (Figs. 17.14 I and 17.15). Cell divisions are mainly restricted to the region behind the notch and in the lateral wings. The prothallus is about 0.3 to 0.5 mm in diameter. There is also a thick central cushion which is formed as a result of divisions in the cells behind the apical notch. From the posterior region of the prothallus numerous secondary rhizoids arise.

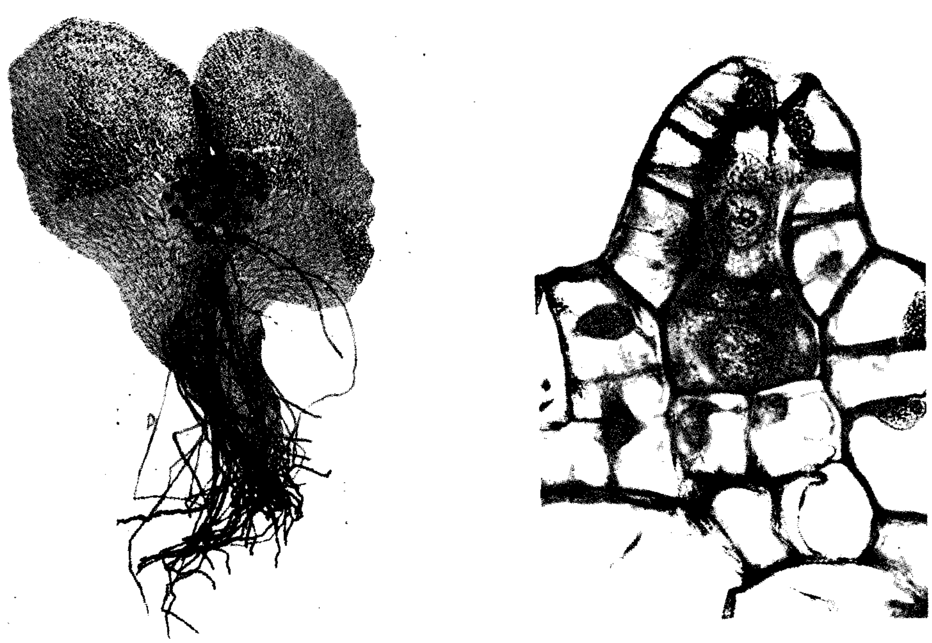


Fig. 17.15:A) Photograph of fern prothallus showing archegonium. B) Section of archegonium showing egg, ventral canal cell and neck canal cell (courtsey of Prof. P. Dayanandan)

In *Pteris* the sex organs and rhizoids develop on ventral side of adult prothallus (Fig. 17.14 I). Normally such prothalli are monoecious. The antheridia occur among the rhizoids whereas the archegonia are restricted to the cushion behind the apical notch.

An antheridium develops from a superficial bulging cell of prothallus which divides by transverse division into a basal cell and antheridial initial (Fig. 17.16 A). A curved cell wall appears in the antheridial cell which touches the basal cell (Fig. 17.16 B). As a result of this an upper dome cell or central cell and lower ring cell are formed. One more curved wall in the central cell forms an outer jacket cell and a central primary androgonial cell. By a periclinal division of jacket cell an upper cap cell and second ring cell are formed (Fig. 17.16 C). The central primary androgonial cell by repeated divisions forms 32 spermatids (Figs. 17.16 D, E) whose protoplasts metamor

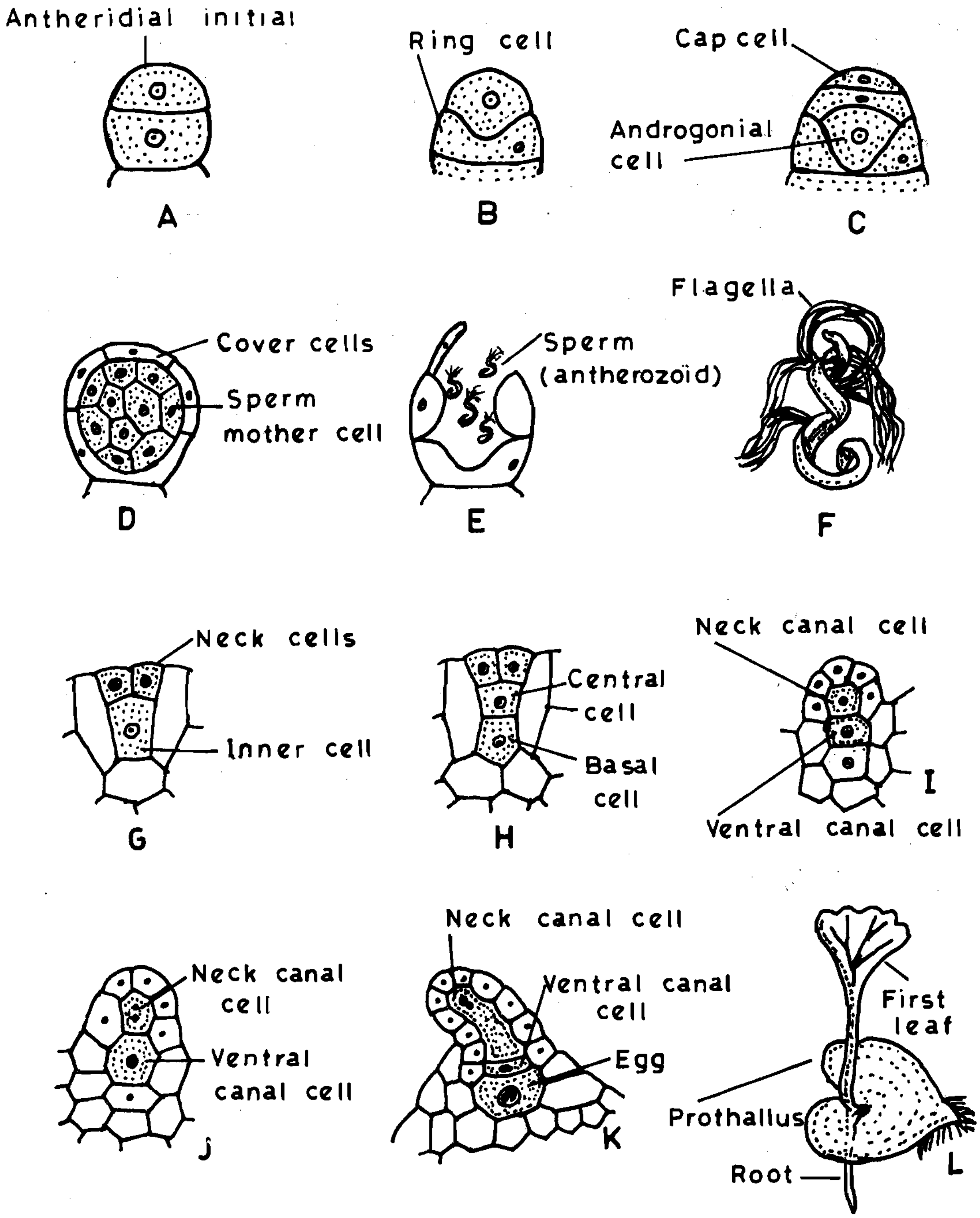


Fig. 17.16: *Pteris:* A - E) Different stages in the development of antheridinm. F) A spermatozoid. G-K) Different stages in the development of archegonium. L) Prothallus with sporophytic plant.

phose into multiflagellate spermatozoids (Fig. 17.16 F). At maturity the outer wall of the antheridium is made up of three cells: (i) the basal cell (first ring cell) which may be funnel-shaped (ii) the annular or the second ring cell and (iii) the apical cap cell or the cover cell. During dehiscence the cap cell is thrown off. It often collapses during the process.

Like antheridium, archegonium also develops from a superficial cell which divides by a transverse division into an upper primary cover cell and a lower inner cell. The lower cell by transverse divisions forms an upper primary cover cell, middle central cell and a lower basal cell. The cover cell by two vertical divisions at right angles to each other forms 4 primary neck cells (Fig. 17.16 G). Divisions of the central cell result in an upper primary neck canal cell and a lower primary ventral cell (Fig. 17.16 I,J). The primary neck cell divides transversely to form a neck of 3-7 cells in height. Only one neck canal cell which is binucleate, is present. The primary ventral cell forms an upper smaller ventral canal cell and a lower larger egg cell (Fig. 17.16 K). At maturitythe archegonium has two distinct parts: neck and venter. The neck is composed of 4 longitudinal rows of cells with four cover cells at the top. Inside the neck is present neck canal cell(s). The lower swollen venter region contains an egg and a ventral canal cell.

Fertilization requires water as male gametes are flagellated. Water is available in the space between the ventral surface of the prothallus and the soil. Both kinds of sex organs are in contact with moist substratum and open on the lower surface of the prothallus. The antherozoids or sperms are attracted by malic acid which diffuses out into the water from the mucilage exuded by the open necks of the archegonia. When they finally enter the neck, one of the antherozoids fuses with the egg. The fertilized egg secretes a wall around it. The egg of only one archegonium is fertilized in each prothallus. After fertilization the growth of the prothallus ceases.

The first division of the zygote is parallel to the long axis of the archegonium and unequal. The smaller cell towards the apex of the prothallus is the epibasal cell and the larger is the hypobasal cell. Further divisions result in the formation of multicellular embryo, and differentiation of various organs is evident at 32-celled stage. The anterior superior octant forms shoot. The first leaf arises from anterior inferior octant, whereas root develops from the posterior inferior octant and the foot is formed by posterior superior octant. During further development root grows rapidly and establishes contact with the soil and the first leaf emerges out of the prothallus and finally a new plant is formed (Fig. 17.16 L).

SAQ 17.5

In the following statements about *Pteris* choose the alternateive correct word given in the parentheses.

i) The sporangia are produced on the (dorsal/ventral) surface of the leaf.
ii) A (true/false) indusium covers the sorus.
iii) The annulus is composed of (eight/sixteen) cells.
iv) The development of sporangia is (leptosporangiate/ eusporangiate) type.
v) The prothalli are (monoecious/dioecious).
vi) The sex organs are present on the (dorsal/ventral) surface of prothallus.

17.2.6 *Cyathea*

Like *Pteris, Cyathea* is a true fern. In the following account you will learn about reproductive structures of *Cyathea* and also about the differences between these two genera of Filicophyta.

Reproductive organs

In *Cyathea* the spore producing organs i.e., sporangia are found on the ventral side of **pinnules**. These sporangia are clustered together in the form of distinct sori. Sori are arranged in a single series on either side of the midrib of the pinnule (Fig. 17.17 A). Each sorus is present on a lateral vein and its position on the vein varies in different species. The receptacle bearing the sorus is globose or elongated and is sufficiently raised above the surface of pinnule. In ***Cyathea*** the indusium is well developed. It rises as a cup-like structure from the base of the receptacle and covers the entire sorus when it is young. At maturity the apical portion of the indusium splits irregularly and only its base persists (Figs. 17.17 B,C). In some species the development of indusium is very slow and the developing sporangia are protected by hairs, while in others the indusium grows at much faster rate and soon covers the developing sporangia.

The development of sporangia starts with the appearance of sporangial initials on the receptacle. These initials arise in a basipetalous manner. The development of sporangium is of leptosporangiate type as seen in *Pteris*. A young sporangium has a single-layered outer wall and

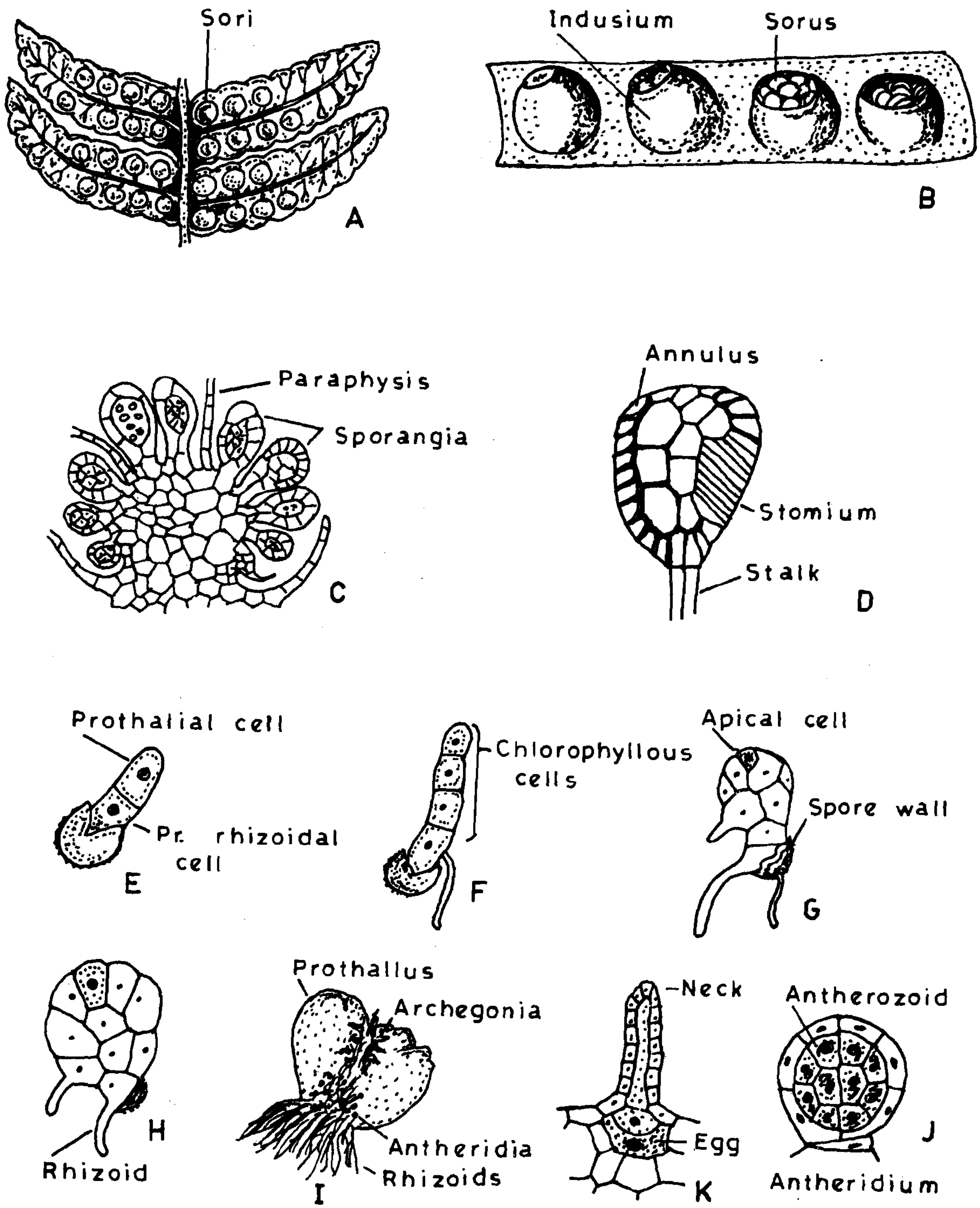


Fig. 17.17: ***Cyathea:*** **A) Portion of leaf showing sori on ventral surface. B) A portion of A enlarged. C) V.S. of sorus showing various stages of sporangial development. D) A single sporangium. E-H) Different stages of prothallus development from germinating spores. I) A mature prothallus. J) An antheridium. K) An archegonium.**

two-layered tapetum. It contains four to sixteen spore mother cells. A mature sporangium has a distinct stalk and a small capsule. The stalk is composed of 4 vertical rows of cells. The capsule has obliquely vertical annulus that incompletely encircles the capsule of the sporangium. A distinct stomium is also present (Fig. 17.17 D). A transverse dehiscence slit appears in this region at maturity and spores are dispersed.

Development of Gametophyte

The spores germinate under suitable conditions. The first division is transverse (Fig. 17.17 E). It divides spore into the lower primary rhizoidal cells and the upper prothallial cell. The former cell develops a primary rhizoid and the latter grows into a short filament of chlorophyllous cells (Fig. 17.17 F). Further longitudinal division results in the formation of a flat plate of cells (Fig. 17.17 G). By further division it differentiates into plate-like gametophyte with one apical cell (Fig. 17.17 H), but later on apical cell is replaced by a group of meristematic cells. At maturity the prothallus is heart-shaped. Behind the apical notch there is a cushion which is several cells in thickness. In *Cyathea* scale-like hairs occur on the ventral surface of prothallus (Fig. 17.17 I).

Generally the sex organs are borne on the ventral surface of the prothallus. They usually develop on the posterior end. The archegonia are initiated on the cushion just behind the apical notch. The development of antheridia and archegonia is similar to that of *Pteris* or in other leptosporangiate ferns. However, in *Cyathea* antheridia possess a single stalk cell and two opercular (cap) cells. The two opercular cells are formed by division of the primary opercular cell. The mature archegonium possesses a neck composed of 4 longitudinal rows and each row is about 9 cells high (Fig. 17.17 K). Inside the neck a neck canal cell is present and this may be binucleate or tetranucleate. In the venter region a single ventral canal cell and an egg is present. Fertilization takes place in the presence of water and fusion of antherozoid with egg results in the formation of zygote. The first division of zygote is vertical and is followed by two more divisions in different planes forming octant stage. At this stage, apical cells of the primary organs of sporophyte differentiate. The primary leaf or the cotyledon emerges from the prothallus and primary root grows first and establishes the young sporophyte.

SAQ 17.6

In the following statements fill in the blank spaces with appropriate word(s).

i) In *Cyathea* sporangia form distinct ....
ii) Sori are arranged on either side of the .... of pinnules.
iii) A .... cup-shaped indusium is present around each sorus in *Cyathea.*
iv) Development of sporangium is of .... type.
v) Prothalli of *Cyathea* are ....

17.2.7 *Marsilea*

In the previous unit you have read that morphologically *Marsilea* is quite different from other pteridophytes. In the following account you will learn about peculiar features of reproductive biology of *Marsilea.*

Reproductive bodies

Marsilea is heterosporous. The micro and megaspores develop within the respective micro and megasporangia which are produced in highly specialised structures known as **sporocarps**. These are flattened, spherical to ovoid in shape and bear a stalk. They are inserted slightly above the base of petiole (Fig. 17.18 A). In *Marsilea polycarpa* large number of sporocarps are present on one side of the petiole, but generally in other species one sporocarp is present on one petiole. In *Marsilea quadrifolia* branching of the stalk of sporocarp may result in the formation of 2-3 sporocarps per petiole. In some species the sporocarps have distinct external ridge, the raphe and two bumps. The raphe represents the end of attachment of the stalk (Fig. 17.18 B).

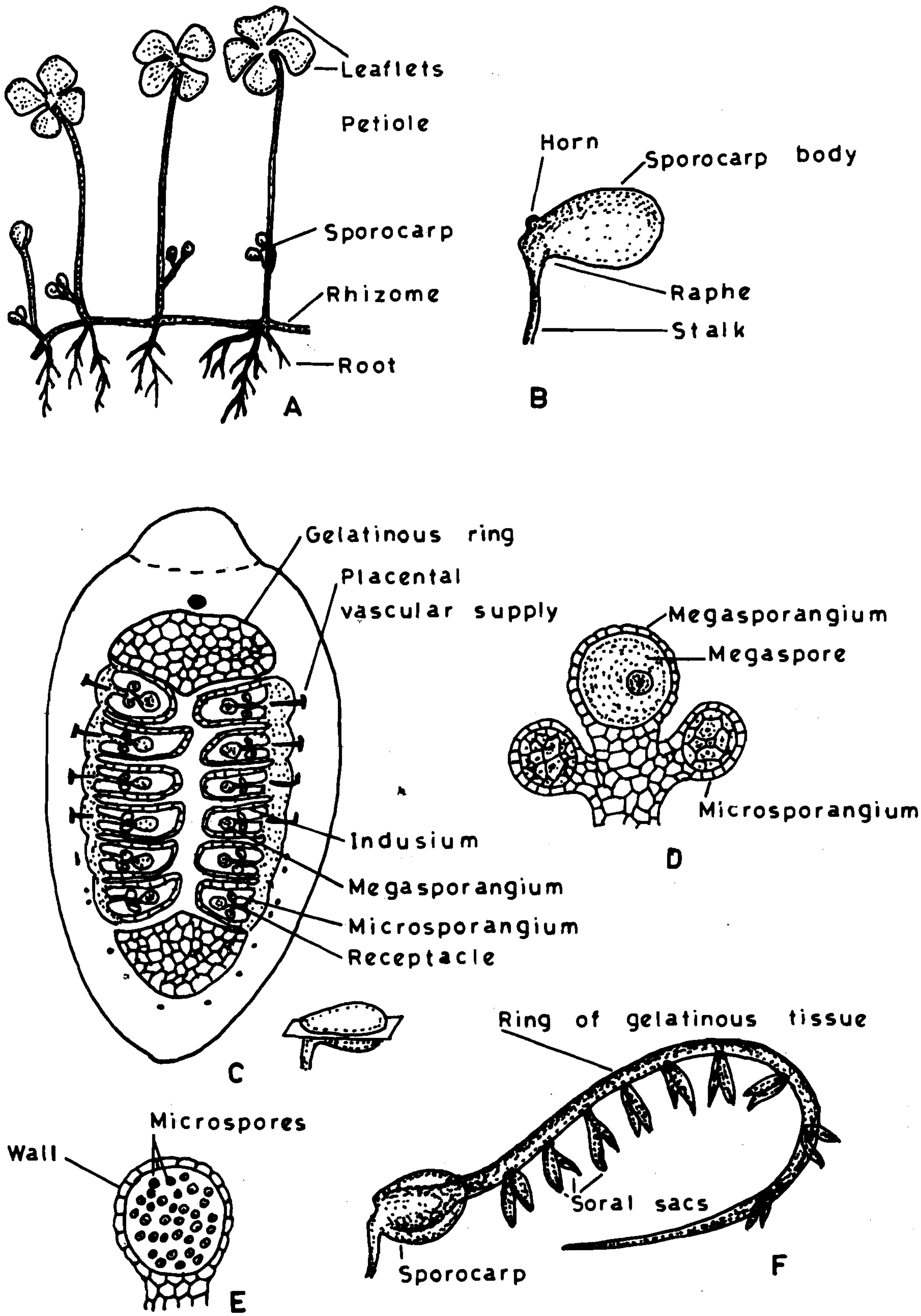
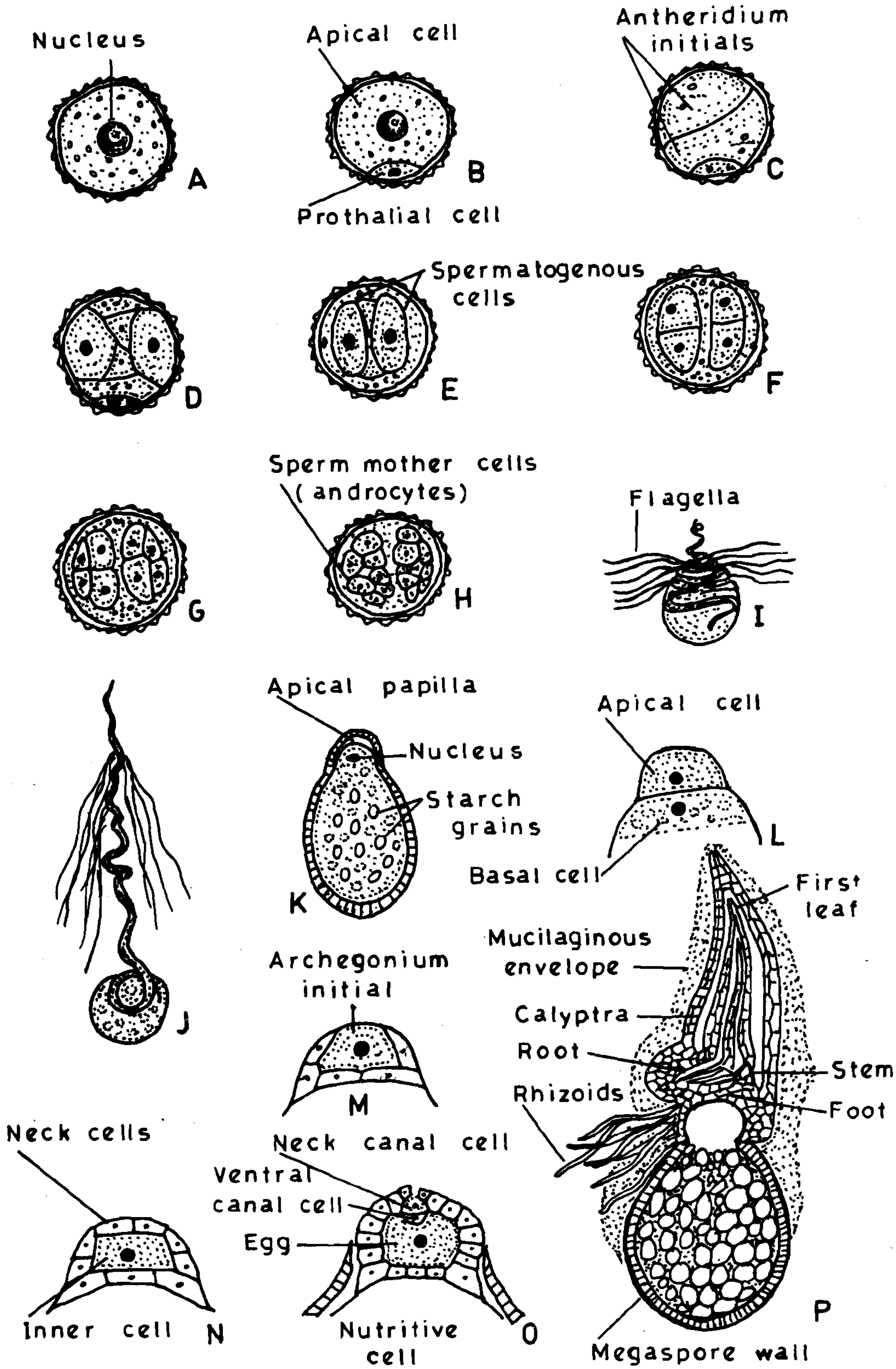


Fig. 17.18: ***Marsilea*****: A) Plant with sporocarps. B) Detailed structure of sporocarp. C) Horizontal section through sporocarp. D) Young sorus with terminal megasporangium and lateral microsporangium. E) A single microsporangium. F) A dehisced sporocarp showing gelatinous structure bearing soral sacs.**



ig. 17.19: *Marsilea:* A) A microspore. B) Two-celled microgametophyhte. C to H) Stages in the development of male gametophyte. I-J) Multiflagallate sperms (Antherozoids). K) Mature megaspore. L-O) Different stages in the development of female gametophyte, and archegonium. P) Longitudinal section of sporophyte still enclosed in calyptra.

The wall of sporocarp is thick and resistant to injury and desiccation. A ring of gelatinous tissue is present in the cavity inside the sporocarp. On either side there are two rows of elongate sori which extend transversely to the long axis of the sporocarp (Fig. 17.18 C). Each sorus arises on ridge-like placenta on receptacle which is attached to the gelatinuous ring and also to the wall of sporocarp on one side. They are covered by two-layered membranous indusium. Number of sori in each sporocarp varies from 2 to 20 in different species. Megasporangia are borne on a raised receptacle. Each megasporangium has a single large megaspore (Fig. 17.18 D). On the sides of megasporangium are borne microsporangia which contain numerous microspores (Figs. 17.18 D, E).

At maturity sporocarp splits open in the form of two valves. This occurs due to absorption of water by gelatinous ring which expands. The sori are separated from the wall of sporocarp by an abscision layer along the receptacle. This is followed by the breaking of ring at one end and causes the emergence of elongate worm-like structure with the sori (Fig. 17.18 F). Due to their thick walls sporocarps can survive long periods of drought and remain viable up to 35-40 years. The spores are released by the decomposition of surrounding tissue. The microspores are small and globular cells with a centrally placed prominent nucleus (Fig. 17.19A). They have some starch grains located near the wall. The microspores germinate soon after dispersal. The nucleus migrates to one side and first division is unequal forming smaller lens-shaped cell and a larger cell. The larger cell through a series of divisions, differentiate into two spermatogenous cells which produce 32 sperms (Figs. 17.19 B to H). In *Marsilea* antherozoids are multiflagellate and screw-shaped with a prominent vesicle (Figs. 17.19 I and J). The megaspore is a large, white papillate structure. It is enclosed by a gelatinous layer and its nucleus is located near the *papilla* (Fig. 17.19 K). The first division produces a small cell which lies in papilla (Fig. 17.19 L). The larger basal cell occupies the rest of the spore and has abundant reserve food. In *Marsilea* female gametophyte produces only one archegonium. The stages in the development of archegonium can be seen in (Figs. 17.19 M-O). An opening is present at the apex of gelatinous sheath around megaspore. The sperms get attached to the sheath and pass downwards to the archegonium through the opening in the sheath. The embryo is restricted to the papilla region. First division is longitudinal and the second is transverse, giving rise to quadrant stage. Two outer segments of this quadrant form leaf and root, whereas two inner ones form stem and foot (Fig. 17.19 P).

SAQ 17.7

Which of the following statements are true and which are false? Write **T** for true and **F** for false statement in the given boxes.

i) In *Marsilea* sporangia are produced in specialised structures known as sporocarps. ☐

ii) Each megasporangium contains 4 megaspores. ☐

iii) Antherozoids are biflagellated in *Marsilea*. ☐

iv) Megaspore is a papillate structure. ☐

v) More than one archegonia are produced by each female gametophyte. ☐

vi) Each male gametophyte produces 32 sperms. ☐

In addition to the above described method of sexual reproduction, pteridophytes can also reproduce by vegetative reproduction.

17.3 VEGETATIVE REPRODUCTION

In addition to the above described methods of sexual reproduction, pteridophytes can also reproduce by vegetative methods. In the following account you will learn about some methods of vegetative propagation.

Vegetative propagation by means of gemmae or brood cells has been observed in *Psilotum* and *Lycopodium*. In *Psilotum* gemmae are minute, ovoid, multicellular outgrowths present admist the rhizoids or on the axils of branches. These gemmae grow by means of 2-sided apical cells. After detachment from parent plant they develop into a new plant. In *Lycopodium* gemmae are also known as **bulbils**. These are short reduced axes surrounded by thick and fleshy leaves.

In *Selaginella, Lycopodium, Equisetum* and *Pteris* vegetative propagation by fragmentation is also common. In this method, death and decay of older parts results in the separation of young branches and each of the branches develops into a new plant.

In *Lycopodium* and *Selaginella* under adverse conditions the tips of apical buds accumulate reserve food and are surrounded by compactly arranged leaves. On the onset of favourable conditions these resting buds resume growth and form new plants.

Vegetative reproduction also takes place by the formation of root tubercles in *Lycopodium, Selaginella* and *Equisetum*. These tubercles are multicellular structures and originate from cortex region of the root. They are protected by thick-walled cells and have abundant reserve food material. In *Marsilea* stem forms tubers for vegetative propagation.

17.4 SUMMARY

In this unit you have learnt:

- In general, in pteridophytes sporangia bear spores which under favourable conditions germinate and produce prothalli. The jacketed sex organs are borne on the prothalli. Male gametes are flagellated and number of flagella varies in different groups.
- In *Rhynia*, the sporangia are terminal and pointed. They occur singly and produce only one type of spores. Details of gametophytes are not known due to lack of fossils.
- In *Psilotum* 3-lobed sporangia called synangia are present on short lateral branches. They are homosporous. Spores are kidney-shaped.
- In *Lycopodium* and *Selaginella* sporangia are borne on leaves known as sporophylls which form strobili at the apices. In *Lycopodium* only one type of spores are produced, whereas in *Selaginella* microspores and megaspores are produced inside the microsporangium and megasporangium, respectively.
- In *Equisetum* sporangia are produced on stalked, peltate sporangiophores. Spores of *Equisetum* have pseudoelaters.
- In *Pteris* sporangia are produced on the margins of fertile leaves and they are protected by false indusium. Sporangia have well defined annulus and stomium which help in the dispersal of spores. Sex organs are highly reduced.
- In *Cyathea* sporangia form distinct groups known as sori and are present on ventral surface of leaves. Sori are protected by a true cup-shaped indusium.
- In *Marsilea* sporangia are produced in highly specialised structures known as sporocarps. It is heterosporous. Megasporangia are terminal and micro-sporangia are lateral. Only one megaspore is produced in a megasporangium.

17.5 TERMINAL QUESTIONS

1. Briefly describe the characteristic features of reproductive organs of pteridophytes.

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2. Describe the development of gametophyte in *Psilotum*.

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3. Draw a vertical section of strobilus of *Selaginella*.

4. Describe the various types of gametophytes found in *Lycopodium*.

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5. With the help of labelled diagramme describe the structure of strobilus of *Equisetum*.

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6. Describe the features of sporocarp of *Marsilea.*

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7. Enumerate the various steps involved in the formation of prothallus from a spore in *Pteris.*

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17.6 ANSWERS

Self-assessment Questions

17.1 a) (i) F,
(ii) T,
(iii) F,
(iv) F,

b) (i) F,
(ii) F,
(iii) T,
(iv) T,
(v) T

c) (i) synangium,
(ii) 1-3 tracheids,
(iii) monoecious,

(iv) tapetum,
(v) triradiate.

17.2 (i) sporophylls,
(ii) strobilus/cone
(iii) antheridia, archegonia,
(iv) superficial

17.3 a) (i) T,
(ii) F,
(iii) T,
(iv) T

b) (i) eusporangiate,
(ii) larger,
(iii) biflagellate
(iv) within

c) Ref. to sections 17.2.2 and 17.2.3

17.4 a) (i) T,
(ii) F,
(iii) F,
(iv) T

b) (i) sporangiophores,
(ii) peltate,
(iii) four
(iv) elaters,
(v) longitudinal,
(vi) marginal

17.5 (i) ventral,
(ii) false,
(iii) sixteen,
(iv) leptosporangiate,
(v) monoecious,
(vi) ventral

17.6 (i) sori,
(ii) midrib,
(iii) true,
(iv) leptosporangiate,
(v) heart-shaped

17.7 (i) T,
(ii) F,
(iii) F,
(iv) T,

(v) F,

(vi) T

Terminal Questions

1. Ref. to section 17.2

2. Ref. to section 17.2.1