Baghdad University
College of Science
Biotechnology Department

Lectures in

Phycology

Second Stage

BY
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Lecture 1:

<u>Introduction:</u>

Eichler in 1883 classified plant kingdom into two groups:

Group 1: Cryptogamia: The group of plant which produces spores. This group involves Algae, Fungi, Lichen, Bryophyte (involves: Mosses & Liver worts) and Pteridophyta (involves: Ferns, Equista & Cycopodia).

Group 2: Phanerogamia: The group of plants which produces seeds and involves: Angiosperm and Gymnosperm.

Algae, Fungi and Lichen were classified as Thallophyta which involves the plants lacking the presence of true stems, leaves and roots.

The second classification system for algae has been performed by Whittaker in 1969 who classified the living organisms into five kingdoms as follows:

Kingdom 1: Monera: This involves the unicellular or multicellular organisms but prokaryote such as Bacteria and Blue-green Algae.

Kingdom 2: Protista: This involves the unicellular or multicellular organisms but Eukaryote such as Protozoa & other Algae.

Kingdom 3: Mycetae:Mycota: This involves fungi , unicellular or multicellular organisms but heterotrophs

Kingdom 4: Metaphyta: This involves all higher plants.

Kingdom 5: Metazoa: This involves all animals .

Algae and the fossil record:

The cyanobacteria are the oldest group of algae with definite fossil remains in the form of stromatolites (Fig. 2.53), dating back about 2700 million years. When the cyanobacteria evolved, the atmosphere contained little or no oxygen and was composed primarily of methane (CH_4), ammonia (NH_3), and other reduced compounds. Photosynthesis by the cyanobacteria eventually built up the oxygen content of the atmosphere to what it is today (20%). The first eukaryotic algae appeared in a form similar to the extant Glaucophyta, with endosymbiotic cyanobacteria instead of chloroplasts. It is difficult to fix this date exactly because these first algae were composed of soft tissues and would not have been preserved. In order to appear in the fossil record, algae would usually have to be large or to have some calcified ($CaCO_3$) or silicified (SiO_2) structures, which are preserved in sedimentary rocks.

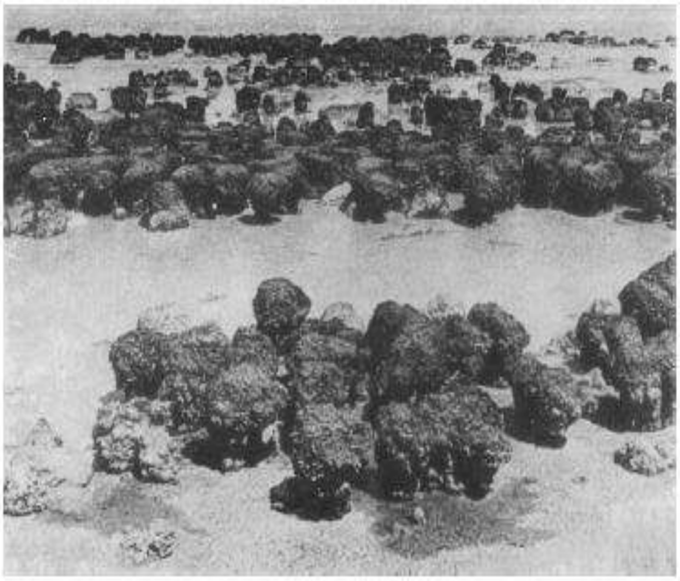


Fig. 2.53 Cyanobacterial stromatolites in the process of formation in Shark Bay, Western Australia. (From Logan, 1961.)

The term algae `sing. alga means different things to different people, and even the professional botanist. Thus, laymen have given them such names as ‘pond scums’ frog spittle’, water mosses, and sea weeds, while some professionals shrink from defining them. The reasons for this are that algae share their more obvious characteristics with other plants, while their really unique features are more subtle.

So algae are autotrophic plants which contain chlorophyll A, and they have simplicity structure lacking the presence of true stems, leaves and roots as well as the transport vessels.

How then does one distinguish algae from other chlorophyllous plants? The distinguishing characteristics reside in the phenomenon of sexual reproduction as it occurs in algae in which it differs from that in other green plants.

1) In the unicellular algae, the organisms themselves may function as gametes such as in *Chlamydomonas* Figure 1a.

2) In some multicellular algae, the gametes may be produced in special unicellular containers or gametangia such as in *Ulothrix* and *Oedogonium* Figure 1b.

3) In others, the gametangia are multicellular Figure 1c. every gametangial cell being fertile, that is, producing gamete such as in *Ectocarpus*. None of these characteristics occur in liverworts Figure 1d,e, mosses, ferns, or angiosperms.

In their asexual reproduction, many algae produce flagellated spores and / or nonmotile spores in unicellular sporangia, or if the latter are multicellular, every cell is fertile.

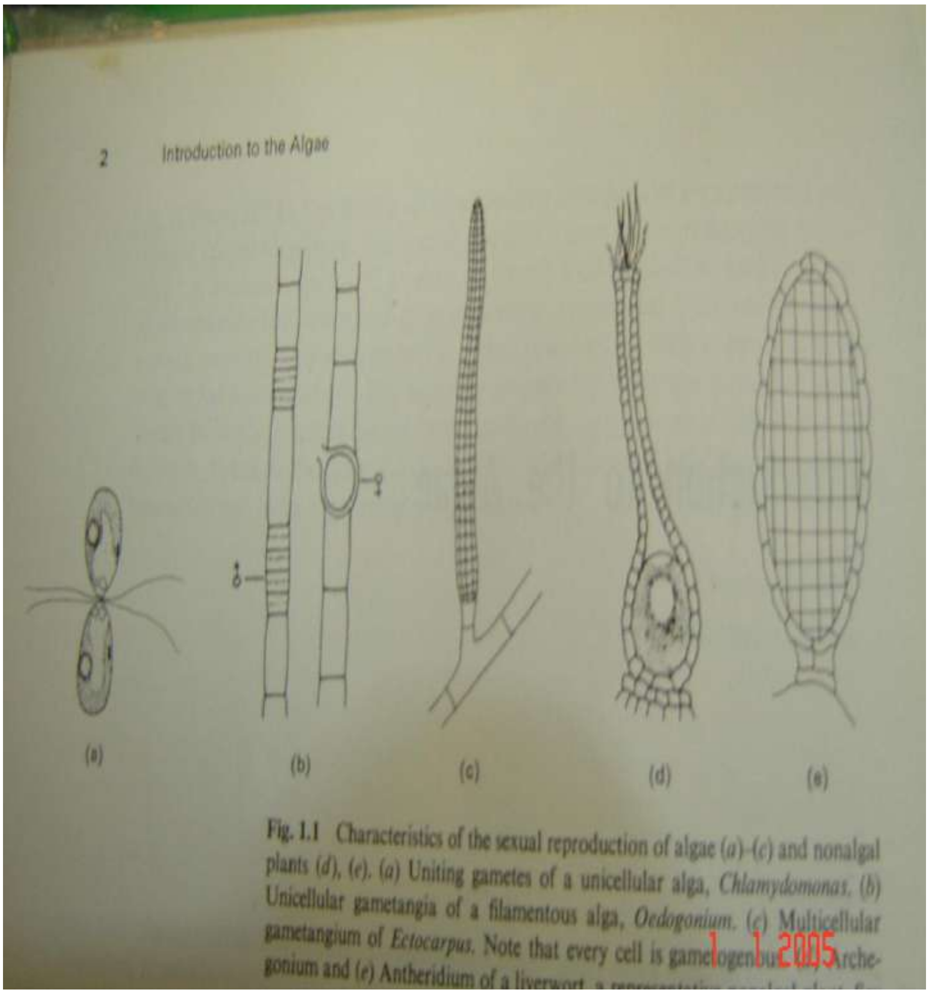


Figure 1. Characteristics of the sexual reproduction of alga (a)-(c) and nonalgal plants(d),(e). (a) Uniting of a unicellular alga, *Chlamydomonas*, (b) Unicellular gametangia of a filamemtous alga, *Oedogonium*. (c) Multicellular gametangium of *Ectocarpus*.Note that every cell is gametangous. (d) Archegonium and (e) Antheridium of a liverwort, a representative nonalgal plant

<u>The occurrence and distribution of algae:</u>

When it said that algae are ubiquitous, as in fact they are, such a statement might seem to tax credulity by one, for example, who was observing a desert scene or permanent snowfield, but even in such diverse habitats algae are present.

Algae are aquatic or subaerial. By the latter in meant that they are exposed to the atmosphere rather than being submerged in water. Aquatic algae grow in water of low salinity (as low as 10ppm), called freshwater, and in marine waters where solutes are usually 33-40%, although some algae occur in such locations as the Laguna Madre Texas where the salinity may rise to 100% in dry seasons; this is in contrast to such an algal habitat as Mountain Lake, Virginia, in which the solutes total only 3.6ppm. Some algae are remarkably tolerant to varying salinities such as *Enteromorpha* that live on ships that ply both freshwater and oceans. A number of algae live in brackish water; the latter is unpalatable for drinking but contains less salt than ocean water; for such algae the salinity optimum is less than that of freshwater.

With respect to their solutes, lakes are classified as oligotrophic or eutrophic. The former have been defined as those having less than 100ppm of solutes, while the latter may have considerably higher concentrations. Oligotrophic lakes, as would be expected, support a sparser algal flora, with respect to numbers of organisms, than eutrophic lakes, but the number of species may be greater. Bodies of freshwater have been also classified as alkaline, hard-water lakes (with pH>7) and as acid soft-water lakes (with pH <7), and their floras differ. Some species of algae can tolerate a broad range of pH, while others are more restricted. Bodies of water in which algae grow differ also in the concentration of dissolved oxygen and carbon dioxide and that of many other substances, as well as in temperature and turbidity (which affects depth of light penetration and hence photosynthesis and algal growth.

1) Aquatic algae (Hydrophyte algae):

1-1) May be suspended (planktonic) or (phytoplankton). The plankton consists of a flora and fauna, together with bacteria and often fungi, of suspended organisms. Plankton algae may be collected by drawing plankton net through the water. Plankton nets are composed of silk with finely woven meshes, commonly 180 pores to the square inch. This serves as a strainer that filters out and concentrates many planktonic algae and other microorganisms. Planktonic algae may also concentrate for microscopic study by centrifugation. Planktonic algae under certain combinations of nutrition favorable to them increase enormously in number and form water blooms. Diatoms, green algae, *Euglena* and blue green algae are most frequently present in blooms.

There are two types of planktonic algae:

A) Euphyte plankton (True phytoplankton): These planktonic algae spend all their life period as plankton in water such as Diatoms.

B) Tycophyte plankton: The origin of this group is benthos, but they may convert into planktonic in case of changing in an environment condition and then return to their origin when this condition removed such as *Diatoma vulgare.*

1-2) Benthophyte algae: (Benthic):

Benthic algae grow attached to various substrates and may be classified as **epilithic** (living on stones), **epiplic** (attached to mud or sand), **epiphytic** (attached to plants), and **epizoic** (attached to animals).

1-3) Thermophyte algae:

These thermophlic algae that inhabit hot springs mostly blue green algae, grow at temperatures between 50-73°C.

1**-4) Halophyte algae:**

These types of algae inhabit the aquatic environments which the salinity raises to 100%. Others can inhabit aquatic environments with wide range of pH. Some of these inhabit acidic water which contaminated with organic substances such as phosphate and nitrate as nutrients for these types of algae are used as pollution indicators such as *Spirulina*, *Merismopedia*, *Oscillatoria* and some time *Euglena*.

1-5) Cryophyte algae (snow algae):

Finally, among aquatic algae we must mentioned those that thrive on long-persistent snows such as *Chlamydomonas nivalis* which inhabits on snow below 0°C and gives red color.

2) Terrestrial algae:

These algae inhabit earth or land. Authors have classified desert soil algae as **endodaphic** (living in soil**)**, **epidaphic**(living on the soil surface**)**, **hypolithic** (on the lower surface of stones on soil**)** and as rock algae, including **chasmolithic** algae(in rock fissures**)** and **endolithic** algae (rock penetrating**).** Several filamentous blue green algae are pioneers in plant succession on bare soil, where they form crusts that cut down on evaporation from the soil and also prevent erosion**.**

Corticolous or tree bark inhabiting algae, including blue green algae were reported in a considerable number from such habitats. A number of blue green and green algae grow as members of lichen associations, *Trebouxia* is one of the most frequently encountered.

Some algae live **endozoically** in various protozoa, coelenterates, mollusks, and worms. *Chlorella* like algae are present within *Paramecium, Hydra*, mollusks and some freshwater sponges. Several algae grow as **endophytes** within other plants. Here may be mentioned the blue green alga *Anabaena azollae*, which grows within the water fern *Azolla*, and the species of *Anabaena* or *Nostoc*, which live within the thalli of the hornwort *Anthoceros* and in the root of cycads and rhizomes of *Gunnera*, an angiosperm. Many of the blue green algae, like certain bacteria, in soil fix gaseous nitrogen into a combined form and are thus of great importance in improving soil fertility.

3) Airborne algae or Aerial algae:

Airborne algae are present in the air as free living organisms either unicellular or multicellular. These algae release in the air with dust particles carried by air currents.

Form of the algal plant body:

The form of the plant body of algae varies from the relative simplicity of the single cell to the complexity exhibited by the giant kelps and rock weeds. While small algae like *Micromonas pusilla* (1x1.5 micrometer) and species *Chlorella* (5-8 Micrometer) are in the range of bacterial size, although eukaryotic, kelps, some of which are the largest of algae, mat attain of 60m.

The forms of algal bodies:

1) **Unicellular form:** Unicellular algae are either motile such as *Euglena*
   or non-motile such as *Chlorella.*
2) **Colonial form:** Two types of colonial algae are known. Those which have fixed number cells at its origin called a **coenobium**, either motile such as *Pandorina* or non-motile such as *Scendesmus*

which has 2-16 cells. The number of cell is not augment during the individual's existence, even if some cells are accidentally lost or destroyed, and these types of colonies are reproduce by spores. The second type of colonial algae is **the aggregate** which is indefinite in cellular number, continues to grow by cell division of its components, and reproduces by fragmentation. This type of algae are in various forms:

- **Coccoid** such as in *Microcysits.*
- **Palmelloid** which the cells are aggregate in gelatinous mass such as *Tetraspoa*.
- **Dendroid** which the cells are aggregate as yaup aggregations.
- **Amoeboid or Rhizopodial:** in this form the cells are amoeboid form and connected with each other by filiform rhizopodia such as in Chrysophycophyta.

3) **Filamentous form:**

- **Simple filament:** which is formed by the cell division but in one direction, the resulted cells remain contact with each other to form the filament such as *Ulothrix*, if the simple filament do not coated with membrane it is called **trichome**.
- In some algae, some of the filament cells may divide laterally to form branches which are regular and opposite such as in *Cladophora* or irregular and requital such as in *Pithophora*.
- There are other types of branches in some algae which called **false branched form**, in this type the algal body is not branched at the beginning, but some time a dint is occurs in cell wall of one cell nearest the heterocystis, and this dint continuous in division to form false branch in one side, other

false branch may forms in other side of filament such as in *Scytonema*.

4) Tubular form: In this form the algal body is hollow and it is consist of

Plate of cells, the borders combines to form the tubular form such as in *Enteromorpha*.

5) Siphonous form: In this form there are no cellular septa, multinucleate protoplast (coenocytic) and there is a big central vacuole such as in *Vaucharia*.

6) Parenchymatous form (membranous):

Algal body consists of plate of cells forming membrane-like shape. And may appears as a wide plate segment as in *Ulva* or this plate may divides to form blade-like shape as in *Fucus*. In some algae, the algal body seems to be the collection of many filaments to form parenchyma-like shape which called pseudoparenchyma such as in *Nemalion*.

7) Heterotrichous form:

This form is distinguish by presence of two filament groups, some of them grow vertically which is called erect system and the second group grows horizontally and called prostrate system, and the two systems may be grow equally or one system may grows faster than other such in *Stigeoclonium.*

8) Thallus form:

In this form the algal body can distinguished by main erect axis like the stem with axial nodes produce green peripheral branches like leaves and there are branching rhizoids in the end of axis that anchor the plant to the substrate such as in *Chara*.

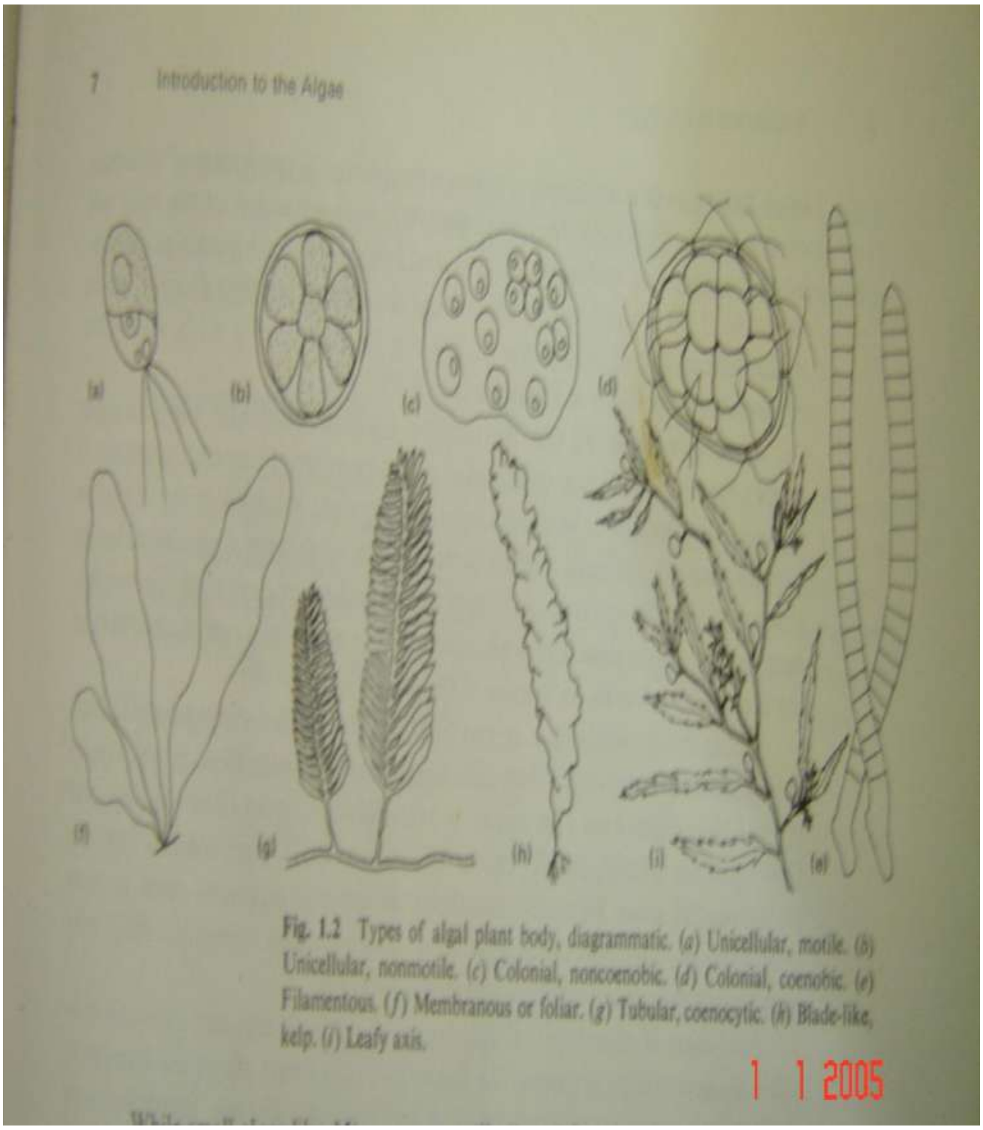


Figure 2: Types of algal plant body, diagrammatic. a) Unicellular, motile. b) Unicellular, nonmotile. c) Colonial,noncoenobic. d) Colonial, coenobic. e) Filamentous. f) Membranous or foliar. g) Tubular, coenocytic. h) Blade-like kelp. i) Leafy axis.

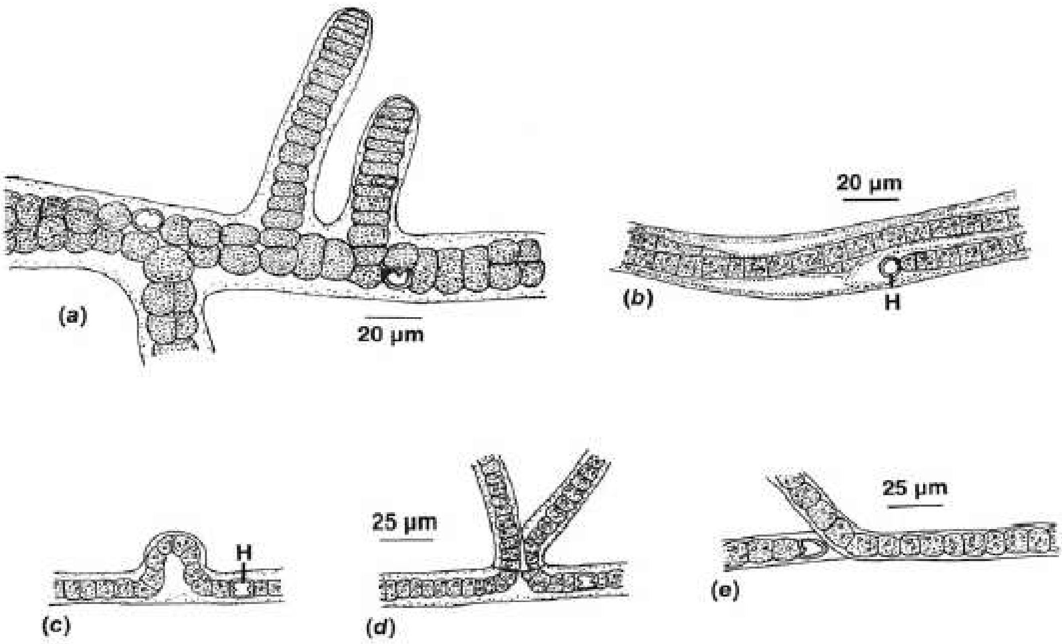


Fig. 2.58 (*a*) *Stigonema turfaceum* showing true branching. (*b*) *Desmonema wrangelii* with a number of trichomes in a sheath. (*c,d*) *Scytonema arcangelii* illustrating formation of false branches. (*e*) *Tolypothrix tenuis* with a single false branch. (H) heterocyst. (After Smith, 1950.)

heterocyst and eventually result in a break of th trichome, with one of the broken ends of the tr chome protruding through the sheath as a fals branch. The second type of false branching result in the formation of two false branches, as i

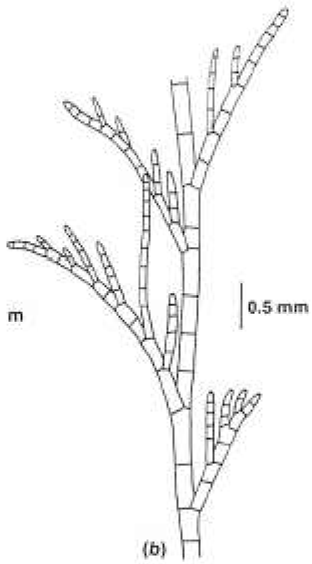


Fig. 5.35 (*a*) *Chaetomorpha aerea*. (*b*) *Cladophora microcladioides*. (After Smith, 1969.)

<u>Lecture 2:</u>

<u>Cell structure:</u>

1- Cell wall:-

The algal cell usually surrounds with cell wall which consists of two layers. The outer layer is a slimy, mucilaginous while the main component of inner layer in most algae is **cellulose micro fibrils**. The arrangement of these micro fibrils is longitudinally, transversely or randomly. The cell wall also contains **hemi-cellulose, pectin, chitin and cuticle**. The cell wall in **Chlorophycophyta** contains **xylane, mannon** as well as **cellulose**. In **Cyanophycophyta** the **mucopeptide components** are presence in their cell wall. While in **Phaeophycophyta,** the cell wall contains **muramic acid, algenic acid and fucoidan**. The cell wall of red algae –**Rhodophycophyta-** is usually a **sulfated galactan** of which **agar, porphyran, furclleran, and carrageenan** are examples. **Euglenoid cells** are naked and the cell is surrounding with different modified plasma membrane which called **periplast**. In **Diatomes** and **Chrysophycophyta,** the main component of cell wall is **silica.**

2- Protoplast:

Protoplast contains all cell components which are:-

Plastids:

Plastids are present in all algal groups except **blue- green algae** which lacking of presence true plastid. The singular photosynethetic lamella or one thylakoid band is diffused in protoplast or peripheral cytoplasm and the accessory pigments also occur on their surfaces in the form of small particles, phycobilisomes.

In Rhodophycophyta: The plastid surrounds with double layers of chloroplast envelop and the photosynethetic lamella is singular -one thylakoid band-, the phycoblisomes also occur on their surfaces.

In Chlorophycophyta and Charophycophyta: The plastid surrounds with double layers of chloroplast envelop. Bands of two to six thylakoids are present in many green algae, and dense stacks of them, or grana, like those in land plants. ribosomes and DNA are also present.

In Euglenophycophyta and Pyrrhophycophyta: The plastid surrounds with double layers of chloroplat envelop with one endoplasmic reticulum around the outer envelop. The ribosomes are present on the surface of E.R. the photosynthetic lamella consist of three thylakoid bands.

In Cryptophycophyta: The plastid surrounds with double layers of chloroplast envelop with two membrane of endoplasmic reticulum usually continuous with the outer membrane of the nuclear envelop. The ribosomes are present on the surface of E.R. the photosynthetic lamella consist of 2 thylakoid bands.

In Phaeophycophyta, Xanthophycophyta, Chrysophycophyta and Diatomes, the chloroplast is like above except the thylakoid consists of three bands Fig.1.12.

The other components of chloroplast in algae are ribosomes, and most algae have prokaryotic DNA and RNA. Plastid has ability to fission when the algal cell is fission , so some scientists believe that the structure of chloroplast is similar to prokaryotic cell. In green algae the pyrenoid is the site of starch formation, one or more starch grains forming within the chloroplast closely appressed to the surface of the pyrenoid. It has been suggested that the pyrenoid is the region of temporary storage for early products of photosynthesis that, upon overproduction, are converted into starch. An alternate view is that the pyrenoid is the site of production of starch synthetase that polymerize glucose molecules from the chloroplast into starch on pyrenoid surface. In other algal groups, pyrenoids are present in cytoplasm. The starch center in Chlorophycophyta and Charophycophyta consists of central part surrounded with five or more of compressed starch plates, and there are micro- tubules between the starch centers and the stroma of plastid which the access food will transport through these tubes and then convert it into storage food as starch. Plastids are differing in their forms, locations, and numbers, in numbers, there are 7, 8 or 10 plastids, in forms, girdle, discoid, cup, spiral, stellate, reticulate, and band like-shaped. In location it is either parietal or central.

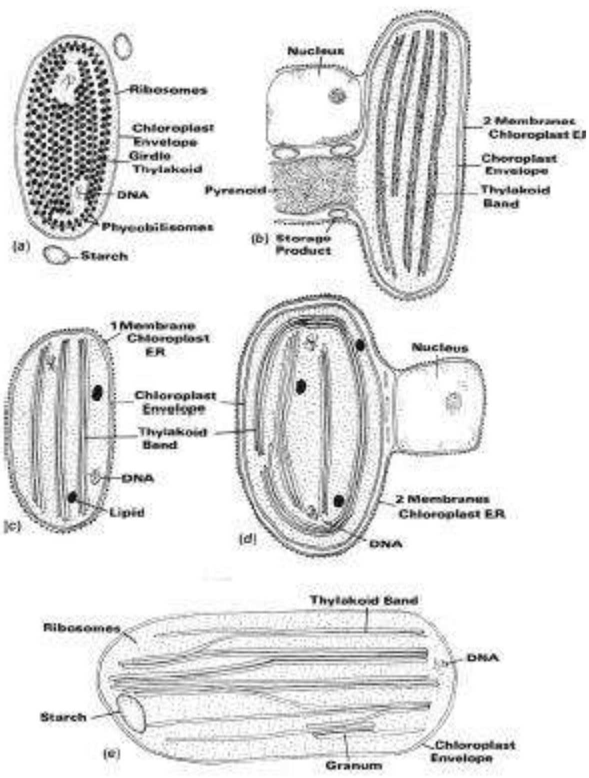
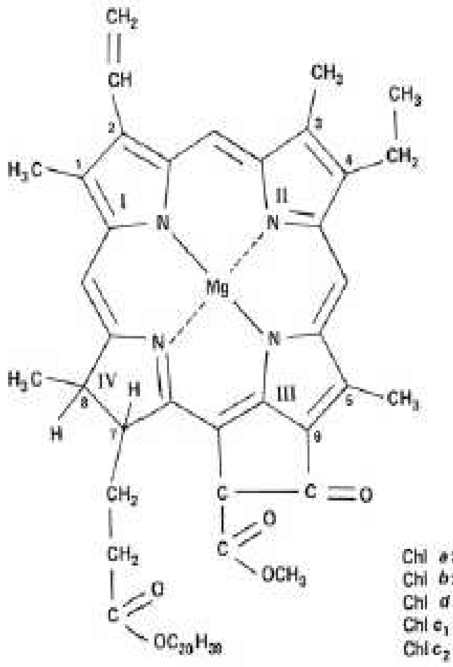


Figure1-12 Types of chloroplast structure in eukaryotic algae. (*a*)One thylakoid per band , no chloroplast endoplasmic reticulum (Rhodophyta). (*b*) Two thylakoids per band, two membranes of chloroplast E.R. (Cryptophyta). (*c*) Three thylakoids per band, one

membrane of chloroplast E.R. (Dinophyta, Euglenophyta). (*d*) Three thylakoids per band, two membranes of chloroplast E.R. (Prymnesiophyta and Heterokontophyta). (*e*) Two to six thylakoids per band, no chloroplast E.R. (Chlorophyta).

<u>Plastid pigments </u>: The photosynthetic algae have chlorophyll in their chloroplasts. **Chlorophyll** is composed of a porphyrin-ring system that is very similar to that of hemoglobin but has a magnesium atom instead of an iron atom (Fig. 1.18).

Fig. 1.18 The structure of the chlorophylls. (From Meeks, 1974.)



Chl *a*: as shown in structure
Chl *b*: II-3 = CHO
Chl *d*: I-2 = CHO
Chl c_1: IV-7 = CH=CHCOOH; double bond at IV-7, 8
Chl c_2: IV-7 = CH=CHCOOH; double bond at IV-7, 8
II-4 = $CH{=}CH_2$

The algae have four types of chlorophyll, *a*, *b*, *c* (*c*1 and *c*2), and *d*. **Chlorophyll *a* is the primary photosynthetic pigment (the light receptor in photo system I of the light reaction)** in all photosynthetic algae and ranges from 0.3% to 3.0% of the dry weight. **Chlorophyll *a* is insoluble in water and petroleum ether but soluble in alcohol, diethyl ether, benzene, and acetone.** The pigment has two main absorption bands in vitro, one band in the red light region at 663 nm and the other at 430 nm (Fig. 1.19).

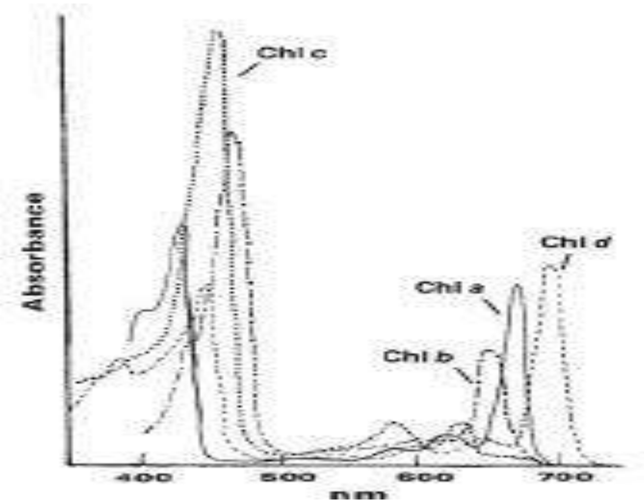


Figure 1-19: The Absorption spectra of chlorophyll a, b, c, and d

Whereas chlorophyll ***a* is found in all photosynthetic algae**, the other algal chlorophylls have a more limited distribution and function as accessory photosynthetic pigments. **Chlorophyll *b*** is found in the **Euglenophyta and Chlorophyta** (Fig. 1.18). **Chlorophyll *b* functions photo synthetically as a light-harvesting pigment transferring absorbed light energy to chlorophyll *a*.** The ratio of chlorophyll *a* to chlorophyll *b* varies from 2:1 to 3:1. The solubility characteristics of chlorophyll *a* are similar to chlorophyll *b*, and in vitro chlorophyll *b* has two main absorption maxima in acetone or methanol, one at 645 nm and the other at 435 nm (Fig. 1.19). **Chlorophyll *c*** (Fig. 1.18) is found in the **Dinophyta, Cryptophyta, and most of theHeterokontophyta.** Chlorophyll *c* has two spectrally different components: chlorophyll *c*1 and *c*2. **Chlorophyll *c*2 is always present**, **but chlorophyll *c*1is absent in the Dinophyta and Cryptophyta.** The ratio of chlorophyll *a* to

chlorophyll *c* ranges from 1.2:2 to 5.5:1. Chlorophyll *c* probably functions as an accessory pigment to photo system II. The pigment is soluble in ether, acetone, methanol, and ethyl acetate, but is insoluble in water and petroleum ether. Extracted chlorophyll *c*1 has
main absorption maxima at 634, 583, and 440 nm in methanol, whereas chlorophyll *c*2 has maxima at 635, 586, and 452 nm. **Chlorophyll *d*** (Fig. 1.18) **occurs in some cyanobacteria** (Murakami et al., 2004). It has three main absorption bands at 696, 456, and 400 nm.

Carotenoids are yellow, orange, or red pigments that usually occur inside the plastid but may be outside in certain cases. In general, naturally occurring carotenoids can be divided into two classes:
(1) oxygen-free hydrocarbons, the **carotenes**; and
(2) their oxygenated derivatives, the **xanthophylls**.
The most widespread carotene in the algae is β-carotene (Fig. 1.21).

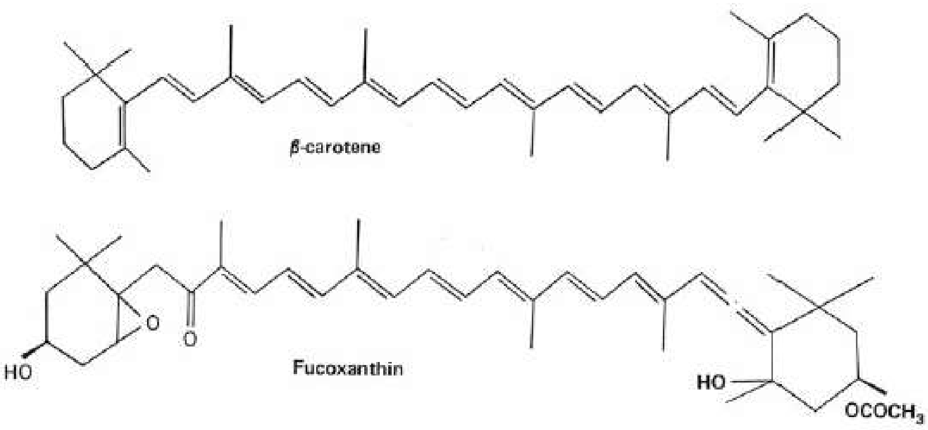


Fig. 1.21 The structure of β-carotene and fucoxanthin.

There are a large number of different xanthophylls, with the Chlorophyta having xanthophylls that most closely resemble those in higher plants. Fucoxanthin (Fig. 1.21) is the principal xanthophyll in the golden-brown algae (Chrysophyceae, Bacillariophyceae, and Phaeophyceae), giving these algae their characteristic color. Like the chlorophylls, the carotenoids are soluble in alcohols, benzene, and acetone but insoluble in water.

(The cyanobacteria and chloroplasts of the Rhodophyta and Cryptophyta have evolved membrane-peripheral antenna complexes containing phycobiliproteins that transfer light energy to photosytem II reaction centers. Like chlorophyll b/c/d, the phycobiliproteins expand the range of light energy that can be utilized in photosynthesis. Light tends to become blue-green as it courses down the water column, and this light is better absorbed by the biliproteins than chlorophyll a).

Phycobiliproteins are water-soluble blue or red pigments located *on* (Cyanophyta, Rhodophyta) or *inside* (Cryptophyta) thylakoids of algal chloroplasts. (*They are described as **chromoproteins** (colored proteins) in which the **prosthetic group** (non- protein part of the molecule) or **chromophore** is a tetrapyrole (bile pigment) known as **phycobilin**. The prosthetic group is tightly bound by covalent linkages to its **apoprotein** (protein part of the molecule). Because it is diffcult to separate the pigment from the apoprotein, the term **phycobiliprotein** is used. There are two different apoproteins, _α and β_, which together form the basic unit of the phycobiliproteins. To either α_or β_are attached the colored chromophores*). The major "blue" chromophore occurring in **phycocyanin** and **allophycocyanin** is phycocyanobilin, and the major "red" chromophore occurring in **phycoerythrin** is phycoerythrobilin (Fig. 1.22).

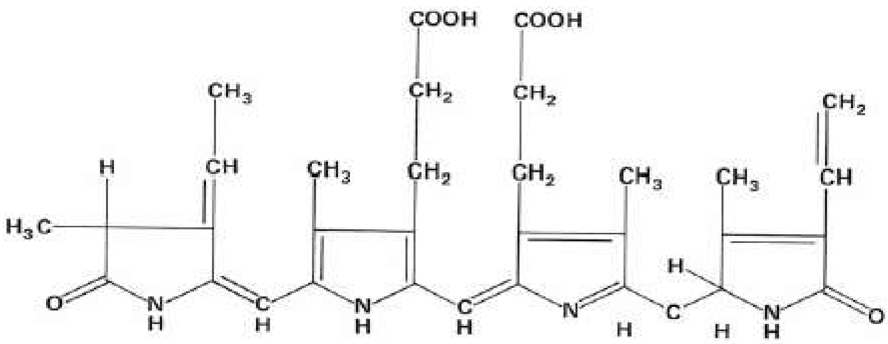


Fig. 1.22 The structure of phycoerythrobilin.

The general classification of phycobiliproteins is based on their absorption spectra. There are three types of phycoerythrin: R-phycoerythrin and B-phycoerythrin in the Rhodophyta, and C-phycoerythrin in the Cyanophyta. There are also three types of phycocyanin: R-phycocyanin from the Rhodophyta and C-phycocyanin and allophycocyanin from the Cyanophyta. In addition, in the Cryptophyta there are three spectral types of phycoerythrin and three spectral types of phycocyanin.

Storage products

The storage products that occur in the algae are as follows:

High-molecular-weight compounds

1 -1,4 Linked glucans

a- **Floridean starch** (Fig. 1.28): This substance occurs in the Rhodophyta and is similar to the amylopectin of higher plants. It stains red-violet with iodine, giving a color similar to that of the stain reaction of animal glycogen. Floridean starch occurs as bowl-shaped grains from 0.5 to 25 μm outside the chloroplast, inferring the host in the original endosymbiosis took over formation of storage product. This differs from the Chlorophyta where starch is produced in the chloroplast. Despite the differing locations of starch synthesis, the Rhodophyta and Chlorophyta use a common pathway in the synthesis of starch.

b- **Myxophycean starch:** Found in the Cyanophyta, myxophycean starch has a similar structure to glycogen. This reserve product occurs as granules (ά-granules), the shape varying between species from rod-shaped granules to 25-nm particles to elongate 31- to 67-nm bodies.

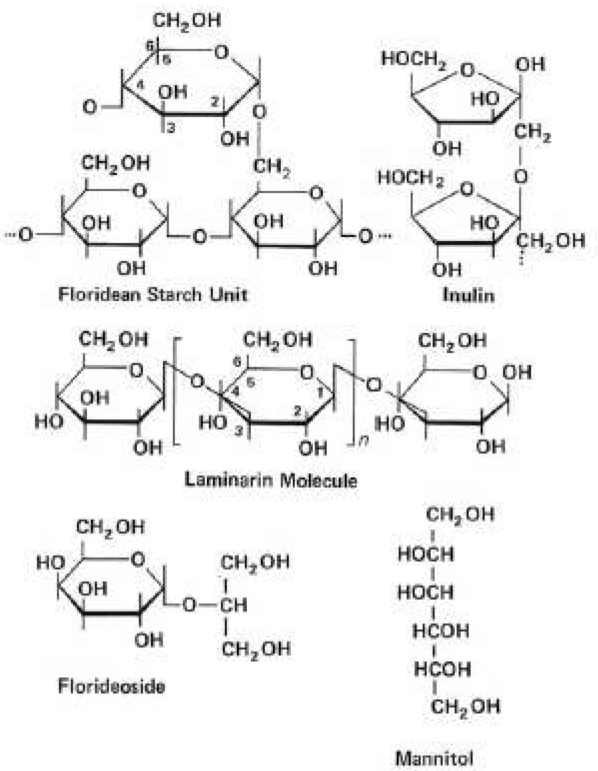


Fig. 1.28 The structure of floridean starch, inulin, laminarin, and floridoside. (After Percival and McDowell, 1967.)

c- **Starch:** In the Chlorophyta, starch is composed of amylose and amylopectin. It occurs inside the chloroplast in the form of starch grains (Fig. 1.12(*e*)). In the Cryptophyta, starch has an unusually high content of amylose and occurs as grains between the chloroplast envelope and the chloroplast E.R. (Fig. 1.12(*b*)). In the Dinophyta also, starch occurs in the cytoplasm outside of the chloroplast, but its structure is not known.

2 -1,3 Linked glucans

a- **Laminarin** (Fig. 1.28)**: In the Phaeophyceae,** laminarin consists of a related group of predominantly β-1,3 linked glucans containing 16 to 31 residues. Variation in the molecule is introduced by the number of 1→ 6 linkages, the degree of branching, and the occurrence of a terminal mannitol molecule. The presence of a high pro portion of C-6 inter residue linkages and of branch points seems to determine the solubility of the polysaccharide in cold water: the greater the number of link ages, the higher the solubility**. Laminarin occurs as an oil-like liquid outside of the chloroplasts, commonly in a vesicle surrounding the pyrenoid.**

b- **Chrysolaminarin (leucosin):** In the Chrysophyceae, and Bacillario - phyceae, chrysolaminarin consists of β-1,3 linked D-glucose residues with two 1→6 glycosidic bonds per molecule. Chrysolaminarin occurs in vesicles outside of the chloroplast and has more glucose residues per molecule than laminarin.

c- **Paramylon:** In the Euglenophyta and Xanthophyceae, paramylon occurs as water-soluble, single-membrane-bounded inclusions of various shapes and dimensions outside of the chloroplast. Paramylon consists solely of **β -1,3 linked glucose residues**, and the molecule is about as large as that of chrysolaminarin.

3 Fructosans: *Acetabularia* (Chlorophyta) has an inulin-like storage product consisting of a series of 1,2 linked fructose units terminated by a glucose end group (Fig. 1.28).

Low-molecular-weight compounds

1 Sugars: Chlorophyta and Euglenophyta form sucrose as a reserve product; **trehalose is found in the Cyanophyta and at low levels in the Rhodophyta.**

2 Glycosides: The glycerol glycosides, floridoside(Fig. 1.28) and isofloridoside, are widely distributed in the Rhodophyta.

3 Polyols: Mannitol (Figs. 1.28) occurs in Rhodophyta and haeophyceae. It is also present in lower green algae, where it replaces sucrose as a photosynthetic product. Free glycerol occurs widely in the algae and is an important photosynthetic product in several zooxanthellae (endo symbiotic algae in animals) and in some marine Volvocales, especially *Dunaliella*.

Lecture 3:

The nucleus:

Among living organisms, **only the bacteria and blue-green algae are prokaryotic, which means that they lack membrane-bounded nuclei.** This is considered by biologists to be of such fundamental significance that they often classify bacteria and blue-green algae in a category "prokaryota" segregated from all other living things.

All other algal groups are characterized by presence of membrane bounded- nuclei and they are classified in a category "Eukaryota". The **nucleus** in dinoflagellates in division **Pyrrhophycophyta** has long been focus of attention because of its many unusual properties, including the persistence of the chromosomes in a condensed configuration during interphase and the absence of centromeres or a spindle, and it is classify in a category "mesokaryotic". The nucleus is relatively large and variable in shape with presence of nuclear membrane and the DNA contains a protein like the blue-green algae in its structure.

The flagella:

The flagella of motile cells of most green algae that have been investigated are equal in length –isokontan- and smooth. The flagella of algal cells differ in their place of insertion on the cell and in their number, length, and appendages. These variations have been summarized in Fig:1.9

1- Flagella may be smooth, that is, lacking hairs except for a delicate terminal fibril; these are referred to as **acronematic flagella**. Some smooth flagella lack the terminal fibril and thus are bluntly terminated.

2- **Pleuronematic flagella** have one or more rows of lateral hairs flimmer or mastigonemes-. When these hairs arise unilaterally from the flagellum, it is said to be **stigonematic**; if the mastigonemes are arranged in two rows, the term **pantonematic** is applied. If this latter flagellum also has a terminal fibril, it is said to be **pantacronematic**. If the flagellum contains scales on its outer surface as well as hairs, it is said to be **scaly flagellum** such as in *Prasinea*. Transaction showing 9+2 arrangement of component fibrils within flagellar sheath.

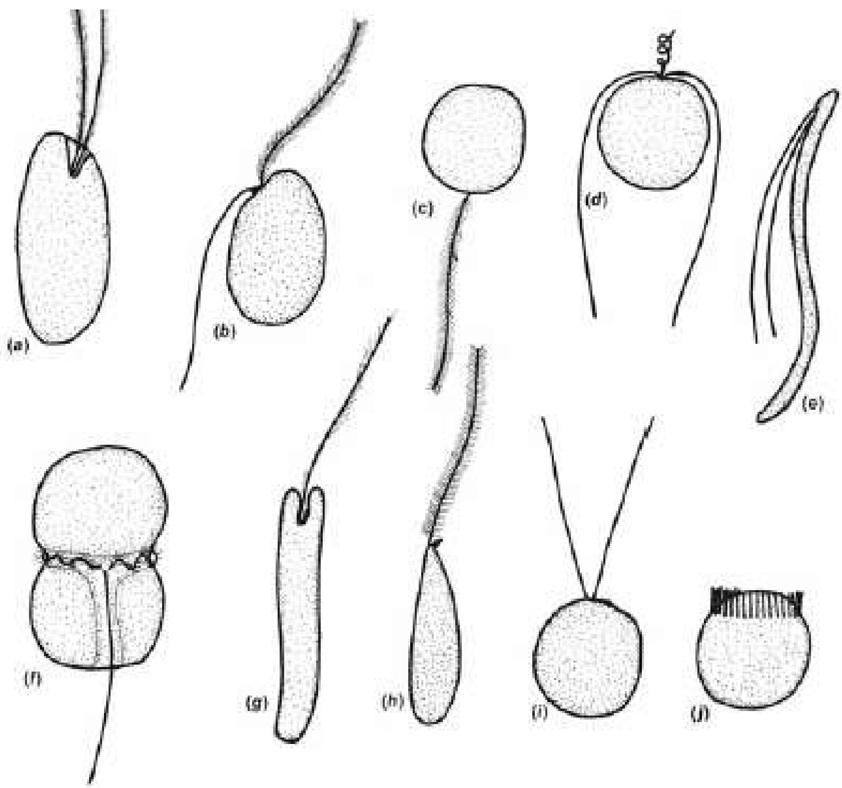


Fig. 1.9 The shape of eukaryotic motile algal cells and their flagella. The drawings represent the common arrangement of flagella in the groups. There are a number of modifications in structure that are not included here. (*a*) Cryptophyta; (*b*) most of the Heterokontophyta; (c) Bacillariophyceae of the Heterokontophyta; (*d*) Prymnesiophyta; (*e*) Chlorophyta; (*f*) Dinophyta; (*g*) Euglenophyta; (*h*) Eustigmatophyceae of the Heterokontophyta; (*i, j*) Chlorophyta.

flagellum is produced by an imbalance i
assembly or disassembly of flagellar compo
(Rosenbaum and Witman, 2002). Thus, disa
bly occurs faster than assembly in flagellar r
tion. The opposite occurs during flagellar gr
The differences in length of flagella arise fro
shorter flagellum being delayed in the i
stages of construction. The assembly rate

Growth in Algae:

Growth of various multicellular algae may be **diffuse** or **generalized** or it may be **localized**. In generalized growth, all of the cells may undergo division, so that the organism undergoes overall increase in size as in *Ulva* -Fig 2f-. In localized growth, cell multiplication is restricted to certain parts of the organism. **Localized** growth may be **apical**, **basal**, or **intercalary**. **Apical growth** is that which is restricted to extremities of the organism or at its tips and occurs, for example, in *Cladophora* and *Fucus* and *Dictyota* among other algae. Basal growth is less common but may be observed in one pattern of ontogeny of *Bulbochaete*. Intercalary growth is localized neither at the apex nor base but at one or several other loci. This is well illustrated in green algae *Oedogonium* in which only certain cells of the filament undergo division, in the **tricothallic growth** of certain brown algae like *Desmarestia*, and development of the blade of *Laminaria*.

Algal reproduction:

Both sexual and asexual reproduction are of widespread occurrence in algae; in some, however, sexual reproduction does not occur, either through its phylogenetic loss or because, seemingly, it has not developed. By sexual reproduction at the cellular level is meant the union of cells, plasmogamy; the union of their nuclei, karyogamy; the association of their chromosomes and genes; and meiosis. Sexual reproduction affords the opportunity for exchange and formation of new combinations of genetic materials. Sexual reproduction has apparently not yet been confirmed in the Euglenophycophyta but occur in at least some members of all the other division of algae. Asexual reproduction is increase in progeny not involving cellular and nuclear union and association of parental genetic materials.

Asexual reproduction:

In some algae the organism reproduces by cell division. These divisions may be repeated in rapid succession, designated repeated bipartition -Fig 1.3a, c-, to form new individuals like the parental cell. This process is also sometime called **binary fission**. In colonial and other multicellular types of algae, cell division and subsequent enlargement result in growth. In the division of some unicellular algae the division products – aplanospores and autospores- remain associated for a period within the persistent and enlarging parental cell wall, a phenomrnon that has been interpreted as incipient colony formation Fig 1.3f-. Noncoenobic colonial, filamentous, and other types of multicellular algae reproduce by various types of **fragmentation**, the fragments having the capacity through continuing growth of developing into new individuals. Even fragments of such highly developed algae as *Entermorpha* and *Polysiphonia* among others, when abscised from parent plants, can develop into new individuals. In the filamentous blue-green algae, the fragments, which exhibit gliding motility, are called hormogonia -Fig 1.3i- . In some algae there are special buds or gemma-like fragments that are detached from the parent plant as agents of propagation. The **propagules** of *Sphacelaria* Fig 21.10 – exemplify these. It should be noted that fragmentation is not a method of reproduction **in coenobic algae**. Instead, these undergo **autocolony formation**. An autocolony is a miniature colony produced by a parental colony that resembles. In this process some or the entire component cells of a coenobium form miniature colonies by repeated cellular bipartition Fig 21.1d. **Such colonies in other algae may be organized from zoospores as in *Hydrodictyon* and *Pediastrum*** Fig 3.56.In addition to fragments; algae produce a variety of –usually- unicellular agents of asexual reproduction called spores. Among these, **akinetes** are of widespread occurrence in the **blue- green and green algae.** An akinete Fig 2.16 is essentially a vegetative –somatic- algal cell that has thickened its wall and thus has become able to withstand desiccation and other conditions hostile to vegetative development. **Many green, yellow-green, and brown algae produce flagellate agents of asexual reproduction known as zoospores** Fig 1.3d, e- , the name implying that their motility is an animal-like trait. In a number of instances the potential **zoospores may omit their motile phas**e and begin their development within the parental cell wall. Such ontogenetically potential zoospores are then called **aplanospores** Fig 1.3f-. Aplanospores that thicken their walls are known as **hypnospores**. A number of other types of nonmotile spores are produced by various algae. Among these are autospores Fig 1.3h- of **green and yellow-green algae. Autospores** are superficially like aplanospores but differ in lacking the ontogenetic capacity for motility. Furthermore, they are in form miniatures of the parental cells that produced them. The **monospores, bispores**, **tetraspores**, **paraspores**, and **carpospore** of **red algae** and the **statospores** and **auxospores** of the **golden algae** are other types of asexual spores in algae. Spores may be produced within and by ordinary vegetative cells or within special cells or groups of cells in the algae. The specialized spore-producing structures are various types of **sporangia-** zoosporangium and aplanosporangium.

Sexual reproduction and life cycles:

Sexual reproduction is widespread in the algae as noted above. Certain algae have proved to be instructive in that whether their flagella reproductive cells function as asexual zoospores or as gametes seemingly depends, at least in part, on environmental conditions. Of the latter, **level of concentration of nitrogen in the surrounding medium** seems to be of primary importance. Such lack of differentiation between asexual cells and gametes occurs, for example, in *Chlamydomonas* and in certain species of *Chlorococcum*. Other algae, by contrast, produce zoospores that differ morphologically from gametes, although in some of these such as *Ulva*, the differentiated gametes have the capacity to grow into new individuals without sexual union i.e., **parthenogenetically**. In certain unicellular algae, e.g, *Chlamydomonas*, the organisms may function as gametes. The latter may be morphologically indistinguishable or **isogamous** Fig 1.3l. or one member of uniting pair may consistently be smaller than the other, the gametes, therefore, being designated as **anisogamous** Fig 1.3m-; or the gametes may be extremely dimorphic, the larger, nonmotile and called an egg, and the smaller, motile by flagella, the sperm Fig 1.3n-. This last type of sexual reproduction is called **oogamy**. **Heterogamy** is a more general term that includes anisogamy and oogamy. ***In the oogamous red algae the male gamete is nonflagellate but in some cases is amoeboid in movement. In the order Zygnematales of green algae and certain diatoms, the gametes also are nonflagellate and amoeboid.*** Isogamy, anisogamy, and oogamy are sometimes interpreted as a progressively, more advanced evolutionary series. ***The evidence cited to support this interpretation is the indiscriminate paring of gametes of different sizes in some cases of isogamy- occasioned by the different ages of members of the pair- and an intermediate condition between heterogamy, with the unequal gametes both flagellate, and oogamy –as in Sphaeroplea- in which the female gametes may or may not be flagellate. It is of interest that sexual reproduction in single genus Chlamydomonas may be isogamous, anisogamoua, or oogamous, depending on the species.***

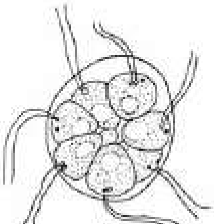
The gametes may be morphologically identical with vegetative cells- e.g. Chlamydomonas- or as in case of many multicellular algae, they differ markedly from vegetative cells. They may arise from relatively unmodified vegetative cells that function as gametangia – e.g. Sphaeroplea- or the gametangia may be morphologically specialized – Oedogonium, Fucus, and Nemalion-.

The female gametangium in oogamous algae is unicellular oogonium. In the red algae and several species of green algae Coleochaete, the oogonium bears a protuberance or trichogyne, which is the receptive site for male gametes.

The oogonia in red algae are called **carpogonia**.

Flagellate male gametes are produced in special gametangia called **antheridia**. The nonflagellate male gametes of red algae called **spermatia** and are borne within minute gametangia called **spermatangia**. ***Further details regarding algal gametangia are deferred to the discussion of the algal genera themselves***.

The distribution or occurrence of compatible sexual potentialities in the algae varies among the species and genera. In those algae in which the gametes are differentiated into male and female- the anisogamous and oogamous algae- , the male and female gametes may occur on the same individual of the species. The individual and species in this case are said to be **bisexual, monoecious,** or **hermaphroditic**. In the other algae, the male and female gametes are produced always on different individuals; such individuals, accordingly, are **unisexual**, and the species to which they belong is **dioecious.** In algae, the compatible gametes involved in unions may arise from one individual or they may come from different ones. The authors would designate the first case as **monoecism** or **bisexuality** and the second as one of **dioecism** or **unisexuality** of individuals or populations of such individuals. Others have designated the monoecism of isogamous algae as **homothallism** and their dioecism as **heterothallism**.



(d)

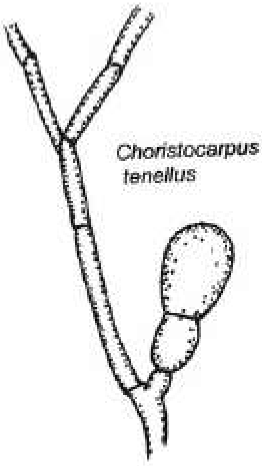
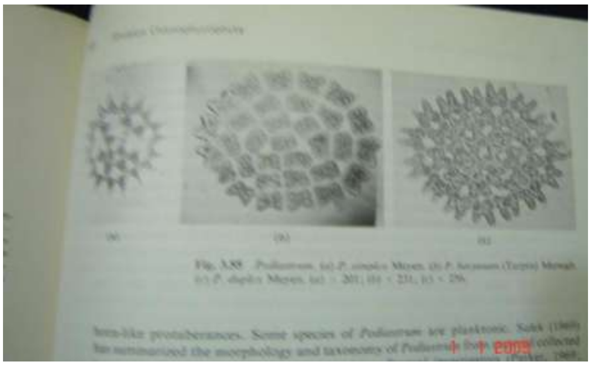


Fig. 21.10 *Choristocarpus tenellus* showing the uniseriate filament and a propagule with an apical cell.



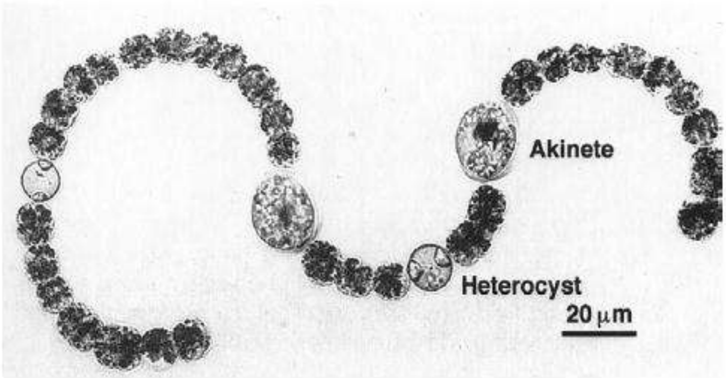
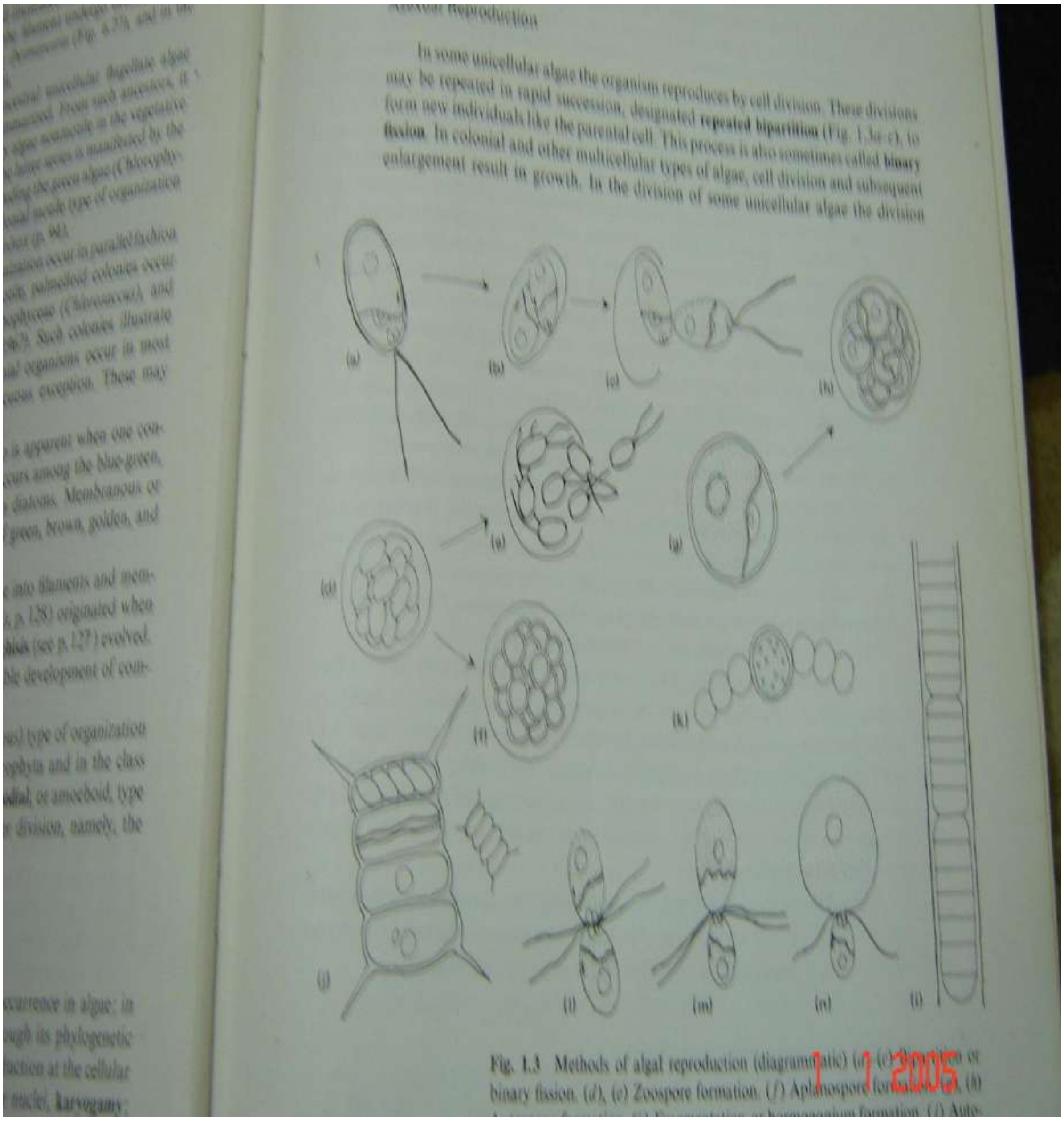


Fig. 2.16 Light micrograph of *Anabaena crassa* showing vegetative cells, akinetes, and heterocysts. (From Li et al., 1997.)

the gas vesicle is quite rigid, with the gas i
it at a pressure of 1 atm. The membrane i



The life cycle of algae in which sexual reproduction occurs may belong to one of three fundamentally different patterns illustrated diagrammatically in Fig 1.4. The first type is - **haploid life cycle** –a-, the organism at maturity produces gametes 1n which may unite to form zygotes which undergo a period of dormancy. Upon germination of the zygote, its nucleus undergo meiosis, so that the products of its germination- zoospores, aplanospores, or juvenile plants-, like the adults, are haploid, the zygote alone, in this type of life cycle, is diploid and the organism may be said to undergo **zygotic meiosis**. Note Fig 1,4a that the organism may reproduce itself asexually.

A second type of algal life cycle is- **diploid life cycle** –b- Here the sole free-living organism present in the life cycle is diploid, meiosis occuring as in all animales- during gametogenesis, this is **gametic meiosis**. Here again, the diploid phase may propagate itself by asexual agents.

The third type of algal life cycle is – **diplobiontic type-** c-. Two free living types of individuals occur in such life cycle, namely, a haploid, gamete-producing plant- **gametophyte-** and a diploid, spor-producing one –

sporophyte-. The gametes unite to form zygote, which, without undergoing a period of dormancy, grow into diploid sporophytes. As these mature and form spores, meiosis occurs during sporogenesis, so that **sporic meiosis** is said to occur.These spores develop into gametophytes.The sporophytes themselves are diploid and the gametophytes haploid. Note also that both the gametophytes and sporophytes may reproduce themselves by asexual agents. These plants may be morphologically similar, in which case the cycle is said to be **isomrphic**, or they may differ morphologically in a **heteromorphic** life cycle. This type of life cycle has one important variation that occur in red algae and is included in the discussion of them. In this life cycle , furthermore, illustrate the broad phenomenon of **alternation of generation**, which means that a haploid gametophyte is followed in the life cycle by a diploid sporophyte and the latter, in turn, by a haploid gametophyte.

One further phenomenon is relevant to this discussion, namely, parthenogenesis, both the male and female gametes develop into new individuals without gametic union.

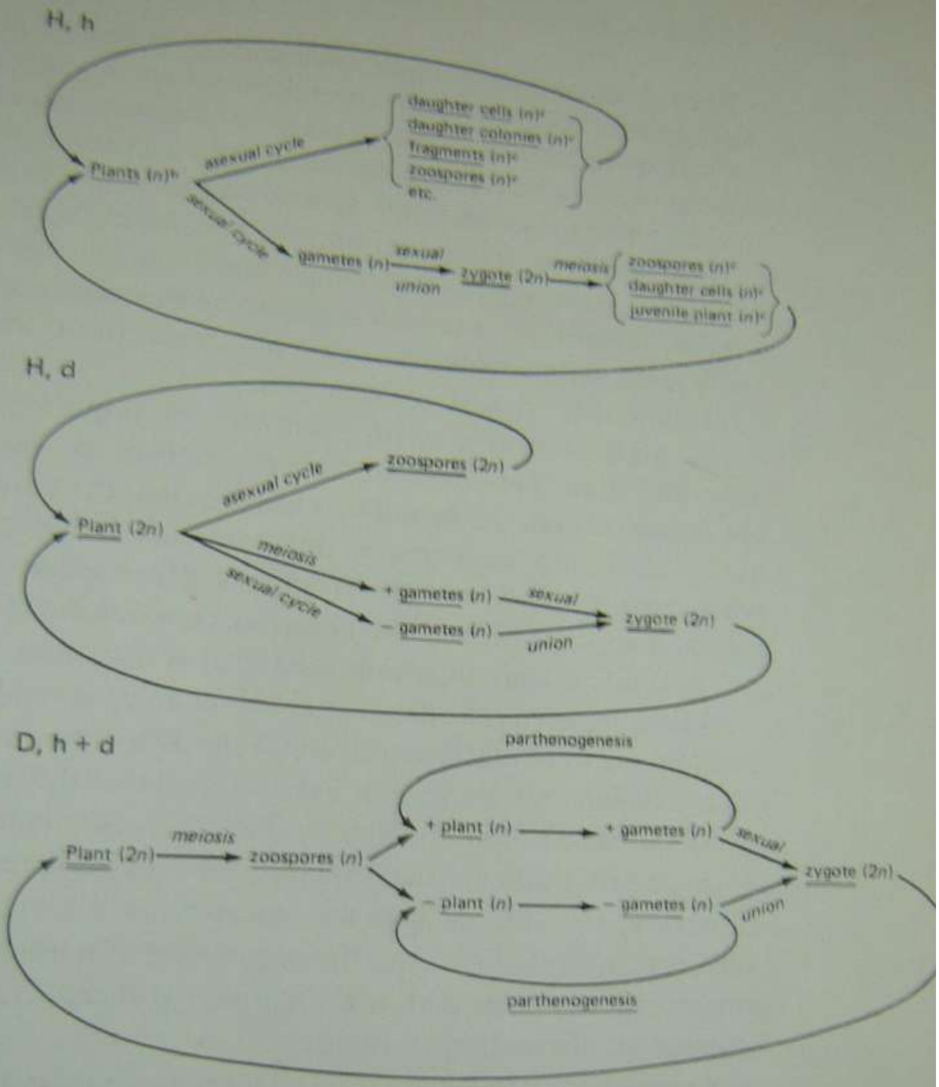


Fig. 1.4 (*a*)–(*c*) Types of algal life cycle[a]. (After Bold.)

[a]Haploid phases are underlined once; diploid phases twice. Both haploid and diploid plants may replicate themselves asexually by fragments and/or various types of spores.

[b]If the plants are unisexual, + and − or male and female plants occur.

[c]Alternate phases that characterize specific algae.

constitution of the free-living organisms in the cycle. Here again, the may propagate itself by asexual agents. The H, d type of life cycle occurs ...) green algae (p. 190.) and, according to one interpretation, in

<u>Lecture: 4 & 5</u>

<u>Classification:</u>

The first classification system in nineteenth century was classified algae into four divisions according to their morphology and color:

Division 1- Myxophycophyta

Division 2: Chlorophycophyta

Division 3: Phaeophycophyta

Division 4: Rhodophycophyta.

In this system the Blue-green algae was classified within green algae. While the golden algae and diatoms were classified within brown algae.

After the discovering light microscope and E.M, the new classification systems were developed, and these systems were classified algae according to the following characteristics:

1- Study the fine structure of plastids and pigments.
2- Study the nature and structure of storage food.
3- Study the nature and the components of cell wall.
4- Study the structure, position, and the number of flagella.
5- Study the reproduction methods, growth, as well as the occurrence.

The classification systems which appeared in twentieth century are:

1- Morris in 1973.
2- Bold and Wynne in 1973.
3- Kumar and Singe in 1978.

Bold and Wynne was classified algae into four divisions and three classes as follows:

Division1- Cyanophycophyta- Cyanobacteria- are the only prokaryotic algae.

The eukaryotic algae were included:

Division 2: Chlorophycophyta which involves Prochlorophycophyta; algae that represent an intermediate position in the evolution of blue- green algae and green algae.

Division 3: Charophycophyta.

Division 4: Chrysophycophyta which involves three classes:

Class1: Chrysophyceae

Class 2: Xanthophyceae

Class 3: Bacillariophyceae

In Kumar and Singe classification system, the prochlorophycophyta and Charophycophyta were combined with green algae and the golden algae was separated into three divisions: Chrysophycophyta, Xanthophycophyta and Bacillariophycophyta.

The classification system which will use in our lectures classified algae into ten divisions as follows:

Division 1: Cyanophycophyta

Division 2: Chlorophycophyta

Division 3: Euglenophycophyta

Division 4: Charophycophyta

Division 5: Chrysophycophyta

Division 6: Xanthophycophyta

Division 7: Bacillariophycophyta

Division 8: Phaeophycophyta

Division 9: Pyrrhophycophyta

Division 10: Rhodophycophyta.

Fourth edition
Robert Edward Lee in 2008
Colorado State University, USA

There are four distinct groups within the algae. The remainder of the text is divided into four parts based on these four groups.

1- Prokaryotes. The cyanobacteria are the only prokaryotic algae.

2- Eukaryotic algae with chloroplasts surrounded by the two membranes of the chloroplast envelope. The components of a eukaryotic ribosome.

3- Eukaryotic algae with the chloroplast surrounded by one membrane of chloroplast endoplasmic reticulum.

4- Eukaryotic algae with the chloroplast surrounded by two membranes of chloroplast endoplasmic reticulum.

The standard botanical classification system is used in the systematic of the algae:

Phylum – phyta

Class – phyceae

Order – ales

Family – aceae

Genus

Species

Group 1 Prokaryotic algae

Cyanophyta (cyanobacteria): chlorophyll *a*; phycobiliproteins.

Group 2 Eukaryotic algae with chloroplasts surrounded only by the two membranes of the chloroplast envelope.

Glaucophyta: algae that represent an intermediate position in the evolution of chloroplasts; photosynthesis is carried out by modified endosymbiotic cyanobacteria.

Rhodophyta (red algae): chlorophyll *a*; phycobiliproteins; no flagellated cells; storage product is floridean starch.

Chlorophyta (green algae): chlorophylls *a* and *b*; storage product, starch, is found inside the chloroplast.

Group 3 Eukaryotic algae with chloroplasts surrounded by one membrane of chloroplast endoplasmic reticulum.

Euglenophyta (euglenoids): chlorophylls *a* and *b*; one flagellum with a spiraled row of fibrillar hairs; proteinaceous pellicle in strips under the plasma membrane; storage product is paramylon; characteristic type of cell division.

Dinophyta (dinoflagellates): mesokaryotic nucleus; chlorophylls *a* and *c*1; cell commonly divided into an epicone and a hypocone by a girdle; helical transverse flagellum; thecal plates in vesicles under the plasma membrane.

Apicompexa: heterotrophic flagellates with colorless plastids.

Group 4 Eukaryotic algae with chloroplasts surrounded by two membranes of chloroplast endoplasmic reticulum.

Cryptophyta (cryptophytes): nucleomorph present between inner and outer membrane of chloroplast endoplasmic reticulum; starch formed as grains between inner membranes of chloroplast endoplasmic reticulum and chloroplast envelope; chlorophyll *a* and *c*; phycobiliproteins; periplast inside plasma membrane.

Heterokontophyta (heterokonts): anterior tinsel and posterior whiplash flagellum; chlorophyll *a* and *c*; fucoxanthin; storage product usually chrysolaminarin occurring in vesicles.

Chrysophyceae (golden-brown algae)

Synurophyceae

Eustigmatophyceae

Pinguiophyceae

Dictyochophyceae

Pelagophyceae

Bolidophyceae

Bacillariophyceae (diatoms)

Raphidophyceae (chloromonads)

Xanthophyceae (yellow-green algae)

Phaeothamniophyceae

Phaeophyceae (brown algae)

Prymnesiophyta (haptophytes): two whiplash flagella; haptonema present; chlorophyll *a* and *c*; fucoxanthin; scales common outside cell; storage product chrysolaminarin occurring in vesicles.

The prokaryotic algae

The cyanobacteria or blue-green algae form a natural group by virtue of being the only prokaryotic algae. Prokaryotic algae have an outer plasma membrane enclosing protoplasm containing photosynthetic thylakoids, 70S ribosomes, and DNA fibrils not enclosed within a separate membrane. Chlorophyll *a* is the main photosynthetic pigment, and oxygen is evolved during photosynthesis.

Cyanobacteria

The Cyanophyceae or blue-green algae are, today, usually referred to as the cyanobacteria (blue-green bacteria). The term cyanobacteria acknowledge that these prokaryotic algae are more closely related to the prokaryotic bacteria than to eukaryotic algae. For the last quarter century,cyanobacteria were thought to have evolved about 3.5 billion years ago. These reports were based on interpretation of microfossils, difficult at best with such small organisms. It now appears that these investigators selected specimens that fit the assumptions of the authors, with most phycologists now rejecting their claims. Based on other reports, the actual time of evolution of cyanobacteria is thought to be closer to 2.7 billion years ago. **Cyanobacteria have chlorophyll *a* (some also have chlorophyll *b* or *d*), phycobiliproteins, glycogen as a storage product, and cell walls containing amino sugars and amino acids. At one time, the occurrence of chlorophyll *b* in cyanobacteria was used as a criterion to place the organisms in a separate group, the Prochlorophyta. Modern nucleic-acid sequencing, however, has shown that chlorophyll *b* evolved a number of times within the cyanobacteria and the term Prochlorophyta has been discarded.**

Morphology:

The simplest morphology in the cyanobacteria is that of unicells, free-living (see Figs. 2.19(*c*), or enclosed within a mucilaginous envelope (Figs.2.48. Subsequent evolution resulted in the formation of a row of cells called a **trichome**. When the trichome is surrounded by a sheath, it is called a **filament**. It is possible to have more than one trichome in a filament, 2.58(*b*)). The most complex thallus is the branched filament (Fig.2 .58(*a*)). Such a branched filament can be **uniseriate** (composed of a single row of cells) or **multiseriate** (composed of one or more rows of cells). The algal forms in cyanophycophyta are:

1- **Unicellular** form such as *Gloeocapsa.*
2- **Colonial form-** aggregate, either **regular** such as *Merismopedia* or **irregular** such as *Microcysitis*.
3- Filamentous form: **Simple filament** such as *Oscillatoria*, or **false branched filament** such as *Scytonema* , and **true branched filament** such as *Stigonema.*
4- **Heterotrichous** form such as *Hyella.*

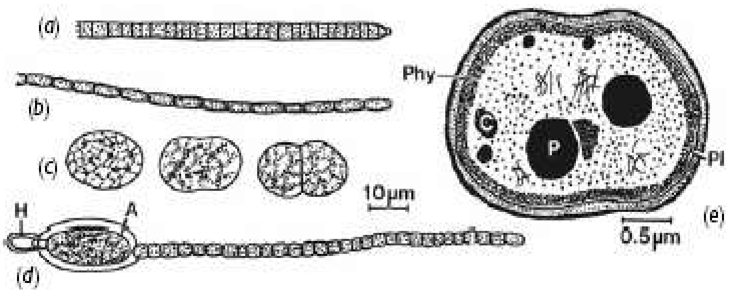


Fig. 2.19 (*a*) *Oscillatoria agardhii*. (*b*) *O. limnetica*. (*c*) *Synechococcus aeruginosus*. (*d*) *Cylindrospermum majus*. (A) Akinete; (H) heterocyst. (e) Drawing of the fine structure of *Gloeobacter violaceus*. (C) Cyanophycin granule; (P) polyphosphate body; (Phy) probable layer of phycobiliproteins; (Pl) plasmalemma. ((*c*),(*d*) after Prescott, 1962; (e) after Rippka et al., 1974.)

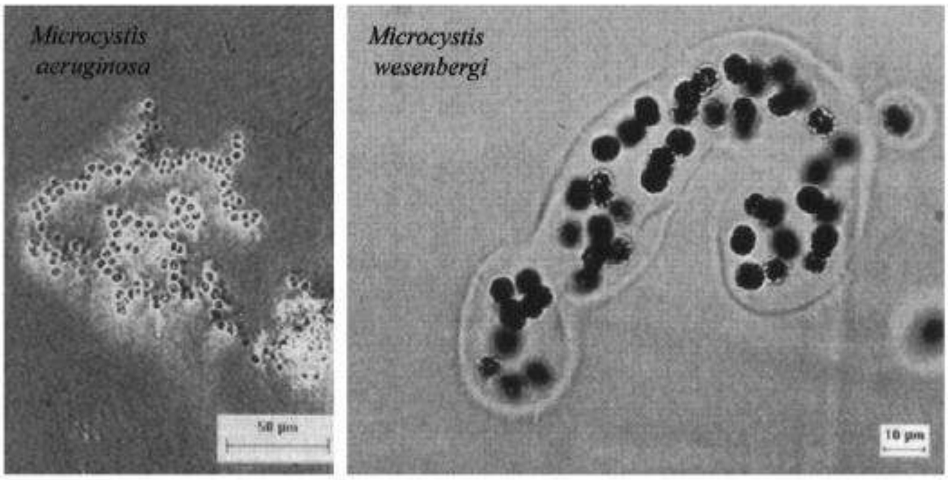


Fig. 2.48 Light micrographs of two species of *Microcystis*. (From Bittencourt-Oliveira et al., 2001.)

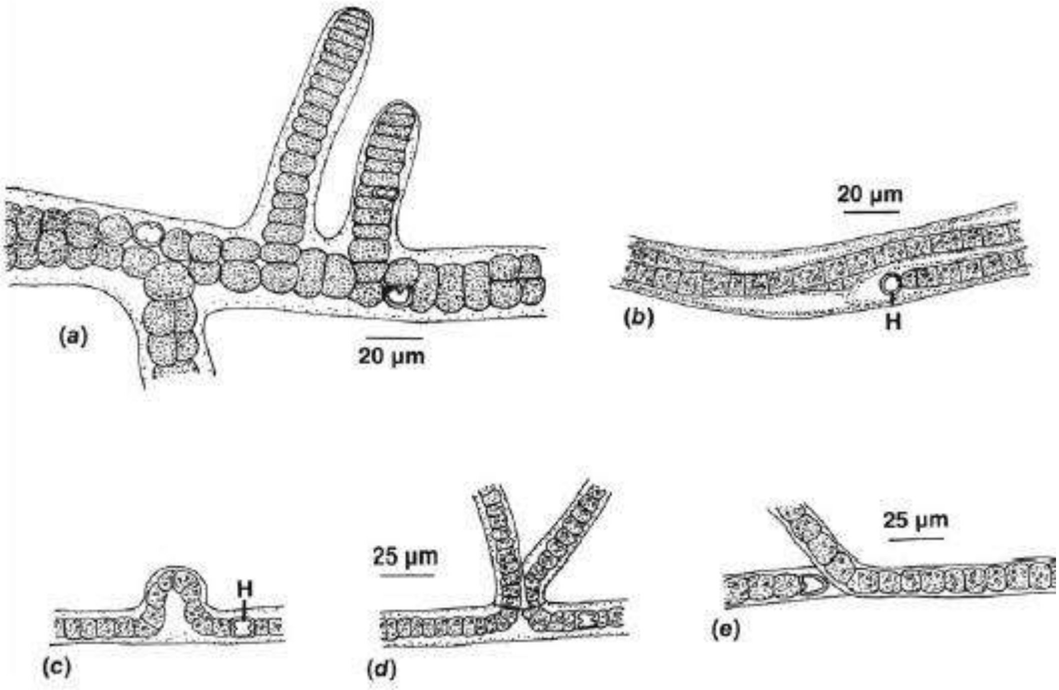


Fig. 2.58 (*a*) *Stigonema turfaceum* showing true branching. (*b*) *Desmonema wrangelii* with a number of trichomes in a sheath. (*c,d*) *Scytonema arcangelii* illustrating formation of false branches. (*e*) *Tolypothrix tenuis* with a single false branch. (H) heterocyst. (After Smith, 1950.)

<u>Cell wall and gliding</u>: The cell wall of cyanobacteria is basically the same as the cell wall of Gram-negative bacteria (Fig. 2.1). A **peptidoglycan layer** is outside of the **cell membrane**. The peptidoglycan is an enormous polymer composed of two sugar derivatives, *N*-

acetylglucosamine and *N*-acetylmuramic acid, and several different amino acids (Fig. 2.2). Outside of the peptidoglycan is a **periplasmic space**, probably filled with a loose network of peptidoglycan fibrils. An **outer membrane** surrounds the periplasmic space. Some cyanobacteria are capable of gliding, that is, *the active movement of an organism on a solid*. The mechanism of gliding movement is not completely understood. It has been suggested that it is a sort of propulsion caused by the secretion of slime and also by contractile waves on the surface of the cell. The minute pores in the wells revealed by E.M. have been suggested as the pathways for mucilage secretion. On the other hand, it was found fibrils in the wall that they though to be involved in motility and the sites of waves of propulsion of the trichomes. This movement is slow in *Oscillatoria* and quick in *Spirulina.*

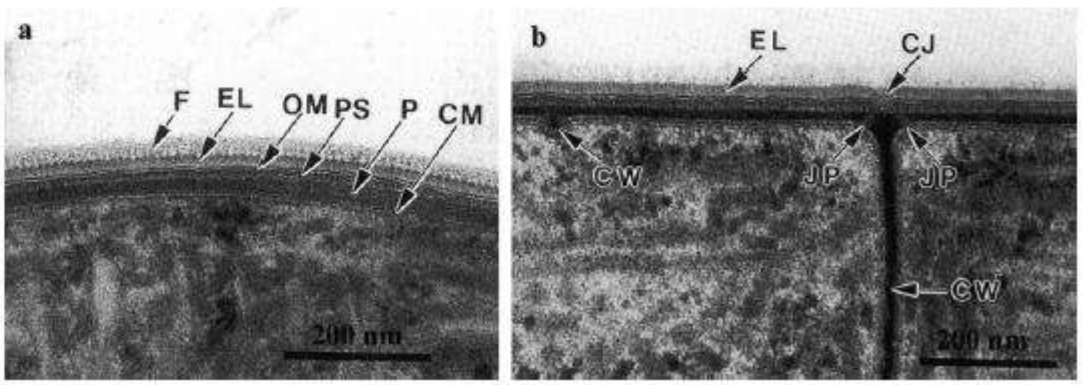


Fig. 2.1 Transmission electron micrographs of sections of the wall of the cyanobacterium *Phormidium uncinatum*. The cell wall (CW) contains layers similar to those of a Gram-negative bacterium, e.g., the cytoplasmic membrane (CM), peptidoglycan layers (P), periplasmic space (PS) and outer membrane (OM). In addition, the cyanobacterium contains the additional two external layers typical of a motile cell, the serrated external layer (EL) and hair-like fibers (F). (CJ) Circumferential junction; (JP) junctional pore. (From Hoiczyk and Baumeister, 1995.)

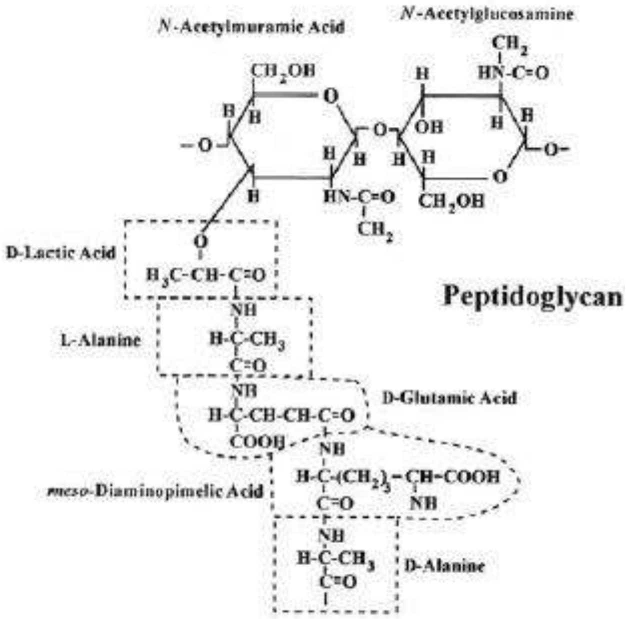


Fig. 2.2 The structure of a peptidoglycan molecule in the cell wall of cyanobacteria.

Protoplasmic structure:

Many of the protoplasmic structures found in the bacteria occur in the cyanobacteria. In the central protoplasm are the **circular fibrils of DNA** which are not associated with basic proteins (**histones**) (Figs. 2.11). The peripheral protoplasm is composed principally of **thylakoids** and their associated structures, the **phycobilisomes** (on the thylakoids, containing the phycobiliproteins) and **glycogen granules**. The **70S ribosomes** are dispersed through out the cyanobacterial cell but are present in the highest density in the central region around the nucleoplasm. **Cyanophycin** is a non-ribosomally synthesized protein-like polymer that occurs in the cytoplasm in structured granules that are not surrounded by a membrane (Fig. 2.13). Cyanophycin is a polymer that consists of equimolar amounts of arginine and aspartic acid arranged as a polyaspartate backbone (Fig. 2.12). Cyanophycin functions as a temporary nitrogen reserve in nitrogen-fixing cyanobacteria, accumulating during the transition from the exponential to the stationary phase and disappearing when balanced growth resumes. Nitrogen is stored in phycobilisomes in cyanobacteria that do not fix nitrogen.

Carboxysomes (polyhedral bodies) are similar to the carboxysomes in bacteria and contain the carbon dioxide-fixing enzyme **ribulose-1,5-bisphosphate carboxylase/oxygenase.**

Polyphosphate bodies (**metachromatic** or **volutin granules**) (Fig. 2.11) are spherical and appear similar to lipid bodies of eukaryotic cells in the electron microscope. Polyphosphate bodies contain stored phosphate, the bodies being absent in young growing cells or cells grown in a phosphate-deficient medium, but present in older cells. **Polyglucan granules** (α-**granules**) (Fig. 2.11) are common in the space between the thylakoids in actively photosynthesizing cells. These granules contain a carbohydrate, composed of 14 to 16 glucose molecules, that is similar to amylopectin.

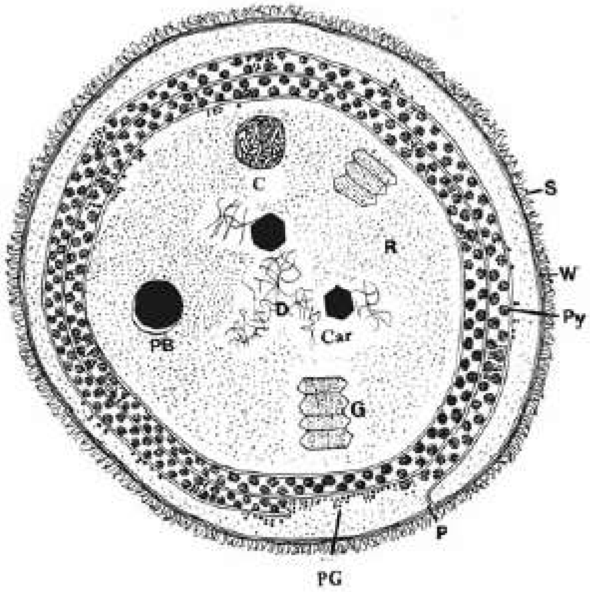


Fig. 2.11 Drawing of the fine-structural features of a cyanobacterial cell. (C) Cyanophycin body (structured granule); (Car) carboxysome (polyhedral body); (D) DNA fibrils; (G) gas vesicles; (P) plasmalemma; (PB) polyphosphate body; (PG) polyglucan granules; (Py) phycobilisomes; (R) ribosomes; (S) sheath; (W) wall.

$$H_2N - \underset{|}{\overset{\text{Arg}}{}}\!\!\!\text{Asp} - \overset{\substack{\text{Arg}\\|}}{(\text{ASP})_n} - \overset{\substack{\text{Arg}\\|}}{\text{ASP}} - \text{COOH}$$

Fig. 2.12 Cyanophycin is composed of equimolar amounts of arginine (Arg) and aspartic acid (Asp) arranged as a polyaspartate backbone.

Gas vacuoles

A gas vacuole is composed of gas vesicles, or hollow cylindrical tubes with conical ends, in the cytoplasm of cyanobacteria (Fig. 2.11). Gas vesicles do not have true protein-lipid membranes, being composed exclusively of protein ribs or spirals arranged similarly to the hoops on a barrel. It is possible to collapse the gas vesicles by applying pressure to the cells, the collapsed vesicles having the two halves stuck together. The membrane is permeable to gases, allowing the contained gas to equilibrate with gases in the surrounding solution. The membrane must, however, be able to exclude water. It has been postulated that the inner surface must be **hydrophobic**, thereby preventing condensation on it of water droplets, and restraining, by surface tension, water creeping through the pores. At the same time these molecules must present a **hydrophilic** surface at the outer (water-facing) surface in order to minimize the interfacial tension, which would other wise result in the collapse of the gas vacuole. Cyanobacteria possessing gas vacuoles can be divided into two physiological-ecological groups. In the first group are those algae having vacuoles only at certain stages of their life cycle, or only in certain types of cells. In *Gloeotrichia ghosei* and in certain species of *Tolypothrix* and *Calothrix*, gas vesicles appear only in hormogonia. The hormogonia float when they are released, and it is possible that the buoyancy provided is of significance in dispersal of these stages. The second group consists of planktonic cyanobacteria, including species of *Anabaena*, *Gloeotrichia*, *Microcystis*, *Aphanizomenon* , *Oscillatoria*,*Trichodesmium*, and *Phormidium*. These algae derive positive buoyancy from their gas vesicles, and as a consequence form blooms floating near the water surface.

Pigments :

The major components of the photosynthetic light-harvesting system of the cyanobacteria are **chlorophyll** *a* in the thylakoid membrane, and the **phycobiliproteins**, which are water-soluble chromoproteins assembled into macro molecular aggregates (phycobilisomes) attached to the outersurface of the thylakoid membranes. The Cyanophyceae have four phycobiliproteins: **C-phycocyanin**, **allophycocyanin**, **C-phycoerythrin** and **phycoerythrocyanin** . All cyanobacteria contain the first two, whereas C-phycoerythrin and phycoerythrocyanin occur only in some species. The phycobiliproteins of the cyanobacteria change in concentration in response to light quality and growth conditions.

Cyanobacteria that produce the red phycoerythrin and the blue phycocyanin in white light, suppress phycoerythrin synthesis in red light and phycocyanin synthesis in green light (**complementary chromatic adaptation**.

Akinetes:

Akinetes are generally recognized by their larger size relative to vegetative cells and conspicuous granulation due to high concentrations of glycogen and cyanophycin. The most consistent property of akinetes is their greater resistance to cold compared with vegetative cells. Akinetes have often been compared to endospores in Gram-positive bacteria. Akinetes, however, are neither as metabolically quiescent nor as resistant to various environmental extremes. Akinetes only occur in cyanobacteria that form heterocysts. In *Aphanizomenon* (Fig. 2.18(*b*) the development of akinetes from vegetative cells involves an increase in cell size, the gradual disappearance of gas vacuoles, and an increase in cytoplasmic density and number of ribosomes and cyanophycin granules.

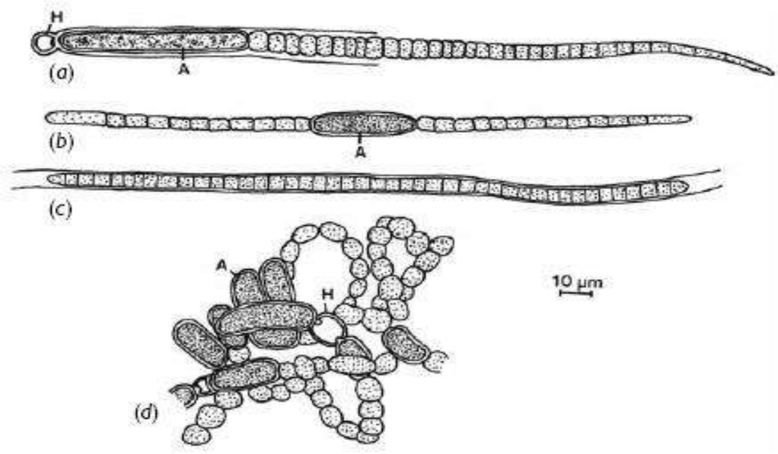


Fig. 2.18 (*a*) *Gloeotrichia echinulata*. (*b*) *Aphanizomenon flos-aquae*. (*c*) *Phormidium inundatum*. (*d*) *Anabaena flos-aquae*. (A) Akinete; (H) heterocyst. (After Prescott, 1962.)

Heterocysts:

Heterocysts are cell with homogeneous- appearing contents – as viewed with the light microscope- and transparent walls. Heterocysts are larger than vegetative cells and appear empty in the light microscope (whereas akinetes appear full of storage products) (Fig. 2.18(*a*). With E.M. heterocysts are surrounded by two or three layers of cell wall lacking pectin while contain cellulose and chitin. Thylakoid appears as reticulate structures in protoplast and there is small amount or no biliprotein pigments and the dominant pigment is chlorophyll a, with a few ribosomes inside cell. Heterocysts may be **terminal**, either **basal** such as in *Rivularia* or **apical in** *Anabaenopsis*, **or intercalary** such as in *Anabaena* and may be evenly distributed among the vegetative cells. Where they are connected to the latter, the wall is modified in the form of a polar nodule through which there is a channel; the septum across the end of the pore channel is transverse by microplasmodesmata that seemingly provide continuity between the heterocyst and vegetative cell. Fig 2-25.

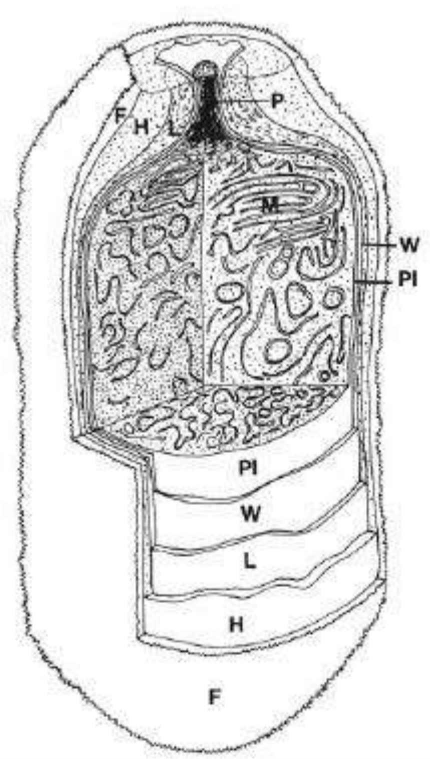


Fig. 2.25 Three-dimensional view of a heterocyst. The envelope has homogeneous (H), fibrous (F), and laminated (L) layers. (M) Membranes; (P) pore channel; (Pl) plasmalemma; (W) cell wall. (After Lang and Fay, 1971.)

The role of heterocysts are nitrogen fixation and in relation to akinete and false branched formation. It is found that heterocysts increase in number when nitrogen in the environment has been depleted. It is also found that heterocyst contains nitrogenase. Others suggest that heterocysts play a role in reproduction.

Reproduction:

1- **Vegetative reproduction:**

a- **Binary fission:** it is occur in unicellular and aggregate colonies.

b- **Fragmentation:** it is occur in aggregate colonies.

c- Hormogonia formation:

Hormogonia (or hormogones), which are characteristic of all truly filamentous cyanobacteria, are ***short pieces of trichome that become detached from the parent filament and move away by gliding, eventually developing into a separate filament.*** In some algae, specialized separation discs or necridia (Fig. 2.34a,b) are involved in the breaking of the hormogone from the parent filament, whereas in others, the filament just fractures.

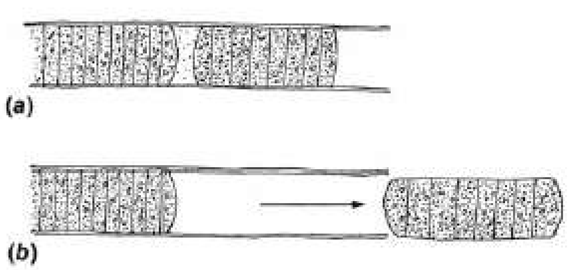
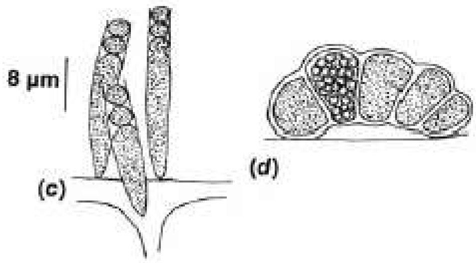


Fig. 2.34 (*a*),(*b*) Formation of a hormogonium in *Oscillatoria*. (*c*) Baeocyte formation in *Chamaesiphon incrustans*. (*d*) Baeocyte formation in *Dermocarpa pacifica*. (After Smith, 1950.)



2- <u>Asexual reproduction:</u>

a- Exospore formation: The cells are attached at their bases. As they mature, the protoplast at the distal pole abstracts a chain of spores called exospoes, so called because they are soon exposed to the environment and shed such as in *Chamaesiphon* Fig.2.c.

b- Endospore formation: The cells of *Dermocarpa* are spherical to slightly saccate or pyriform and grow attached to the substrate in groups. Reproduction is accomplished solely by endospores which may develop in large numbers within the vegetative cells Fig 2.34d.

c- **Nannospore formation:** The cells of *Gloeocapsa* are divided very fast and continuously forming a minute spores –nannospores- in normal conditions.

d- **Hormospore formation:** In *Scytonema* when the conditions are not suitable, the terminal vegetative cells surrounded with a thick sheath and remain active, and they will grow into new individuals when the conditions become suitable.

Occurrence and Habitat:

Blue green algae are **ubiquitous** in water of a great range of salinity and temperature, and they occur in and on the soil and also on rocks and their fissures. In 1973, it was reported the occurrence of *Gloeocapsa*, *Nostoc*, and *Lyngbya* in the supralittoral zone of marine shores. A number have been recovered from the atmosphere. In general, blue-green algae seem to be more abundant in neutral or slightly alkaline habitats, although some – e.g. *Chroococcus*, are said to occur in bog waters at pH 4.0. But others reported that blue-green algae were absent from waters whose pH was less than 4 or 5, while certain eukaryotic algae were present.

Blue- green algae are both planktonic and benthic. Among the former, several are characteristically members of water bloom, for example, *Microcystis*, *Anabaena*, and *Trichodesmium*, the last common in tropical waters, including the Red Sea (which probably was so named because of the color of the algae). At least two blue-green algae, *Microcystis aeruginosa* and *Anabaena* flos-aquae, are responsible for acute poisonings of various animals.

Blue-green algae, along with certain bacteria, occur in alkaline hot spring such as those of Yellowstone and various other parts of the world where they live at maximum temperatures of 73-74ºC (thermophilic environment).

Blue-green algae may form mats on the surface of bare soil as primary colonizers and are important in adding organic matter to the soil in preventing incipient erosion. Some Cyanocholronta of soil have been shown to have remained viable for 107 years and they have been recovered from house dusts. A number of Blue-green algae grow in association with other organisms, thus, *Gloeocapsa* and *Nostoc,* among others, are the phycobionts of lichens, while others like *Nostoc* and / or *Anabaena* occur within the plant bodies of certain liverworts, water ferns and angiosperms where they fix nitrogen. Certain types are associated with Protozoa, where they have been called cyanelles. In addition to poisoning animals, blue- green algae may be deleterious to human beings such as *Lyngbya majuscule* that toxic factors have been isolated from it and causes dermatitis.

Classification:

Nucleic acid sequencing of cyanobacteria is beginning to elucidate the evolutionary relationships among cyanobacteria. These studies have shown that there is little in common between the morphology of cyanobacteria and their evolutionary relationship. The one exception is the cyanobacteria with heterocysts, which all appear to be closely related. With the classification of cyanobacteria in such a state of flux, I have chosen to simplify the classification by the

cyanobacteria dividing into three orders:

Order 1 Chroococcales: single cells or cells loosely bound into gelatinous irregular colonies.

Order 2 Oscillatoriales: filamentous cyanobacteria.

Order 3 Nostocales: filamentous cyanobacteria with heterocysts.

Chroococcales:

This order included basically unicellular cyanobacteria which are held together in palmelloid colonies by mucilage. *Gloeothece* (Fig. 2.56(*a*)), *Microcystis* (Figs. 2.48, 2.56(*b*)), *Synechococcus* (Fig. 2.19(*c*), and *Synechocystis* (Fig. 2.8) are some of the genera in this order. Although the organisms in this order have a similar morphology, studies involving nucleic acid base composition have shown that the order is actually composed of several distinct and widely separated groups *Prochlorococcus marinus* (Fig. 2.20) is the dominant photosynthetic organism in tropical and temperate oceans. The cyanobacterium is 0.5 μm in diameter, making it the smallest photosynthetic organism. The cells have chlorophyll *a* and *b*, and lack phycobilin pigments. The complete genome of *Prochlorococcus marinus* has been determined (Dufresne *et al.*, 2003).

Gloeobacter violaceus (Fig. 2.19(*e*)), a cyanobacterium without internal thylakoids, appears to be the most primitive cyanobacterium based on nucleic acid sequencing studies (Honda *et al*., 1999).

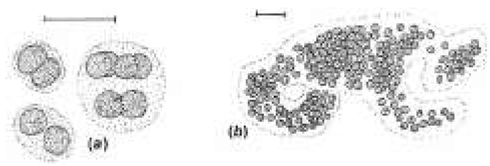


Fig. 2.56 (*a*) *Gloeothece magna.* (*b*) *Microcystis aeruginosa.* (*c*) *Phormidium autumnale.* (*d*) *Lyngbya birgei.* (*e*) *Hydrocoleus* sp. (*f*) *Spirulina major.* (*g*) *Trichodesmium lacustre.* (*h,i*) *Pleurocapsa minor*, surface view showing cells with endospores (*h*) and vertical section of thallus showing erect threads (*i*).
Bar = 10 μm.

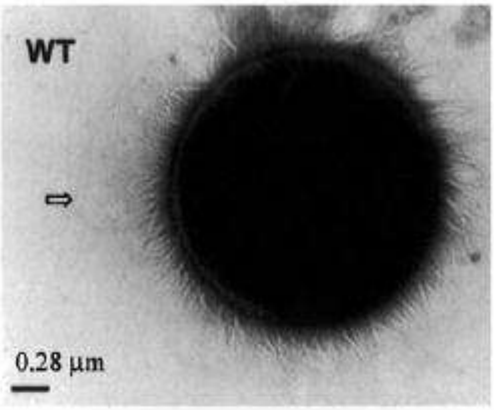


Fig. 2.8 Transmission electron micrographs of negatively stained whole cells of *Synechocystis* showing pili. (WT) Wild type. (From Bhaya et al., 1999.)

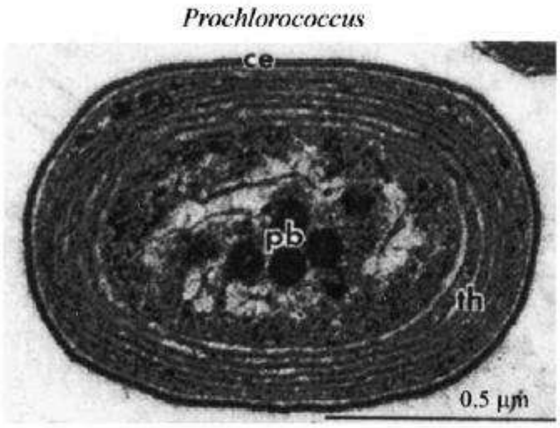


Fig. 2.20 Transmission electron micrographs of a section of *Prochlorococcus*, a chlorophyll *b* containing cyanobacterium, and of *Acaryochloris marina*, a chlorophyll *d* containing cyanobacterium. *Prochlorococcus* is the smallest known photosynthetic organism. (Ca) Carboxysome (polyhedral body); (Cy) cytoplasm; (pb) polyhedral body; (th) thylakoids. (Arrow) channel-like structures perforating thlyakoids. (Arrowheads) areas of accumulation of phycobiliproteins. (*Prochlorococcus* micrograph from Partensky, Hess and Vaulot, 1999; *Acaryochloris* micrograph is from Marquardt et al., 2000.)

Oscillatoriales:

These are filamentous cyanobacteria without heterocysts. Representative cyanobacteria are *Oscillatoria* (Fig., 2.34(*a*), (*b*), 2.19(*a*), (*b*)), *Trichodesmium* (Fig. 2.31a, *Phormidium* (Figs. 2.31c), *Lyngbya* (Fig.

2.31(*d*)), *Hydrocoleus* (Fig. 2.31(*e*)), and *Spirulina* (Fig. 2.51). ***Pleurocapsa* (Fig. 2.31(*h*) I**, is composed of an erect and a prostrate system and is therefore **heterotrichous**. *Pleurocapsa* is a widely distributed **lithophyte** (grows on rocks) in the marine and freshwater environment. Initially it consists of a filament creeping over the surface. Later the filament branches and forms a pseudoparenchymatous disc. Development may stop here, or the prostrate basal disc cells may form erect threads (Fig. 2.31(*i*)). Endospores are formed internally by
the division of a vegetative cell in three planes.

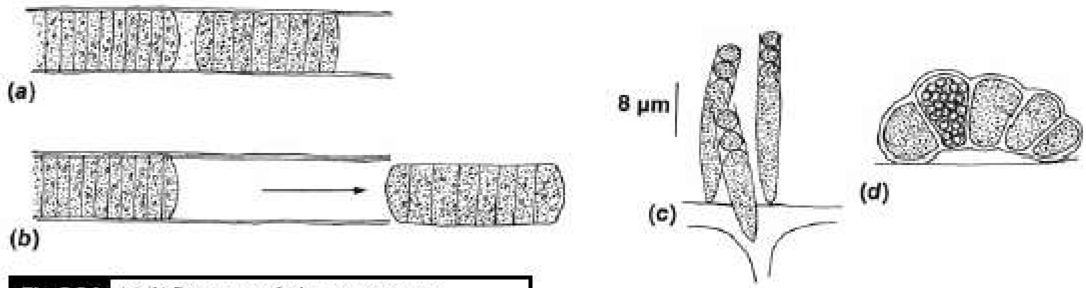
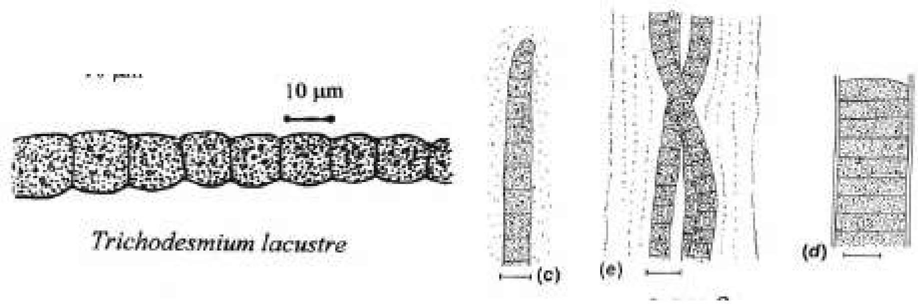


Fig. 2.34 (*a*),(*b*) Formation of a hormogonium in *Oscillatoria*. (*c*) Baeocyte formation in *Chamaesiphon incrustans*. (*d*) Baeocyte formation in *Dermocarpa pacifica*. (After Smith, 1950.)



a

Fig.2-31

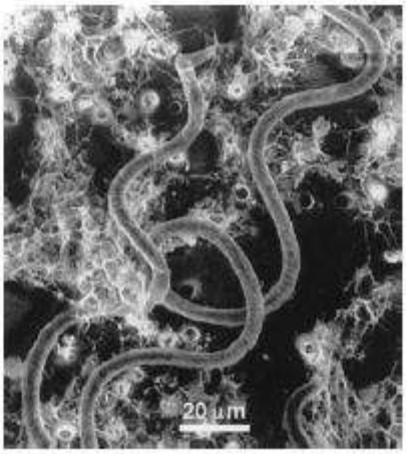


Fig. 2.51 Scanning electron micrograph of *Spirulina platensis*. (From El-Bestaway et al., 1996.)

Nostocales:

The cyanobacteria in this order, such as *Nostoc* (Figs. 2.57a), *Anabaena* (Figs. 2.16), has heterocysts. The most common method of reproduction is by hormogonia. ***In some genera there is a polarity: heterocysts and/or akinetes are at the base, and a colorless hair is at the apex of the filament. A hair is a region of the trichome where the cells are narrow, elongated, highly vacuolated, and apparently colorless.***

Rivularia (Fig. 2.57(*d*)) forms colonies in which the sheaths of one filament are confluent with others. The sheaths are usually heavily encrusted with lime and are very firm. *Rivularia* grows in fresh water submerged on stones and plants. These algae then resemble species of genera such as *Oscillatoria* (Figs. 2.17, 2.34(*a*), (*b*), 2.19(*a*), (*b*)). Hairs can also be induced to form by growing the algae under conditions of phosphorus deficiency. Addition of phosphorus results in the loss of hairs and the formation of hormogonia. False branching occurs in some genera in this order. ***It results when the trichome lodges in the sheath, commonly in the area of a large heterocyst (Fig. 2.58(c), (d)). Committed cell division in the trichome results in (1) a rupture of the sheath and (2) a break in the trichome that gives the appearance of a***

branch. The first type of false branching results in only one false branch protruding through the sheath, as in Tolypothrix (Fig.2.58). This type is due to the death of a cell or the formation of a separation disc or necridium (Fig. 2.34) (biconvex in shape because of pressure from adjacent cells, the necridia lyse as they mature). These weak points are normally next to a heterocyst and eventually result in a break of the trichome, with one of the broken ends of the trichome protruding through the sheath as a false branch. The second type of false branching results in the formation of two false branches, as in Scytonema (Figs. 2.58(c), (d), 2.59). Here a loop is formed that protrudes through the sheath. Eventually the loop breaks in the middle as cell division continues, resulting in two false branches. It is probable that the large heterocysts lodging in the sheath cause the immovability of the trichome in the sheath. Experimental evidence that this is so comes from experiments with algae grown in high combined-nitrogen levels, which inhibit both heterocyst formation and false branching. Stigonema has true branching with a tendency toward multiseriate thalli. The branching axis of Stigonema is partly or wholly multiseriate (Figs.2.58, 2.59). Stigonema occurs on wet rocks and reproduces by hormogonia formed on the younger branches. The genus is the most morphologically complex in the cyanobacteria and is often differentiated into upright and prostrate filaments (heterotrichy).

Lecture 6:

Disision 2: Chlorophycophyta:

Introduction:

Lewin observed that the *Synchococcus didemni* which classified within Blue-green algae has cellular structures does not involve in this division such as:

1- This alga contains chlorophyll b which is not present in blue- green algae.

2- There are no phycobilisome granules within thylakoids.

3- Thylakoid stacks are in pairs.

This alga is prokaryote. While have characteristics similar to those in green algae such as:

1- Presence of Chlorophyll b.

2- Has no biliprotein pigments and phycobilisomes.

3- Thylakoid stacks are in pairs, 2-6 and reach up to 20.

So this scientist classifies the alga in division prochlorophcophyta as follows:

Division: Prochlorophycophyta

Class: Prochlorophyceae

Order: Prochlorales

Genus: *Prochlorum*

Species: *P. didemni*

Division 2: Chlorophycophyta: Grass-Green Alage:

Occurrence and Habitat:

The Chlorophyta are primarily fresh water; only about 10% of the algae are marine, whereas 90% are freshwater. Some orders are predominantly marine (Caulerpales, Dasycladales, Siphonocladales), whereas others are predominantly freshwater (Ulotrichales, Coleochaetales) or exclusively freshwater (Oedogoniales, Zygnematales). The freshwater species have a cosmopolitan distribution, with few species endemic in a certain area. In the marine environment, the green algae in the warmer tropical and semitropical waters tend to be similar everywhere in the world. This is not true of the Chlorophyta in the colder marine waters; the waters of the Northern and Southern hemispheres have markedly different species. The warmer waters near the equator have acted as a geographical barrier for the evolution of new species and genera.

General characteristics:

1- The vegetative forms are different, unicellular, colonial form motile or non-motile, simple or branched filament, heterotrihous, membranous, and tubular forms.

2- The Chlorophyta, or **green algae**, have chlorophylls *a* and *b*, and form starch –amylose and amylopectin- with the chloroplast, usually in association with a pyrenoid. The Chlorophyta thus differ from the rest of the eukaryotic algae in forming the storage product in the chloroplast instead of in the cytoplasm.

3- No chloroplast endoplasmic reticulum occurs around the chloroplasts.

4- Chloroplast pigments are similar to those of higher plants; chlorophyll *a* and *b* are present. The main carotenoid is **lutein**. The siphonaceous genera, as well as the unicells *Tetraselmis* and *Mesostigma*, are the only green algae to have **siphonoxanthin** and its ester **siphonein.** Accumulation of carotenoids occurs under conditions of nitrogen deficiency, high irradiance or high salinity. This is particularly true in *Dunaliella* where β-carotene accumulates between thylakoids in the chloroplast, and *Haematococcus*, where **astaxanthin** accumulates in lipid globules outside the chloroplast.

5-Cell walls usually have cellulose as the main structural polysaccharide, although **xylans** or **mannans** often replace cellulose in the Caulerpales.

6- Green algae are eukaryotic, uninuclear or multinuclear. The algal cell contains Golgi bodies, mitochondria, endoplasmic reticulum.

7- Motile grnera have 1-4 whiplash flagella or some times reach to 120 flagella such as in *Oedogonium*. The flagella are equal in length.

8- Green algae are reproduce by binary fission, fragmentation, spore formation such as zoospors, aplanospores, hypnospores, autospores, autocolonies, akinetes, and palmelloid stage and sexually by isogamous, anisogameous, oogamous, and conjugation and parthenogenesis may also be occur.

9- Different types of life cycle may observed, haploid, diploid, and diplobionetic with presence of alternation of generations.

<u>Cell fine structure:</u>

Cellular organization of *Chlamydomonas* Fig 5.55 has been studied intensively at both the light- and electron-microscopic levels. The chloroplast varies in form among the many species of *Chlamydomonas*. It may be parietal and cup- or urn-shaped, or H-shaped- in optical section-, or otherwise. It usually contains one or more pyrenoids and eye spot in the anterior of plastid. One or two to many contractile vacuoles occur in the colorless cytoplasm; when they are two, they are anterior; otherwise they may be distributed over the surface of the protoplast. Two anterior whiplash flagella-equal in length- and central nucleus can be seen.

Under E.M. the cell is seem to be surrounded with gelatinous sheath and the cell wall consists of 2-3 layers. The plasma membrane is in the inner side of the cell wall and it is extending and surrounds the flagella too. The protoplast contains; a big nucleus with a nucleolus, mitochondria, Golgi apparatus, contractile vacuoles, endoplasmic reticulum and ribosomes. The plastid appears to be surrounded with 2 layers of chloroplast envelop, and pairs of thylakoid stacks are within it. In the Chlorophyta, the eyespot or stigma is always in the chloroplast, usually in the anterior portion near the flagella bases. The eyespot consists of one to a number of layers of lipid droplets, usually in the stroma between the chloroplast envelope and the outermost band of thylakoids. The eyespot is usually colored orange-red from the carotenoids in the lipid droplets Fig.5.56.

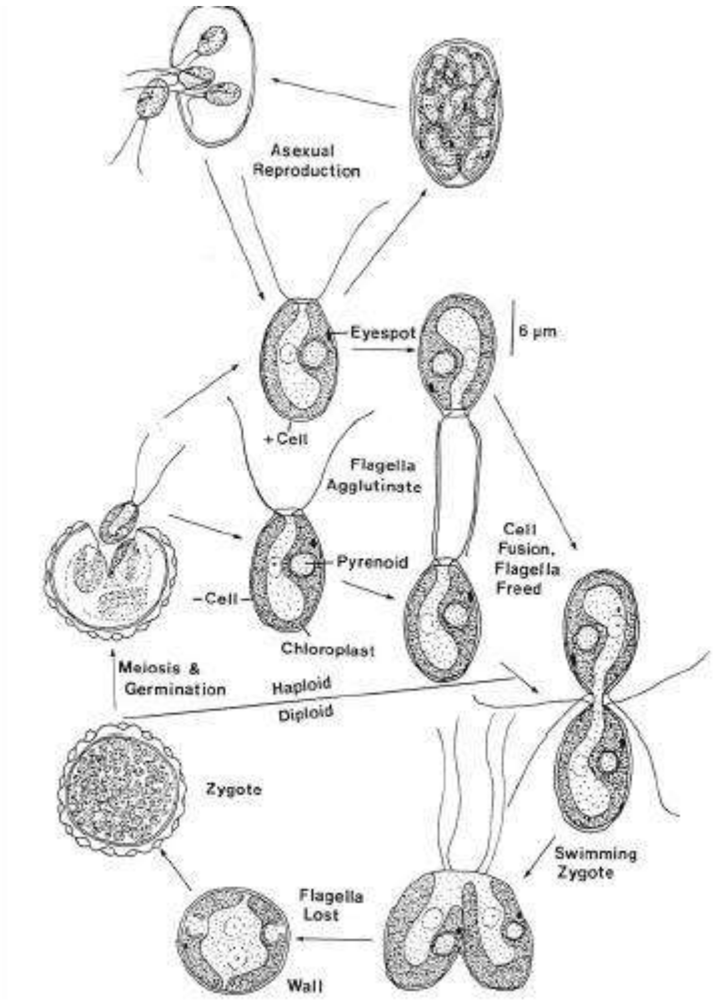


Fig. 5.55 The life cycle of *Chlamydomonas moewusii.* (Adapted from Brown et al., 1968.)

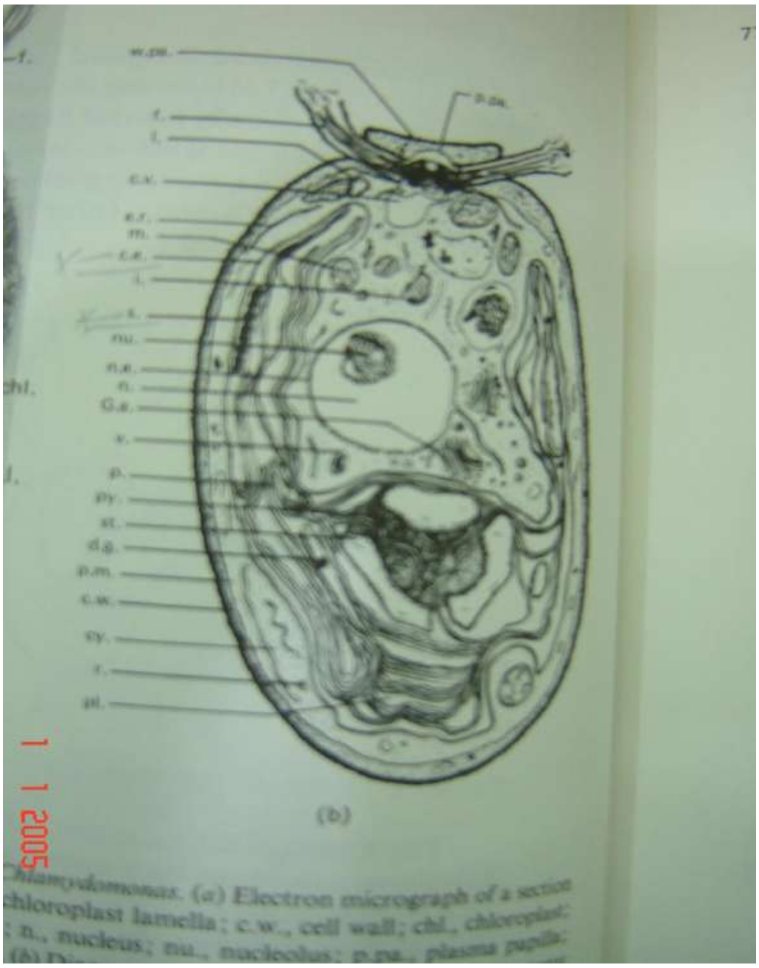


Fig.5.56: Ultrastructure of Chlamydomonas. C.V., Chloroplast envelop; e.r., endoplasmic reticulum; f. flagellum; G.a., Golgi apparatus; i., inclusion; l., lipid body; m., mitochondria; n., nucleus; n.e., nuclear envelop; n.u., nucleolus; p., plastid; p.pa., plasma papilla; p.m., plasma membrane; py., pyrenoid; r., ribosomes; s., stigma; st., starch; v., vesical; w.pa., wall papilla.

<u>Phototaxis and eyespots</u>

There are two types of phototactic movement in the Chlorophyta: movement by flagella and movement by the secretion of mucilage.

Most of the flagellated cells that show phototactic movement have an eyespot. The phototactic response varies with light intensity; Strasburger in 1878 (Bendix, 1960) observed that organisms with positive phototaxis at moderate light intensities exhibited negative phototaxis at very high light intensities. He also noted that at a given light intensity, temperature has an effect on phototaxis. *Haematococcus* zoospores at a given light intensity will be negatively phototactic at 4 °C, positively phototactic at 16–18 °C, and very strongly phototactic at 35 °C. Similar results were obtained with *Ulothrix* and *Ulva*.

A second type of phototactic movement in the Chlorophyta uses secretion of mucilage. In 1848, Ralfs, in his monograph on desmids, described their movement to the surface of mud brought into the laboratory, and presumed this movement to be due to the stimulus of light. The movement in desmids is brought about by the extrusion of slime through cell wall pores in the apical part of the cell.

<u>Classification of Cholophycophyta:</u>

The classification of green algae, as in the case with most other algal divisions, differs with the classifier. The following orders of single class Chlorophyceae are recognized by Bold and Wynne in 1978.

Order 1: Chlorellales order 2: Volvocales order 3: Tetrasporales

Order 4: Ulotrichales order 5: Oedogoniales order 6: Cladophorales

Order 7: Zygnematales order 8: Chaetophorales order 9: Ulvales

Order 10: Siphonocladales order 11: Chlorosarcinales

order 12: Dasycladales order 13: Caulerpales

order 14: Acrosiphonales order 15: Chlorococcales

Chlorellales:

In this order, the algae that have a non-motile vegetative thallus where the thallus comprises only a single cell or a coenobium composed of a definite number of cells arranged in a specific manner. Asexual reproduction occurs by zoospores or aplanospores that are commonly autospores. Sexual reproduction can be isogamous, anisogamous, or oogamous. The order is exclusively fresh-water.

Hydrodictyon reticulatum (Fig. 5.82), or the water net, is a free-floating, relatively rare freshwater alga that forms colonies that are net-like with polygonal or hexagonal meshes. The net is formed by multinucleate elongated cells joined end to end, probably by lectins such as concanavalin A. Each cell has a large central vacuole and a reticulate chloroplast with pyrenoids. In asexual reproduction a daughter net is produced inside, and subsequently released. Asexual reproduction begins with the disappearance of pyrenoids, coinciding with the accumulation of starch grains in the fragmenting chloroplasts. Regularly spaced nuclei are surrounded by fragments of chloroplasts. A vesicle forms around and outside of the tonoplast, restricting most of the protoplasm to a small area around the periphery of the cell. The protoplasm divides to produce uninucleate, biflagellate zoospores that actively swim about inside the parent cell. The zoospores stop swimming, become joined in certain areas, and retract their flagella. A daughter net has now been formed within the parent cell, which is released to enlarge to a mature colony.

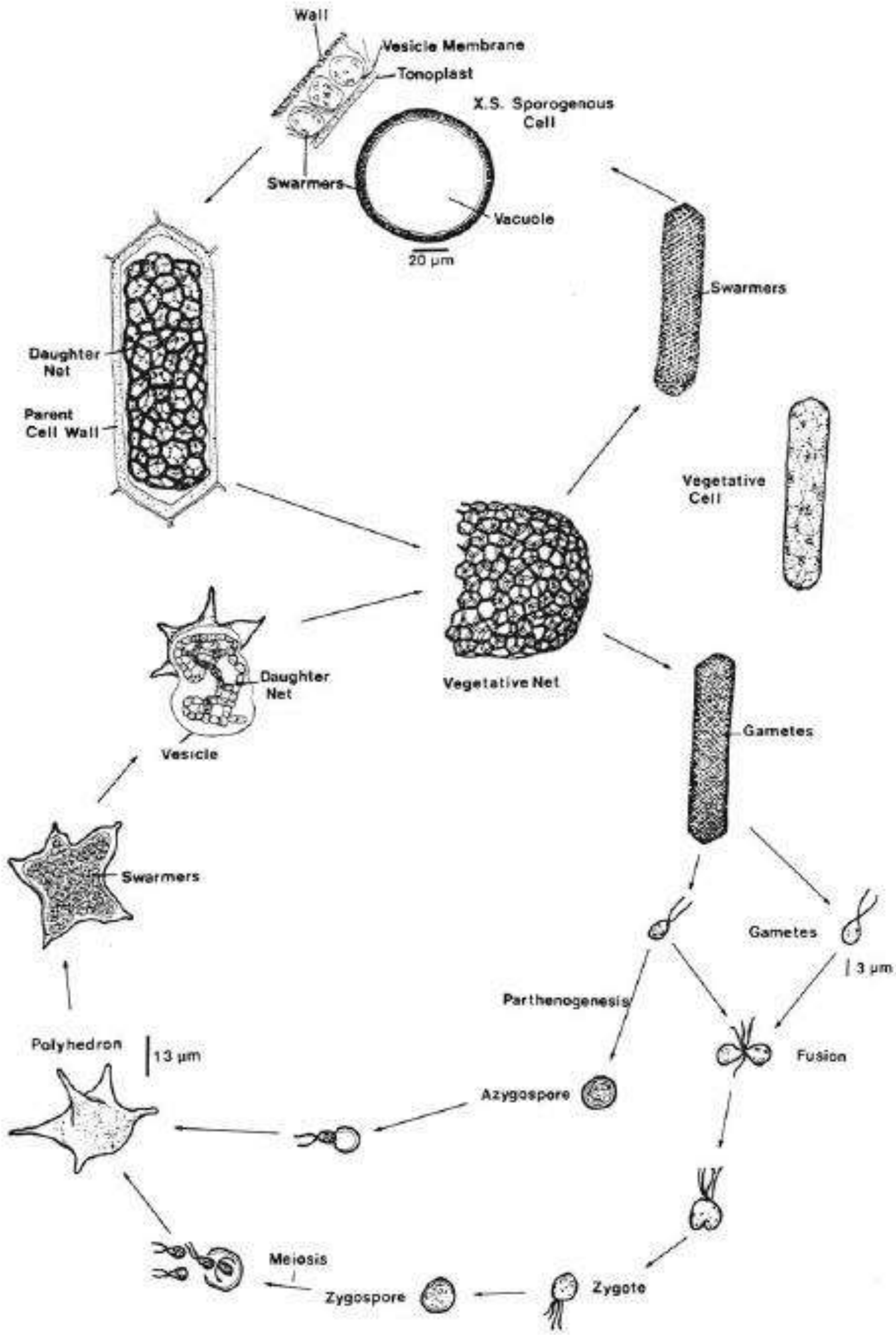


Fig. 5.82 The life cycle of *Hydrodictyon reticulatum*. (Adapted from Pocock, 1960; Marchant and Pickett-Heaps, 1971, 1972a–d.)

The sexual reproduction is isogamous. It occurs by the formation of motile gametes resulting from the fission of cell contents and nucleus. The fusion of isogametes gives zygote which undergoes meiosis to form zygospores. These zygospores start to form colony resemble to parent but smaller than it.

Chlorella cells are spherical with a cup-shaped chloroplast (Fig. 5.83). The only method of reproduction is by daughter cells-autospores- that resemble the parent cell.

Scenedesmus is a common alga (Fig. 5.83), often occurring as almost a pure culture in plankton. Cells in the colony occur in multiples of two, with four or eight cells being most common.

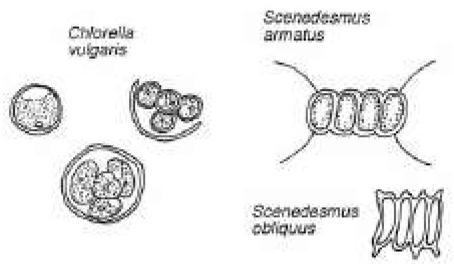
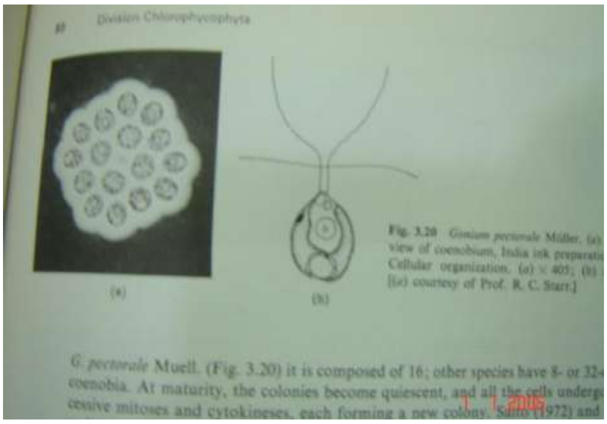


Fig. 5.83 Drawing of *Chlorella vulgaris* (with autospores), *Scenedesmus armatus*, and *S. obliquus*.

Volvocales:

In the Volvocales the vegetative cells are flagellated and motile. The algae can be unicellular such as *Chlamydomonas* or multicellular – coenobia- *colonies with a definite number of cells arranged in a specific Manner*- such as *Gonium, Pandorina, Eudorina* and *Volvox*. The cell of each genus is uninucleate with two equal whiplash flagella. Almost all of these organisms are fresh water, being abundant in waters high in nitrogenous compounds. Asexual reproduction begins by the ***Chlamydomonas*** cell coming to rest and usually retracting or discarding the flagella. The protoplast then divides into 2, 4, 8, or 16 daughter protoplasts within the parent wall (Fig. 5.55). These protoplasts develop walls and flagella, and are released on gelatinization of the parent wall, if growing in liquid medium.

The genus *Gonium* apparently the simplest members of the volvocaceae. The coenobium consists of 16; others have 8or 32- *Chlamydomonas*-like cells. Asexual reproduction occurs by zoospores and sexually by motile isogametes Fig 3.20.



Pandorina: The main characteristics of this genus are:

1- It is spherical-shaped colony.
2- Cells of the coenobium uniform in size.
3- Cells are pyriform, few, and large. The flagellum is almost equal to cell in length.
4- Reproduce asexually by zoospores and sexually by motile isogametes.

Eudorina: The main characteristics of this genus are:

1- It is spherical-shaped colony.
2- Cells of the coenobium are uniform in size.
3- Cells are spherical, arranged in alternating tiers. The number of cells is more than in *Pandorina* but small in size. The length of flagellum is four time than cell length.

4- Reproduce asexuallt by zoospores and sexually by motile anisogametes.

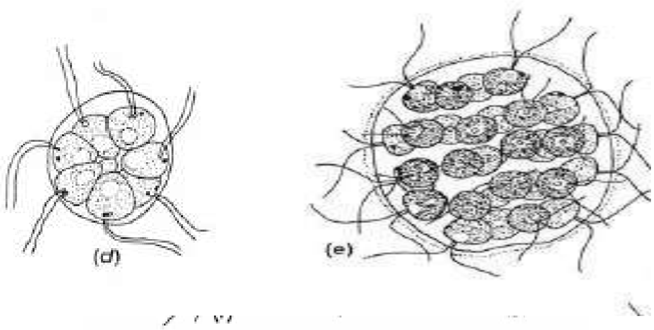


Fig. 5.65 Colonial Volvocales. (*a*) *Stephanoon askenasyi*. (*b*) Front and side views of *Platydorina caudata*. (*c*) Side and front views of *Gonium* sp. (*d*) *Pandorina morum*. (e) *Eudorina unicocca*. (*f*) *Volvulina steinii*. (*g*) *Pleodorina* sp. ((*a*),(*d*) after Huber-Pestalozzi, 1961.)

<u>Lectures 7 & 8:</u>

***Volvox* :-**

Colonies of *Volvox carteri* are oval to spherical with 2000 to 6000 cells arranged in a single layer (Figs. 5.68, 5.69). Each colony contains a large number of somatic cells and a smaller number of reproductive cells. The protoplast of each somatic cell is typically chlamydomonad and has a single cup-shaped chloroplast with a basal pyrenoid, an anterior eyespot, a central nucleus, two contractile vacuoles, and two flagella. Daughter colonies are enclosed in vesicles that expand into the anterior of the colony.

Vegetative, female, and male colonies of *V. carteri* have similar somatic structure, but each contains a different type of reproductive cell.

Vegetative colonies contain cells (gonidia) that give rise to daughter colonies by repeated division; female colonies have eggs, which form zygotes after fertilization; and male colonies contain male initial cells, which divide to form sperm bundles.

Female and male colonies develop from gonidia as well as the vegetative colonies.

Asexual reproduction occurs in *Volvox* as follows. Each young asexual and adult colony of *Volvox carteri* consists of about 2000 small biflagellate somatic cells embedded in the surface and 16 large **gonidia** which are positioned slightly below the surface of a transparent sphere of extracellular matrix. The biflagellate somatic cells are specialized for motility and phototaxis, are incapable of dividing, and are programmed to die at the end of two asexual reproductive cycles. In contrast, the gonidia are non-motile, specialized for growth and reproduction, and potentially immortal.

Asexual reproduction in *Volvox carteri* resembles that of classical metazoan models, such as snails, sea urchins, and nematodes. As such, it has been used as a model for embryogenesis research.

Asexual reproduction is completed in 48 hours (Fig. 5.70) and begins with a series of 11–12 rapid cleavage divisions of the gonidium to produce an embryo, with each cell division preceded by a round of DNA replication. The first five divisions are symmetrical, resulting in an embryo with 32 cells of equal size and shape. At the sixth division, 16 cells in the anterior hemisphere divide asymmetrically, producing large-small sister pairs. Each large cell is a gonidial initial destined to produce a gonidium, whereas the smaller sister cells and each of the symmetrically dividing cells of the posterior hemisphere are somatic initials that will differentiate to mature somatic (vegetative) cells. The gonidal initials divide asymmetrically two or three more times, generating an additional somatic cell at each division. Then the gonidial initials withdraw from the division cycle, whereas the somatic initials continue cleaving until they have completed 11 or 12 division cycles altogether. As a consequence of asymmetric divisions, and a different number of divisions completed, gonidial initials are around 30 times the volume of somatic initials at this point. It is the difference in the size of the cells at the end of cleavage, and not a difference in the quality of the cytoplasm, that determines whether the cells will follow the gonidial or somatic pathway of development.

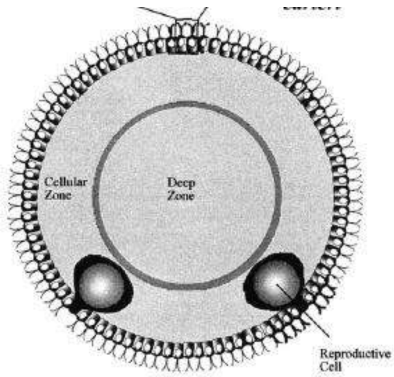


Fig.5.68

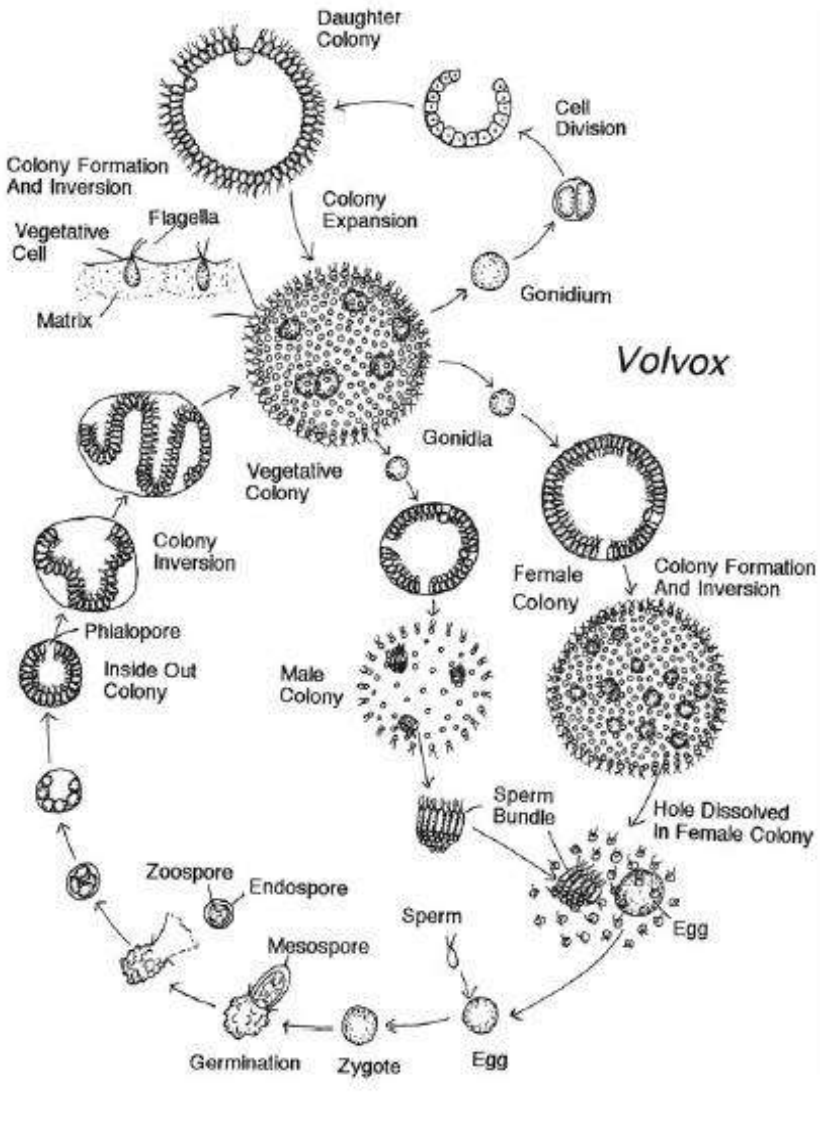


Fig. 5.69 The life history of *Volvox carteri*. (Adapted from Smith, 1944; Kochert, 1968.)

Tetrasporales:

These algae have immobile vegetative cells that are capable of cell division, unlike those in the Chlorellales or Volvocales. The colonies are non-filamentous, and flagellated cells are formed by many genera. Asexual reproduction occurs *via* the formation of zoospores, aplanospores, or akinetes.

Sexual reproduction is isogamous, by fusion of biflagellate gametes. Almost all the organisms are freshwater. Conventional wisdom has stated that the Tetrasporales evolved from the Volvocales by loss of motility in the vegetative condition. However, data from small subunit ribosomal DNA indicate the line leading to the Tetrasporales is more primitive than the line leading to the Volvocales. Two families will be considered here:

Family 1 Tetrasporaceae: cells with pseudocilia.

Family 2 Palmellaceae: cells without pseudocilia.

Tetrasporaceae

The elongated gelatinous thalli of the Tetrasporaceae have vegetative cells in groups of two to four, with each cell having two pseudocilia. **Pseudocilia** are longer than flagella but are evidently related to them because the pseudocilia have a normal basal body but an abnormal 9+ 0 configuration of microtubules near the base of the pseudocilia. The number of microtubules lessens and becomes more irregular as the end of the pseudocilium is approached. Colonies of *Tetraspora gelatinosa* (Fig. 5.76) are green, amorphous masses with an outer layer of vegetative cells. They are found in quiet freshwater and can be attached or free-floating. Each cell has a large cup-shaped chloroplast with a central pyrenoid and two pseudocilia. Growth of the thallus results from vegetative division of the cells. In the formation of isogametes, a vegetative cell divides two to three times, resulting in four or eight pyriform gametes, each with an eyespot and a cup-shaped chloroplast. The biflagellate gametes break free from the colonial mucilage and fuse with each other at their anterior ends. The quadriflagellate zygote swims for a while before settling, retracting its flagella, and forming a cell wall. The zygote germinates, forming four or eight aplanospores without pseudocilia. These aplanospores enlarge, and when they have reached the size of vegetative cells, they divide to form daughter cells that have pseudocilia. The aplanospores and their daughter cells are held together by mucilage, and the aggregation makes up the typical thallus of *Tetraspora*.

Palmellaceae

Members of the Palmellaceae have their cells united in small gelatinous colonies that are generally amorphous but may be of definite shape. *Palmella* (Fig. 5.63) is a freshwater alga composed of cells united by a gelatinous matrix forming colonies of indefinite shape.

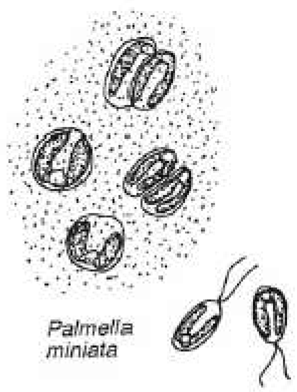


Fig. 5.63 Drawings of motile cells of *Hematococcus* sp. and *Dunaliella salina*, and palmelloid and motile cells of *Palmella miniata*.

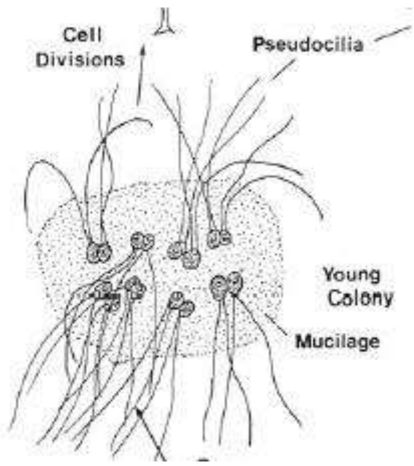


Fig.5.76 *Tetraspora gelatinosa*

<u>Ulotrichales:</u>

Uninucleate filamentous green algae with a parietal chloroplast constitute this order.

Ulothrix (Fig. 5.31) is found in quiet or running freshwater and occasionally on wet rocks or soil. The thallus consists of unbranched filaments of indefinite length that are fixed to the substratum by a special basal cell. All of the cells except the basal one are capable of cell division and forming zoospores or gametes. Species with narrow cells form 1, 2, or 4 quadriflagellate zoospores per cell, whereas those with broad cells form 2, 4, 8, 16, or 32 zoospores per cell. The zoospores have a conspicuous eyespot and are liberated through a pore in the side of the parent wall. Zoospores from species with narrow filaments are the same size, whereas those from broad-celled species form macro- and microzoospores that differ from each other in size, position of the eyespot, and length of the swarming period. Zoospores that are not discharged from the parent may secrete a wall and become thin-walled aplanospores. These later germinate to form a new filament.

Gametes of *Ulothrix* are formed in the same way as zoospores but are biflagellate. The gametes are of the same size, with fusion occurring only between gametes from different filaments; and there is never any parthenogenetic development of unfused gametes. The zygote remains for a while, settles, secretes a thick wall, and undergoes a resting period during which it accumulates a large amount of storage material. The first division of the zygote is meiotic, with the zygote forming 4 to 16 zoospores or aplanospores. **(In many northern lakes in the United States and Canada, *Ulothrix zonata* grows abundantly in early spring in shallow waters along rocky shorelines. *Ulothrix zonata* is dominant until the water temperature reaches 10 °C, when it disappears owing**

to massive conversion of the thallus to zoospores. At this time, *Cladophora glomerata* becomes the dominant attached alga.

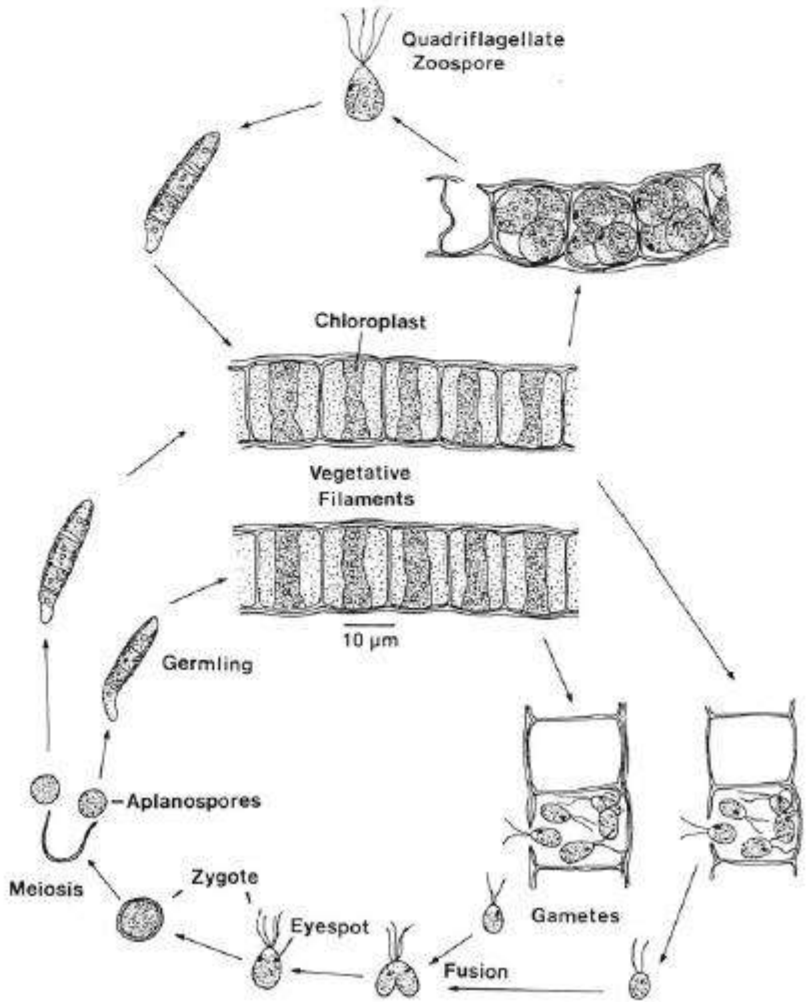


Fig. 5.31 The life cycle of *Ulothrix zonata*. (Adapted from Smith, 1955.)

Oedogoniales:

The filamentous, freshwater, uninucleate algae in this order are characterized by a unique type of cell division and the production of motile reproductive cells with a whorl of flagella at one pole (stephanokonts). Sexual reproduction is oogamous, and asexual reproduction can be by zoospores or akinetes. The Oedogoniales and its single family, the Oedogoniaceae, have only three genera – *Oedogonium*, *Oedocladium*, and *Bulbochaete*. *Oedogonium* is unbranched, whereas *Oedocladium* and *Bulbochaete* are branched.

***Bulbochaete* has long colorless hairs (Fig. 5.93(*a*)); *Oedocladium* lacks hairs (Fig. 5.93(*b*), (*c*)). These algae are usually present in permanent bodies of in moving water; they are seldom in the fruiting condition. Normally fruiting takes places in the summertime. The plants may be epiphytic on aquatic plants and other algae, or they may be free-floating. Chloroplasts in this order are reticulate, extending from one end of the cell to the other. The many pyrenoids are at the intersections of the reticulum. Plasmodesmata are present between cells, and the ones in *Bulbochaete* are similar to those of higher plants.**

Growth in *Oedogonium:*

Cell division involves the breaking of the parent wall and the formation of apical caps. In *Oedogonium*, cell division (Fig. 5.94) is initiated by the formation of a ring under the wall in the upper part of the cell. The ring enlarges by the coalescence of material produced in the cytoplasm. While the ring is being produced, the nucleus migrates to the center of the cell and divides mitotically. During late telophase, the new cross wall begins to form by means of a phycoplast. The daughter cells elongate, causing a split in the parent wall near the apical ring. This rent in the cell wall is covered by the material in the apical ring, which expands as the cells elongate. Each daughter cell eventually elongates to about the same length as the mother cell, elongation being completed within 15 minutes. The material of the ring becomes the cuticle, and a new cell wall is laid down under it. During the elongation of the daughter cells, the new transverse wall has moved up to the base of the newly formed secondary wall and fused with it.

Because cell division is intercalary in *Oedogonium*, division of every cell in the filament and repeated division of the daughter cells result in alternate cells with and without caps of old cell walls. This theoretical condition usually does not occur in nature. Repeated division of the distal daughter cell commonly results in filaments in which a cell with an apical cap is successively followed by several cells without caps.

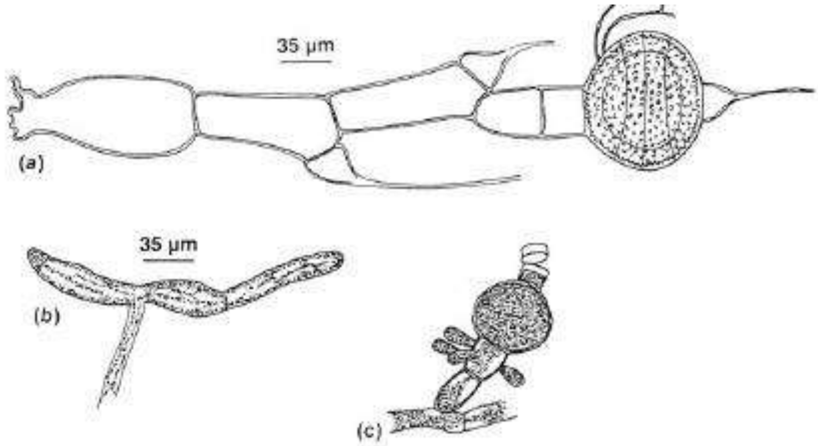


Fig. 5.93 (*a*) *Bulbochaete gigantea*, filament with zygote. (*b*),(*c*) *Oedocladium hazenii*, germling with rhizoid (*b*) and portion of a filament with empty androsporangia, immature dwarf males, and an unfertilized egg (*c*). (After Smith, 1950.)

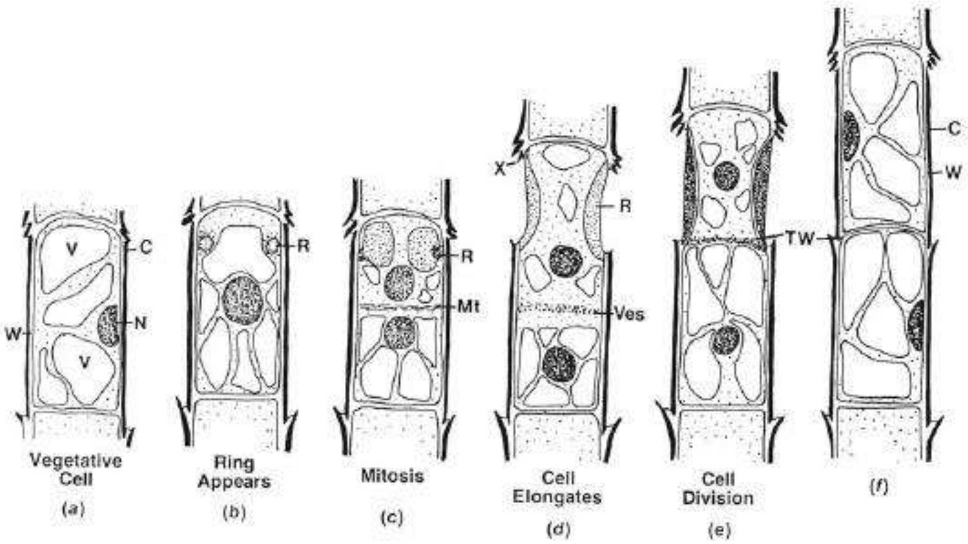


Fig. 5.94 Cell division in *Oedogonium*. (C) cuticle; (Mt) microtubules; (N) nucleus; (R) ring; (TW) transverse wall; (V) vacuole; (Ves) vesicles; (W) wall; (X) cap. (After Hill and Machlis, 1968.)

Asexual reproduction in *oedogonium*:

Asexual reproduction (Fig. 5.95) is by means of zoospores in all three genera. Zoospores are formed singly within a cell and usually only in those cells with apical caps. The earliest sign of zoosporogenesis is the appearance of a small electron- dense mass in an invagination of the nuclear envelope. From this the centrioles appear and multiply rapidly, forming two adjacent rows near the nucleus. The nucleus, with its two rows of centrioles, moves to the lateral wall. The two rows of centrioles move apart in the center to form a circle of centrioles under the plasmalemma. The centrioles extrude the flagella and the flagella roots. The Golgi secretes a fibrillar hyaline layer around the zoospore, which makes up the vesicle in which the zoospore is initially encased. The Golgi also secretes mucilage to the base of the zoospore, which probably aids in extrusion of the zoospore. The lateral wall of the parent cell splits at the apical cap, and the zoospore in a vesicle emerges through the aperture. The vesicle has two layers with a ring; it opens in the area of the ring, releasing the zoospore. The zoospore has about 30 flagella linked together by a striated root at the apical end; it swims for about an hour, settles, retracts its flagella, and develops a holdfast that attaches to the substrata. This then develops into a new filament. Aplanospores can also be formed, and resemble oogonia.

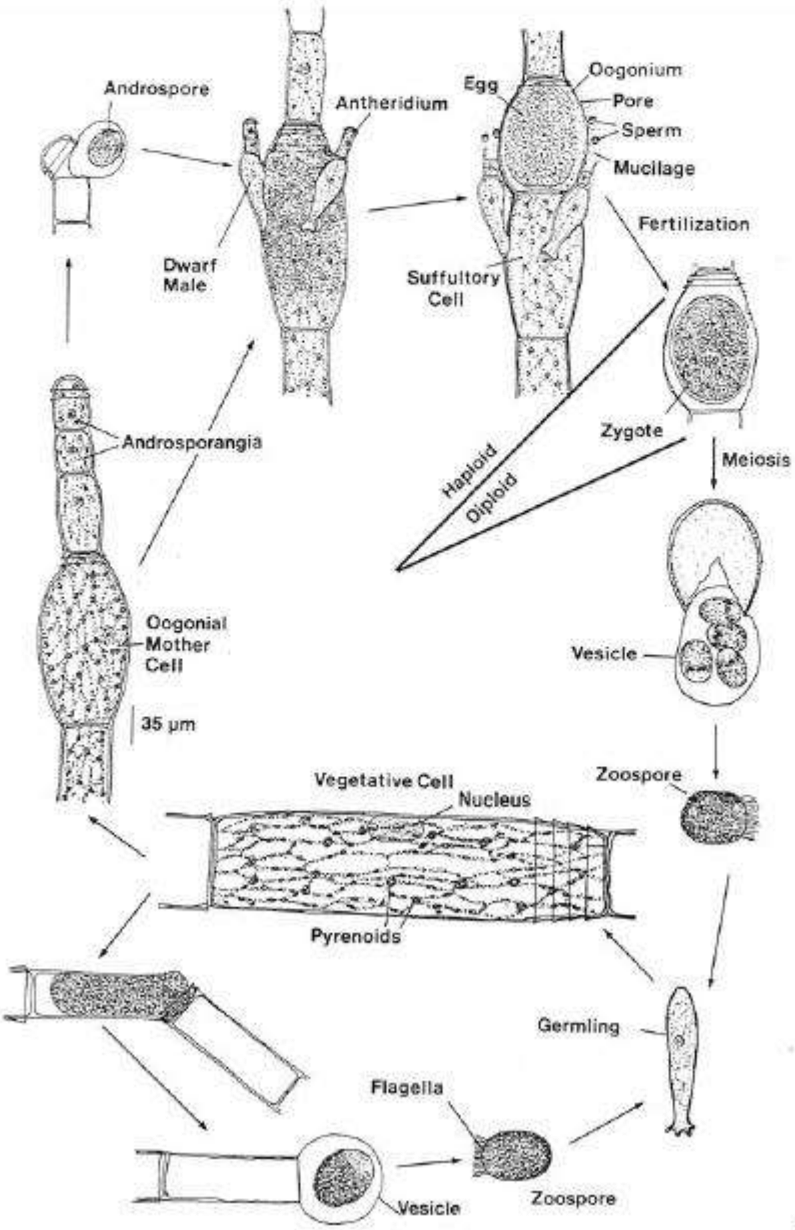


Fig. 5.95 The life cycle of a nannandrous species of *Oedogonium*. (Adapted from Smith, 1955.)

Sexual reproduction in *Oedogonium*:

Sexual reproduction is oogamous and, depending on the behavior of the male filaments, either macrandrous if the male filament forms the sperm directly, or nannandrous if the sperm are produced in a special dwarf male filament. In many species of *Oedogonium*, it is relatively easy to induce sexual reproduction by placing old filaments in fresh media and saturating the atmosphere with carbon dioxide. Nitrogen limitation has also been reported to induce the formation of oogonia.

Oogonia have a similar developmental pattern in macrandrous (Fig. 5.96) and nannandrous species (Fig. 5.95). The intercalary or terminal oogonial mother cells divide transversely, with one cell becoming the oogonium and the other either a suffultory (supporting) cell or a second oogonial mother cell. If one cell becomes another oogonial mother cell, then the oogonia are produced in series. The oogonia initially are wider than the vegetative cells and have a number of apical caps at their upper end from previous cell divisions. As the oogonium matures, it swells and becomes globose, forming a small pore or crack in the oogonial wall. The protoplast develops into an egg. Just prior to fertilization the central nucleus moves to just under the fertilization pore and gelatinous material is extruded through the pore.

Macrandrous species form terminal or intercalary antheridia by an unequal division of an antheridial mother cell (Fig. 5.96). In this division, the upper cell is much shorter than the lower. The lower cell then divides repeatedly to produce a series of 2 to 40 antheridia. Each antheridium forms two sperm, which are liberated in a vesicle by transverse splitting of the wall. The sperm then escape from the vesicle. The sperm are similar in structure to the zoospores but smaller and more elongated with a crown of about 30 flagella , and are yellowishgreen because of their reduced plastids. In a macrandrous species such as *Oedogonium* *cardiacum*, the sperm are attracted to the oogonium by a chemotactic substance secreted by the oogonium.

In nannandrous species, male filaments form **androsporangia** in a manner similar to the formation of antheridia by macrandrous species, except only one **androspore** is produced per sporangium. The androspore can develop in one of three ways depending on the environment.

1- In an environment with low nitrate or ammonium concentration, the androspore produces a cyst that will eventually produce another androspore. The cycle will continue until the nitrate or ammonium concentration in the environment increases.

2- If there is a large amount of nitrate or ammonium in the water, the androspore will produce a vegetative male thallus that is indistinguishable from the parent. This is similar to the situation in nature when a rainstorm washes nutrients into a nutrient depleted environment.

3- If the environment contains the female pheromone "circein," the androspore is attracted to the female oogonium that is secreting the pheromone. The androspore attaches to the oogonial mother cell and causes the oogonial mother cell to divide into the oogonium and a lower **suffultory cell** to which the androspore is now attached. The production of the substance that attracted the androspore now ceases. ***(If the attachment of the androspores to the oogonial mother cell is prevented by coating the oogonial mother cell with agar, then the oogonial mother cell continues to attract androspores, but the divison of the oogonial mother cell does not occur. Female differentiation beyond the oogonial mother cell stage must be triggered by direct contact of the attached androspore. The main advantage of a nannandrous system is that differentiation of the male is a prerequisite for differentiation of the female, thus ensuring the presence of a male for the receptive female.***)

The attached androspore on the suffultory cell next elongates and develops into a two-celled dwarf male filament. The growth of the dwarf male is toward the oogonium under the influence of a chemotactic substance secreted by the oogonium. The apical cell of the male filament is an antheridium, which forms two sperm. The oogonium secretes a thick gelatinous sheath that includes the tip of the dwarf male. The sperm are released and trapped in this gel. After about 1 hour of random movement in the gel, the sperm aggregate at a certain spot on the upper third of the oogonium. The sperm extend their anterior end so that this end is flexible. A protoplasmic papilla suddenly appears through the wall of the oogonium, and all the spermatozoids in the vicinity attach to this papilla by their anterior ends. Within a second the papilla is withdrawn through the pore in the wall, taking with it a single sperm. The remaining sperm hover about the pore for about 5 minutes before they disperse in the gel. Four hormone-controlled steps are thus involved in fertilization: (1) the chemotaxis of the androspores; (2) the directed growth of the dwarf males; (3) the triggering of the division of the oogonial mother cell; and (4) the chemotaxis of the sperm to the prospective opening of the oogonium.

Nannandrous species are thought to have evolved from macrandrous ones by parthenogenetic germination of sperm to form dwarf male filaments. The zygote is separated from the oogonial wall by a space, and after fertilization a wall is soon formed around the zygote. As the zygote matures, there is an accumulation of reddish oil in the protoplasm. Eventually the zygote is liberated by decay of the oogonial wall. It undergoes a rest period during which its nucleus divides by meiosis to form four haploid nuclei. Shortly before germination, the protoplast becomes green and forms four daughter protoplasts, each of which becomes a zoospore. The zoospores are released and develop into filaments in the same manner as in asexual reproduction. The life cycle is thus mostly haploid, the zygote being the only diploid structure.

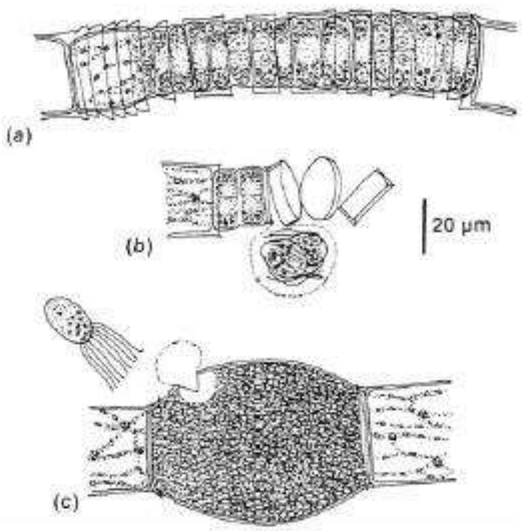


Fig. 5.96 Gametogenesis in the macrandrous *Oedogonium crassum*. (*a*) Antheridia. (*b*) Liberation of sperm. (*c*) Oogonium with a single egg attracting a spermatozoid. (After Smith, 1955.)

Cladophorales:

The filamentous genera in this order have multinucleate cells, usually with a parietal or reticulate chloroplast. The filaments may be branched or unbranched. The reticulate chloroplast has pyrenoids at the intersections of the reticulum.

Cladophora (Fig. 5.35(*b*)) and *Chaetomorpha* (Figs.5.35(*a*), each with an isomorphic alternation of generations, are common members of this order. *Cladophora*, found in freshwater and marine habitats, may be the most ubiquitous macro alga in fresh waters worldwide. This filamentous alga can reach nuisance levels as a result of cultural eutrophication. *Cladophora* is predominantly benthic, and is often found in the region of unidirectional flow or in periodic wave action. In freshwater, it is a mid- to late-succession species. *Cladophora* is colonized by a wide variety of epiphytes because it offers a substrate that is anchored against flow disturbance.

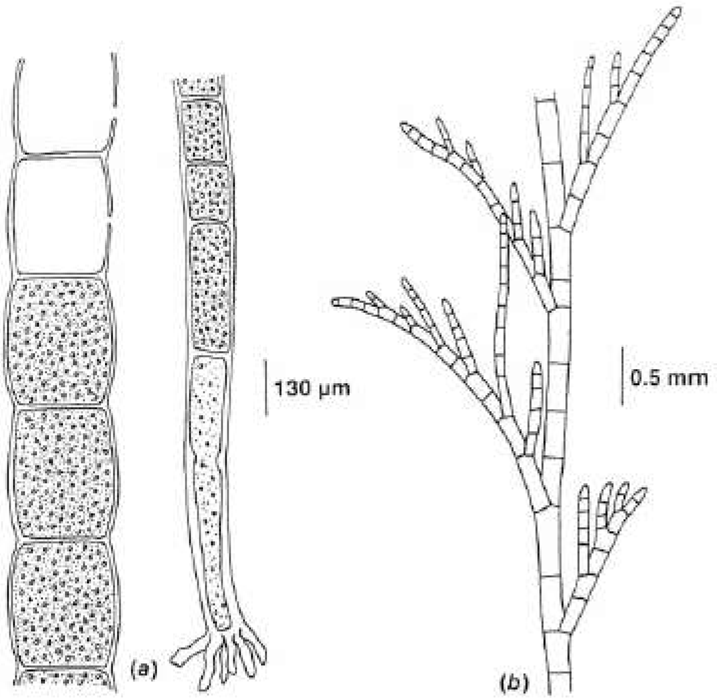


Fig. 5.35 (*a*) *Chaetomorpha aerea.* (*b*) *Cladophora microcladioides.* (After Smith, 1969.)

Zygnematales:

The Zygnematales are a closely related group of freshwater algae that are unique among the Chlorophyta in having sexual reproduction by isogamous conjugation in which the gametes are non-flagellated. The union of the two gametes can be through a conjugation tube formed by the parent cells, or the gametes can move from their parent cells into the medium and fuse. The zygote or zygospore forms a cell wall and goes through a resting period before germinating meiotically. The life cycle is therefore primarily haploid, with the zygote representing the diploid generation. Zygnematalean algae, particularly *Mougeotia* (Fig. 5.17(*e*)), dominate freshwaters affected by acid precipitation. There are basically three types of chloroplasts in the order: (1) spirally twisted bands extending the length of the cell as in *Spirogyra* (Fig. 5.18) and *Spirotaenia* (Fig. 5.17(*b*)); (2) an axial plate extending the length of the cell as in *Mougeotia* (Fig.5.17(*e*)) and *Mesotaenium* (Fig. 5.17(*a*)); and (3) two stellate chloroplasts next to each other as in *Cylindrocystis* (Fig. 5.17(c)). ***In those cells with flat axial chloroplasts, there is a marked chloroplast orientation in response to light intensity. In Mesotaenium and Mougeotia (Fig. 5.17), the chloroplast presents a surface view to the light under low intensities. When irradiated with high-intensity light, or red light at low intensity, the chloroplast rotates to present an edge view. Actin microfilaments attached to the chloroplasts are directly responsible for movement of the chloroplast with a phytochrome system directing actin functioning***. Within the Zygnematales there are three families (some phycologists group the last two families into one family).

Family 1 Zygnemataceae: cylindrical cells united permanently into unbranched filaments; cell wall without pores.

Family 2 Mesotaeniaceae: : basically non-filamentous; cell walls without pores; new no semicell formed in cell division.

Family 3 Desmidaceae: basically non-filamentous; cell walls with pores; new semicell formed in cell division.

Zygnemataceae:

The cells of the Zygnemataceae are permanently united into unbranched filaments, and the cell walls lack pores. Union of the two aplanogametes is usually by the establishment of a conjugation tube between two cells. Members of the Zygnemataceae are among the most common filamentous freshwater algae, favoring small stagnant bodies of water, but with a few found attached in the littoral zone of lakes (*Spirogyra adnata*) and in flowing water. ***They are especially abundant in the spring months, generally occurring as bright green free-floating masses, with some type of attaching organ present in young stages of several genera. Planktonic species of Spirogyra or Mougeotia often have twisted or spirally coiled threads. Zygogonium (Fig. 5.17(d)), which lives next to thermal springs with acidic waters, is responsible for the dense purple mats that occur in the hot springs of the Yellowstone National Park, where it lives at temperatures of 21 to 30 °C and a pH of 2.4 to 3.1; the optimum temperature for photosynthesis is 25 °C, and the pH ptimum is 1to 5.***

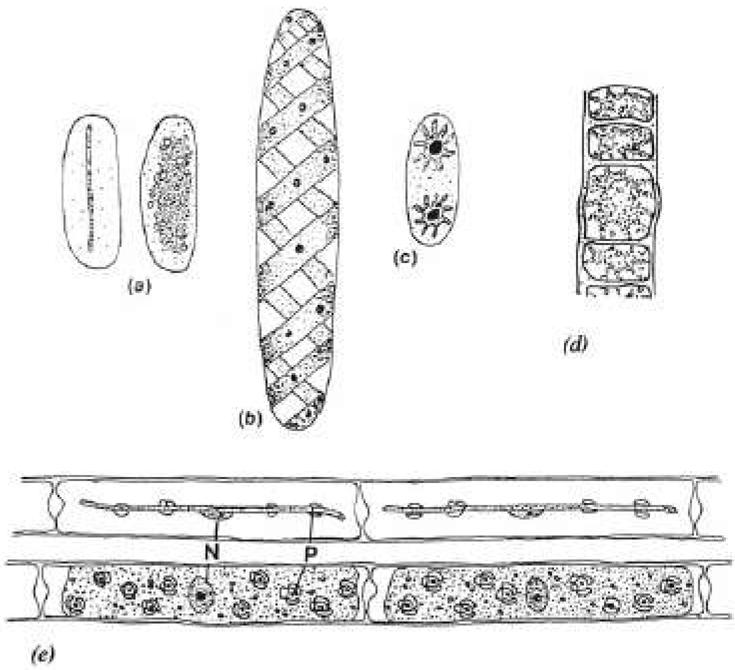


Fig. 5.17 (*a*) *Mesotaenium de greyi*, high- and low-intensity orientations of the chloroplast. (*b*) *Spirotaenia condensata*. (*c*) *Cylindrocystis brebissonii*. (*d*) *Zygogonium* sp. (*e*) *Mougeotia scalaris*, above-profile and below-surface views of the chloroplast. (N) Nucleus; (P) pyrenoid.

Spirogyra occurs primarily in the springtime because it tolerates high light intensities in cool water. *Spirogyra* has ribbon shaped chloroplasts with a number of pyrenoids along the length of the chloroplast (Fig. 5.18). A nucleus is suspended in the center of the cell. Every cell in the filament except the basal one is capable of cell division. Asexual reproduction occurs by fragmentation of the filaments, whereas sexual reproduction is by conjugation, which is initiated by two filaments coming to lie next to one another, and being bound together in a layer of mucilage. The cells of one filament put out papillae toward the cells of the opposite filament. Subsequently, papillae arise from opposite and corresponding points on the other filament so that the two papillae are in contact from the beginning of their formation. The two threads are then pushed apart as the papillae elongate. A hole is dissolved at the tips of the papillae so that the conjugation tube is continuous from one cell to the next. The male gamete (the protoplast that moves through the conjugation tube) contracts by the bursting of small contractile vacuoles within the cell membrane, which is followed by a similar contraction of the female gamete as the male gamete moves through the conjugation tube. The male protoplast fuses with the female inside the parent wall of the female. The zygote (zygospore) secretes a three-layered wall around it self. The three layers of the wall from the outside to the inside are the **exospore**, **mesospore**, and **endospore**. The **exospore** is sometimes sculptured (Fig. 5.19) and contains cellulose and/or pectin. The **mesospore** is sometimes colored and contains sporopollenin. The **endospore** is thin and colorless, and contains cellulose and pectin. Ripening of the zygote is accompanied by the disappearance of chlorophyll and the conversion of the starch into yellowish oil. During the resting period of the zygote (in nature until the following spring), the nucleus divides meiotically to form four haploid nuclei, three of which disintegrate. The zygote germinates by sending out a tubular growth that ruptures the outer two wall layers while the inner wall extends to accommodate the growth. The outgrowth then undergoes transverse divisions to form the first cells of the filament. The life cycle is thus primarily haploid, with the zygote being the only diploid cell.

Conjugation is referred to as “physiologically anisogamous” because of the different behavior of morphologically similar gametes. The above type of conjugation, which is called **scalariform** conjugation, occurs between two separate filaments. Another type of conjugation is **lateral** conjugation, which occurs between cells of the same filament. Here a conjugation tube is formed between adjacent cells, or in some cases the cross wall between adjacent cells simply dissolves. The members of this family would seem to be excellent tools for the study of fertilization, but this is not so because of the difficulty of inducing sexual reproduction at will. *Spirogyra* mats show an unusual phototactic movement toward blue light (optimal at 470 nm), but not red light. Directing blue light from an angle toward scattered *Spirogyra* filaments cause the filaments to align toward the light within one hour***.((The filaments bind with other filaments to form thicker parallel bundles that curve and form an open-loop shape. The bundles of filaments join and form a larger mat when they meet. The coordination of filaments is essential for the phototactic movement. The filaments always form a bundle before they start moving toward light. A single filament repeatedly curls, straightens, and bends, but there is no phototactic movement. Filaments will only glide on other filaments. The exact mechanism involved is not known, but it may be that filaments oriented toward blue light prolong movement and shorten their movement when they are not oriented toward the light.))***

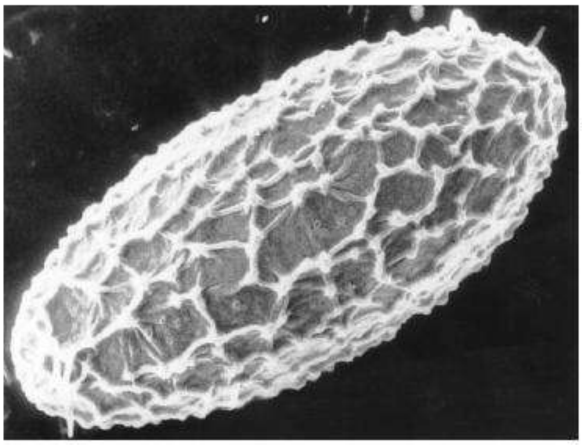
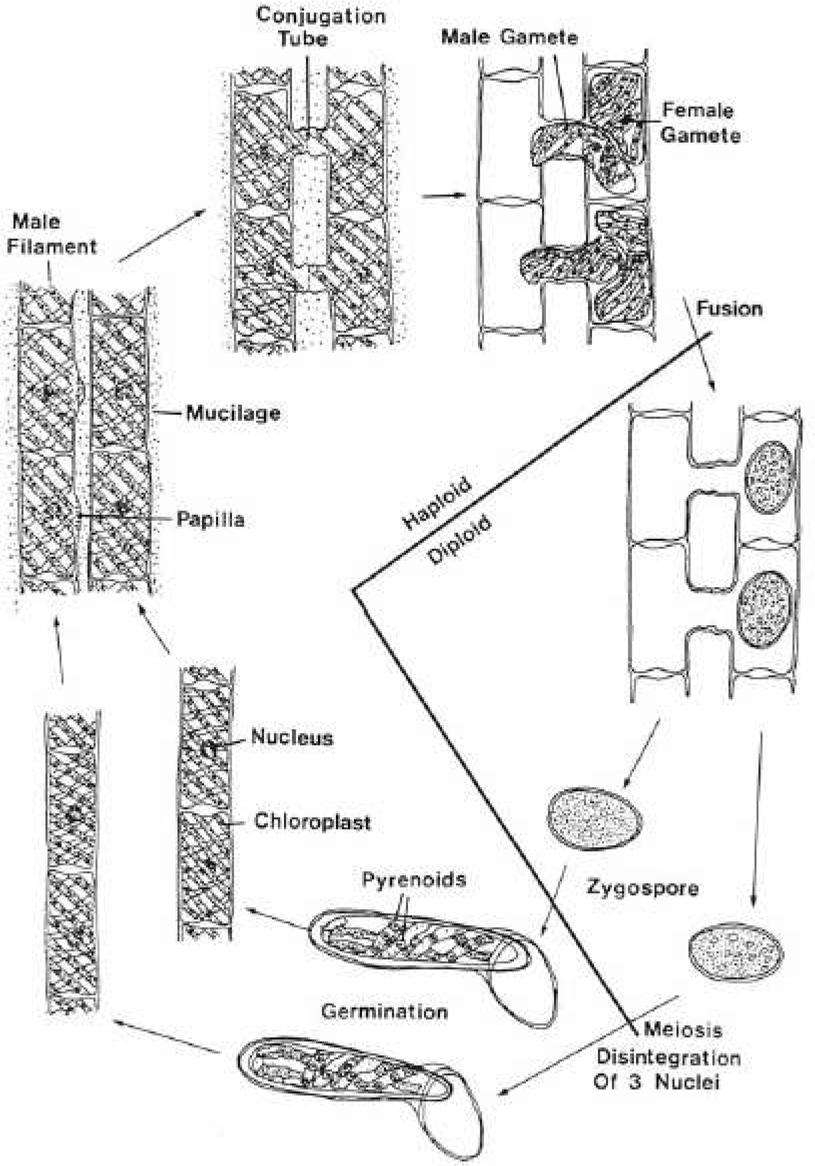


Fig. 5.19 Scanning electron micrograph of a zygote of *Spirogyra acanthopora* showing the sculpturing of the wall. (From Simons et al., 1982.)



Siphonocladales:

These organisms have multicellular thalli, are wholly marine, and are usually tropical. The cells are multinucleate, with reticulate chloroplasts, and divide in a distinct manner known as **segregative cell division**. Most of the organisms have siphonoxanthin (Fig. 5.1) (except *Dictyos - phaeria*) in addition to the normal pigments of the Chlorophyta. Sexual reproduction appears to be isogamous in most cases.

Siphonocladus tropicus initially has an undivided single-celled primary vesicle (Fig. 5.52). In segregative cell division, the continuous protoplast of the primary vesicle breaks into spherical masses of varying size that soon become surrounded by a wall and enlarge to fill the area within the expanding parent vesicle. After each segment has become firmly pressed against adjacent ones, it sends out a lateral protuberance, which constitutes a branch initial. The mature thallus consists of an erect axis with lateral branches.

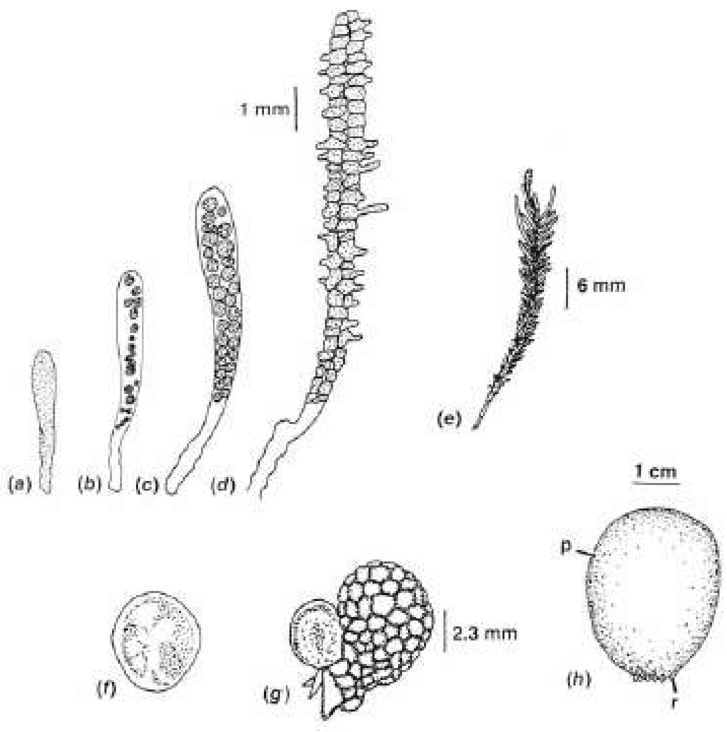


Fig. 5.52 Segregative cell division in *Siphonocladus tropicus*: (*a*) germling; (*b*) cytoplasm in spherical masses; (c) expansion of cytoplasmic masses; (*d*) lateral branches forming; (e) mature thallus. *Dictyosphaeria cavernosa*: (*f*) young aseptate vesicle; (*g*) secondary vesicle attached to primary vesicle. (*h*) *Ventricaria ventricosa* (*Valonia ventricosa*). (p) Primary vesicle cell; (r) rhizoidal cell. ((*f*),(*g*) after Egerod, 1952; (*h*) after Taylor, 1960.)

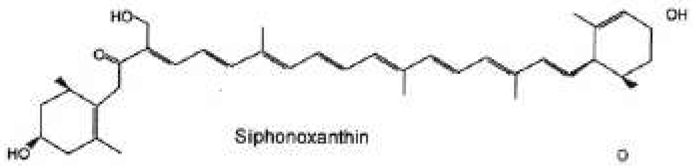


Fig. 5.1 The chemical structures of carotenoids of the Chlorophyta.

Lecture 9:

Charophycophyta:

This is the line of algal evolution that led to the development of land plants. The motile cells of the advanced members of the division are similar to the flagellated male gametes of the bryophytes and vascular cryptogams.

((The motile cells of the Charophycophyta are asymmetrical and have two laterally or subapically inserted flagella. The microtubular root system contains a multilayered structure that is associated with a broad microtubular root and a second, smaller, microtubular root. No eyespots occur. Sexual reproduction results in the formation of a dormant zygote. Meiosis occurs when the zygote germinates. Glycolate is broken down by glycolate oxidase, whereas urea is broken down by urease.)) The algae in the division are predominantly freshwater algae.

Charales:

The green algae in the Charales have a complex plant body with apical growth and differentiation of the body into **nodes** and **internodes**. Reproduction is oogamous, with sterile cells surrounding the antheridia and oogonia. **The male gametes have a cell covering of scales**. No zoospores are formed. ***((A phragmoplast develops during cell division, resulting in the formation of a cross wall with plasmodesmata. Land***

plants (embryophytes)probably evolved from algae similar to those in the Charales. As such, the Charales are sometimes separated from the rest of the green algae and grouped with embryophytes as streptophytes.))

The algae in the Charales are primarily fresh water, with only a few species occurring in brackish water. They are most common at the bottom of clear lakes, usually forming extensive growths. Many of the Charales are heavily calcified, with concentrations of plants on the bottom of lakes leading to the formation of **marl** ($CaCO_3$ and $MgCO_3$ deposits) and hence the common name of the Charales, **stoneworts**. Calcification in *Chara* and *Nitella* results from the precipitation of calcium carbonate ($CaCO_3$) in water high in Ca^{+2}.

((The localized OH^- efflux at certain areas of the internodal cell raises the local CO_3^{-2} ion concentration, leading to $CaCO_3$ supersaturation and precipitation. In Chara corallina, rectangular crystals of calcite are deposited in bands on the surface of the cell wall of the cylindrical internodal cell. These bands correspond to localized alkaline (pH 9.5 to 10.5) regions on the cells. There is no organic material associated with the crystals, and they are formed entirely outside the cell wall.))

The algae in the Charales have an axis divided into nodes and internodes (Fig. 5.26). Each **node** bears a whorl of branches composed of a number of cells that cease to grow after they have reached a certain length. The **internode** consists of a single long cell in *Nitella*. In some genera, such as *Chara*, the internodal cell is ensheathed (corticated) by a layer of vertically elongated cells of a much smaller diameter originating at the nodes (Fig. 5.26).

The Growth:

Growth occurs by a dome-shaped apical cell, each derivative of the apical cell dividing transversely into two daughter cells. The upper daughter cell is the nodal initial, and the lower is the internodal initial. The **nodal initial** matures into the cells of the node, and the **internodal initial** matures into the single long cell of the internod. The axis is attached to the substratum by uniseriately branched rhizoids. The rhizoids are positively geotropic and grow downward. Near the rhizoid tip are a group of **statoliths** consisting of vacuoles containing crystallites of barium sulfate that may be associated

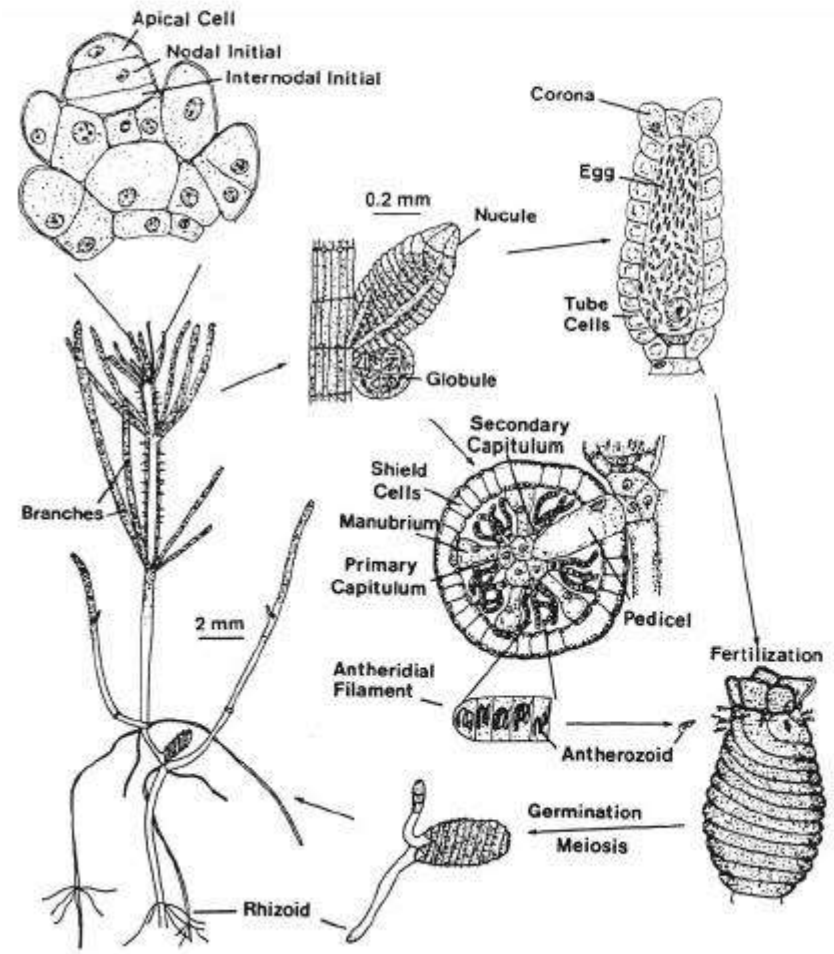


Fig. 5.26 The life cycle of *Chara* sp. (Adapted from Smith, 1955; Scagel et al., 1965.)

with the response of the rhizoids to gravity.

Internodal cell:

The uninucleate cells have many small ellipsoidal chloroplasts in longitudinal, spirally twisted, parallel rows. In the center of the cells is a single large vacuole. The large size of the internodal cell and its vacuole has made the cell a favorite tool of physiologists interested in the control of ion uptake in plants. **Cytoplasmic streaming** is particularly evident in these large internodal cells. The cytoplasm is divided into an inner **endoplasm** next to the vacuole, and an outer **ectoplasm** containing the chloroplasts (Fig. 5.27).

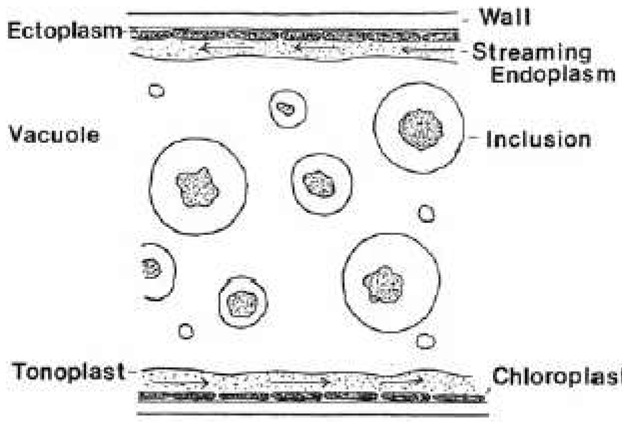


Fig. 5.27 Schematic view of part of an internodal cell of *Nitella*. The chloroplasts are stationary in the ectoderm, whereas the endoderm moves by cytoplasmic streaming. (After Kamitsubo, 1980.)

Asexual reproduction

The Charophyta do not form zoospores, but there are specialized asexual bodies may be effected by (1) star-shaped aggregates of cells developed from the lower nodes, called **amylum stars** because they are filled with starch; (2) **bulbils** developed on rhizoids; and (3) protonema-like outgrowths from a node.

Sexual Reproduction:

The sexual organs are the **globule** (male) and **nucule** (female) (Fig. 5.26), the terms antheridium and oogonium not being appropriate because the sexual reproductive structures include both a sex organ and a multicellular sheath derived from cells beneath the sex organ. Globules and nucules are borne on nodes, usually on the same plant. In *Chara*, the nucule is above the globule. The **globule** develops from haploid nodal cells that occur at lateral branches. 1) Following the first mitotic division of the initial cell, the lower cell develops into a basal cell and does not divide further, while the upper one transforms into the mother cell of the globule (Fig. 5.28). 2) The initial cell of the globule divides three times, longitudinally and transversely, to produce eight cells with their apices joined in the center of the sphere. 3) Successive mitotic divisions produce three cells within each octant yielding a sphere composed of 24 cells. 4) Outer cells become transformed into shield cells that form the colorful cover of the globule due to chromoplasts near the inner wall of the cells. The color changes from pale yellow to orange as the globules mature. 5) The median cells develop into manubria 6) and eight inner cells are transformed into primary capitular cells which give rise to the antheridial filaments. 7) Each cell of an antheridial filament is an antheridium whose protoplast matures into a single antherozoid.

The antherozoid is coiled in a compact helix of two and a half turns in the antheridium (Fig. 5.29). When the antherozoids are mature, the shield cells of the globule separate from one another and expose the antheridial filaments.

Soon after the antheridial filaments are exposed, and antherozoids emerge backward through a pore in the cell wall. Liberation of antherozoids generally takes place in the morning, and their swarming may continue until evening. The sperm have two somewhat unequal flagella attached subterminally near the anterior end of the cell (Fig.5.29). There are three different regions within the body of the sperm: (1) the head region, consisting of a microtubular sheath over the mitochondria taking up one-fourth of the body; (2) the middle region, with microtubules covering the nucleus and taking up half of the body; and (3) the tail region, where the microtubules ensheath the plastids. Scales formed by the Golgi are on the outside of the flagella.

The nucule is supported by a pedicel cell, and in the center is the oogonium with its single egg. Five spirally twisted tube cells cover the oogonium except at the tip, where there are five corona cells. When the nucleus is mature, the spirally twisted tube cells separate from one another just below the corona. Antherozoids swim through these openings to the oogonium, where they penetrate its gelatinized wall. The zygote secretes a thick wall, and the inner wall of the tube cells becomes thickened (Fig. 5.30). Other portions of the walls of the sheath decay, leaving the persisting portions of walls of the tube cells projecting like the threads of a screw. The zygote, with the surrounding remains of the sheath, falls to the bottom of the pool and there germinates after a period of weeks or months.

The zygote can be carried considerable distances attached to water fowl. The zygote will not germinate in darkness and needs white or red light. Meiosis occurs in the first division of the zygote; thus the thallus is haploid, and the zygote is the only diploid part of the life history.

Because calcification occurs in most genera, the group is well represented as fossils, especially by the female fructification, which when calcified is termed a **gyrogonite**.

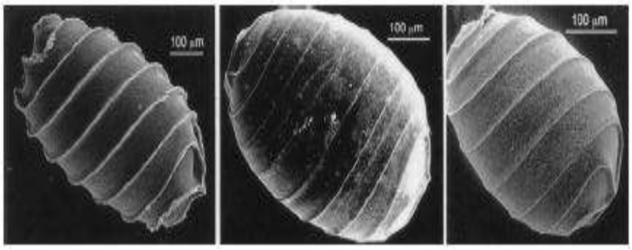


Fig. 5.30 Scanning electron micrographs of zygotes of *Chara muelleri* (left) and *Chara fibrosa* (middle, right). (From Casanova, 1997.)

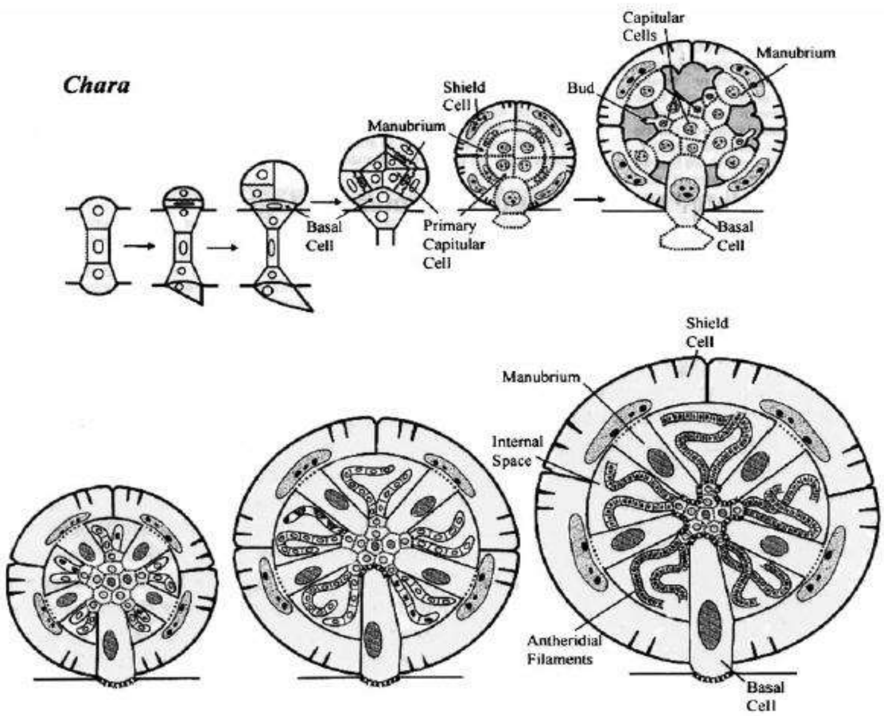


Fig. 5.28 The development of a globule of *Chara*. (From Kwiatkowska, 2003.)

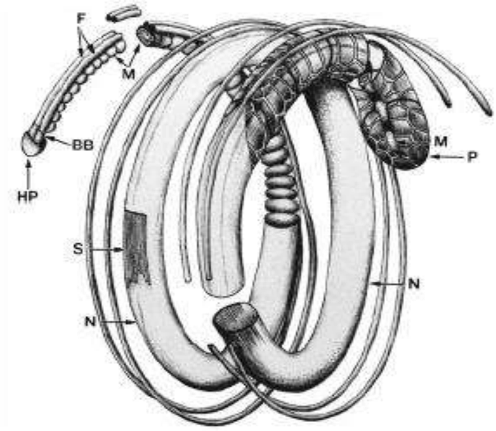


Fig. 5.29 Reconstruction of the mature spermatozoid of *Chara vulgaris*. (BB) Basal bodies; (F) flagella; (HP) head piece; (M) mitochondrion; (N) nucleus; (P) plastid; (S) spline of microtubules. (From Duncan et al., 1997.)

Euglenophycophyta:

Euglenoid flagellates occur in most freshwater habitats: puddles, ditches, ponds, streams, lakes, and rivers, particularly waters contaminated by animal pollution or decaying organic matter . Usually larger bodies of purer water, such as rivers, lakes, and reservoirs, have sparser populations of less common euglenoids as planktonic organisms.

General characteristics:

Euglenoids are characterized by chlorophylls *a* and *b*, one membrane of chloroplast endoplasmic reticulum, a mesokaryotic nucleus, flagella with fibrillar hairs in one row, no sexual reproduction, and paramylon or chrysolaminarin as the storage product in the cytoplasm.

Euglenoid cells are surrounded by a pellicle. *Euglena gracilis* changes its shape two times per day when grown under the synchronizing effect of a daily light–dark cycle. At the beginning of the light period, when photosynthetic capacity is low (as measured by the ability of t

he cells to evolve oxygen), the population of cells is largely **spherical**. The **mean cell length** of the population **increases to a maximum** in the middle of the light period when photosynthetic capacity is greatest, and then decreases for the remainder of the 24-hour period. The population becomes **spherical** by the end of the 24-hour period when the cycle reinitiates. These changes are also observed under dim light conditions and are therefore controlled by a biological clock and represent a **ciradian rhythm in cell shape**.

The contractile vacuole (Figs. 6.1, 6.2, 6.13, 6.14), in the anterior part of the cell next to the reservoir, has an osmoregulatory function, expelling excessive water taken into the cell. The contractile vacuole fills and empties at regular intervals of 15 to 60 seconds. It empties into the reservoir, from which the water is carried out through the canal.

Mitochondria are of typical algal type. Colorless euglenoids always have more mitochondria than do equivalent-sized green ones. When green cells are decolorized by heat or streptomycin, they have a sevenfold increase in mitochondrial volume, reflecting a change from autotrophic to heterotrophic nutrition. The formation of two mitochondrial enzymes, fumarase and succinate dehydrogenase, necessary for dark respiration of substrates, is repressed by light.

<u>Nucleus and nuclear division:</u>

The euglenoid nucleus is of *the* mesokaryotic type**,** ***having chromosomes that are permanently condensed during the mitotic cycle, a nucleolus (endosome) that does not disperse during nuclear division, no microtubules from chromosomes to pole spindles, and a nuclear envelope that is intact during nuclear division. The chromosome number is usually high, and polyploidy probably occurs in some genera. Mitosis in euglenoids begins during early prophase with the nucleus migrating from the center of the cell to an anterior position. Microtubules appear in the nucleus, but they do not attach to the chromosomes. At metaphase, bundles of microtubules are among the***

chromosomes, and the nucleolus has started to elongate along the division axis. In anaphase, the intact nuclear envelope elongates along the division axis, the nucleolus divides, and the daughter chromosomes disperse into the two daughter nuclei.

Eyespot, paraflagellar swelling, and phototaxis :

The **eyespot** (**stigma**) is a collection of orange-red lipid droplets, independent of the chloroplast (Figs. 6.1, 6.2, 6.14). The eyespot is in the anterior part of the cell, curving to ensheath the neck of the reservoir on the dorsal side. In most euglenoids the eyespot consists of a compact group of 20 to 50 droplets, although in *Eutreptia* and *Khawkinea* it may consist of just one or two large droplets. The eyespot has been reported to contain α-carotene and seven xanthophylls, mainly β-caroten, or a β-carotene derivative, echineone. **The independence of the eyespot is emphasized by the existence of colorless species with an eyespot but no plastids**. One flagellum of all green euglenoids bears a lateral swelling near the transition zone from canal to reservoir; in *Euglena* (Figs. 6.2, 6.14(*a*)), the swelling is on the longer flagellum. The swelling is composed of a crystalline body next to the axoneme and inside the flagellar membrane. All euglenoid species with an eyespot and flagellar swelling exhibit phototaxis, usually swimming away from bright light (negative phototaxis) and away from darkness toward subdued light (positive photoaxis) to accumulate in a region of low light intensity. In certain genera (*Euglena* and *Eutreptia*), cell division within the slime layer leads to the formation of a palmelloid colony, which may form extensive sheets of cells covering many square feet of mud surface. *Trachelomonas* is a large genus of free swimming green euglenoids, characterized by encasement of the cell in a patterned mineralized envelope with a rimmed apical pore through which the flagellum emerges (Figs. 6.12, 6.14(*d*)).

(((Most of the species are defined by the form and ornamentation of the envelopes, characteristics that can be changed by varying conditions of growth, especially iron and manganese supply. This has resulted in some described species being growth forms of other species. The process of envelope formation involves mineralization of an initial fibrillar envelope which is probably derived as a secretion of the mucilaginous bodies. It begins with longitudinal division of the parent protoplast, the two daughter cells rotating within the envelope, and one or both squeezing out through the pore. Each naked daughter cell then secretes a new envelope externally, at first delicate and colorless but already the size and shape of the old one. Under good growth conditions, the envelope slowly becomes thicker and ornamented, first yellow, then brown. Under conditions of manganese deficiency, the envelope usually remains thin and unornamented.)))

Chloroplasts and storage products:

((Euglenoid chloroplasts arose from a secondary endosymbiosis. The chloroplasts originated from the chloroplasts of a scaly flagellate in the green algal class Prasinophyceae.)) The euglenoid chloroplasts are surrounded by two membranes of the chloroplast envelope plus one membrane of chloroplast endoplasmic reticulum; the latter membrane is not continuous with the nuclear membrane. The chloroplasts are usually discoid or plate-like with a central pyrenoid. The thylakoids are grouped into bands

of three, with two thylakoid bands traversing the pyrenoid. A shield of **paramylon grains** surrounds the pyrenoid, but outside the chloroplast, in phototrophically grown cells (Figs. 6.2, 6.3, 6.14).

Paramylon granules are distributed throughout the cytoplasm in heterotrophically grown cells in the dark. Gottlieb isolated the granules in 1850, and showed that they were composed of a carbohydrate that although isomeric with starch (amylon), was not stained with iodine. For this reason, they were termed **paramylon granules**.

The liquid storage product, chrysolaminarin, can be an alternative storage product in some Euglenophyceae where it can occur with solid paramylon grains in the same cell. Whereas the paramylon usually occurs as a shield of grains, the chrysolaminarin occurs in vacuoles primarily in the anterior part of the cell.

Nutrition:

The Euglenophycophyta have a number of modes of nutrition, depending on the species involved:

1- Autotrophic: This type of nutrition occurs in genera which have pigments in their plastids such as *Euglena* and *Phacus.*

2- Heterotrophic: This means that the algae are lacking the presence of pigments or plastids. So the nutrition may either be saprophytic on organic materials or halozoic like *amoeba*.

The scientists observed that, the colorless genera like *Astasia* is developed from green genera-autotrophic-. And so we can see the high similarity between this genus and *Euglena* or *Phacus.*

Classification:

Three orders of euglenoids are presented here. Investigations utilizing nucleic acid sequencing have shown the organisms in the Euglenales to have evolved most recently (Marin, 2004).

Order 1 Heteronematales: two emergent flagella, the longer flagellum directed anteriorly and the shorter one directed posteriorly during swimming; special ingestion organelle present.

Order 2 Eutreptiales: two emergent flagella, one directed anteriorly and the other laterally or posteriorly during swimming; no special ingestion organelle.

Order 3 Euglenales: two flagella, only one of which emerges from the canal; no special ingestion organelle.

Euglenales:

In this primarily freshwater order, the flagellum without the paraflagellar swelling has been reduced so that it does not emerge from the canal. Common genera in the order are the green photosynthetic *Euglena* (Figs. 6.1, 6.2, 6.3, 6.14(*a*)).

Euglena:

Euglena appears as unicellular alga with different size and forms according to the species.

With light microscope, *Euglena* appears as spindle- shaped cell with circle or pointed end bounded with flexible periplast which lies under plasma membrane and gives *Euglena* the ability to change its shape. The nucleus is prominent in euglenoid cells and often readily visible in the living individuals in the center or posterior of the cell Fig.6.1. The chloroplasts are vary in form among the different species and genera. They may be small, simple disc; large and plate-like with entire or dissected margins; or ribbon-like and arranged in stellate fashion. Storage food is paramylon {β 1-3 glucose polymer} that occurs outside the chloroplast. In the anterior of euglenoid cells, the eyespot or stigma occurs in the colorless cytoplasm. The stigma lies at about the level of the paraflagellar swelling Fig. 6.2. A contractile vacuole lies at the anterior of cell and discharges periodically into the reservoir. Tinsel flagellum initiates from the reservoir base. as two flagella and {short and long Fig.6.} only one flagellum will be appear outside of reservoir Fig. 6.14.

With E.M. euglenoid cells appear surrounded by a pellicle ***(((that has four main components: the plasma membrane, repeating proteinaceous units called strips, subtending microtubules, and tubular cisternae of endoplasmic reticulum.)))*** The nucleus with nucleolus is also easy to observe. The chloroplast is shown surrounded with two layers of chloroplast envelop and the one layer of endoplasmic reticulum, the photosynthetic lamella consist of three thylakoid bands. Mitochondria, Golgi bodies and paramylon grains can be also observe. The locomotory flagellum or flagella emerge from an anterior invagination of the cell, which consists of a narrow tubular portion, the **canal**, and a spherical or pyriform chamber, the **reservoir** (Fig. 6.2). The canal is a rigid structure, whereas the reservoir easily changes shape and is regularly distorted by the discharge of the contractile vacuole. Tinsel flagellum initiates from the reservoir base as two flagella and {short and long} only one flagellum will be appear outside of reservoir Fig. 6.14.

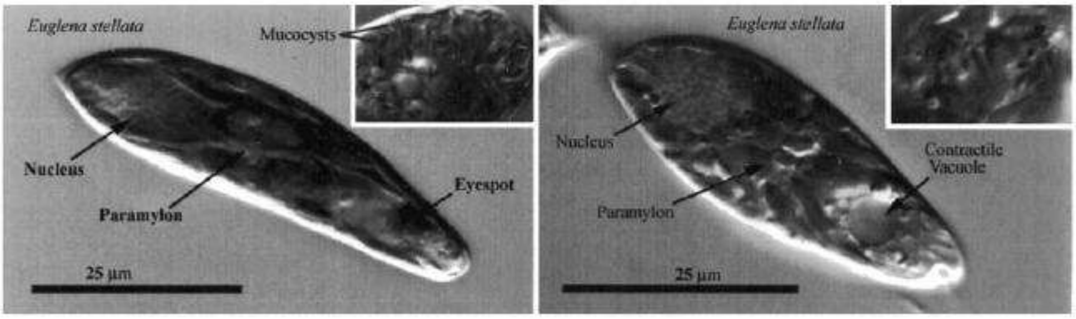


Fig. 6.1 Light micrographs of ***Euglena stellata***. (From Shin and Triemer, 2004.)

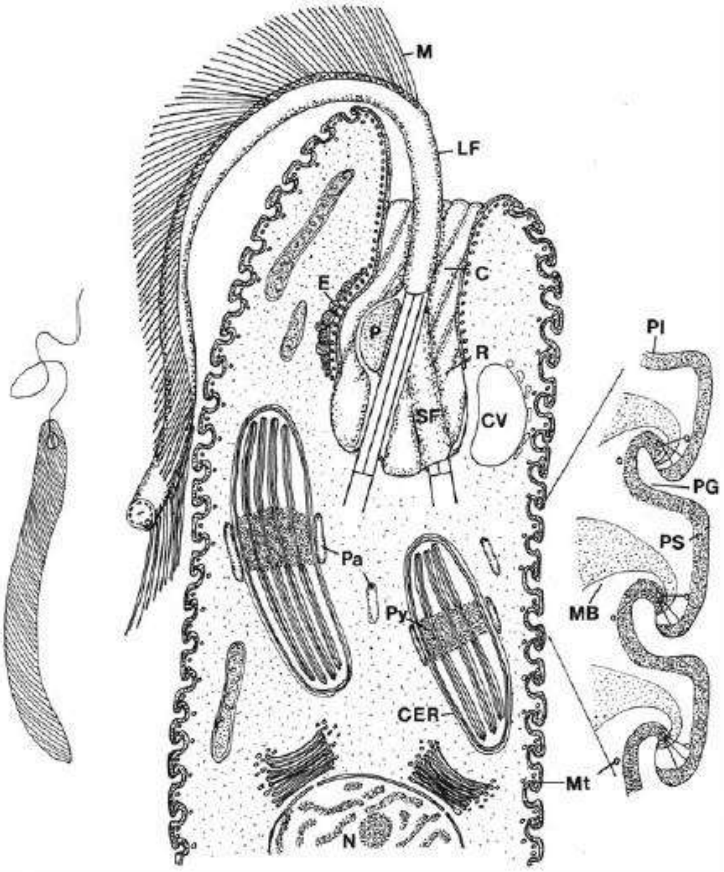


Fig. 6.2 A semidiagrammatic drawing of the fine structure of the anterior part of a ***Euglena*** cell. (C) Canal; (CER) chloroplast endoplasmic reticulum; (CV) contractile vacuole; (E) eyespot; (LF) long flagellum; (M) mastigonemes; (MB) muciferous body; (Mt) microtubules; (N) nucleus; (P) paraflagellar swelling; (Pa) paramylon; (PG) pellicle groove; (Pl) plasmalemma; (PS) pellicle strip; (Py) pyrenoid; (R) reservoir; (SF) short flagellum. (Adapted from Mignot, 1966; Jahn and Bovee, 1968.)

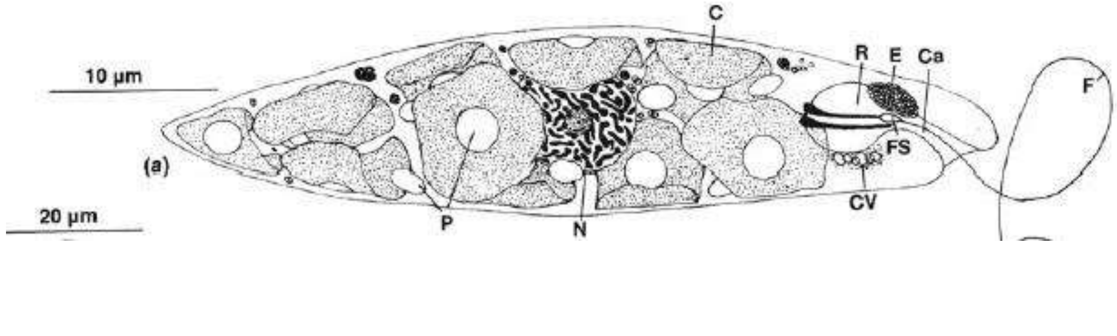


Fig. 6.14 (*a*) *Euglena gracilis*. (*b*) *Astasia klebsii*. (*c*) *Eutreptiella marina*. (*d*) *Trachelomonas grandis*. (*e*) *Phacus triqueter*. (C) Chloroplast; (Ca) canal; (CV) contractile vacuole; (E) eyespot; (Ev) envelope; (F) emergent flagellum; (FS) flagellar swelling; (M) mitochondrion; (N) nucleus; (P) paramylon grains or paramylon sheath around chloroplast; (R) reservoir. (After Leedale, 1967.)

<u>Lecture 10:</u>

Division: Xanthophycophyta: Yellow-green algae.

<u>Introduction:</u>

The individuals in this division were studied within chlorophycophyta, and were divided into two classes:

Class 1: Isokonate: This involves individuals of green algae with two equal flagella.

Class 2: Heterokonate: This involves individuals of yellow-green algae with unequal flagella but these flagella are similar in type. Also it is depended in the similarity of vegetative algal form as follows:

- The unicellular and motile colonial forms of this group are similar to those of order Volvocales – green algae-.
- The Palmelloid individuals are similar to those of order Tetrasporales.
- The filamentous forms are similar to those of Ulotrichales
- The siphoneous forms are similar to those of Caulerpales.

Others were classified this division as a class in division Chrysophycophyta which involves:

Class 1: Chrysophyceae

Class 2: Xanthophyceae

Class 3: Bacillariophyceae

This classification system depends on; type of pigments, storage food, and cell wall structure.

General characteristics:

1- The Xanthophyceae contain primarily freshwater and terrestrial algae with a few marine representatives.

2- The class is characterized by motile cells with a forwardly directed tinsel flagellum and a posteriorly directed whiplash flagellum. Also involves motile and non-motile colonies, simple filaments or simple branched filaments and siphoneous forms.

3- The chloroplasts contain chlorophylls (*a)* and (*c)* ; Chlorophyll (e) is present in *Vaucheria* and *Botrydium*; other pigments are β-carotene, fucoxanthin, dinoxanthin and diadinoxanthin.

4- The eyespot in motile cells is always in the chloroplast, and the chloroplasts are surrounded by two membranes of chloroplast endoplasmic reticulum. The outer membrane of the chloroplast E.R. is usually continuous with the outer membrane of the nucleus.

5-The cell walls of two Xanthophyceae, *Tribonema* and *Vaucheria* are composed of cellulose. In *Vaucheria* cellulose comprises 90% of the wall, with the remaining portion being amorphous polysaccharides composed primarily of glucose and uronic acids. Many of the algae in the class have walls composed of two overlapping halves that fit together as do the two parts of the bacteriologist’s Petri dish. The two-part nature of the wall cannot be delineated with the light microscope unless the cells have been treated with certain reagents such as concentrated potassium hydroxide. Filamentous genera, such as *Tribonema* have a wall composed of H-shaped pieces. These alternately overlap each other so that each protoplast is enclosed by halves of two successive H-pieces.

6- The principal storage product is probably a β-1, 3 linked glucan similar to paramylon, although lipids have been suggested as also being important.

7- Asexual reproduction: xanthophycean organisms multiply asexually by fragmentation, zoospores, and aplanospores. In addition, they have the ability to form specialized resting spores. Fragmentation is limited to the tetrasporine and filamentous colonies, and is due to the breaking of the colony into parts. Zoospores are formed by a majority of the genera. The zoospores are biflagellate, with the forward tinsel flagellum usually being four to six times longer than the shorter whiplash flagellum.

8- There are few reliable reports of sexual reproduction in the Xanthophyceae. Sexual reproduction has only been established in three genera: *Botrydium*, *Tribonema*, and *Vaucheria*. In the first two genera, both gametes are flagellated, whereas in *Vaucheria* reproduction is oogamous.

Four orders will be considered here:

Order 1 Mischococcales: small coccoid cells.

Order 2 Tribonematales: filamentous organisms, not coenocytic.

Order 3 Botrydiales: globose multinucleate thallus with colorless rhizoids.

Order 4 Vaucheriales: filamentous coenocyte.

Mischococcales

This order is characterized by small coccoid cells and contains about two-thirds xanthophyte algae . *Mischococcus* and *Pseudobumilleriopsis* are examples of algae in this order.

Tribonematales

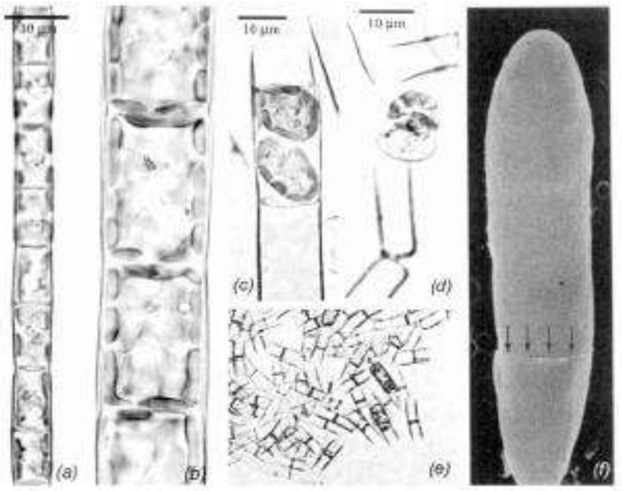


Fig. 19.2 Light microscopy of filaments of *Tribonema regulare* (*a*) and *Tribonema utriculosum* (*b*). (*c*) *Tribonema viride*, zoosporangium containing two zoospores. (*d*) Liberated zoospores of *Tribonema regulare*. (*e*) H-shaped cell walls of *Tribonema regulare* remaining after liberation of zoospores. (*f*) Scanning electron micrograph of a two-celled filament of *Tribonema viridae* showing the margin of an overlapping H-piece (arrows). (From Lokhorst and Star, 2003.)

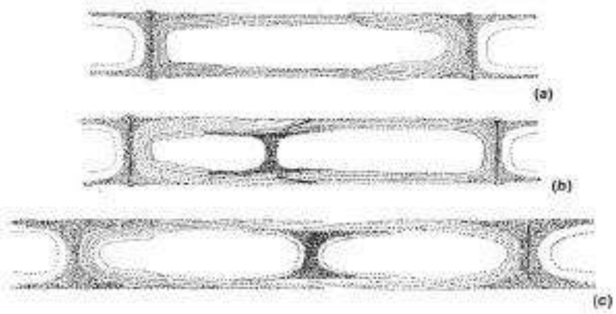


Fig. 19.3 Wall structure of *Tribonema bombycinum*, after treatment with potassium hydroxide. (*a*) Two H-pieces articulated to enclose a single protoplast. (*b*), (*c*) Recently divided cell showing the intercalation of a new H-piece. (After Smith, 1938.)

The algae in this order have cylindrical cells uniseriately united end to end in branched or unbranched filaments. *Tribonema* is composed of barrel-shaped cells that are two to five times longer than they are wide (Figs. 19.2, 19.3). The wall is composed of two H-shaped pieces overlapping in the middle of the cell. The protoplast is uninucleate and contains a number of discoid chloroplasts. Asexual reproduction is by fragmentation of the filaments, by zoospores, or by aplanospores. Aplanospores are produced more frequently than zoospores and are released by the pulling apart of the two portions of the cell wall. Akinetes can also be formed by the filaments. Sexual

reproduction is isogamous, one of a uniting pair of gametes coming to rest and withdrawing its flagella just before the other swims up to it and unites with it.

Botrydiales

Botrydium is a unicellular multinucleate alga consisting of a usually globose aerial portion with chloroplasts and a colorless rhizoidal portion that penetrates the soil (Fig. 19.6***).(((The shape of the aerial part is influenced by environmental conditions. It is usually elongate when growing in shaded habitats and spherical when growing in brightly illuminated places. The erial portion has a relatively tough wall within which is a delicate layer of cytoplasm containing many nuclei and chloroplasts. The branched rhizoidal system has no chloroplasts but does have many nuclei. The cells are incapable of vegetative division, and the only method by which new plants may be formed is by production of zoospores or aplanospores. According to***

Rakov and Fridvalsky (1970), the formation of either aplanospores or zoospores begins at night, and the cells must be illuminated 8 to 9 hours after the beginning of the process for flagella to develop. If there is no illumination, aplanospores develop. In the formation of these spores, three

to five chloroplasts become associated with a nucleus in the mother cell, and cleavage occurs with each zoospore containing the above organelles. If the spore is an aplanospore, then a wall is secreted; if it is a zoospore, no wall is formed. Motile gametes are apparently formed in a similar manner, and sexual reproduction can be isogamous or anisogamous, with the cells being either homothallic or heterothallic.The gametes become apposed by their anterior ends when uniting in pairs to form a zygote. Gametes that have not fused develop parthenogenetically into thalli. A germinating zygote develops directly into a new vegetative thallus.

Botrydium also produces cysts or resting spores during periods of dry conditions. In B. granulatum, the protoplast migrates into the rhizoids

where division occurs to produce a large number of thick-walled cysts. These cysts can either germinate directly to form a new thallus or give rise to zoospores.)))

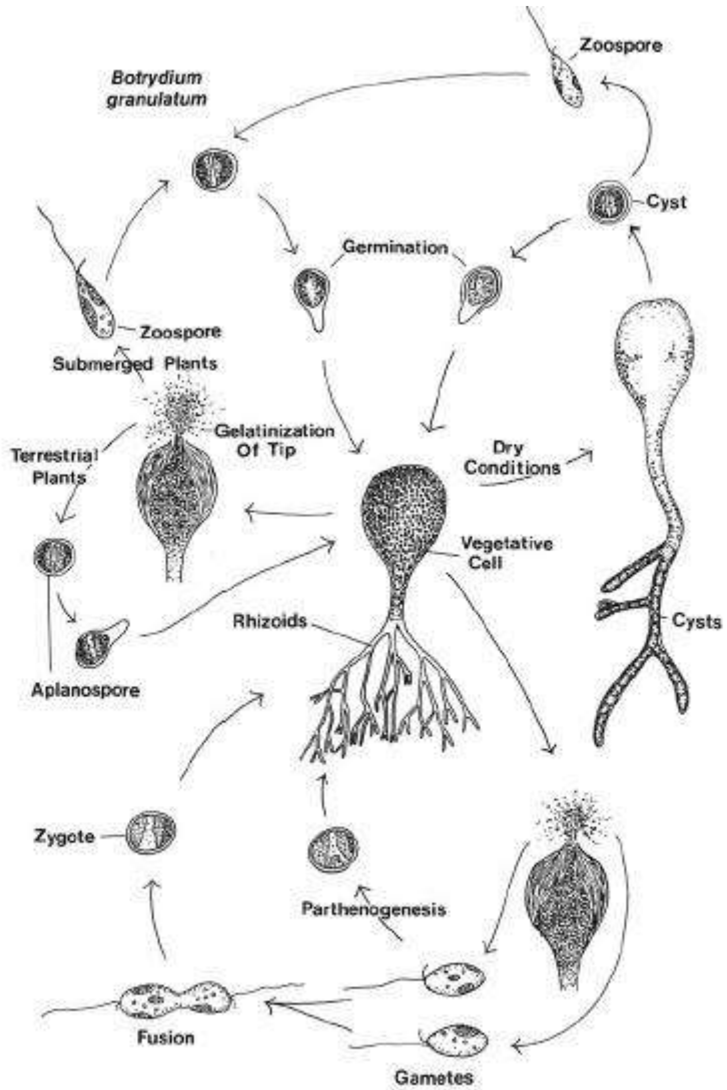


Fig. 19.6 The life cycle of *Botrydium granulatum*. (Adapted from Rostafiński and Woronin, 1877; Kolkwitz, 1926; Rosenberg, 1930.)

Vaucheriales

There is only one genus, *Vaucheria* (Figs. 19.7, 19.8), in this order. *Vaucheria* diverged early in evolution from other members of the order. *Vaucheria* has a relatively thin cell wall within which the cytoplasm is restricted to the periphery of the coenocyte, with the center being occupied by a large central vacuole (Fig.19.7). In the cytoplasm, the numerous elliptical chloroplasts with pyrenoids are to the outside, whereas the nuclei are toward the center. Growth of the filaments is restricted to the apex which has a large number of vesicles, mitochondria, and dictyosomes.

Chloroplasts, nuclei, and the large central vacuole are not found at the growing tip. The large central vacuole contains lipids, degenerated chloroplasts, and crystals and extends the entire length of the filament except for the area immediately behind the growing tip***.((((Cytoplasmic streaming takes place in the area of the large central vacuole and directly involves the nuclei, mitochondria, and their associated dictysomes. The cytoplasmic streaming second based on microfilaments that move the mitochondria and their associated dictyosomes. The chloroplasts do not migrate in patterns of de.nite streaming but have a more or less random movement, not associated with either microtubules or microfilaments.***

Although Vaucheria can develop transverse septa that block off injured portions of the coenocyte, there is little reproduction by accidental breaking of filaments.))) Asexual reproduction of aquatic individuals is usually by means of multi-flagellate, multinucleate zoospores (Fig. 19.8), which are produced singly in club-shaped sporangia at the swollen ends of filaments.

In their production large numbers of chloroplasts and nuclei stream into the tip of the filament, the central vacuole decreases in size, and the tips appear dark green. A band of colorless protoplasm now appears at the base of the developing sporangium, which breaks in the middle to form two protoplasts. The two protoplasts approach each other, and a septum is formed. Within the sporangium, vesicles are produced, around which nuclei become oriented with a pair of basal bodies between each nucleus and the vesicle membrane.

Flagella are produced through the vesicle membrane, and the vesicles migrate to the plasmalemma. The nuclei with their flagella pairs thus come to lie in the peripheral area of the cell. The wall at the apex of the sporangium gelatinizes, forming a narrow aperture; the zoospore pushes its way through the aperture and swims in the medium. The nuclei in the sporangium are separated from each other by a number of vacuoles, and one flagellum of each pair is slightly longer than the other. There is no eyespot or pyrenoid in the zoospore. The zoospores are sluggish in their movements, swimming for only about 15 minutes. On coming to rest, the flagella are withdrawn, and a thin wall is secreted. Germination follows almost immediately by the protrusion of one or two tubular outgrowths, one of which attaches itself to the substratum by means of a colorless lobed holdfast. Instead of producing zoospores, terrestrial individuals may have the entire contents of the sporangium develop into an aplanospore. Zoospores can be obtained if vegetative filaments kept moist for some days are soaked in water, or transferred from a nutritive solution into distilled water, or removed from running water to still water.

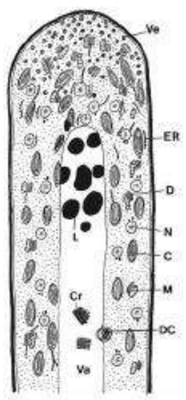


Fig. 19.7 Schematic representation of the tip of a vegetative filament of *Vaucheria dillwynii*. (C) Chloroplast; (Cr) crystal; (D) dictyosome; (DC) degenerate chloroplast; (ER) endoplasmic reticulum; (L) lipid body; (M) mitochondrion; (N) nucleus; (Va) vacuole; (Ve) vesicle. (After Ott and Brown, 1974a.)

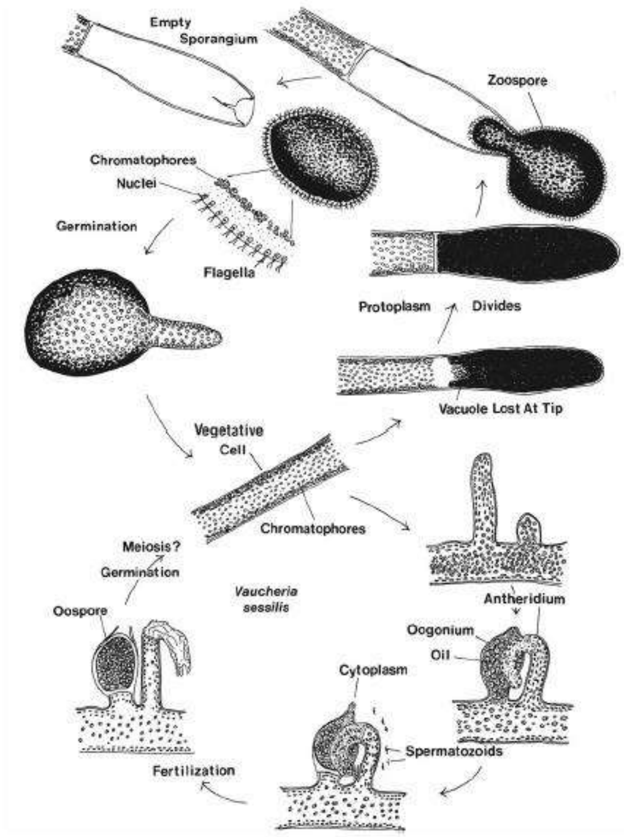


Fig. 19.8 The life cycle of *Vaucheria sessilis*.

Sexual reproduction is oogamous and usually homothallic with meiosis occurring before the production of gametes. The life cycle is therefore diplontic with the diploid phase predominant. Sex organs are common on filaments growing in damp soil or in quiet water, but are infrequent if they are growing in flowing water. The antheridia and oogonia are borne adjacent to each other and on a common lateral branch or on adjacent lateral branches. The sex organs are cut off by a septum. The oogonium has a single egg and is filled with oil and chloroplasts. The mature oogonium produces a beak, the tip of which gelatinizes, forming an aperture. A portion of colorless cytoplasm of the egg projects through the aperture and the egg contracts.

The antheridia usually develop as strongly curved cylindrical tubes that become cut off by a septum, usually fairly high up in the tube.

The mature antheridium has the spermatozoids produced in a specific area between the central and peripheral cytoplasm. The central and peripheral cytoplasm contain those parts of the cytoplasm that are not included in the spermatozoids: the chloroplasts, vacuoles, and many mitochondria. An aperture appears in the antheridium, and the spermatozoids are released. The spermatozoids are cylindrical posteriorly but have a flattened proboscis in the anterior portion (Fig. 19.9). There is a forward projecting tinsel flagellum with two lateral rows of hairs, and a slightly longer trailing smooth flagellum. ***The nucleus is elongated and wormlike, as are the three or four mitochondria. There is neither a chloroplast nor an eyespot, but there is a Golgi body near the basal bodies of the flagella. The proboscis consists of eight or nine microtubules running beneath the plasmalemma with vesicles in between the microtubules.*** **Fertilization is accomplished by the spermatozoids fusing with the egg protoplasm through the aperture in the oogonium. The zygote secretes a wall, and the oil droplets fuse to form a small number of central droplets. The oospore is colored by the oil and the degeneration products of chlorophyll. It remains in the oogonium until it is liberated by the decay of the oogonial wall. The oospore then remains dormant for a few months before germinating, probably by meiosis, into a new filament.**

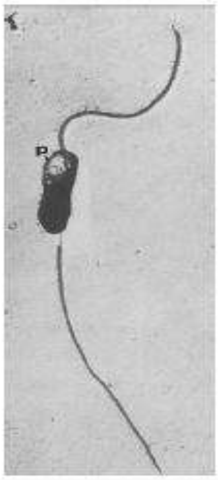


Fig. 19.9 Shadowcast whole mount of a sperm of *Vaucheria synandra*. A proboscis (p) is present on the anterior part of the cell. (From Moestrup, 1970.)

Lecture 11:

Division: Phaeophycophyta – Sea weeds or Brown algae-

General characteristics

1- The Phaeophycophyta, or brown algae, derive their characteristic color from the large amounts of the carotenoid fucoxanthin in their chloroplasts as well as from any phaeophycean tannins that might be present.

The chloroplasts also have chlorophylls *a*, *c*1, and *c*2. There are two membranes of chloroplast E.R., which are usually continuous with the outer membrane of the nuclear envelope.

2- The storage product is laminarin.

3- There are no unicellular or colonial organisms in the division, and the algae are basically filamentous, pseudoparenchymatous, or parenchymatous.

4- They are found almost exclusively in the marine habitat, there being only four genera containing freshwater species, that is, ***Heribaudiella, Pleurocladia, Bodanella,*** **and** *Sphacelaria*

(Fig. 21.1).

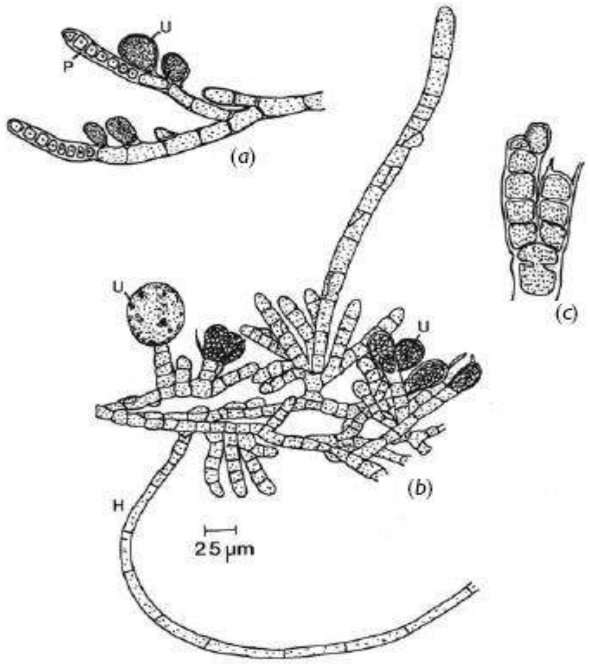


Fig. 21.1 Some freshwater brown algae. (*a*) *Pleurocladia lacustris*. (*b*) *Sphacelaria lacustris*. (*c*) *Heribaudiella fluviatilis*. (H) Hair; (P) pleurilocular sporangia; (U) unilocular sporangia. ((*b*) after Schloesser and Blum, 1980.)

5- Cell walls are generally composed of at least two layers, with **cellulose** making up the main structural skeleton. The amorphous component of the cell wall is made up of **alginic acid** and **fucoidin**, ***(((whereas the mucilage and cuticle are composed primarily of alginic. Alginic acid is basically made up of β-1,4 linked mannuronic acid units that have a variable amount of guluronic acid units attached through C-1 and C-4 linkages. Fucoidin is composed primarily of α-1,2 linked sulfated-fucose units, with a lesser amount of α-1,4 linked sulfated-fucose units. The relative quantities of alginic acid and fucoidin vary between species, different parts of the plant, and different environments. Calcification of the wall occurs only in some species of Padina where calcium carbonate is deposited as needle-shaped crystals of aragonite in concentric bands on the surface of the fan-like thallus.))***

6- Generally the motile cells of the Phaeophycophyta (always zoospores or gametes, as there are no motile vegetative cells) have a long anterior tinsel flagellum with tripartite hairs and a shorter posteriorly directed whiplash flagellum (Fig. 21.2).

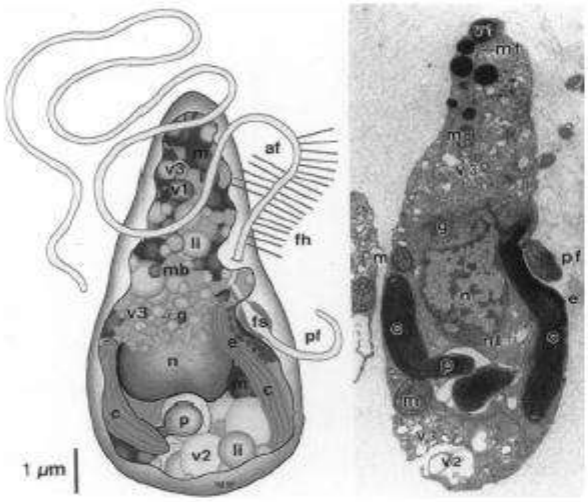


Fig. 21.2 *Left:* Diagrammatic representation of a male gamete of *Ectocarpus siliculosus* showing the distribution of cellular organelles. *Right:* Transmission electron micrograph of a thin section of a male gamete of *E. siliculosus*. (af) Anterior flagellum; (c) chloroplast; (e) eyespot; (fh) flagellar hairs (present along entire length, for clarity only shown on part of the flagellum); (fs) proximal swelling of the posterior flagellum; (g) Golgi apparatus; (li) lipid body; (m) mitochondrion; (mb) microbody; (mt) microtubules; (n) nucleus; (p) pyrenoid; (pf) posterior flagellum; (v1) physode; (v2) storage granule; (v3) vesicles with cell wall or adhesive material. (From Maier, 1997a.)

(((The Fucales (Fig. 21.44) are an exception to this, with the posterior flagellum of the spermatozoid being longer than the anterior flagellum. The posterior flagellum usually has a swelling near the base, and this swelling fits into a depression of the cell immediately above the eyespot. The eyespot consists of 40 to 80 lipid globules arranged in a single layer between the outermost band of the thylakoids and the chloroplast envelope. The eyespot (stigma) acts as a concave mirror focusing light onto the flagellar swelling, which is the photoreceptor site for phototaxis in brown-algal flagellate cells. Light at 420 and 460 nm is most effective in phototaxis in the brown algae, and is probably detected by a flavin-like substance in the flagellar swelling of the posterior flagellum.)))

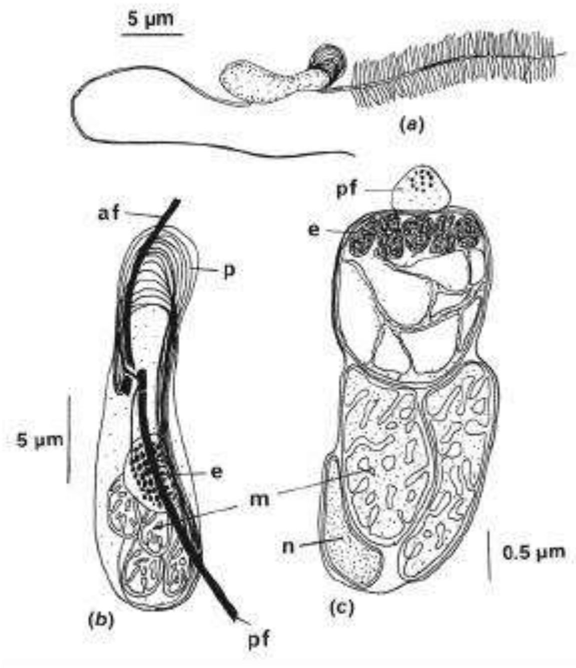


Fig. 21.44 Spermatozoid of *Fucus*. (*a*) Whole spermatozoid. (*b*) Semidiagrammatic drawing showing the anterior flagellum (af), eyespot (e), mitochondria (m), proboscis (p), and the posterior flagellum (pf). (c) Section through a spermatozoid illustrating the close appression of the posterior flagellum (pf) to the eyespot area (e) of the reduced chloroplast. (n) Nucleus. (After Manton and Clarke, 1956.)

7- ***The chloroplasts of the Phaeophycophyta*** have three thylakoids per band ***and are surrounded by the chloroplast envelope and two membranes of chloroplast E.R. (Figs. 21.3, 21.4). The outer membrane of the chloroplast E.R. is generally continuous with the outer membrane of the nuclear envelope (((in the Ectocarpales but appears to be discontinuous in the Dictyotales, Laminariales, and Fucales. Membrane-bounded tubules are common in the area between the chloroplast E.R. and chloroplast envelope where the latter two are not closely appressed. Microfibrils of DNA occur in the plastids, and in Sphacelaria sp. there is a ring-shaped genophore inside the outermost band of thylakoids. The DNA microfibrils are both linear and circular and are attached to the thylakoid membranes.))) The plastids contain chlorophylls a, c1, and c2, with the major carotenoid being fucoxanthin.***

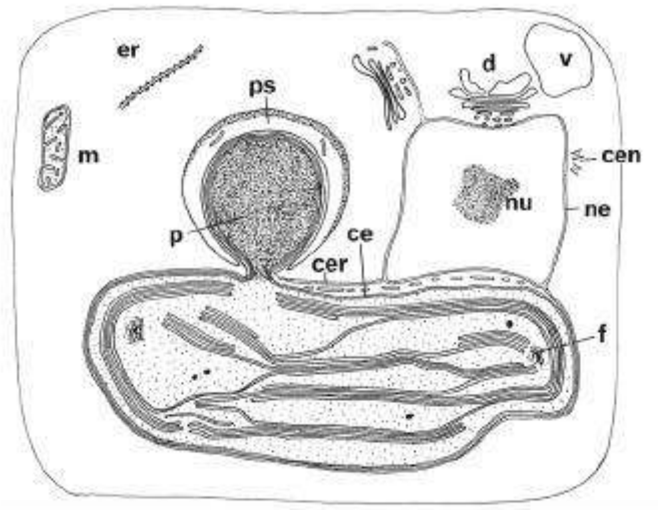


Fig. 21.3 Diagram of a hypothetical brown algal cell. (ce) Chloroplast envelope; (cen) centrioles; (cer) chloroplast endoplasmic reticulum; (d) dictyosome; (er) endoplasmic reticulum; (f) DNA fibrils; (m) mitochondrion; (ne) nuclear envelope; (nu) nucleolus; (p) pyrenoid; (ps) pyrenoid sac; (v) vacuole. (From Bouck, 1965.)

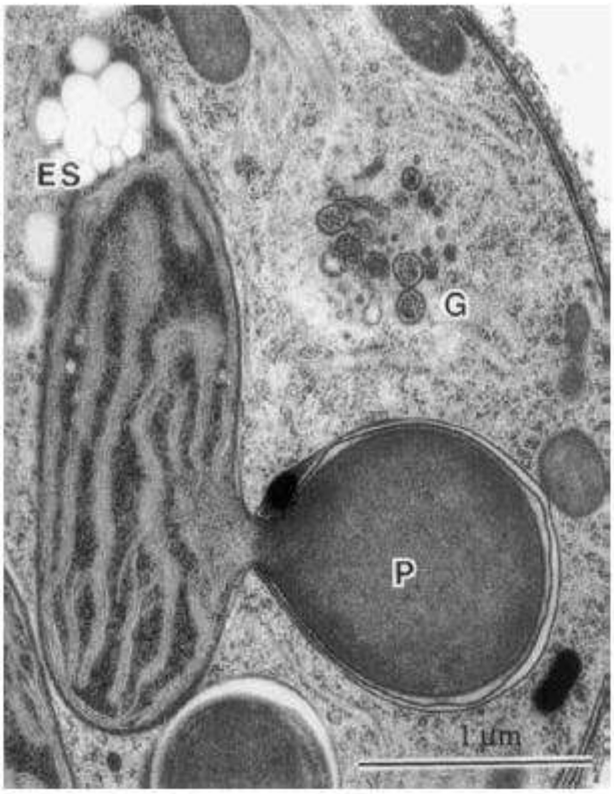


Fig. 21.4 A transmission electron micrograph of a portion of a cell of *Scytosiphon lomentaria*. (ES) Eyespot; (g) Golgi; (P) pyrenoid. (From Nagasato and Motomura, 2002.)

8- ***(((All the phaeophycean orders have representatives with pyrenoids (Figs. 21.3, 21.4), but their presence, even in one species, can vary according to the stage of the plant. If the species is one that has pyrenoids only in some stages, then a pyrenoid is usually present in the eggs and/or sporelings but absent in the macroscopic phase, spermatozoids, and/or zoospores. A pyrenoid in the Phaeophyceae is usually a stalklike structure set off from the main body of the chloroplast and containing a granular substance not traversed by thylakoids. Surrounding the pyrenoid but outside the chloroplast E.R. is a membrane-bounded sac that presumably contains the reserve product))). The long-term storage product is laminarin , a β-1,3 linked glucan. The sugar alcohol, D-mannitol is, however, the accumulation***

product((((up to 25% of the dry weight of some Laminaria species in the autumn) of photosynthesis. In a number of brown algae, the mannitol concentration in the cell increases or decreases as the salinity of the surrounding medium increases or decreases.)))

Reproduction:

1- **Vegetative reproduction:**
   a- Fragmentation such as in *Sargassum*
   b- Propagola formation such as in *Sphacelaria*.
2- **Asexual reproduction:**
   a- Asexual reproduction occurs by formation of pyriform biflagellated spores within a sporangium which consists of one cell and called unilocular sporangium, or within multicellular sporangium which called plurilocular sporangium.
   b- Or by non-motile spores monospores, tetraspores or neutral spores.

(((Note: ***The motile spores which have been form within unilocular sporangia are undergoing meiosis and then mitosis to give 32-64 motile spores -1n-. These spores will give rise to gametophyte after their releasing. While the plurilocular sporangia (Fig. 21.7(a)) give 2n spores which give rise to sporophytes.***

The unilocular sporangium (Fig. 21.7(b)) is generally considered to be the site of meiosis, the haploid zoospores that are released forming the gametophyte generation. The gametophyte then produces the gametes, which fuse to form the zygote. Although meiotic divisions have been considered the rule in the unilocular sporangium, a disturbingly large number of investigations have not found this to be the case.)))

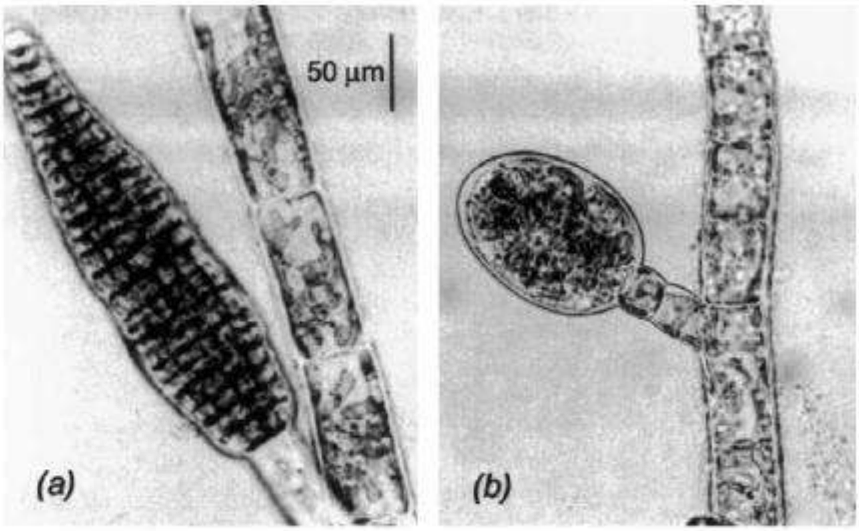


Fig. 21.7 *Ectocarpus fasciculatus*, plurilocular (*a*) and unilocular (*b*) sporangia. (From Dixon et al., 2000.)

3- **Sexual reproduction:**

The sexual reproduction in Phaeophycophyta occurs by motile-isogametes, motile-anisogametes or oogamous. Sometimes, in some genera, the gametes are growing into new individuals without fusion –parthenogenesis-.

Life cycles:

The life cycles in Phaeophycophyta may be haploid, diploid or diplobiontic. The latter with either gametophyte which resemble to sporophyte -isomorphic D.L.C., or gametophyte which not resemble to sporophyte – heteromorphic D.L.C-.

The growth: (only with examples:

The thallus of many Phaeophyceae is relatively large and complex with a number of different types of growth that include:

(1) **diffuse**, with most of the cells of the plant capable of cell division

(*Ectocarpus*).

(2) **apical**, with a single cell at the apex giving rise to the cells beneath (*Sphacelaria*).

(3) **trichothallic**, where a cell divides to form a hair above and a thallus below (*Cutleria*) .

(4) **promeristem**, with a non-dividing apical cell controlling a large number of smaller meristematic, dividing promeristematic cells beneath it (*Fucus*).

(5) **intercalary**, with a zone of meristematic cells forming tissue above and below the meristem (*Laminaria*)

(6) **meristoderm**, with a layer of usually peripheral cells dividing periclinally (parallel to the surface of the thallus) to form a tissue below the meristoderm (usually cortex) and occasionally anticlinally (perpendicular to the surface of the thallus) to add more cells to the meristoderm (*Fucus*).

((((Classification

The Phaeophyceae are an ancient lineage, originating between 150 and 200 million years ago.

The orders considered here are presented in an evolutionary sequence with the Dictyotales and Sphacelariales being the most ancient and the Ectocarpales and the Laminariales the most recent.

Order 1 Dictyotales: growth by an apical cell; meiosis occurring in the production of four to eight non-motile spores; oogamous sexual reproduction.

Order 2 Sphacelariales: growth by an apical cell; daughter cells divided longitudinally to give a polysiphonous structure; isogamous sexual reproduction.

Order 3 Cutleriales: trichothallic growth forming a fan-like thallus in at least one generation; anisogamous sexual reproduction.

Order 4 Desmarestiales: trichothallic growth forming axial cells; oogamous sexual reproduction.

Order 5 Ectocarpales: thallus consisting of filaments or filaments compacted together; reproduction isogamous or anisogamous.

Order 6 Laminariales: diploid thallus parenchymatous resulting from an

intercalary meristem between the stipe and blade; reproduction oogamous.

Order 7 Fucales: growth primarily by a promeristem; gametophyte reduced to egg and sperm; oogamous sexual reproduction.)))

(((<u>Ectocarpales:</u>

These algae consist of filaments or of filaments compacted together. In the order it is possible to see the gradual morphological evolution from a filamentous structure to pseudoparenchymatous (haplostichous) complex structures of compacted filaments (from the Ectocarpaceae to the Ralfsiaceae, and Splachnidiaceae). Along another line, the filamentous thallus has evolved by the division of the filament into true parenchymatous (polystichous) thalli (from the Ectocarpaceae to the Scytosiphonaceae). Most of the algae in the order are heterotrichous, with the thallus consisting of two different parts: (1) the prostrate creeping disc that functions as a holdfast, and (2) the erect filamentous, bulbous, or foliose stage. In some of the algae, both systems are evident (Scytosiphon, Fig. 21.19), whereas in others the erect stage is reduced to filaments of a few cells and the thallus is crustose (Ralfsia, Fig. 21.18), and in yet others the erect stage is predominant with the prostrate system reduced to a small holdfast (Petalonia, Fig. 21.20).

Even within the same alga, there can be a stage that consists of only a thin crust, whereas the alternate stage has a well developed erect stage.

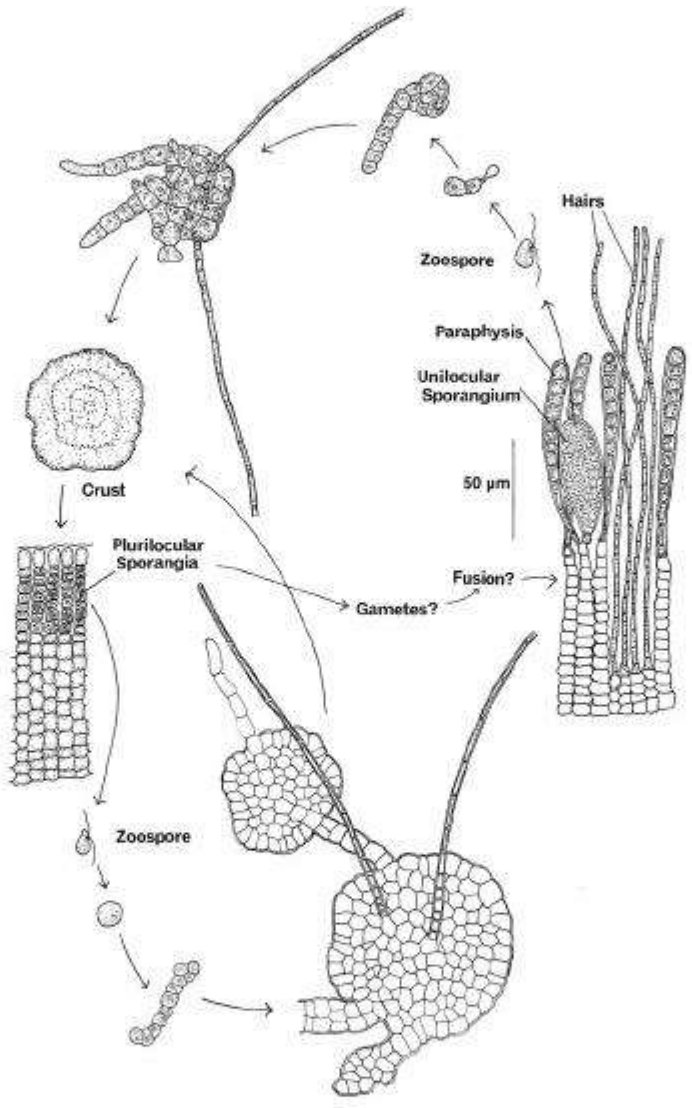


Fig. 21.18 The life cycle of *Ralfsia confusa*. (Adapted from Hollenberg, 1969.)

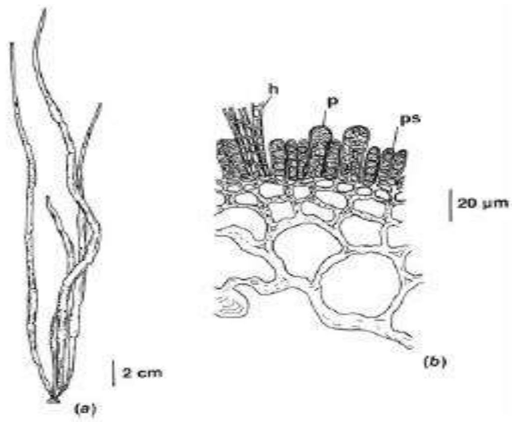


Fig. 21.19 *Scytosiphon lomentaria*. (*a*) Whole plant. (*b*) Portion of a section of the hollow plant showing hairs (h), paraphyses (p), and plurilocular sporangia (ps). (After Taylor, 1957.)

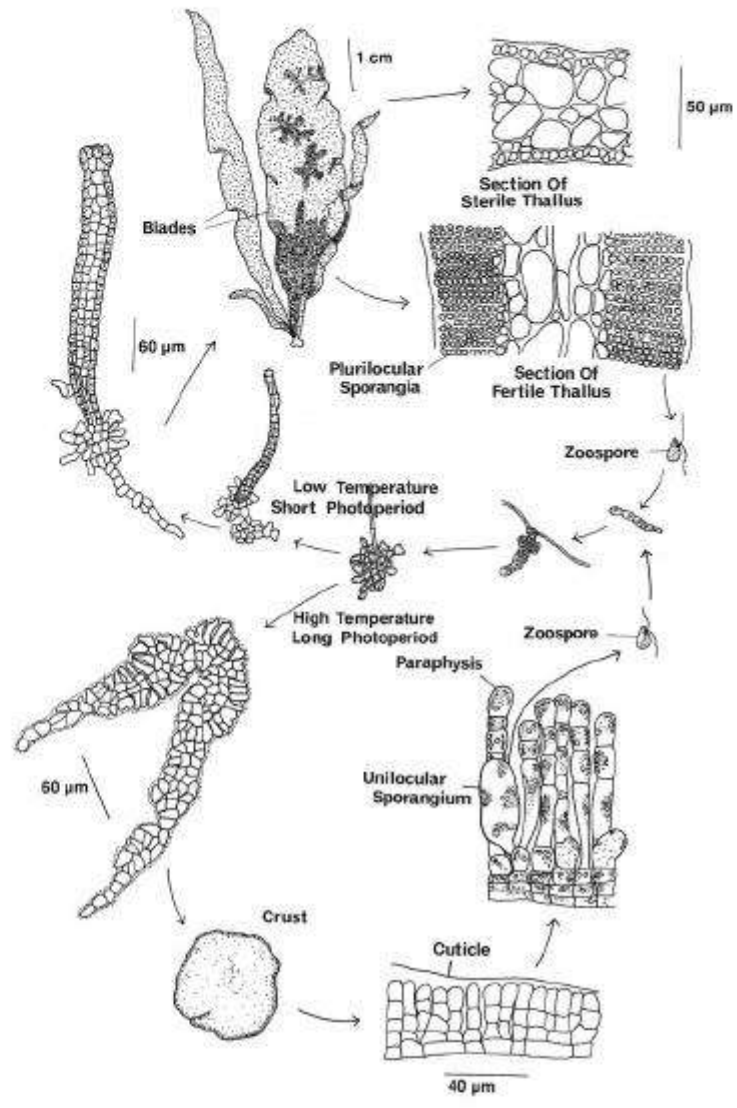


Fig. 21.20 The life cycle of *Petalonia fascia*. (After Smith, 1969; Wynne, 1969.)

Nucleic-acid sequencing studies have shown a strong relationship between the Ectocarpales, Desmarestiales and Laminariales. Four of the families in the Ectocarpales will be considered here.

Family 1 Ectocarpaceae: plants with free- filamentous construction with no adherence of filaments to each other.

Family 2 Ralfsiaceae: algae with a basal layer supporting erect filaments that are compacted together to form a tissue.

Family 3 Scytosiphonaceae: parenchymatous thalli with mostly diffuse growth.

Family 4 Splachnidiaceae: plants with trichothallic growth and unilocular sporangia formed in conceptacles.)))

Ectocarpaceae:

These organisms have free-filamentous construction with no adherence of the filaments to each other. *Ectocarpus* is the prevalent genus, and is composed of freely branched, uniseriate filaments differentiated into prostrate and erect systems.

The prostrate parts are rhizoid-like and often penetrate the substrate. Growth can be diffuse or more or less clearly trichothallic, with intercalary cell divisions confined to certain areas of the filaments. Some workers divide up the family into different genera on the basis of cytology and morphology, whereas others consider that the family contains the single genus *Ectocarpus*.

The life cycle of *E. siliculosus* (Fig. 21.17) can be taken as representative of the family. The haploid and diploid phases are both filamentous, but the diploid filaments have longer cells than the haploid filaments. The diploid plants produce unilocular and plurilocular sporangia either on the same plant or on separate plants. These sporangia discharge their zoospores between 0600 and 1200 hours. ***(((The mother cell of a unilocular sporangium can be distinguished from a branch initial by the spherical shape and large nucleus of the mother cell. The cell is initially vacuolate, but the physodes and vacuoles are soon extruded from the cell and become lodged in the wall.***))) The chloroplasts and nuclei of the unilocular sporangium divide in regular sequence, with the chloroplasts next to the wall and the nuclei in the center of the cell. The nuclei divide meiotically. A chloroplast then becomes associated with a nucleus, and a zoospore is delimited around it. A small perforation occurs at the apex of the unilocular sporangium, and up to 32 haploid zoospores ooze out of the sporangium in a gelatinous matrix. The perforation is small, and zoospores are relatively large, being twice the size of gametes and zoospores from plurilocular sporangia. The zoospores initially swim in a straight pattern, then display circling movements as they explore appropriate surfaces for settling. The zoospores prefer to settle on a hydrophobic surface, preferably one with a microbial film. The zoospores germinate within 2 to 3 hours to produce haploid filaments.

The plurilocular organs (Fig. 21.17) are modified lateral branches that are divided into as many as 660 cubical cells, each containing a motile cell. The plurilocular sporangia on the diploid filaments produce zoospores that remain motile for 3 to 5 hours, settle, and within 2 to 5 hours germinate to produce diploid filaments like the parent. ***The germ tube of the sporeling arises from the narrow, anterior flagellated end of the zoospore, which is always oriented toward the light.*** The plurilocular organs on the haploid filaments are smaller than those on the diploid filaments, and produce either zoospores or gametes. The motile gametes are all of the same size but differ physiologically. The female gametes settle down about 5 minutes after liberation and secrete a sexual hormone called **ectocarpene** [all *cis*- 1-(cycloheptadien-2,5-yl)-1-butene] (Fig. 21.8).

Male gametes (Fig. 21.17) move very rapidly (269 μm per second) in a straight line in open seawater when no female gametes are around. The motile male gametes (which can remain motile for up to 8 hours) swim in circular paths on encountering ectocarpene, the diameter of the circular path decreasing in response to increasing ectocarpene concentration. As soon as the female gamete is reached, a firm contact is established between the apical part of the front flagellum of the male gamete and the plasma membrane of the female gamete. The posterior ends of the two gametes fuse to form the zygote. The process of fusion takes about 20 seconds, and after fusion the zygote loses its attraction for male gametes as indicated by the dispersion of the male gametes near the zygote. The zygotes take 2 to 3 days to germinate, and the sporelings develop more slowly than those from diploid zoospores. Some of the unfused gametes have the ability to germinate parthenogenetically to give rise to haploid filaments again. This germination is slow, requiring 36 to 48 hours.

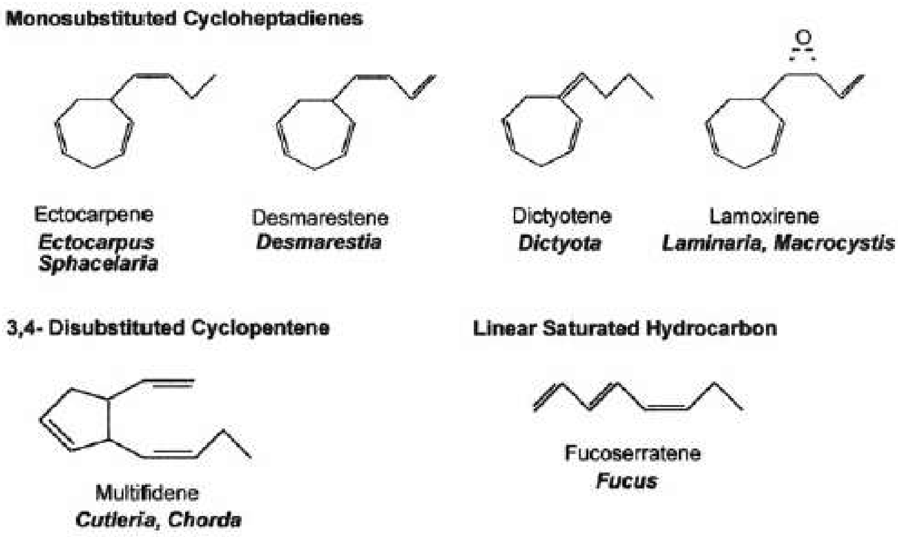


Fig. 21.8 The chemical structure of some brown algal pheromones with the names of the algae that secrete the pheromones. (Modified from Pohnert and Boland, 2002.)

open-chain hydrocarbons containing at l
double bond), most of them incorporatin

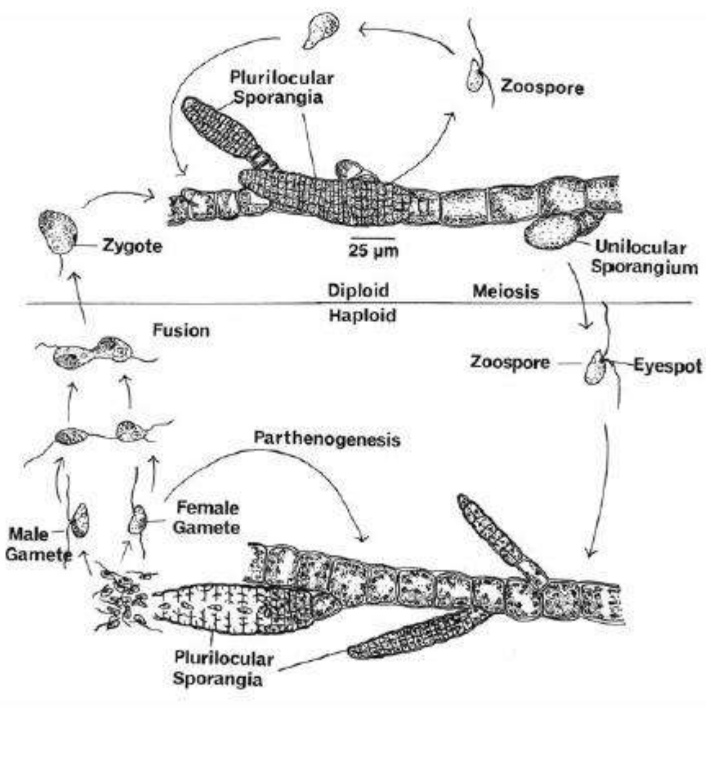


Fig. 21.17 The life cycle of *Ectocarpus siliculosis.*

Lecture 12:

Division: Pyrrhophycophyta: Dinophyceae

1- These organisms are important members of the plankton in both fresh and marine waters, ***although a much greater variety of forms is found in marine members. Generally the Dinophyceae are less important in the colder polar waters than in warmer waters. The highly elaborate Dinophysales are essentially a tropical group***.

2- A typical motile dinoflagellate (Figs. 7.1, 7.2) consists of an **epicone** and **hypocone** divided by the transverse **girdle** or **cingulum**. The epicone and hypocone are normally divided into a number of **thecal plates**, the exact number and arrangement of which are characteristic of the particular genus.

3- There is a **longitudinal sulcus** running perpendicular to the girdle. The longitudinal and transverse flagella emerge through the thecal plates in the area where the girdle and sulcus meet. The longitudinal flagellum projects out from the cell, whereas the transverse flagellum is wave-like and is closely appressed to the girdle.

4- The cells can be photosynthetic or colorless and heterotrophic. Photo synthetic organisms have chloroplasts surrounded by one membrane of chloroplast E.R., which is not continuous with the outer membrane of the nuclear envelope.

5- Chlorophylls *a* and *c*2 are present in the chloroplasts, with **peridinin** and **neoperidinin** being the main carotenoids. About half of the Dinophyceae that have been examined by electron microscopy have pyrenoids in the chloroplasts.

6- The storage product is **starch**, similar to the starch of higher plants, which is found in the cytoplasm. An eyespot may be present.

7- The nucleus has permanently condensed chromosomes and is called a

dinokaryotic or **mesokaryotic** nucleus.

(((8- Generally, dinoflagellates have a transverse flagellum that fits into the transverse girdle and a longitudinal flagellum that projects out from the longitudinal sulcus (Figs. 7.2) .)))

9-The thecal structure of motile Dinophyceae consists of an outer plasmalemma beneath which lies a single layer of flattened vesicles (Figs. 7.2, 7.3(c), 7.5).

(((These vesicles, which normally contain cellulosic plates, give the theca its characteristic structure. The actual form and arrangement of the thecal plates varies from none in the phagotrophic Oxyrrhis marina, to very thick plates with flanges at the edges in Ceratium (Figs. 7.12, 7.57) and Peridinium spp. (Figs. 7.2, 7.11).)))

10- The nutrition in most genera are autotrophic, some of them are heterotrophic, either saprophytic or parasitic. Others are symbiotic.

11- The reproduction occurs:

a- vegetative reproduction as simple fission.

b- Asexual reproduction by naked zoospores called -Gymnodiniate form- or by autospores.

c- Sexually either isogamous or anisogamous, by union gametes from the same individual -homothallic- or from different individuals -heterothallic-.

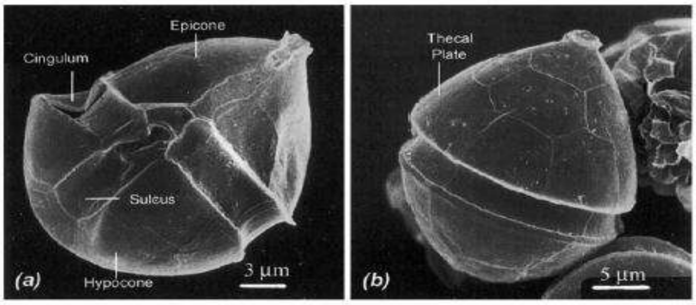


Fig. 7.1 *Scrippsiella trocholdea*. Scanning electron micrographs showing the thecal plates in ventral (*a*) and dorsal (*b*) view. (From Janofske, 2000.)

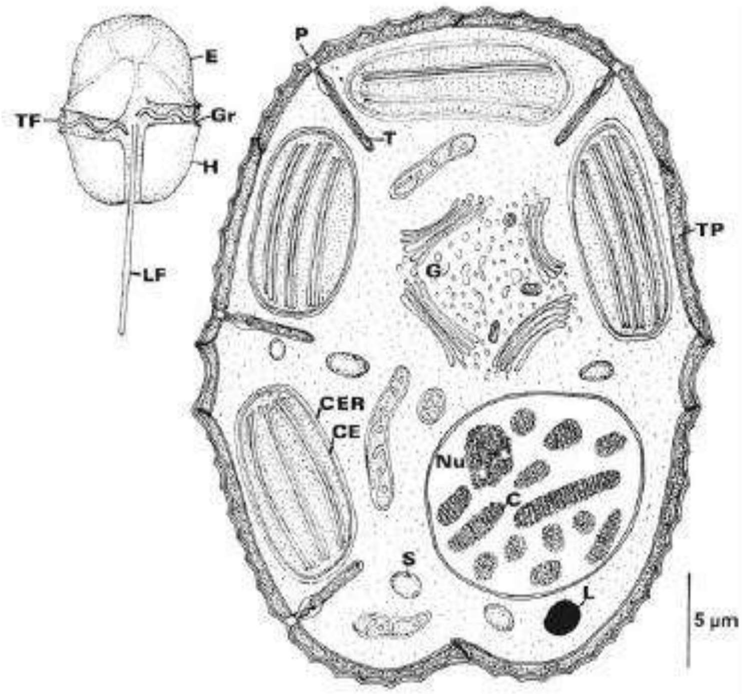


Fig. 7.2 Light and electron microscopical drawings of *Peridinium* sp., a dinoflagellate showing many of the features of the class. (C) Chromosome; (CE) chloroplast envelope; (CER) chloroplast endoplasmic reticulum; (E) epicone; (G) Golgi apparatus; (Gr) girdle; (H) hypocone; (L) lipid globule; (LF) longitudinal flagellum; (Nu) nucleolus; (P) trichocyst pore; (S) starch; (T) trichocyst; (TF) transverse flagellum; (TP) thecal plate.

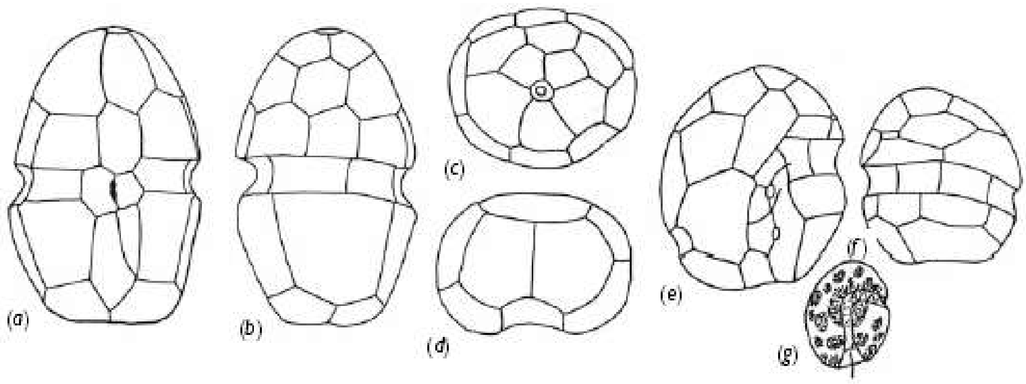


Fig. 7.3 (*a*)–(*d*) *Cachonina niei* showing the arrangement of thecal plates: (*a*) ventral, (*b*) dorsal, (*c*) apical, and (*d*) posterior views. (*e*)–(*g*) *Cryptothecodinium cohnii*: (*e*) ventral and (*f*) dorsal views, (*g*) living cell. ((*a*)–(*d*) after Loeblich, 1968; (*e*)–(*g*) after Chatton, 1952.)

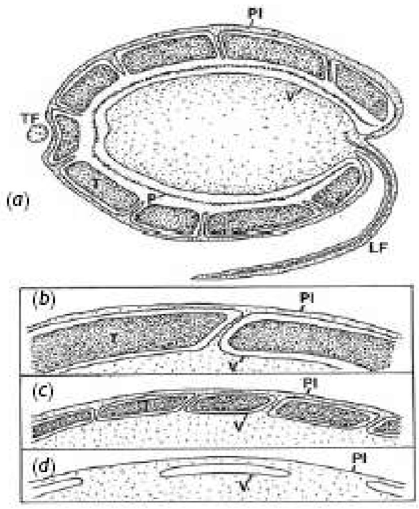


Fig. 7.5 Representative drawings of different types of amphiesmal arrangements in the Dinophyceae. (*a*) Cross section of a dinoflagellate with the most complex type of amphiesma. The outer plasma membrane (Pl) is continuous with the flagellar membrane. The cellulosic thecal plate (T) and a proteinaceous pellicle (P) are enclosed in a large vesicle (V). (*b*)–(*d*) Less complicated types of amphiesma occurring in other Dinophyceae. (LF) Longitudinal flagellum; (TF) transverse flagellum. (After Morrill and Loeblich, 1983a.)

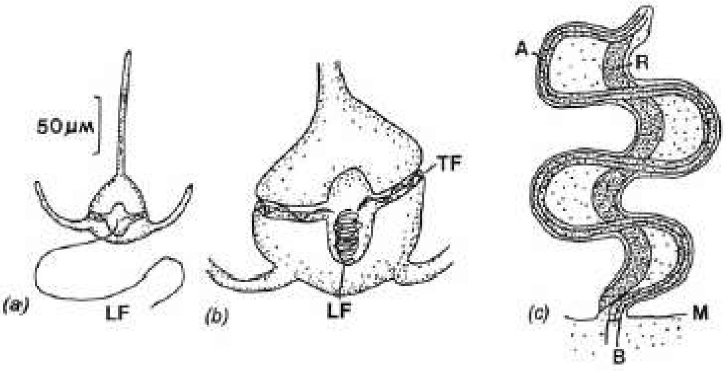


Fig. 7.12 *Ceratium tripos*. (*a*) Vegetative cell with a relaxed longitudinal flagellum (LF) at full length. (*b*) A cell with the longitudinal flagellum (LF) fully contracted and folded in the sulcus. (TF) transverse flagellum. (*c*) Schematic drawing of a retracted flagellum showing the contracted R-fiber (R) and the axoneme (A). (B) Basal body; (M) plasma membrane. (Adapted from Maruyama, 1982.)

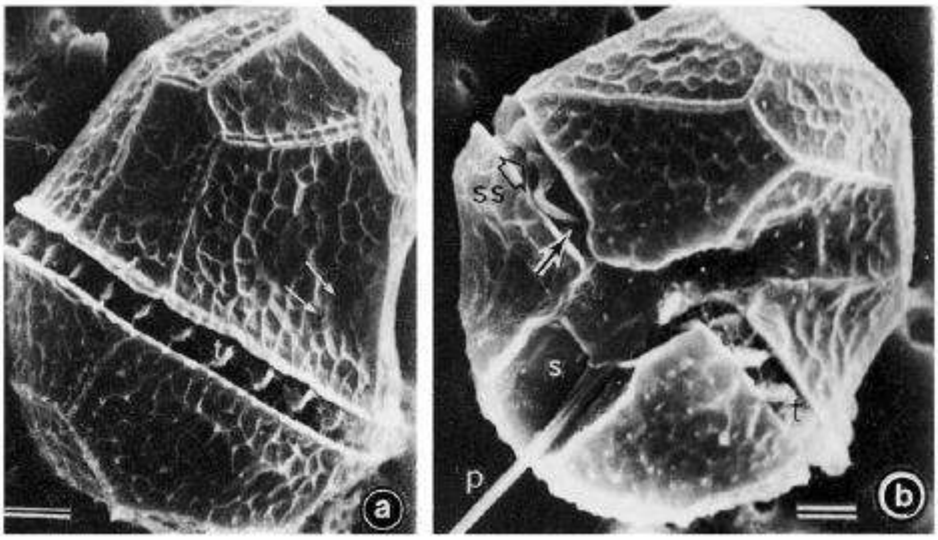


Fig. 7.11 Dorsal and ventral views of cells of *Peridinium cinctum* in the scanning electron microscope. (p) Posterior (longitudinal) flagellum; (s) longitudinal sulcus; (ss) striated strand; (t) transverse flagellum. Bar = 5µm. (From Berdach, 1977.)

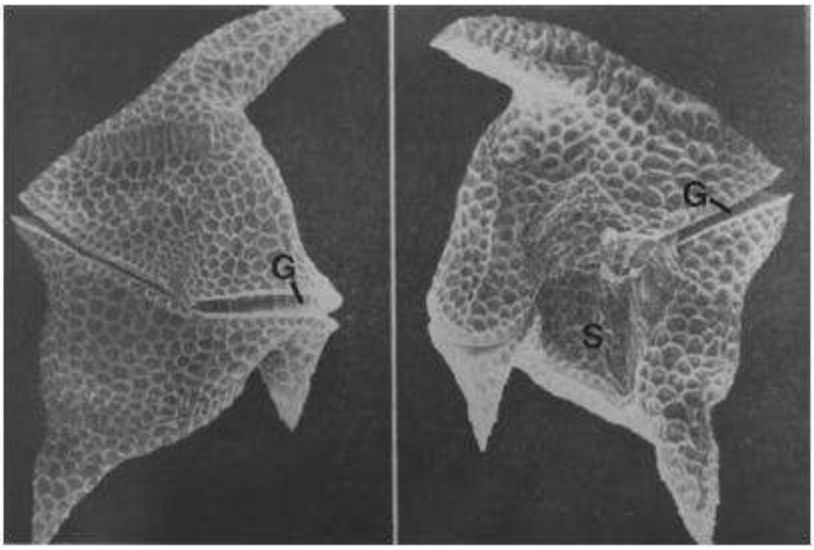


Fig. 7.57 Scanning electron micrographs of both sides of a vegetative cell of *Ceratium cornutum*. (G) Girdle; (S) sulcus. (From Happach-Kasan, 1982.)

Classification:

((There is a single class in the Dinophyta, the Dinophyceae. Four orders are considered here.

Molecular studies have shown that the Prorocentrales, Peridiniales, and Gymnodiniales represent three clear lines of evolution.

The Dinophysiales are probably related to the Prorocentrales since they are both divided vertically into two halves.))

Order 1 Prorocentrales: cell wall divided vertically into two halves; no girdle; two flagella borne at cell apex such as Prorocentrum Fig. 7.55.

Order 2 Dinophysiales: cell wall divided vertically into two halves, cells with elaborate extensions of the theca.

Order 3 Peridiniales: motile cells with an epicone and hypocone separated by a girdle, relatively thick theca such as Peridinium Fig.7.11 and Ceratium Fig 7.57.

Order 4 Gymnodiniales: motile cells with an epicone and hypocone separated by a girdle; theca thin or reduced to empty vesicles such as <u>Gymnodinium</u> Fig. 7.51.

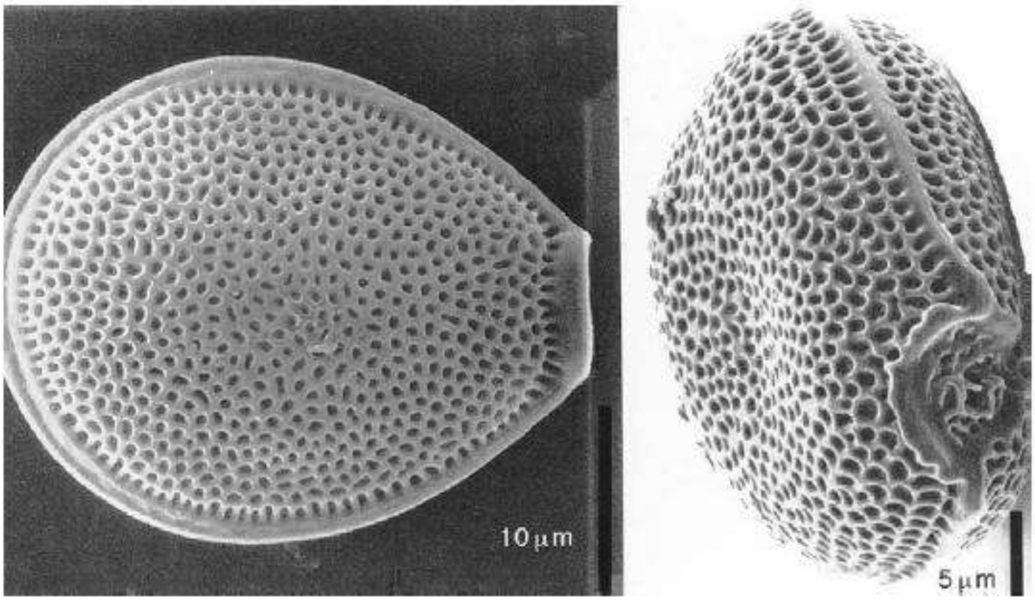


Fig. 7.55 Scanning electron micrographs of *Prorocentrum hoffmannianum*. (From Faust, 1990.)

the Gymnodiniales, which has no, or thin, thecal

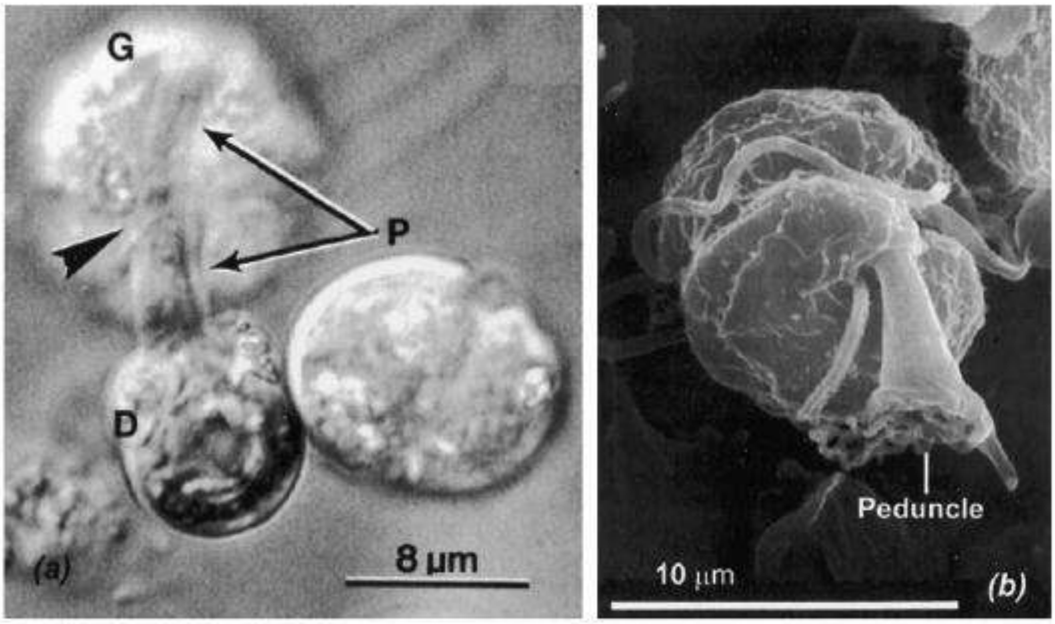


Fig. 7.51 (*a*) Light micrograph of the dinoflagellate *Gymnodinium fungiforme* (G) ingesting the protoplasm of *Dunaliella salina* (D). The peduncle (P) of *G. fungiforme* has attached to *D. salina* with the protoplasm of *D. salina* passing through the enlarged and extended peduncle into the dinoflagellate. (*b*) Scanning electron micrograph of a zoospore of *Pfiesteria piscicida* showing the peduncle. ((*a*) from Spero, 1982; (*b*) from Lewitus et al., 1999.)

Toxins:

Some Dinophyceae have the ability to produce very potent toxins which cause the death of fish and shellfish during **red tides** when there are dinoflagellate blooms that color the water red. The dinoflagellates become lodged in the gills of the shellfish, and when shellfish are eaten by humans or animals, poisoning results.

Historically, red tides and paralytic shellfish poisoning have been mentioned many times. One of the plagues that struck Egypt was described in the Bible: "all the waters that were in the river were turned to blood. And the fish that was in the river died; and the river stank, and the Egyptians could not drink the water of the river.***(((This description is strongly reminiscent of the poisonous red tides. Darwin, in his description of discolored water in 1832 during his voyage on the Beagle, graphically described blooms of algae that were dinoflagellates. Death and illness caused by consumption of poisonous mussels and clams were reported by Captain Cook and Captain George Vancouver during their expeditions to the coast of the Pacific Northwest. An old custom among Indian tribes along the coast of Alaska was to station sentries to watch for the marine luminescence occurring during hot weather, which they understood to be associated with Kal-Ko-O, their name for mussel poisoning.)))***

All of the dinoflagellates that have been convincingly demonstrated to produce toxins contain chloroplasts, indicating that the ability to produce toxins may have been derived from endosymbiotic cyanobacteria.

1 Diarrhetic shellfish poisoning. This occurs primarily in temperate regions and is caused by species of the planktonic dinoflagellates *Exuviaella*, *Dinophysis*, and *Prorocentrum*.

Diarrhetic shellfish poisoning is caused by the polyether carboxylic acids okadaic acid, macrolide toxins, and yessotoxin. The toxins are powerful inhibitors of serine- and threonine-protein phosphatases PP1 and PP2A and induce severe gastroenteritis.

2 Ciguatera fish poisoning. This occurs primarily in tropical regions with the common causative agent being *Gambierdiscus* which is common circumtropically between 32° N and 32° S. The dinoflagellate contains gambieric acids, ciguatoxins, and maitotoxins, putative Ca^{+2} channel activators that result in breakdown of the cell membrane.

3 Paralytic shellfish poisoning. This is caused by species of *Alexandrium* .These dinoflagellates produce a group of toxins that are derivatives of saxitoxin. Saxitoxins are potent neurotoxins acting upon voltage-gated Na^+-channels, preventing influx of Na^+, thereby preventing the generation of an action potential.

A number of factors have been suggested as the cause of red tides:

1 High surface-water temperatures:

Dinoflagellates favor warm water, and are generally more abundant near the surface. This does not necessarily mean that they occur only in warm seas, because the surface of the sea in normally cool areas may be warmed up during periods of hot, calm weather.

2 Wind: A strong, offshore wind aids upwelling, whereas a gentle onshore wind concentrates the bloom near the coast. On the other hand, heavy weather and strong winds disperse the bloom. Storms also result in the death of dinoflagellates and can prevent the development of red tides.

3 Light intensity: There is usually a period of bright, sunny, calm weather before outbreaks.

4 Nutrients: Red tides usually occur after an upwelling has stopped, but the nutrients brought to the surface do not, themselves, appear to be the direct cause of these blooms. It is thought that preceding blooms of diatoms may impoverish the water and reduce one or more of the inorganic nutrients to a level favorable for the growth of dinoflagellates (but too low for the diatoms), and also allow the production of organic nutrients such as vitamin B12, which are important for their growth.

Lecture 13:

Rhodophycophyta:

RHODOPHYCEAE:

(((The Rhodophyceae, or red algae, comprise the only class in the division Rhodophyta. The Rhodophyceae are probably one of the oldest groups of

eukaryotic algae. It is likely that the first red alga evolved into an ecological niche that was unoccupied by cyanobacteria, the only extant photosynthetic alga that evolved oxygen. This ecological niche would have been in waters with a pH less than 5, which, for some unknown reason, cyanobacteria are not able to inhabit. Indeed, modern phylogenetic studies utilizing nucleic-acid sequencing have shown that Cyanidium, an alga that lives in acidic waters, is probably the oldest extant red alga.))

General characteristics:

1-The Rhodophyceae lack flagellated cells, have chlorophyll *a*, phycobiliproteins, floridean starch as a storage product, and thylakoids occurring singly in the chloroplast.

(((2- A majority of the sea weeds are red algae, and there are more Rhodophyceae (about 4000 species) than all of the other major seaweed groups combined. Although marine red algae occur at all latitudes, there is a marked shift in their abundance from the equator to colder seas. There are few species in polar and subpolar regions where brown and green algae predominate, but in temper ate and tropical regions they far outnumber these groups.)))

3-The average size of the plants also differs according to geographical region. The larger species of fleshy red algae occur in cool-temperate areas, whereas in tropical seas the Rhodophyceae (except for massive calcareous forms) are mostly small, filamentous plants***.(((The Rhodophyceae also have the ability to live at greater depths in the ocean than do members of the other algal classes. They live at depths as great as 200 m, an ability related to the function of their accessory pigments in photosynthesis. About 200 species of Rhodophyceae are found in freshwater, where they do not reach as great a size as the red sea weeds. The majority of freshwater red algae occur in running waters of small to mid-sized streams.)))***

4- Cellulose forms the microfibrillar frame work in most rhodophycean cell walls, although in the haploid phase of the Bangiales (*Bangia* and *Porphyra*) a β-1,3 linked xylan (polysaccharide composed of xylose residues) performs this function. Unicellular red algae have an amorphous matrix of sulfated polysaccharides without cellulose surrounding the cells. The amorphous polysaccharides or mucilages occur between the cellulose microfibrils in the rest of the red algae. The two largest groups of amorphous mucilages are the **agars** and the **carrageenans**. These mucilages may constitute up to 70% of the dry weight of the cell wall. Cuticles, composed mostly of protein, can occur outside the cell wall.

5- Chloroplasts are usually stellate with a central pyrenoid in the morphologically simple Rhodophyceae, whereas in the remainder of the Rhodophyceae they are commonly discoid.***(((In the Rhodophyceae with apical growth, the chloroplasts usually originate from small colorless proplastids with few thylakoids in the apical cell. Chloroplasts are surrounded by the two membranes of chloroplast envelope with no chloroplast endoplasmic reticulum present. Thylakoids occur singly inside the chloroplasts. The phycobilin pigments are localized into phycobilisomes on the surface of the thylakoids, a situation similar to that in the cyanobacteria.***

Chlorophyll a is in the chloroplasts. There have been erroneous reports of chlorophyll d occurring in the chloroplast. It has been shown that the chlorophyll d in these studies came from the cyanobacterium Acaryochloris marina, an epiphyte on red algae.

The phycobiliproteins include R-phycocyanin, allophycocyanin, and three forms of phycoerythrin, the phycoerythrins being present in the greatest amount, giving the algae their pinkish color. B-phycoerythrin is present in the more primitive red algae and has been found in Pophyridium, Rhodosorus, Rhodochorton and Smithora. R-phycoerythrin occurs in most higher red algae, and C-phycoerythrin occurs in Porphyridium, Porphyra, and Polysiphonia. The phycobiliproteins are in phycobilisomes on the surface of thylakoids. The phycobilisomes are spherical if both phycoerythrin and phycocyanin are present. The phycobilisomes are discoid if only phycocyanin is present.)))

6- Floridean starch is the long-term storage product, occurring as grains in the cytoplasm outside of the chloroplast.

(((Floridean starch is similar to the amylopectin of higher plants, staining red-violet with iodine. In the more primitive Rhodophyceae the starch grains are clustered as a sheath around the pyrenoid of the chloroplast, whereas in the more advanced Rhodophyceae the starch grains arescattered in the cytoplasm.

7- Pit connections occur between the cells in all of the orders except the Porphyridiales, and the haploid phase of the Bangiales**.** ***(((It has been pointed out that the term "pit connection" is inappropriate because the structure is neither a "pit" nor a "connec tion"; however, because the termhas been used for so long, it is probably best to retain it. A pit connection consists of a proteinaceous plug core in between two thallus cells (Figs. 4.5, 4.6).)))***

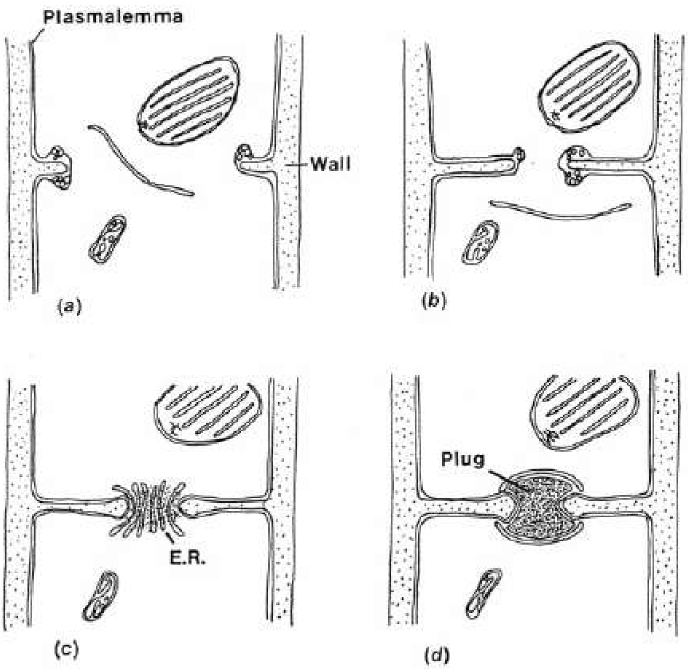


Fig. 4.5 Semidiagrammatic drawing of the formation of a pit connection in a red alga. (*a*) The cross wall begins to furrow inward with the wall precursors found in vesicles derived from the cytoplasm; (*b*) the cross wall septum is complete, leaving an opening (aperture) in the center; (*c*) endoplasmic reticulum lies across the opening in the wall, and electron-dense material condenses in this area; (*d*) the pit connection is formed, consisting of a plug with the plasmalemma continuous from cell to cell. (Adapted from Ramus, 1969, 1971; Lee, 1971.)

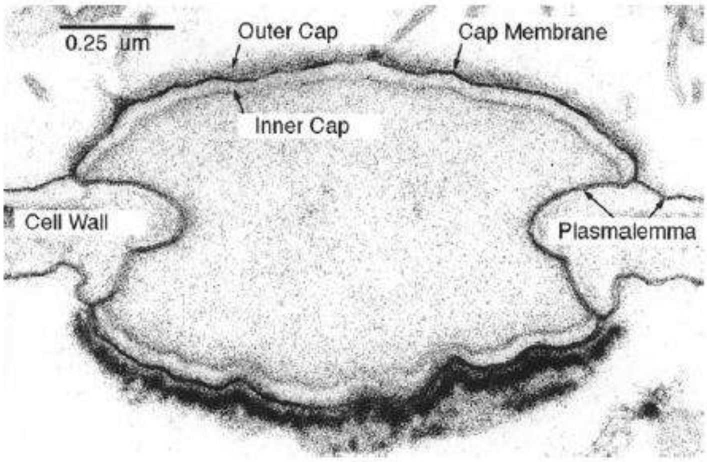


Fig. 4.6 A pit connection between cells of *Palmaria mollis*. The plasma membrane is continuous from cell to cell. The cap membrane is continuous with the plasma membrane. The inner and outer cap layers are on each side of the cap membrane. (From Pueschel, 1987.)

8- All members of the Corallinales and some of the Nemaliales (*Liagora* , *Galaxaura* deposit CaCO3 extracelluarly in the cell walls.

Commercial utilization of red algal mucilages:

The two most important polysaccharides derived from the Rhodophyceae are agar and carrageenan.

Agar is defined pharmaceutically as a phycocolloid of red algal origin that is insoluble in cold water but readily soluble in hot water; a 1.5% solution is clear and forms a solid and elastic gel on cooling to 32 to 39 °C, not dissolving again at a temperature below 85 °C. Agar is composed of two polysaccharides, agarose and agaropectin.

Agar is obtained commercially from species of *Gelidium* and *Pterocladia* as well as from various other algae. ***(((These algae are often loosely referred to as agarophytes. Commercial production of agar was a world monopoly of the Japanese for many years, and even in 1939 Japan was*** *still the major producer. Wartime demands in areas deprived of Japanese agar led to the development of agar industries in many of the Allied countries, some of which have continued and prospered while others have declined or disappeared. The agarophytes are collected by diving, dragging, or raking them offshore at low tide. In the traditional processing procedure the plants are then cleaned and bleached in the sun,*

with several washings in fresh water used to facilitate bleaching. The material is boiled for several hours, and the extract is acidified. This extract is then frozen and thawed. On thawing, water flows from the agar, carrying impurities with it. The agar that remains is dried and marketed as flakes or cakes. The more modern method extracts the agar under pressure in autoclaves. The agar is decolorized and deodorized with activated charcoal, filtered under pressure, and evaporated under reduced pressure. Further purification by freezing is then under taken.

The greatest use of agar is in association with food preparation and technology, and in the pharmaceutical industry. It is used for gelling andthickening purposes, particularly in the canning of fish and meat, reducing the undesirable effects of the can and providing some protection against shaking of the product in transit. It is also used in the manufacture of processed cheese, mayonnaise, puddings, creams, and jellies. Pharma- ceutically agar is used as a laxative, but more frequently it serves as an inert carrier for drug products where slow release of the drug is required, as a stabilizer for emulsions, and as a constituent of cosmetic skin preparations, ointments, and lotions. The use of agar as a stiffening agent for growth media in bacteriology and mycology, which was its main use almost a century ago, is still responsible for a very considerable part of the demand.)))

Carrageenan is a phycocolloid similar to agar but with a higher ash content and requiring higher concentrations to form gels. It is composed of varying amounts of the principal components, k-carrageenan and λ-carrageenans, both negatively charged high-molecular-weight polymers.

Carrageenans are used extensively for many of the same purposes as agar; however, because of their lower gel strength, carrageenans are used less for stiffening purposes than is agar, although for stabilization of emulsions in paints, cosmetics, and other pharmaceutical preparations carrageenans are preferred to agar. Also, for the stiffening of milk and dairy products, such as ice cream, carrageenans have supplanted agar completely in recent years, and it is in this area that demands for these products are the greatest. One particular use is for instant puddings, sauces, and creams, made possible by the gelling action, which does not require refrigeration.

Carrageenans inhibit human immunodeciency virus (HIV) replication and reverse transcriptionase *in vitro* (in the test tube). ***(((Replication of the HIV virus depends on interaction of a glycoprotein on the HIV virus envelope with a receptor on the target cells in the human body. The sulfated carrageenans prevent attachment of the HIV virus to the target cells. This occurs by the stronger negative R-O-SO3◌̄ groups on the carrageenan binding to a loop on the HIV molecule.)))***

A carrageenan-based vaginal microbicide called Carraguard® has been shown to block HIV and other sexually transmitted diseases in vitro. Carraguard has entered clinical trials involving 600 non-pregnant, HIV-negative women in South Africa and Botswana (Spieler, 2002; Smit, 2004).)))

Reproductive structures

The Rhodophyceae have no flagellated cells or cells with any vestigial structure of flagellation, such as basal bodies. In sexual reproduction,

spermatia are produced which are carried passively by water currents to the female organ, the **carpogonium** (Figs. 4.17(*a*), 4.18). The fertilized carpogonium produces **gonimoblast filaments** that form **carposporangia** and diploid **carpospores** (Fig.4.17(*b*)). The carpospores produce the diploid **tetrasporophyte** which subsequently gives rise to haploid **tetraspores**. Advanced red algae form chiefly tetrahedral tetrasporangia (Fig. 4.17(*d*)) with large spores, whereas less advanced groups

generally form cruciate or zonate tetrasporangia (Fig. 4.17(*d*), (*e*)) with smaller spores. Tetraspores are generally larger than carpospores. The tetraspores complete the life cycle by germinating to form the gametophyte.

Although this is the general life cycle of most Rhodophyceae, there are a number of modifications of it.

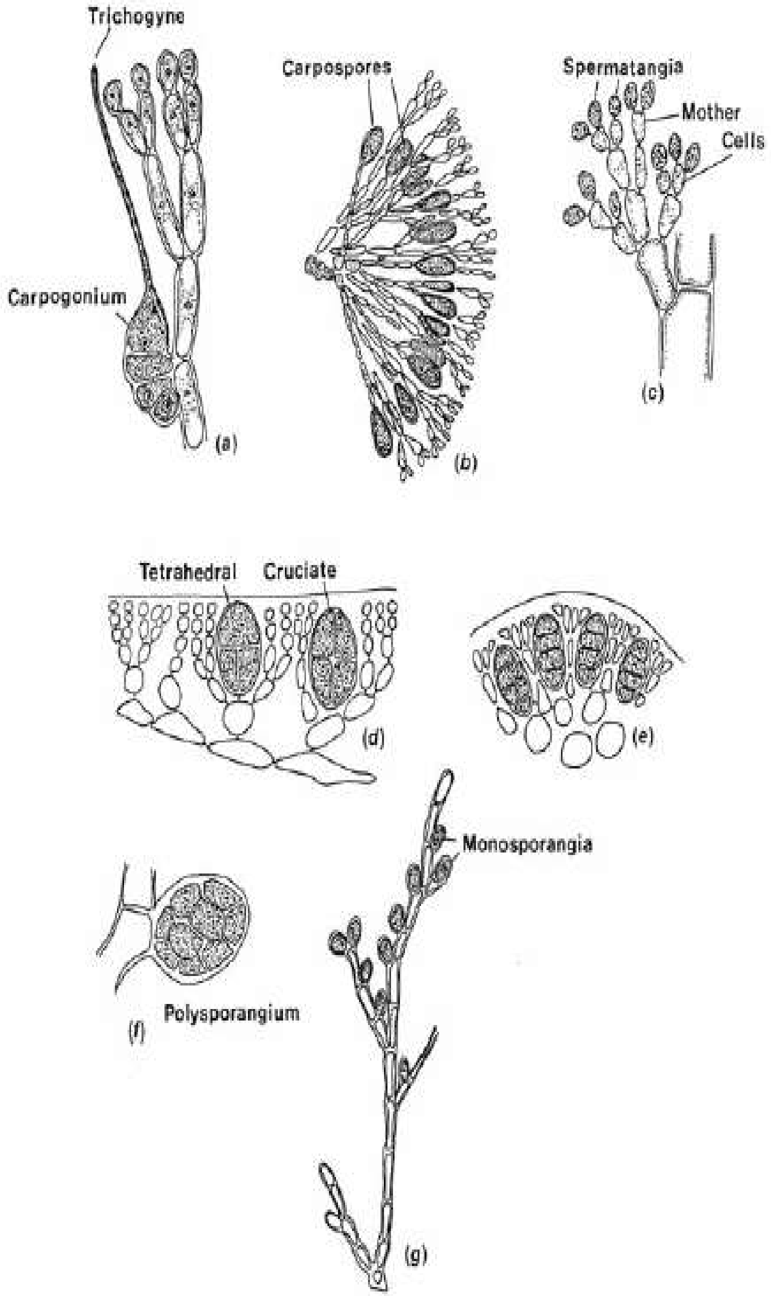


Fig. 4.17 (*a*) A filament of *Liagora viscida* with a carpogonial branch. (*b*) Gonimoblast filaments of *L. viscida* with carpospores. (*c*) A spermatangial branch of *Acrochaetium corymbiferum* with spermatangia and spermatangial mother cells. (*d*) Tetrahedral and cruciate tetrasporangia of *Nemastoma laingii*. (*e*) Zonate tetrasporangia of *Hypnea musciformis*. (*f*) Polysporangium of *Pleonosporium vancouverianum*. (*g*) Monosporangia of *Kylinia rhipidandra*. ((*a*), (*b*), (*c*), (*e*) after Kylin, 1930; (*f*) after Kylin, 1924; (*g*) after Kylin, 1928.)

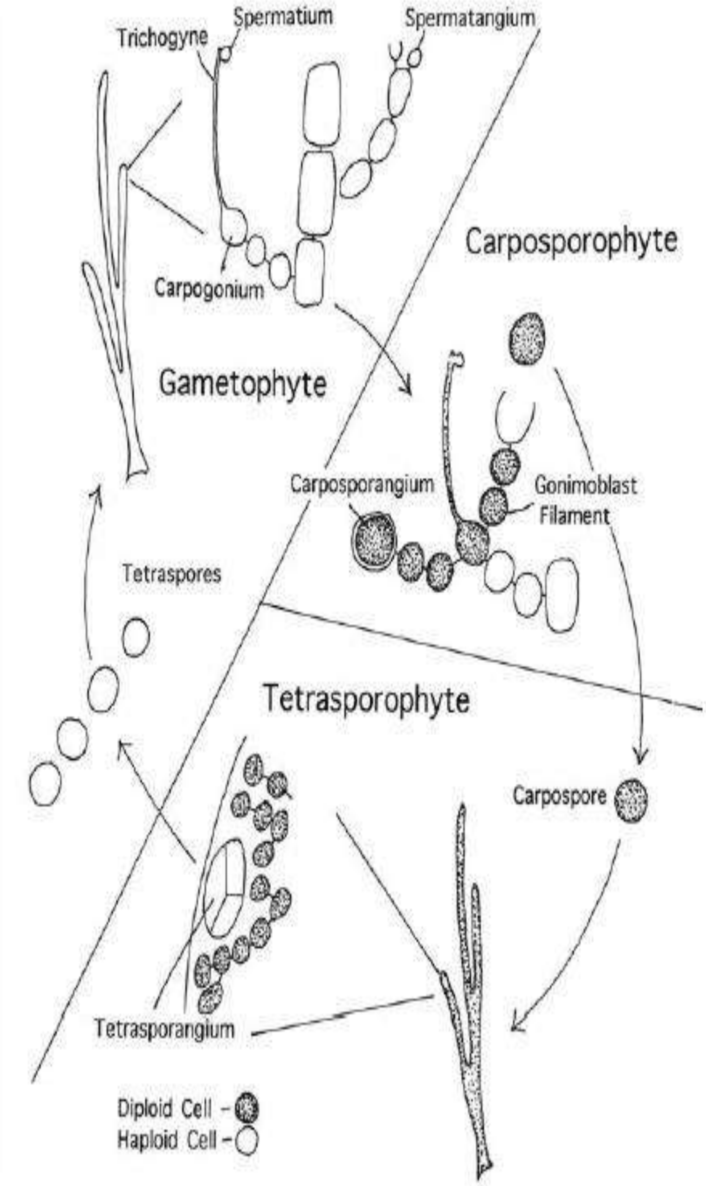


Fig. 4.18 Simplified life cycle of a typical red alga.

Classification:

The Rhodophyta has a single class, the Rhodophyceae. Which involves ten orders as follows:

Order 1 **Cyanidiales:** unicells that inhabit volcanic areas with pH values ranging from 0.5 to 3.

Order 2 **Porphyridiales:** unicells, or multicellular algae that are held together by mucilage.

Order 3 **Bangiales:** plants having a filamentous phase with pit connections and a macroscopic phase without pit connections.

Order 4 **Acrochaetiales:** algae with a uniseriate filamentous gametophyte and tetrasporophyte (if both are present).

Order 5 **Batrachospermales:** uniaxial (one apical cell per branch); gonimoblast usually develops from the carpogonium or hypogenous cell.

Order 6 **Nemaliales:** multi axial (more than one apical cell per branch); usually the gonimoblast develops from the carpogonium or the hypogenous cell.

Order 7 **Corallinales:** heavily calcified algae with the reproductive organs in conceptacles.

Order 8 **Gelidiales:** fleshy agarophytes, carpogonial branch consisting of a single cell, the carpogonium, no differentiated auxiliary cells.

Order 9 **Gracilariales:** fleshy agarophytes, two celled carpogonial branch, no auxiliary cells, or connecting cells.

Order 10 **Ceramiales:** relatively delicate or filamentous forms with an auxiliary cell cut off after fertilization and borne on the supporting cell of a four-celled carpogonial filament.

(((Ceramiales:

These plants have the auxiliary cell cut off after fertilization and borne on the supporting cell of the four-celled carpogonial filament. Most of the plants are relatively delicate filamentous or membranous forms.

In Polysiphonia the uninucleate, dome-shaped apical cell (Fig. 4.45(b)) is polyploid and contains 64 to 128 times the amount of DNA in most of the

mature cells in the alga.

Division of the cells derived from the apical cell is usually not accompanied by DNA replication; there fore, the farther the daughter cell is from the apical cell, the lower the ploidy of the cell, until the ploidy number stabilizes at 1 n. The apical cell forms daughter cells that produce

lateral branches before dividing longitudinally into central and pericentral cells (Figs. 4.44, 4.45).

The pericentrals are the same length as the axial cells. The lateral branches are of two kinds: the ordinary branches and the trichoblasts. The ordinary branches are polysiphonous with unlimited growth, similar to the main axis. The trichoblasts are uniseriate, usually colorless, and bear the sex organs (Fig. 4.45(c)). The trichoblasts progress and drop off from the older parts of the thallus.

Polysiphonia species occur either as lithophytes or as epiphytes on other algae. When the species grows on a solid substrate, some of the polysiphonous axes creep over the substratum to which they are firmly anchored by thick-walled, lobed rhizoids (Fig. 4.45(d)). When it grows as an epiphyte on another alga, the rhizoids penetrate that host tissue. The procarps are produced near the base of a trichoblast (Figs. 4.44, 4.45(g)).

The two basal cells of the trichoblast become polysiphonous, and a procarp develops from a pericentral of the upper of the two basal cells. The pericentral (supporting cell) produces in succession a lateral sterile cell, the four-celled carpogonial branch, and, last, the second sterile cell. The sterile cells divide after fertilization and may have a nutritive role. The cells of the carpogonial branch (with the exception of the carpogonium) are commonly binucleate. A large area of endoplasmic reticulum extends from one pit connection to the other pit connection in each cell of the carpogonial branch. This may be how the message of fertilization is transmitted down the carpogonial branch.

The male plants of Polysiphonia bear spermatangial sori on a trichoblast consisting of a two celled stalk surmounted by the fertile regions (Figs. 4.44, 4.45(e), (f)). The upper stalk cell frequently bears a branch. Fertile regions become polysiphonous, and the two pericentrals divide copiously to form a compact layer of mother cells, each of which gives rise to two or three spermatangia. After the spermatium fertilizes the trichogyne, the auxiliary cell is cut off from the supporting cell. The auxiliary cell

then fuses with the carpogonium. The male nucleus fuses with the female in the carpogonium, and the diploid nucleus divides once. One of the diploid nuclei passes into the auxiliary cell, which subsequently fuses with the supporting cell. The fusion cell also fuses with the axial cell of the fertile segment. The gonimoblast initials are cut off from the fusion cell and develop into a number of gonimoblast filaments.

The terminal cells of these filaments develop into pear-shaped carposporangia. In the meantime, the fusion cell unites with the gonimoblast initial and the fertile cells. The sterile outer envelope of the cystocarp (Fig. 4.45(b)) originates from the other pericentrals of the axial cell that gave rise to the fertile pericentral that acted as the *supporting cell. The young envelope consists of two lateral valves, composed of fused threads, which enclose the procarp like the shells of an oyster, the trichogyne alone projecting. After fertilization the two valves unite, and the envelope becomes two-layered. The carpospores form a tetra sporophyte, which is similar to the gametophyte, and which forms tetrahedrally arranged tetra spores (Fig. 4.45(j), (k)) in polysiphonous*

branches called stichidia. The tetraspores then germinate to form the gametophyte.

Polysiphonia denudata completes its life history in 1.5 months in culture; thus the species probably has several life cycles each year. In some species of Polysiphonia, it is possible to influence stages of the life cycle by changing the photo period, but there appears to be no regularity among the different species.

In the marine environment, herbivorous damselfish exclude other fish from their territories, and maintain dense stands of filamentous

algae. One damselfish, the dusky farmerfish (Fig.4.46), is unique in that it maintains a monoculture of Polysiphonia in coral reefs by selective weeding of other indigestible algae. The farmerfish grazes on the Polysiphonia sp. The relationship between the farmerfish and

Polysiphonia is an example of mutualism (a situation where two populations benefit equally).

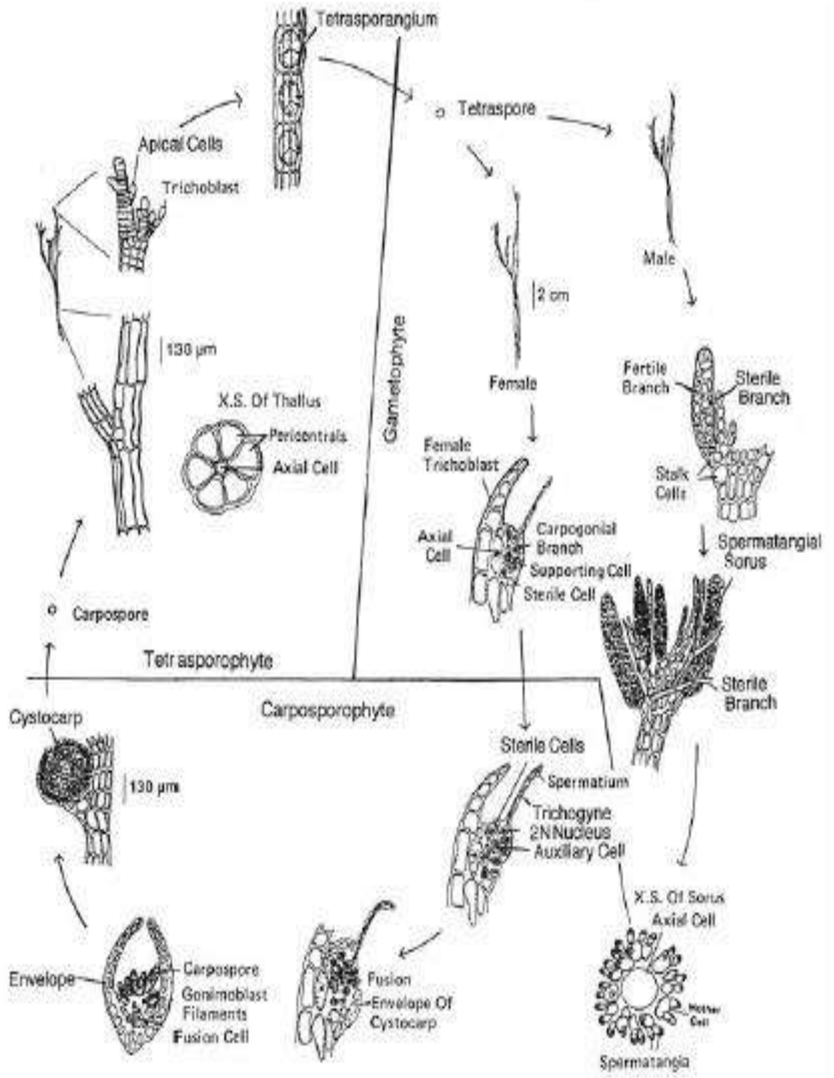


Fig. 4.44 The life cycle of *Polysiphonia* sp. (Adapted from Kylin, 1923; Edwards, 1970a.)

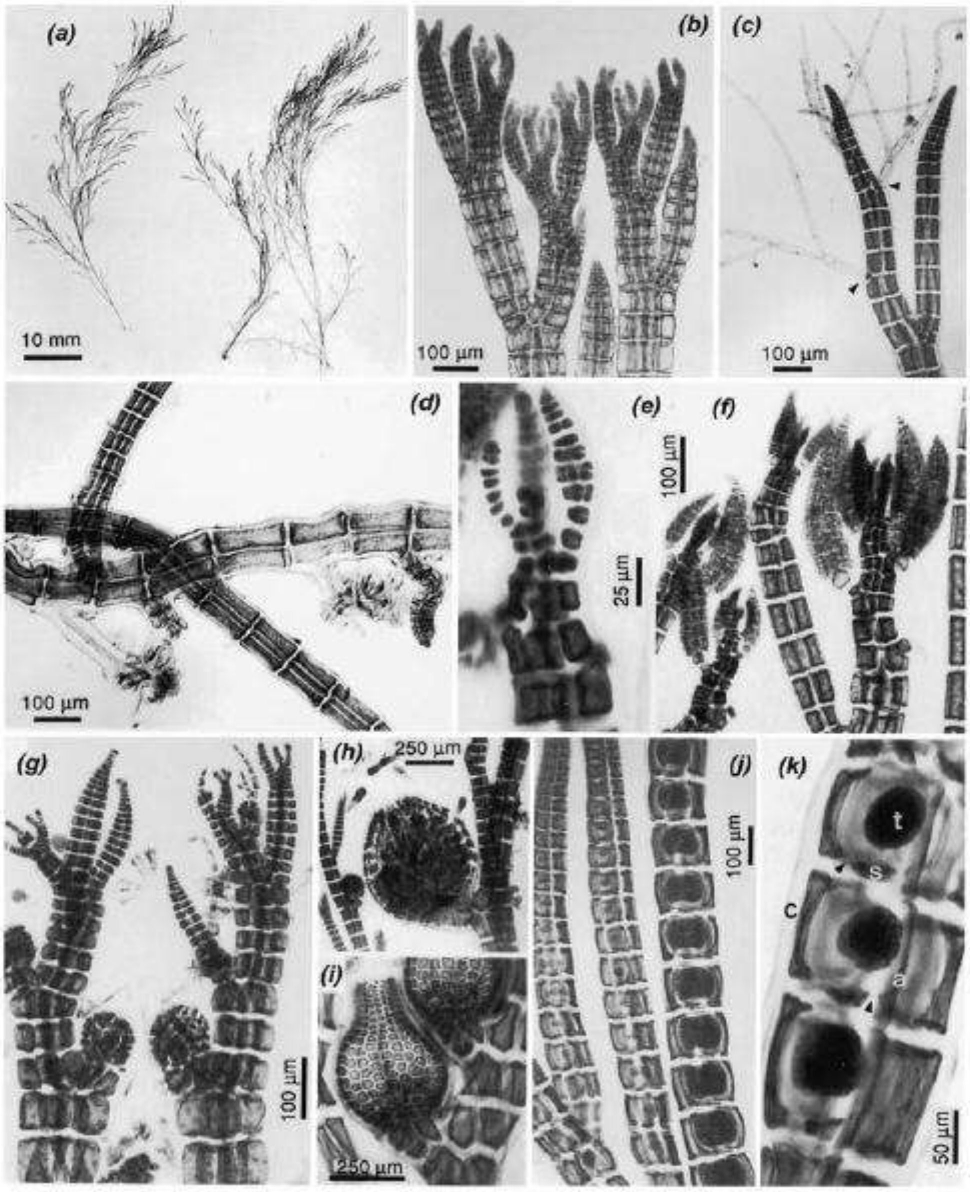


Fig. 4.45 Vegetative and reproductive structures of *Polysiphonia stricta*. (*a*) Habit of thalli from shallow subtidal bedrock. (*b*) Vegetative apices showing large apical cells with oblique branching. (*c*) Trichoblasts, composed of uninucleate cells, attached by small scar cells (arrowheads). (*d*) Prostrate axis attached by unicellular rhizoids in open connection with pericentral cells. (*e*, *f*) Developing and mature spermatangial branches with sterile tips. (*g*) Tips of female thallus with procarps and early postfertilization cystocarps. (*h*) Mature globose cystocarp, with extruded pyriform carposporangia. (*i*) Mature cystocarp. (*j*) Developing and mature tetrasporangia in long straight rows. (*k*) Tetrasporangia (t), showing pit connections (arrowheads) between tetrasporangial stalk cells (s), central axial cells (a), and cover cells (c). (From Kim et al., 2000.)

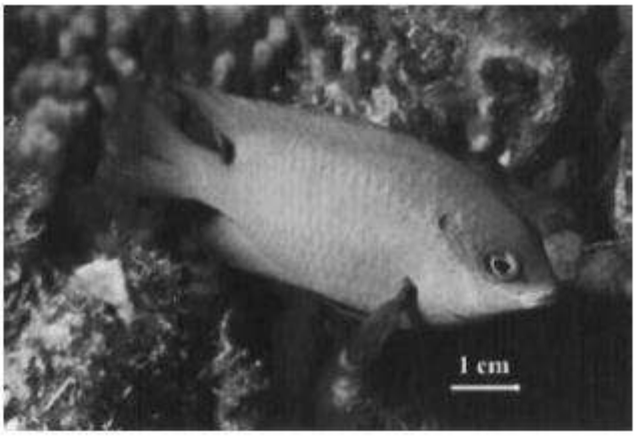


Fig. 4.46 The dusky farmerfish *Stegastes nigricans*, a cultivator of *Polysiphonia* in coral reefs.