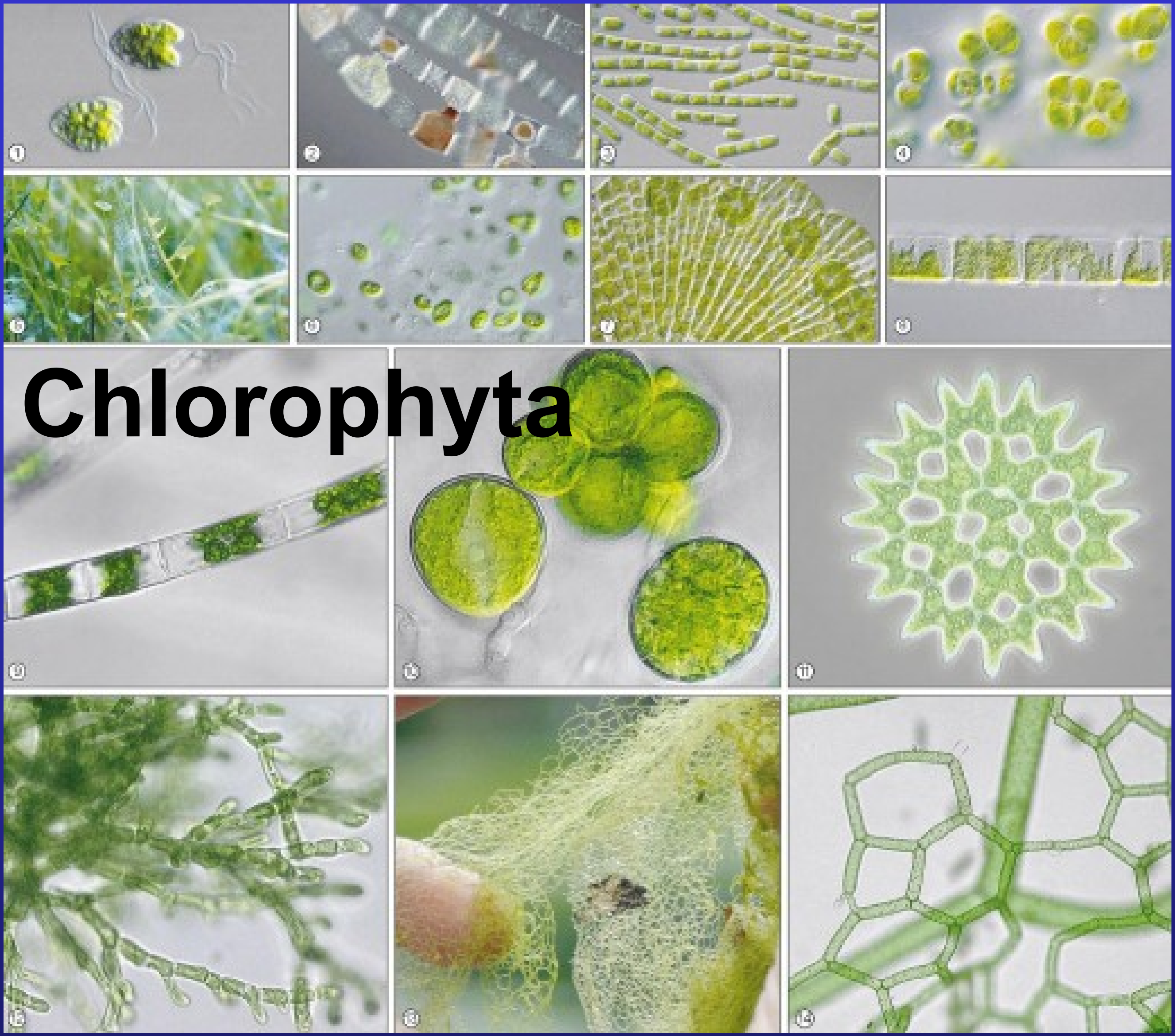
Chlorophyta

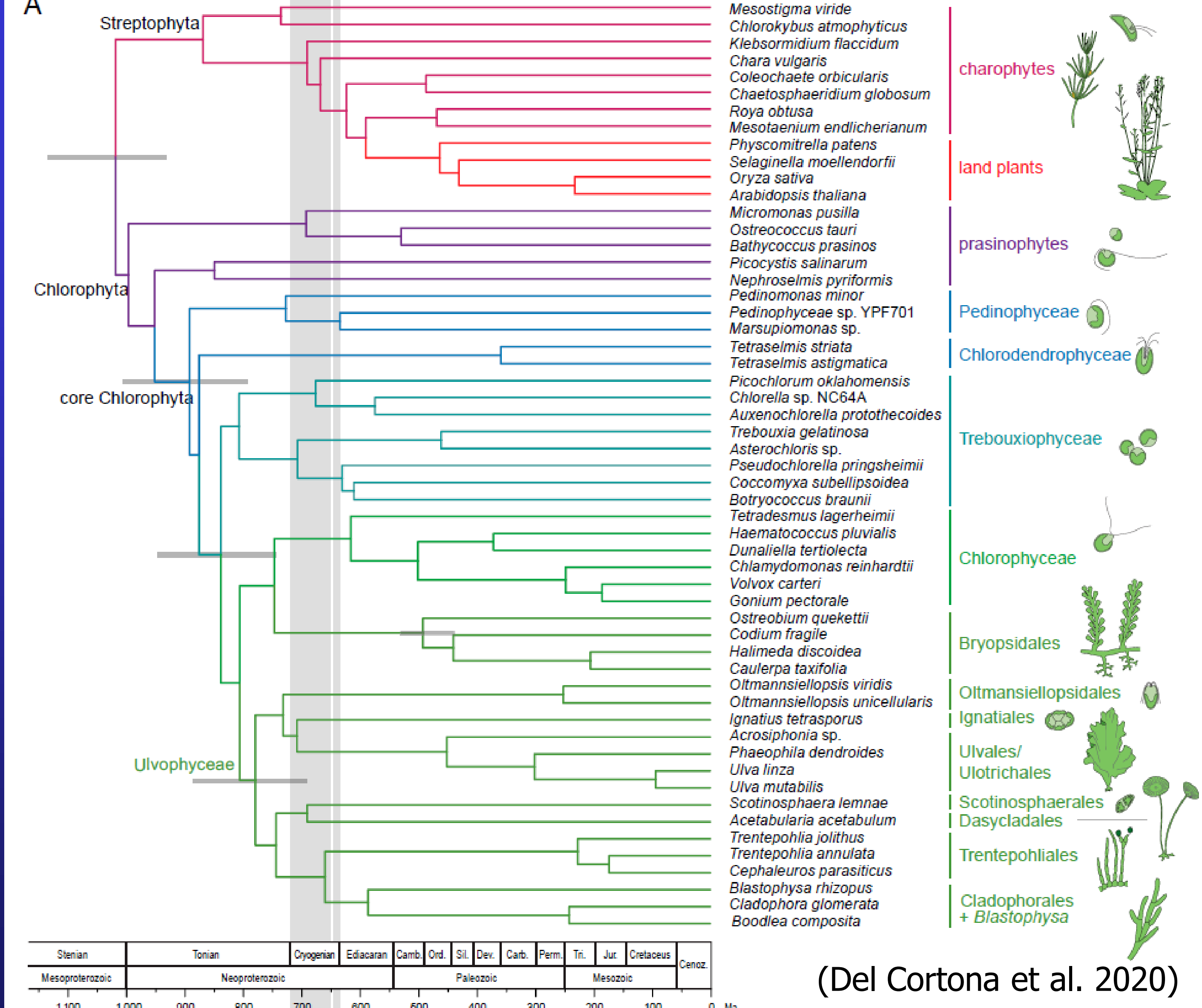


great shape diversity

also in extreme env.

•Exclusively terrestrial groups: Trentepohliales.
•Symbiovarious eukaryotes, including fungi (forming lichens), ciliates, foraminiferans, gastropods, and vertebrates.
•Obligate heterotrophs – parasitic forms, e.g., *Prototheca*.

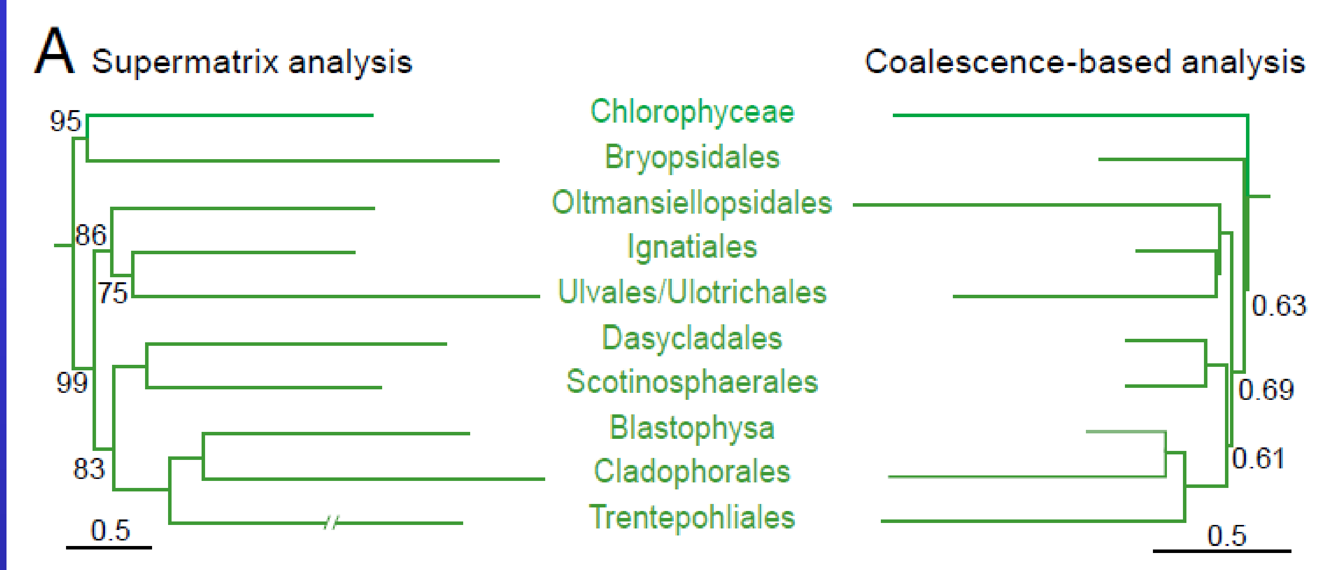
the core Chlorophyta emerged during the Neoproterozoic Era, approximately 1,000 to 700 Mya

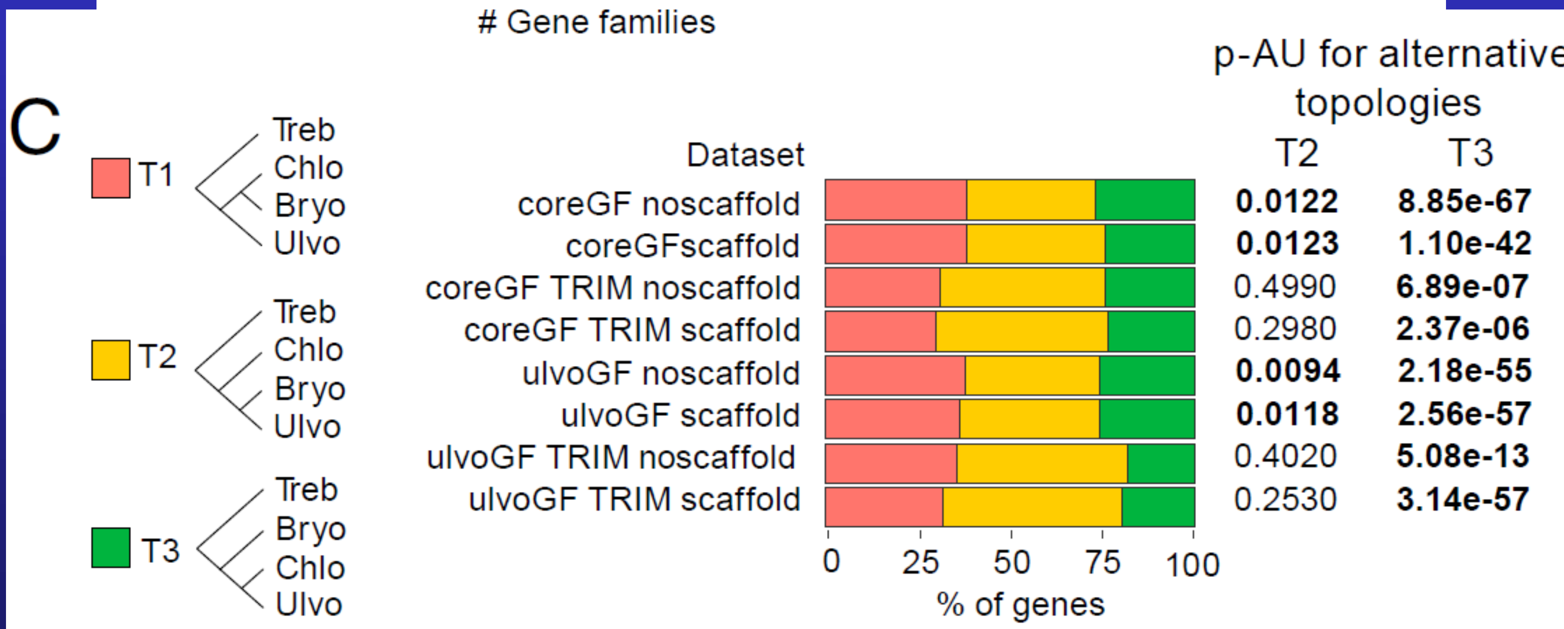


(Del Cortona et al. 2020)

Time-calibrated phylogeny of the green algae. (A) The topology of the tree is based on the ML analysis inferred from a concatenated amino acid alignment of 539 nuclear genes

Del Cortona et al. 2020



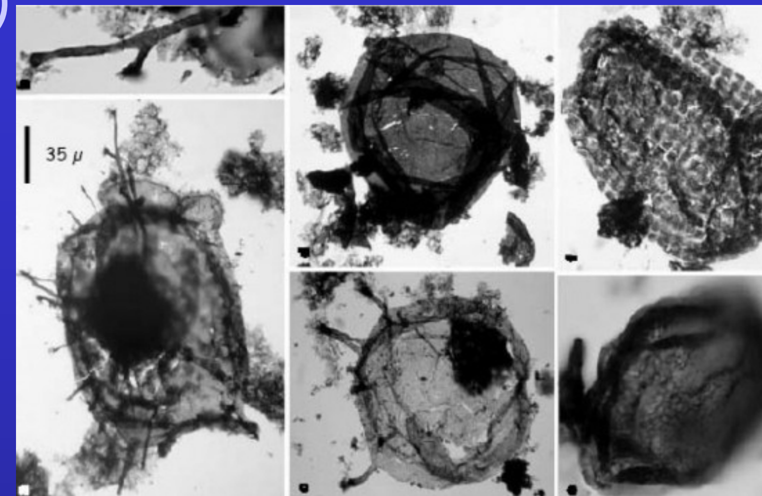


Proportion of genes supporting a sister relationship between Bryopsidales and Chlorophyceae (T1), a sister relationship between the Bryopsidales and remaining Ulvophyceae (T2), and a sister relationship between Chlorophyceae and Ulvophyceae (Bryopsidales excluded) (T3);

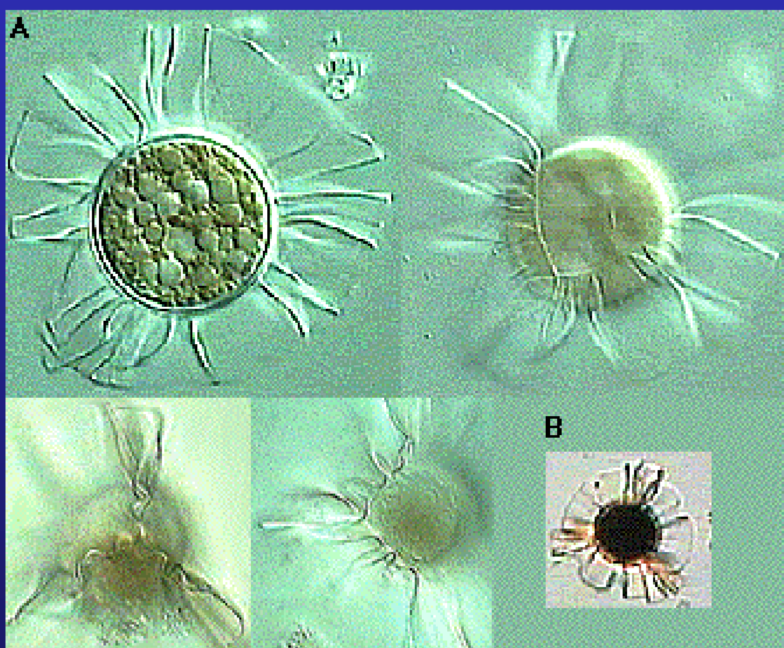
Dating of the green line origin – difficult (1000-700 mya or earlier?)

first fossil Precambrium 1.8 – 2.0 Ga - controversal

Acritarchs



Phycomata



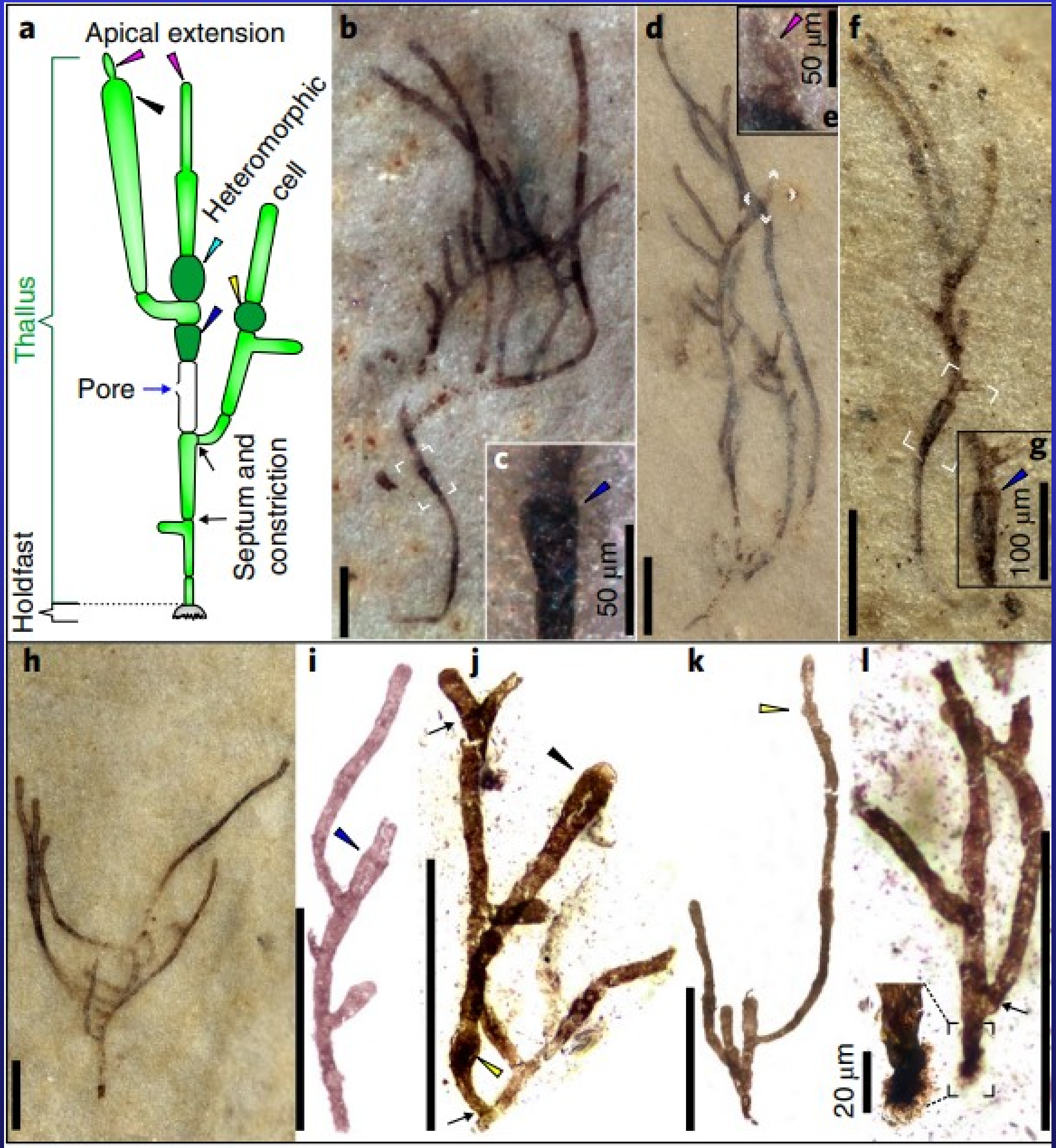
fossil records from late Precambrium (250-540 mya)

Proterocladus (Svalbard)

Cladophora-like? 780 mya

A one-billion-year-old multicellular chlorophyte

abundant millimetre-sized, multicellular and morphologically differentiated macrofossils from rocks approximately 1,000 million years ago. These fossils are described as *Proterocladus antiquus* new species and are interpreted as benthic siphonocladalean chlorophytes, suggesting that chlorophytes acquired macroscopic size, multicellularity and cellular differentiation nearly a billion years ago, much earlier than previously thought.



Gross morphology of P. antiquus new species from the Nanfen Formation, China.

Tang et al. 2020
https://doi.org/10.1038/s41559-020-1122-9

Nuclear DNA Content Estimates in Green Algal Lineages

• Large genomes lead to increased cell size; the aquatic environment provides an advantage - organisms are buoyant, so they can afford this (giant cells characteristic of Charophytes).
• The ancient atmosphere contained low levels of oxygen and ozone and high UV radiation; therefore polyploid (redundant) genomes represented an evolutionary advantage.

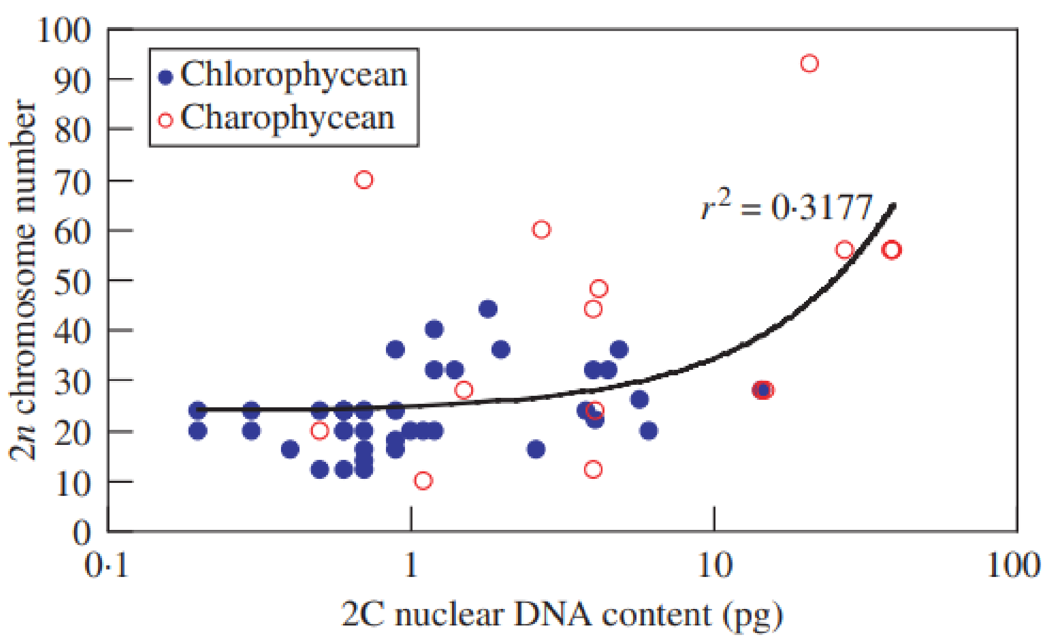
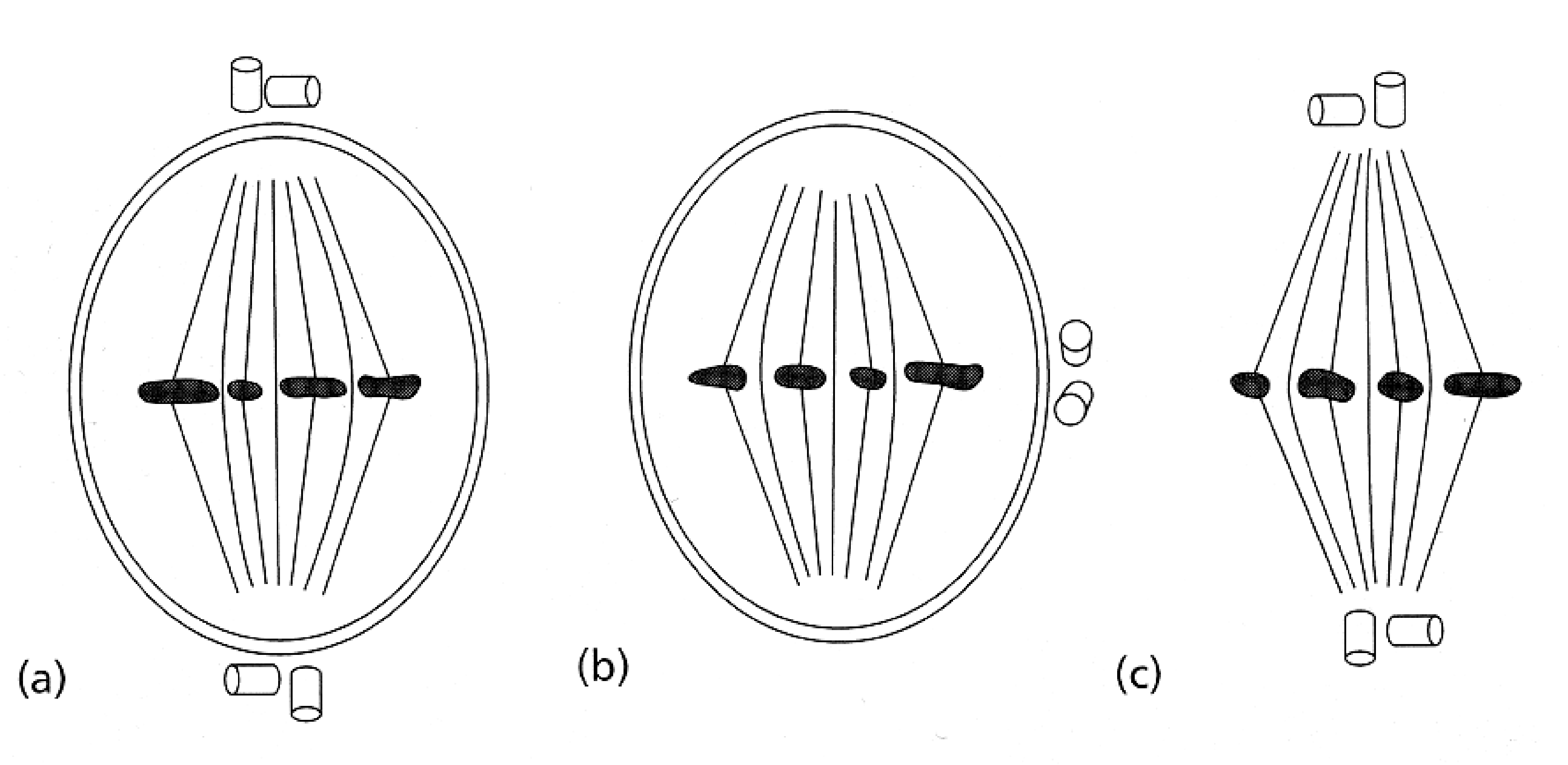


FIG. 11. Comparison of 2*n* chromosome complements and 2C nuclear DNA contents in species of Chlorophyta included in Appendix I.

Kapraun et al. 2007

Chlorophyta - 2C DNA estimates range from 0·01 to 5·8 pg.

Mitosis type



closed **closed metacentric** **open**

Graham, str. 407

Cell cycle

Chlorophyta: mostly haplontic cycle (in the whole cycle, zygotes are the only diploid cell)

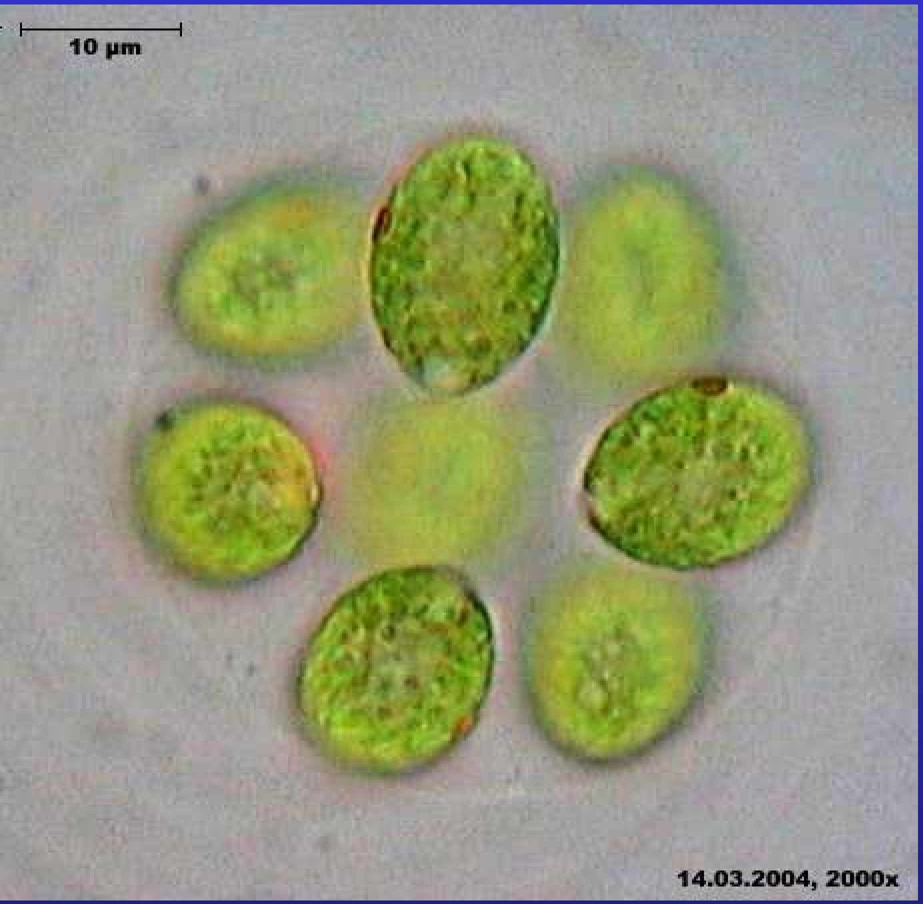
Haplo-diplontic cycle developed repeatedly Ulvophyceae (order Ulvales), Cladophorales, Bryopsidales, Trentepohliales (some species)

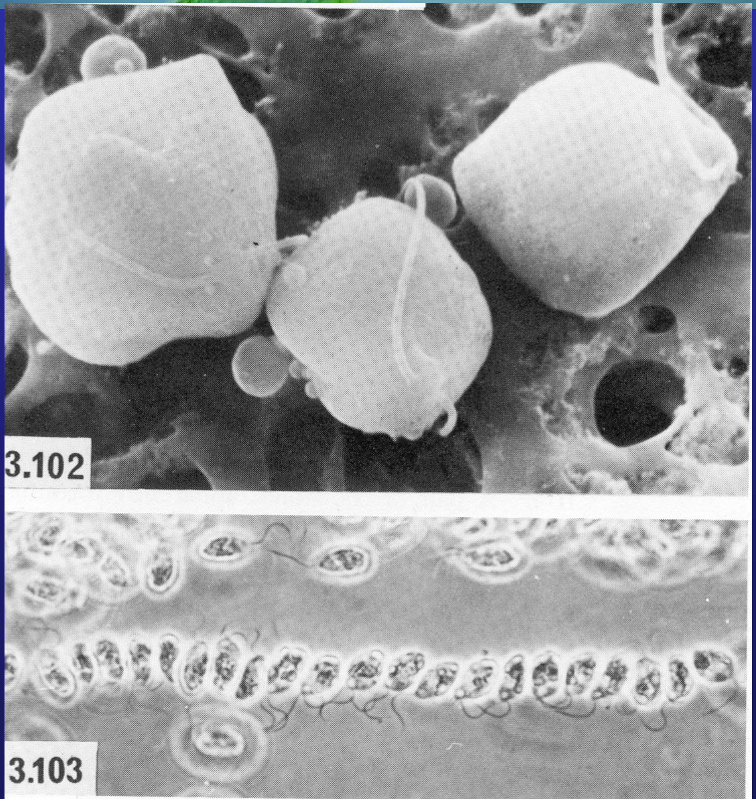
Asexual reproduction

single-celled mostly single-nuclear mitospores (as a product of mitosis)

- zoospores
- aplanospores
- hemiaplanospores
- autospores

Asexual reproduction



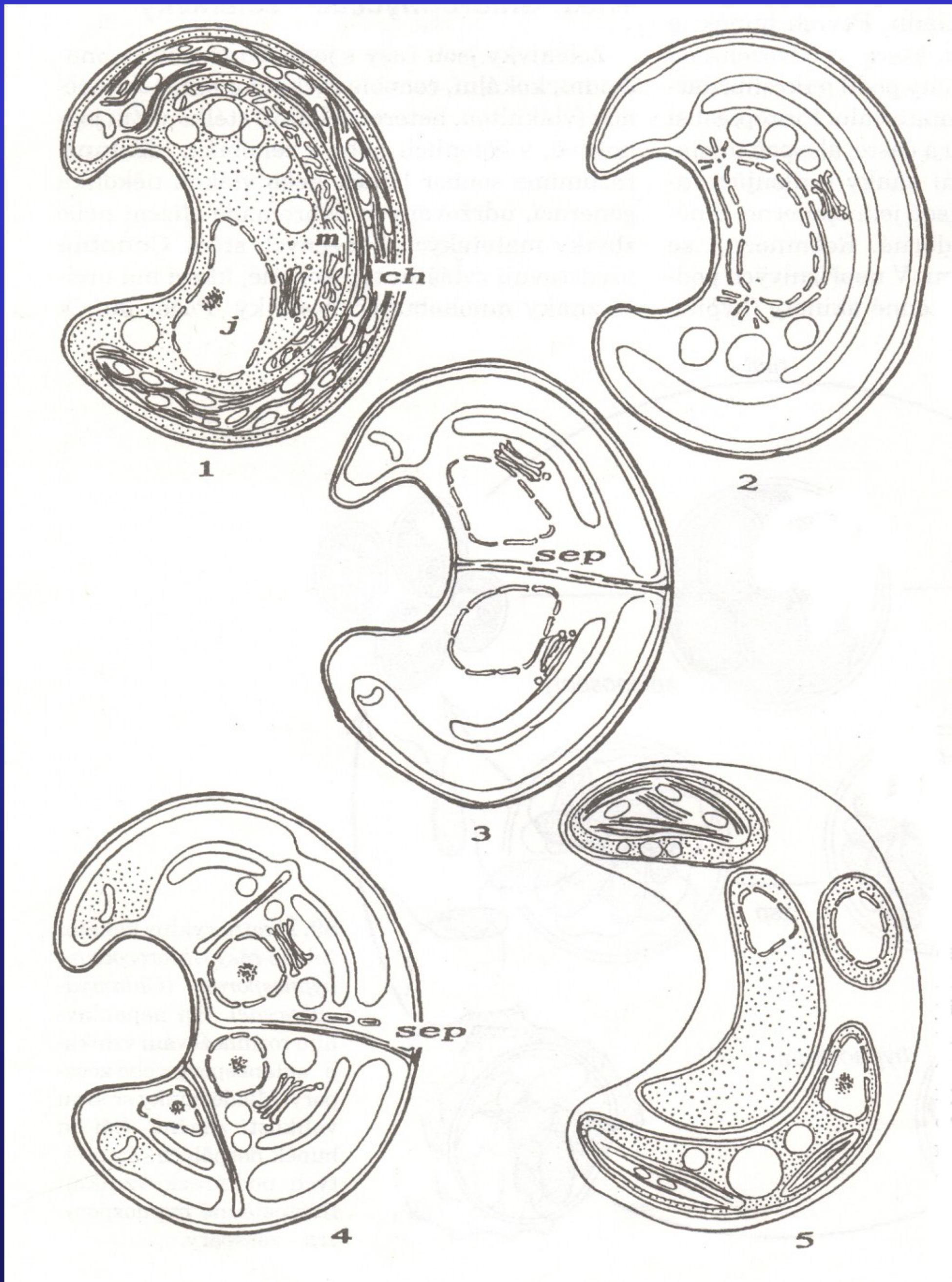


Chlorococcum –
hemiaplanospores (pulsující vakuoly, stigma)

Hydrodictyon - zoospores

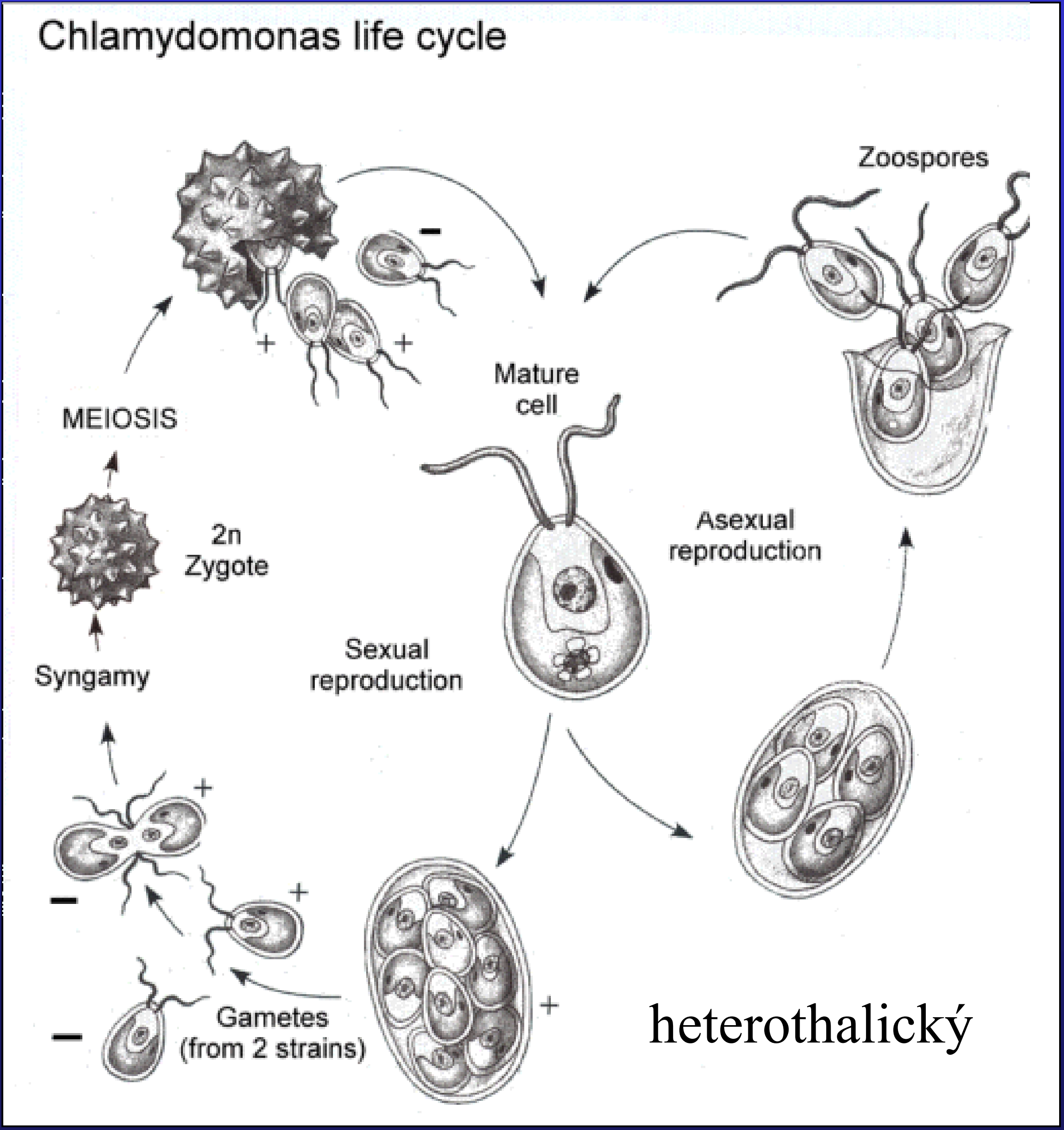
Chlorococcum - zoospores

autospores *Kirchneriella*



Sexual reproduction

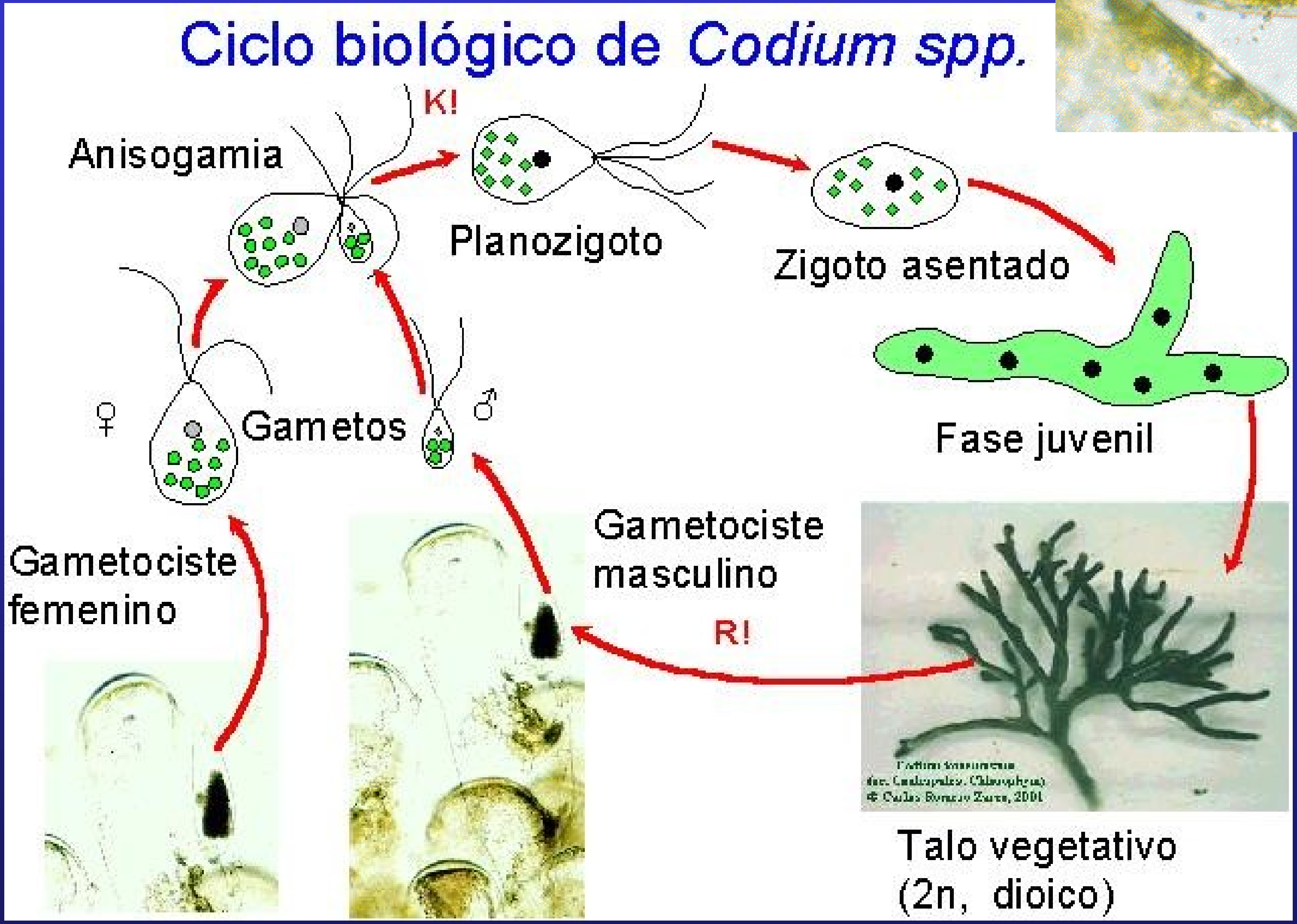
- **izogamy** (hologamy)
- anizogamy
- oogamy



homothalický: +a- gamety v jedné buňce

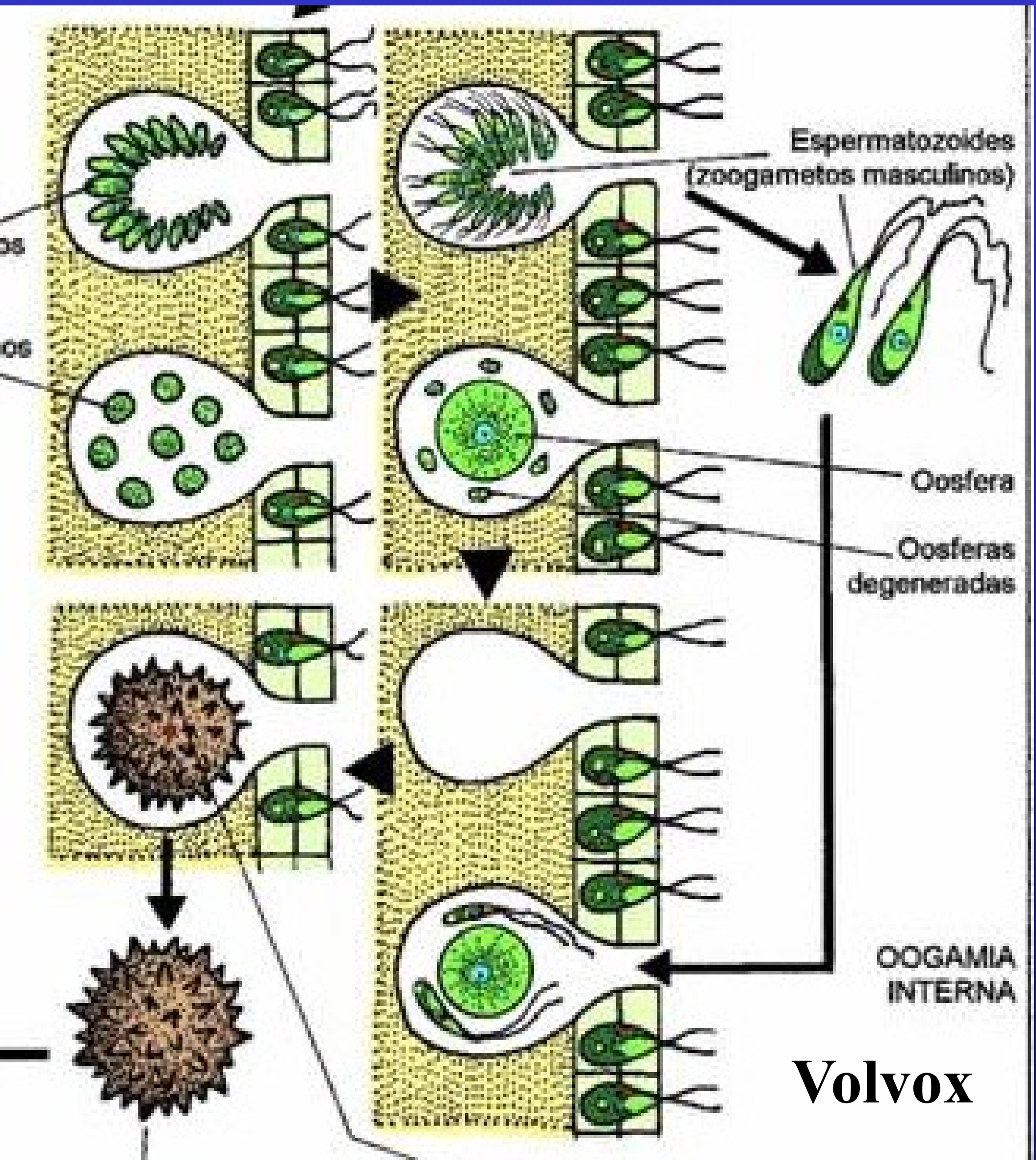
Sexual reproduction

anizogamy



Sexual reproduction

oogamy



Chlorophyceae

monophyletic

Class: Chlorophyceae

Basic Characteristics:

•Various types of thalli (flagellated, coccoid, sarcinoid, filamentous, siphonous)

•Cell wall of flagellates – glycoprotein-based; others – polysaccharide-based (mostly cellulose)

•Zoids with 2 or 4 flagella, cross-arranged microtubule roots, DO or CW orientation of basal bodies; stephanokont zoospores in Oedogoniales

•Closed mitosis, spindle does not persist into telophase, transverse septum (cleavage furrow or cell plate), phycoplast, plasmodesmata

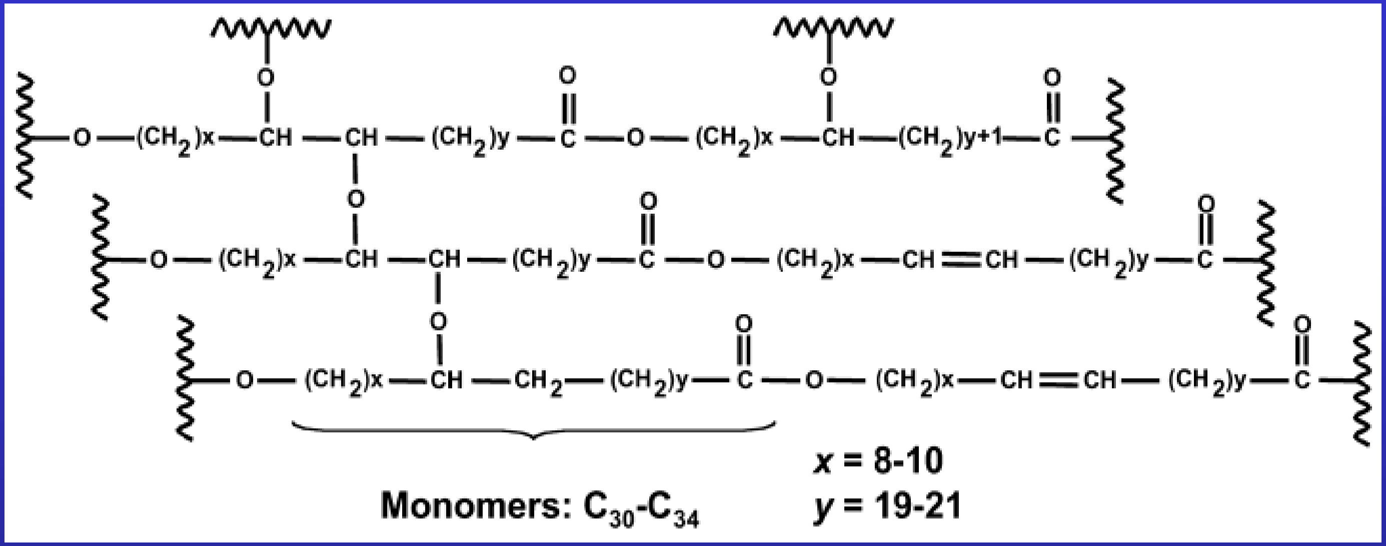
•Asexual reproduction by forming zoospores, autospores, and aplanospores

•Sexual reproduction, haplontic life cycle, often forming thick-walled hypnozygotes, isogamy, anisogamy, oogamy

•Almost exclusively freshwater or terrestrial

•Algaenans – acetate-resistant biopolymers

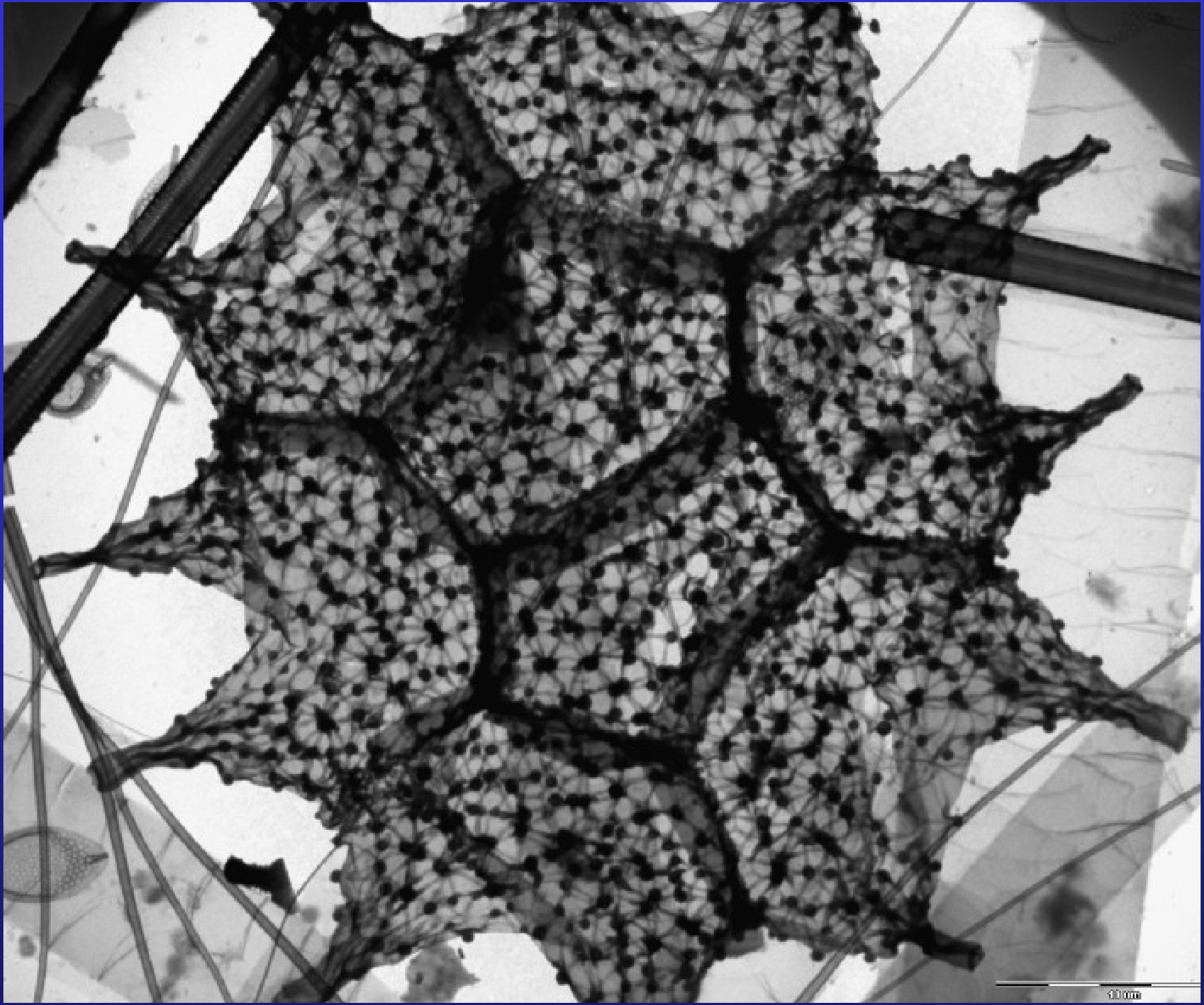
Algaenans – acetoresistent biopolymers



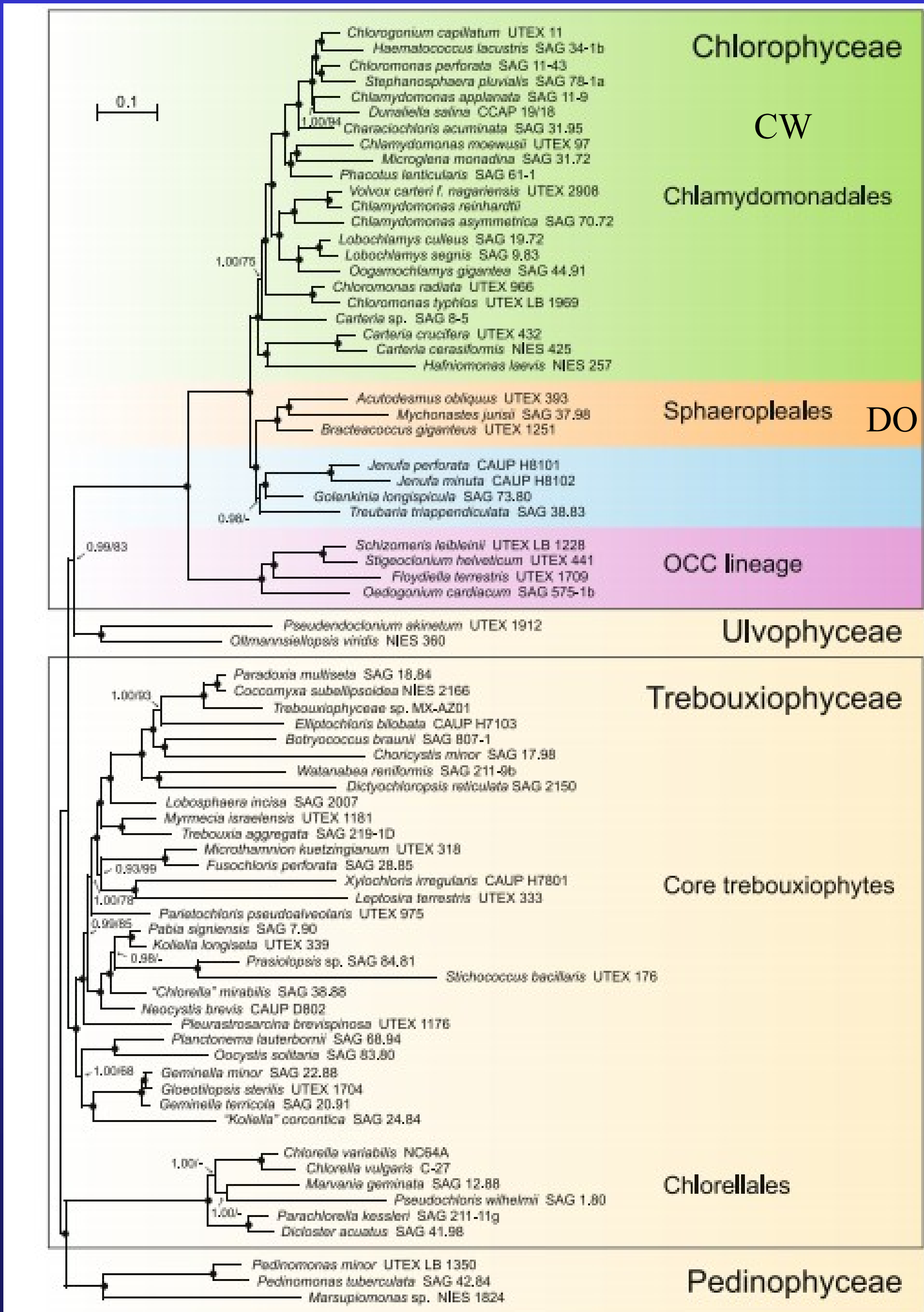
alifatic hydrocarbon chains, crosslinked

Desmodesmus, Tetraedron, Pediastrum,
Coelastrum, Sorastrum,
hypnozygotes *Chlamydomonas*, zygospores
Dunaliella, akinets *Haematococcus*

Adaptive mechanism
Fosilized remnants of the cell wall in palinological samples



Pseudopediastrum boryanum



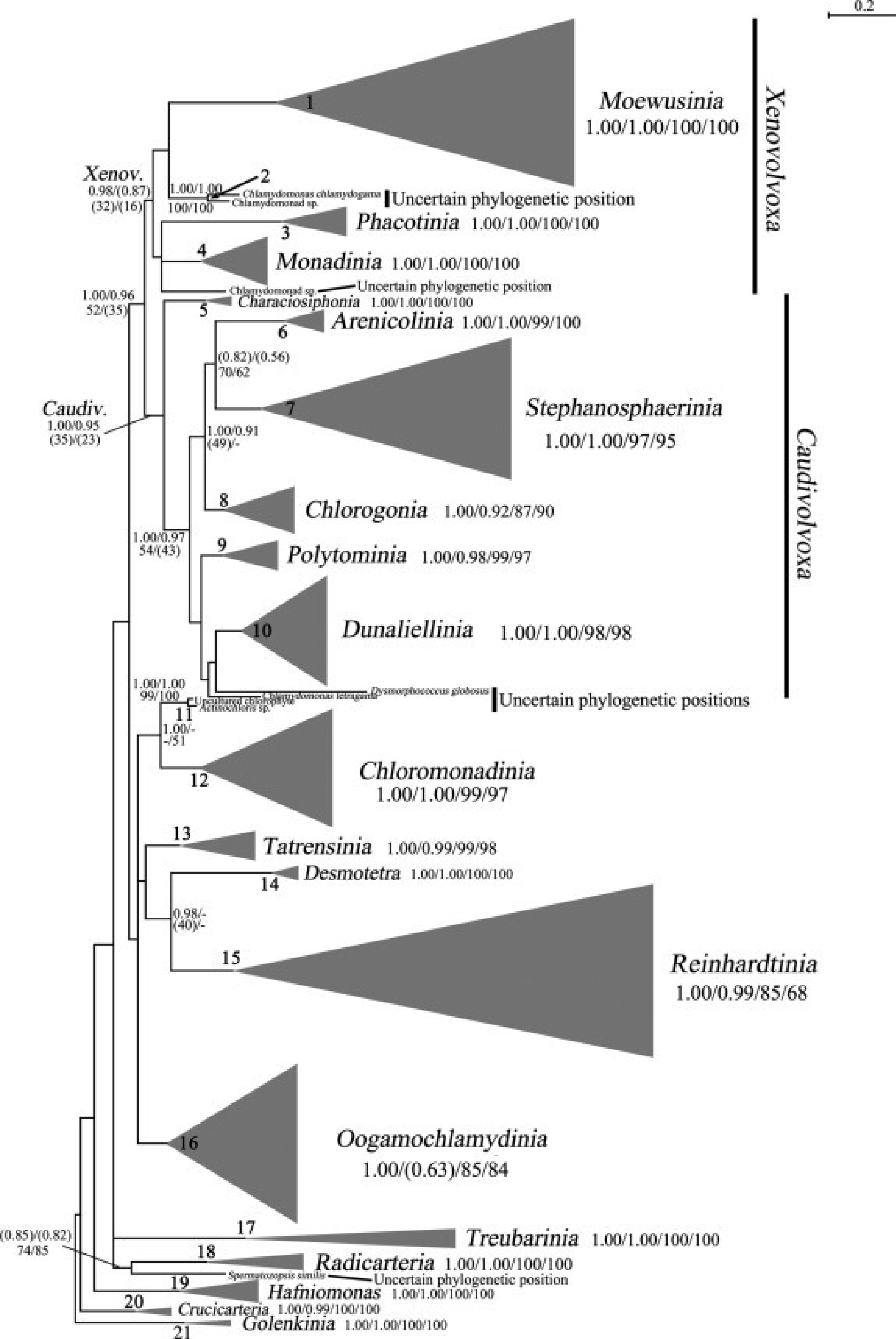
Conclusions: Our phylogenomic study advances our knowledge regarding the circumscription and internal structure of the chlamydomonadales, suggesting that a previously unrecognized lineage is sister to the Sphaeropleales.

Lamieux et al. 2015

Phylogeny of chlorophycean taxa inferred using nucleotide data sets assembled from 69 protein-coding and 29 RNA-coding genes

Chlamydomonadales

Nakada et al. 2008 (Mol. phyl. evol.)

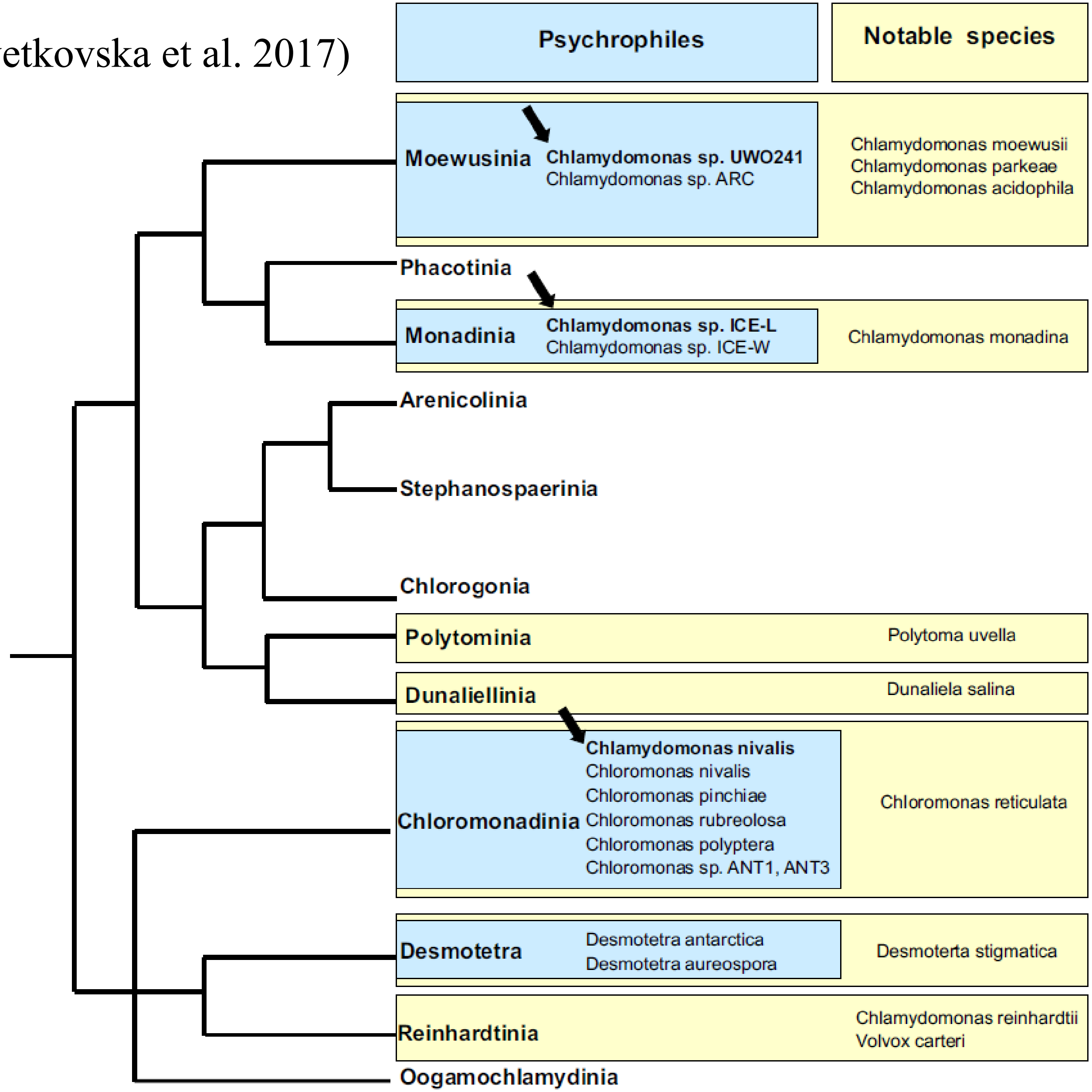


Example of classification based on PhyloCode (vs. International Code of Botanical Nomenclature) 21 well-supported clades)

PhyloCode

PhyloCode – a set of formal rules – naming of entire monophyletic clades. The content of a taxon is based on phylogeny (ancestors and descendants) – a clade is defined as an ancestor and all its descendants – classification based on a phylogenetic hypothesis.

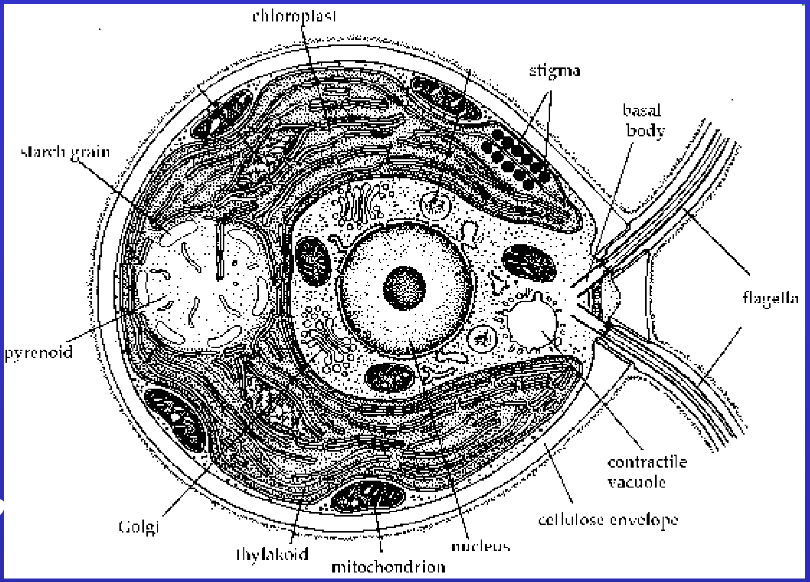
Cvetkovska et al. 2017)

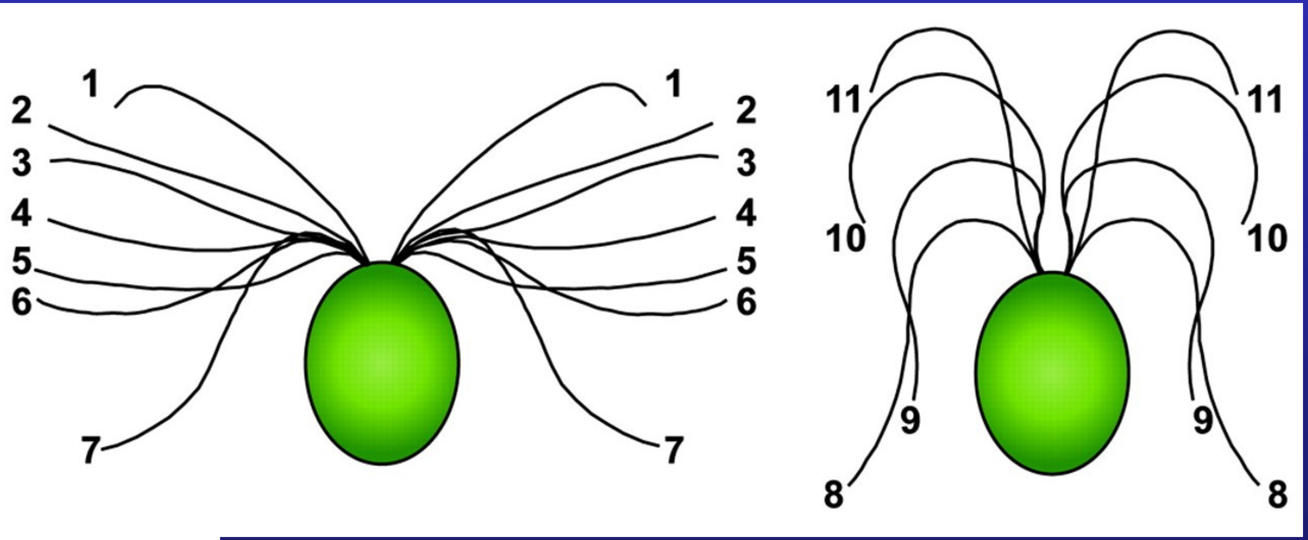


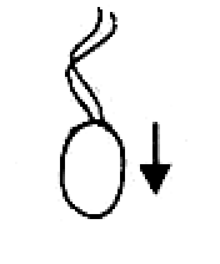
The position of the known psychrophiles in the Chlamydomonadales

<u>Class:</u> *Chlorophyceae*

How does *Chlamydomonas* swim?







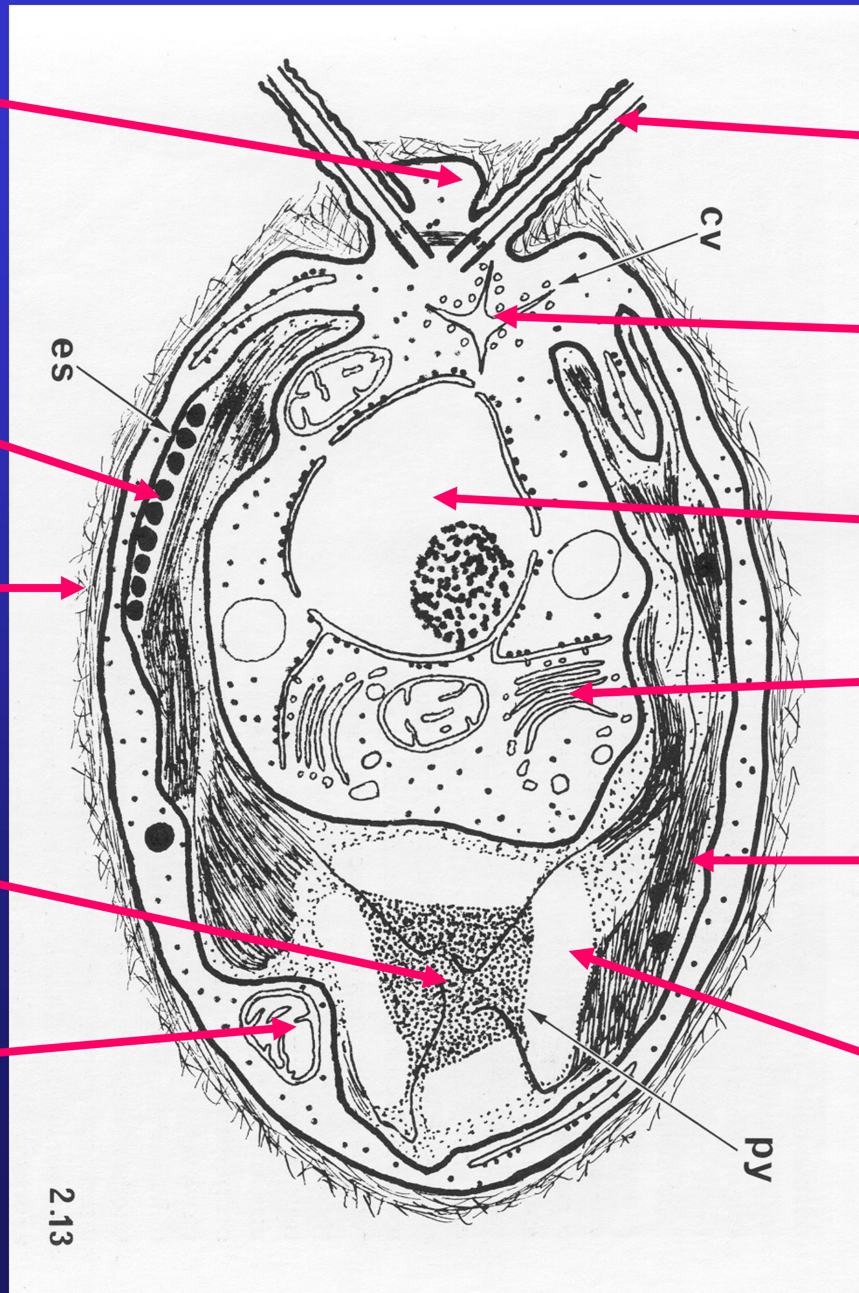
Chlamydomonas reinhardtii – a model of flagellated plant cell

How does the cell move? How does it respond to light?

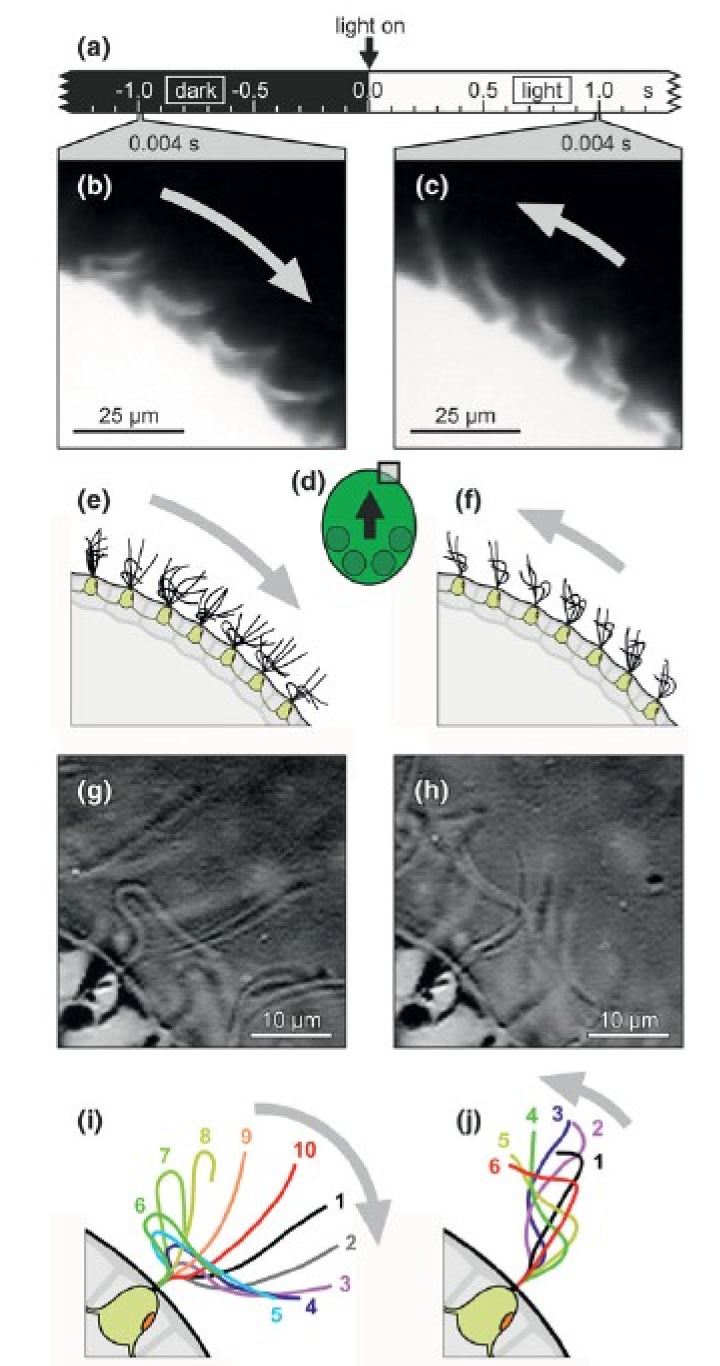
How do they recognize each other?

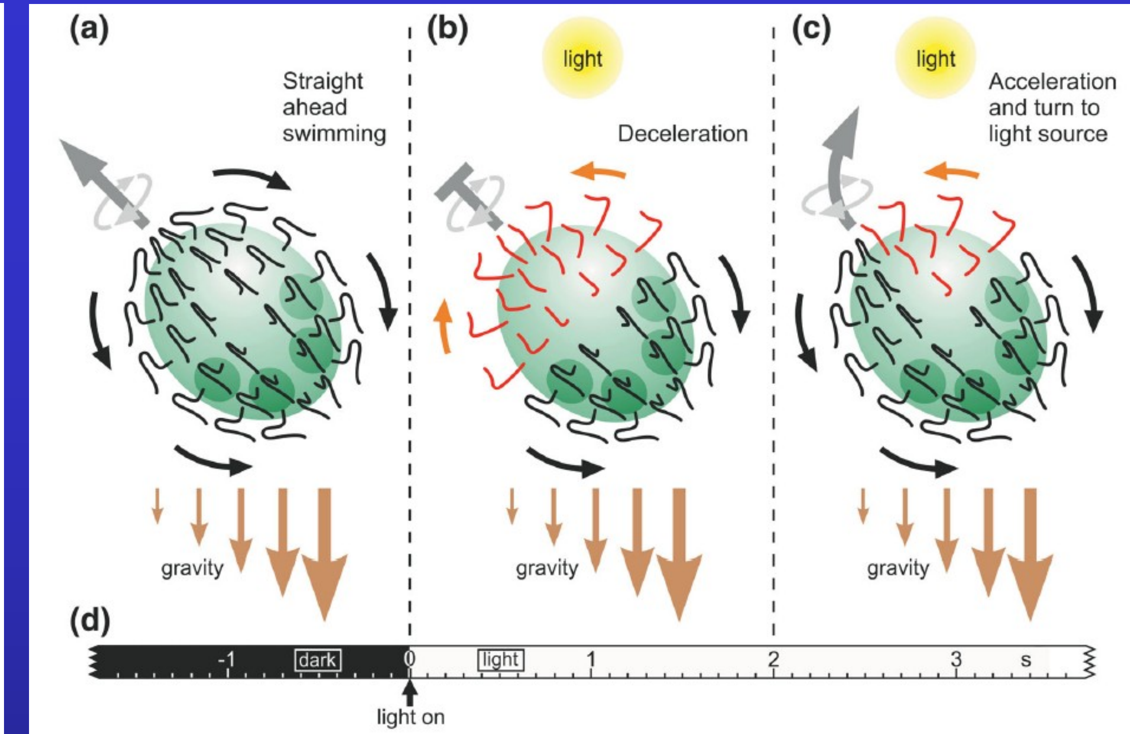
How do they react to changes in environmental conditions? mutants

Chlamydomonas 500 species described



AA hydroxyproline,
autolyzines

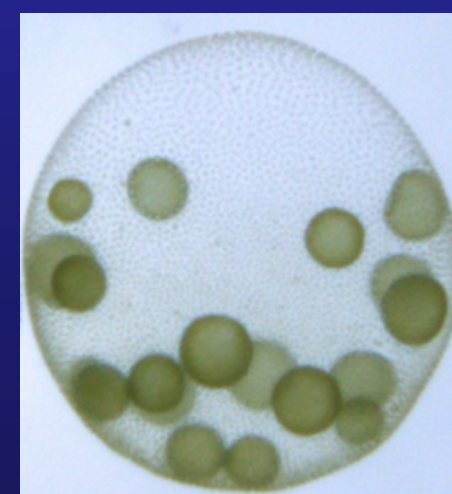




Phototaxis in *Volvox rousseletii*

Ueki et al. 2010

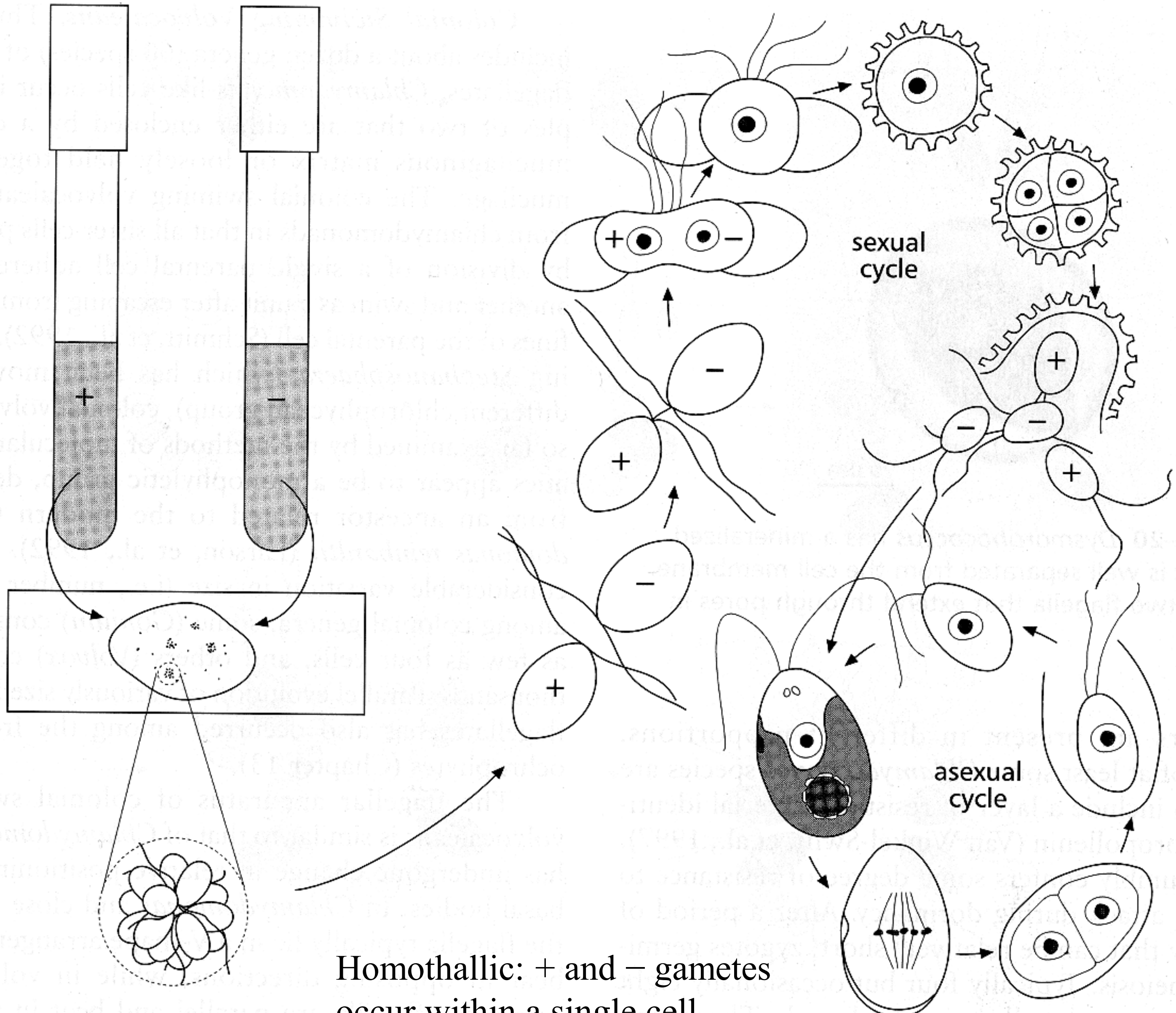
(b, e, g, i) normal beating mode
(c, f, h, j) reverse beating mode



How does *Volvox* swim?

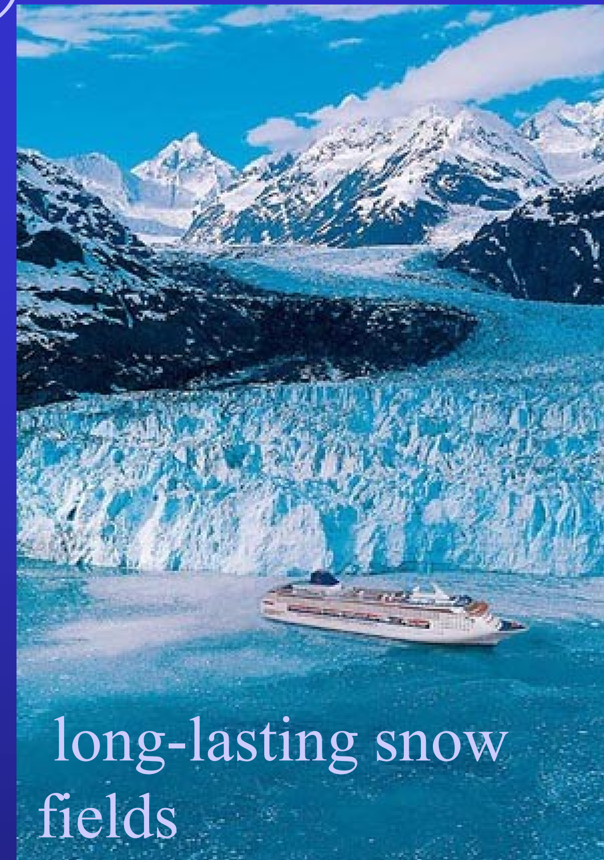
Chlamydomonas

Ch. reinhardtii

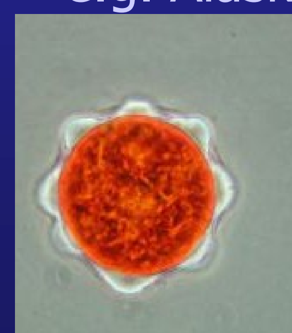


Homothallic: + and − gametes
occur within a single cell.

Sanguina nivaloides *(Chlamydomonas nivalis)*



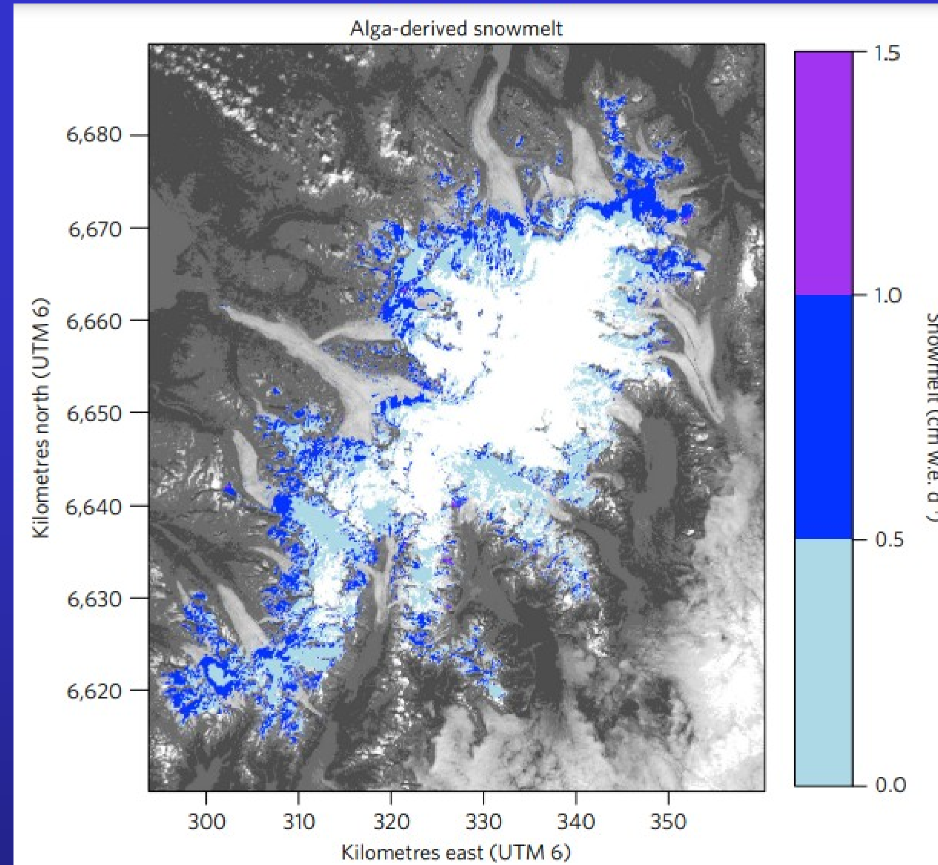
e.g. Alaska glaciers



watermelon snow

Harding Icefield 1813 km^2

Ch. nivalis absorb solar energy, heating themselves and the snow around them – reduces snow's reflectivity by 13%



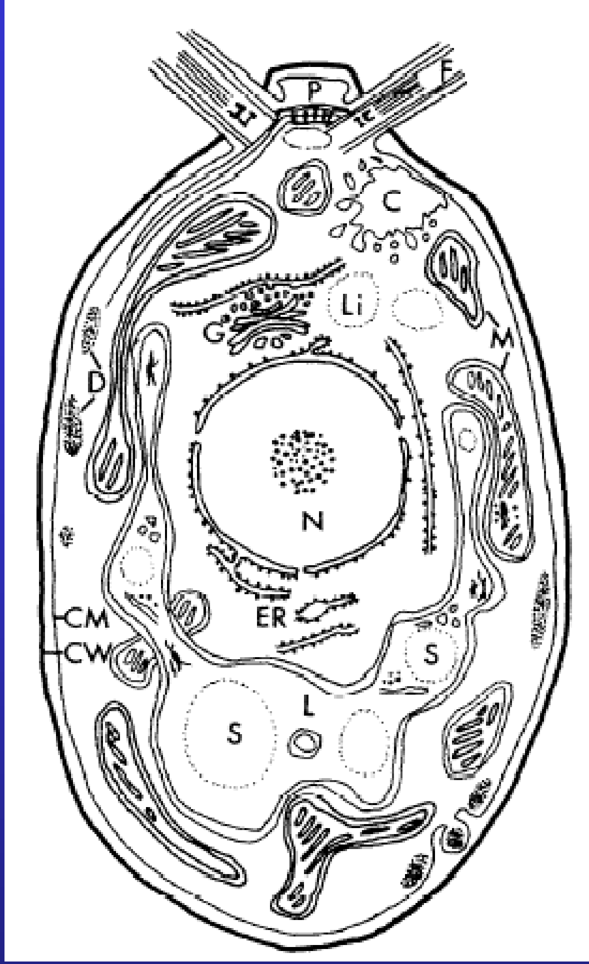
Estimated snow melt Harding Icefield Alaska (2013)

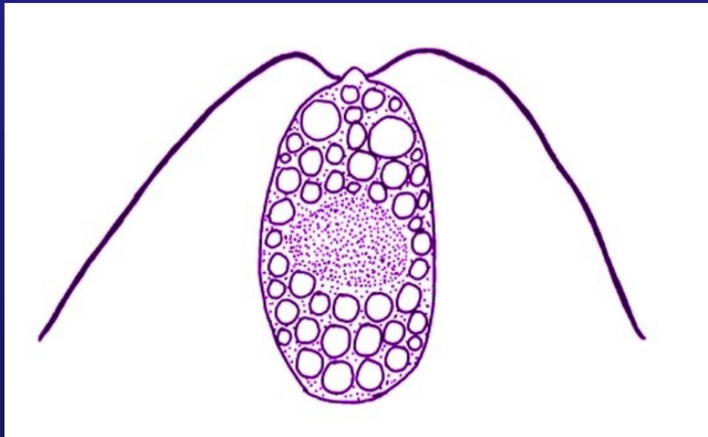
Snow algae accounts for about 17% of the annual melt

Polytoma

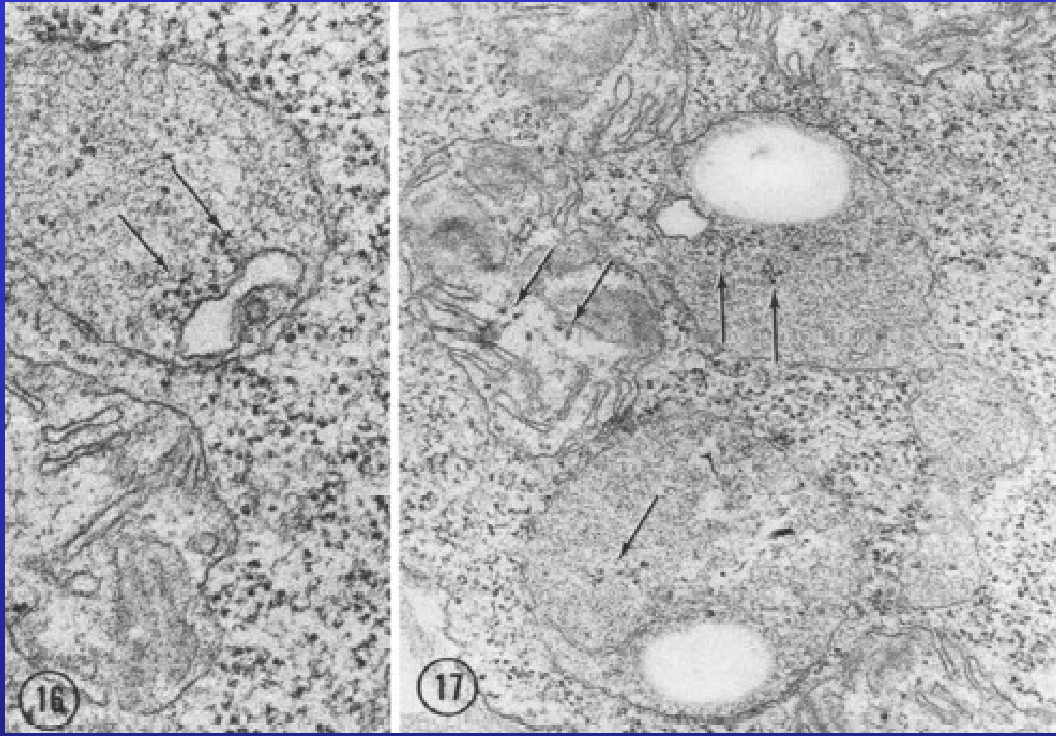
Heterotrophic variation to *Chlamydomonas*
leukoplasts instead of chloroplasts

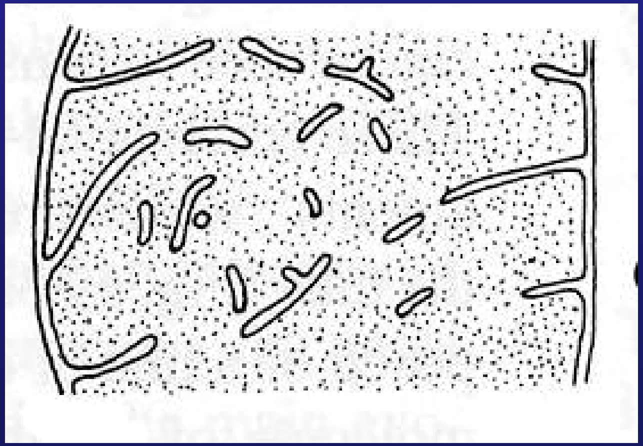
At the bottom of the pools in detritus





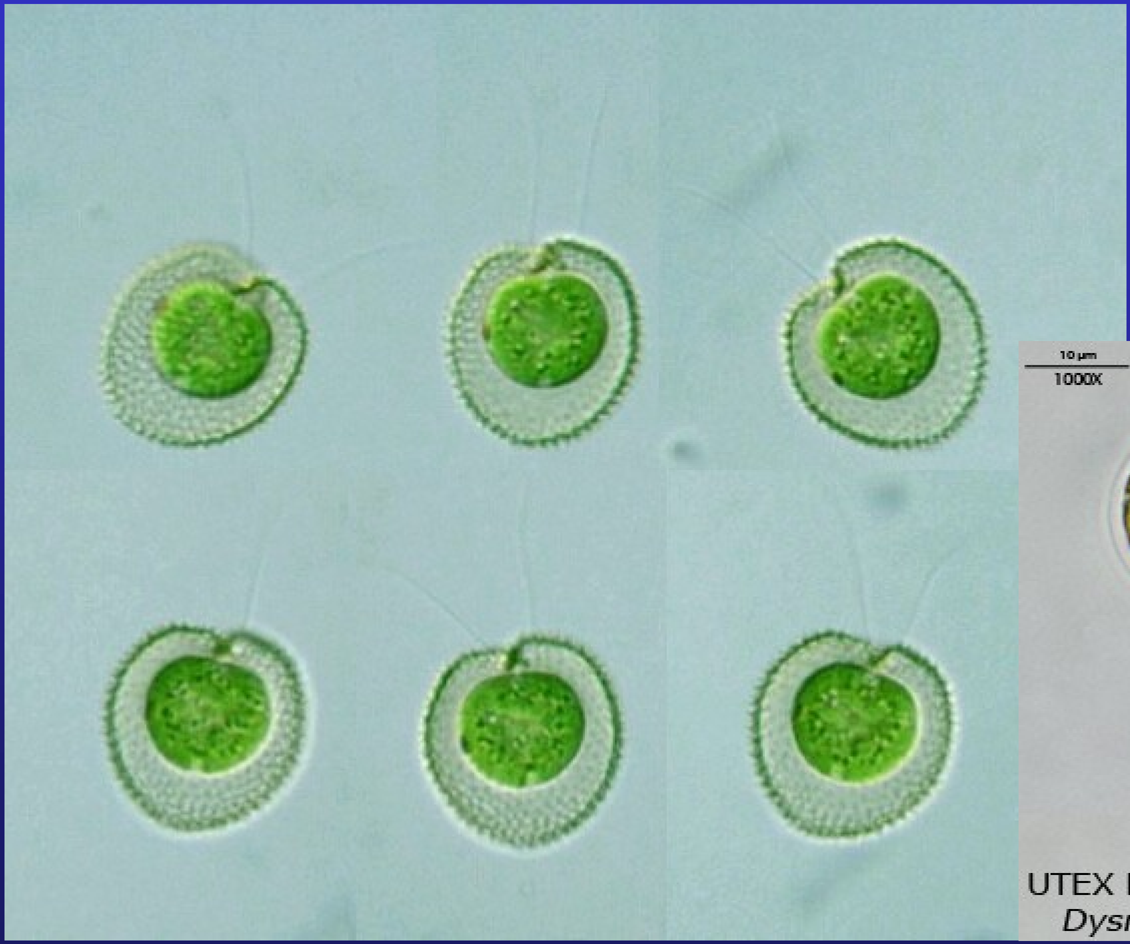
Polytoma

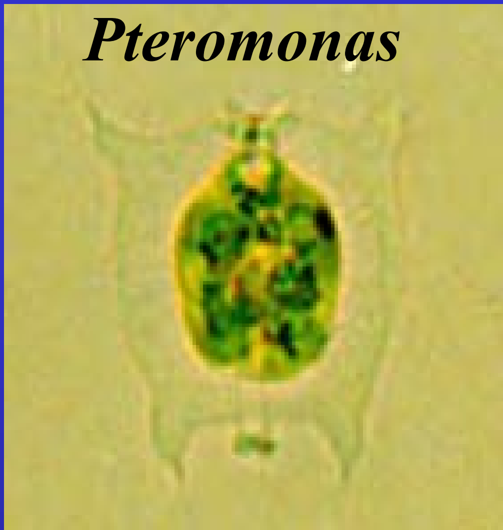


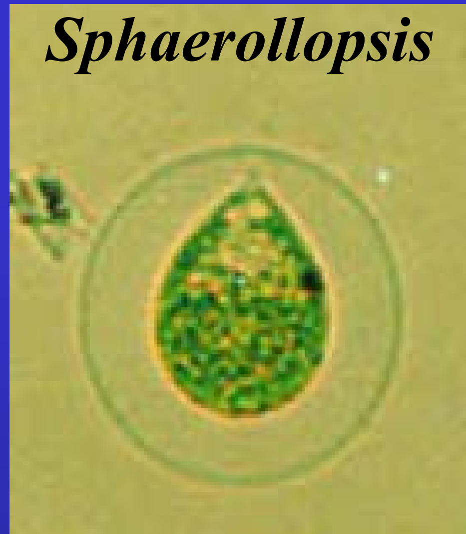


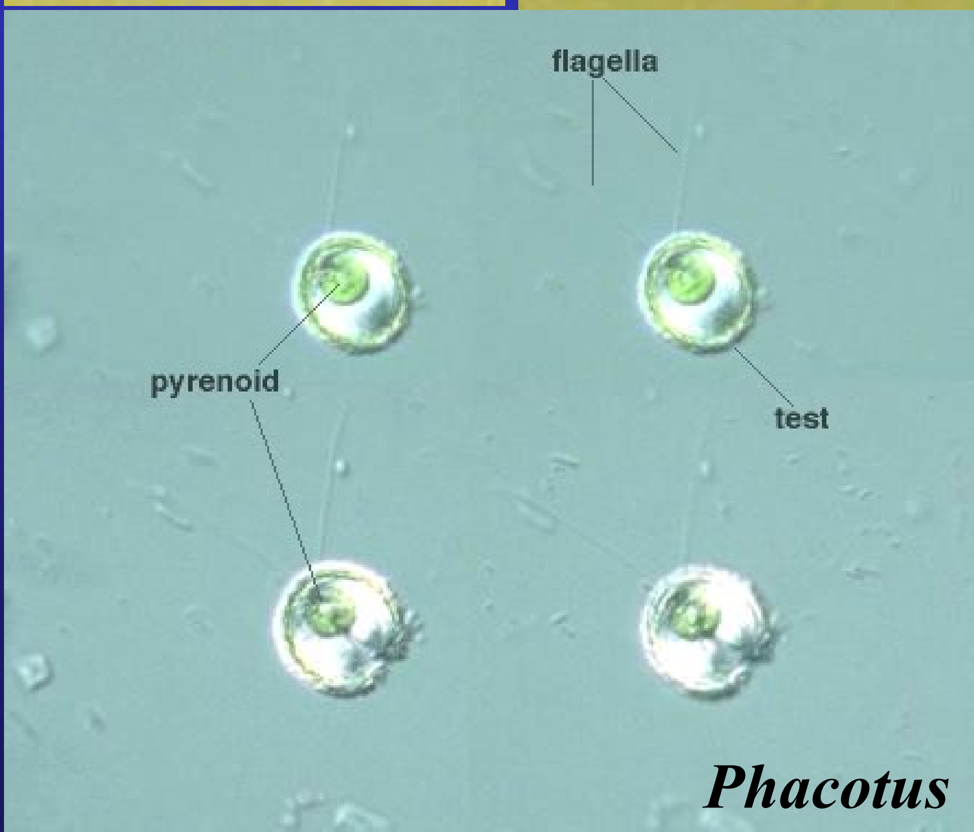
Dysmorphococcus

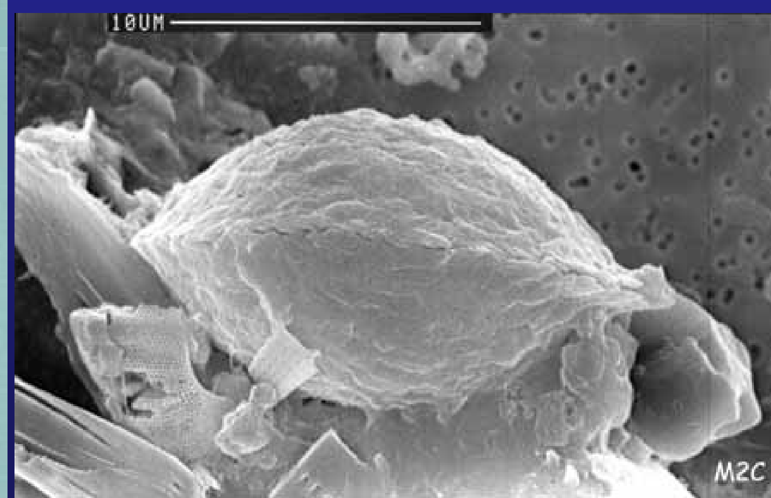
Chlamydomonas – like protoplast; lorica encrusted with manganese and iron salts; freshwater plankton; populations not abundant




Pteromonas

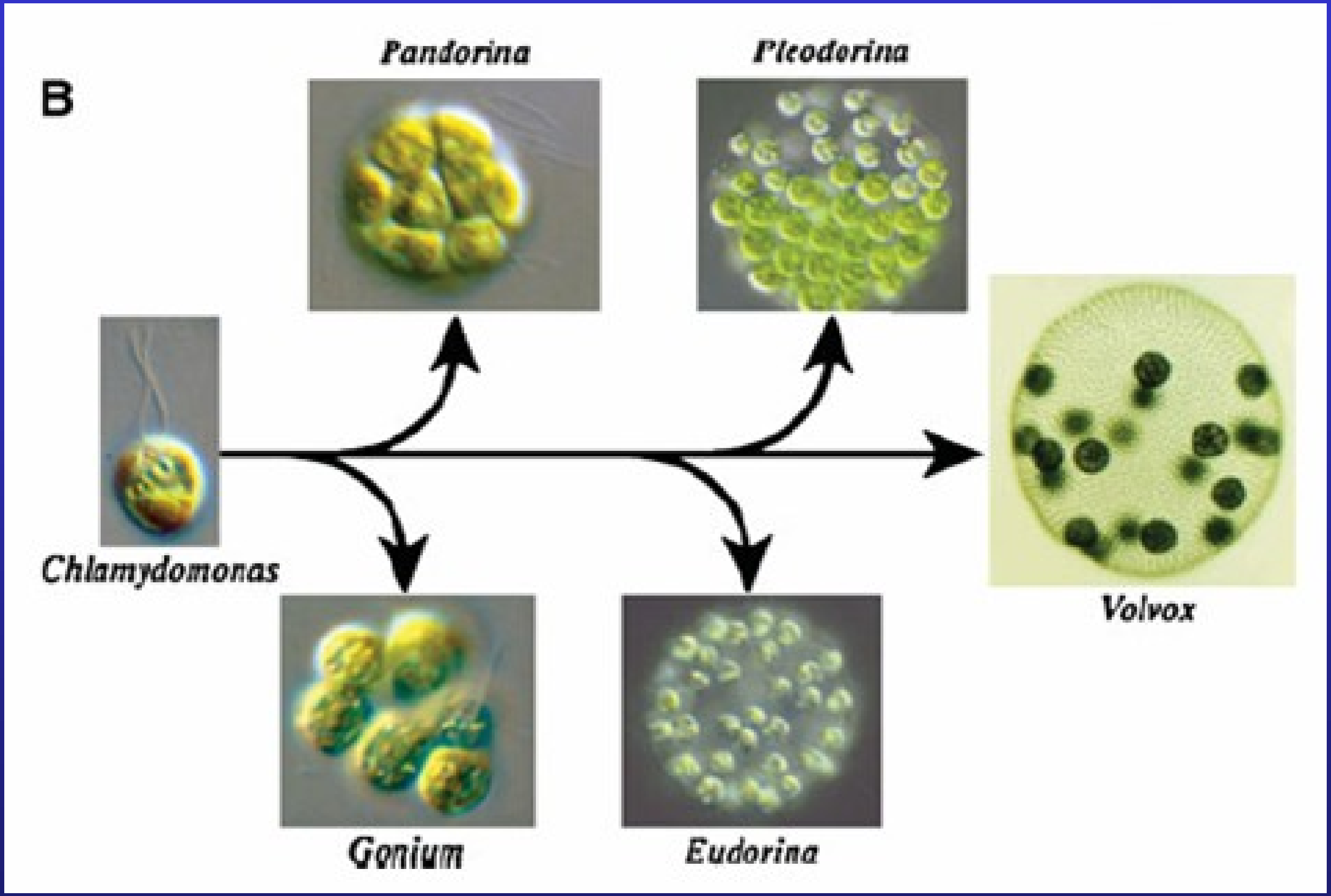

Sphaerollopsis


flagella
pyrenoid
test
Phacotus


10UM
M2C

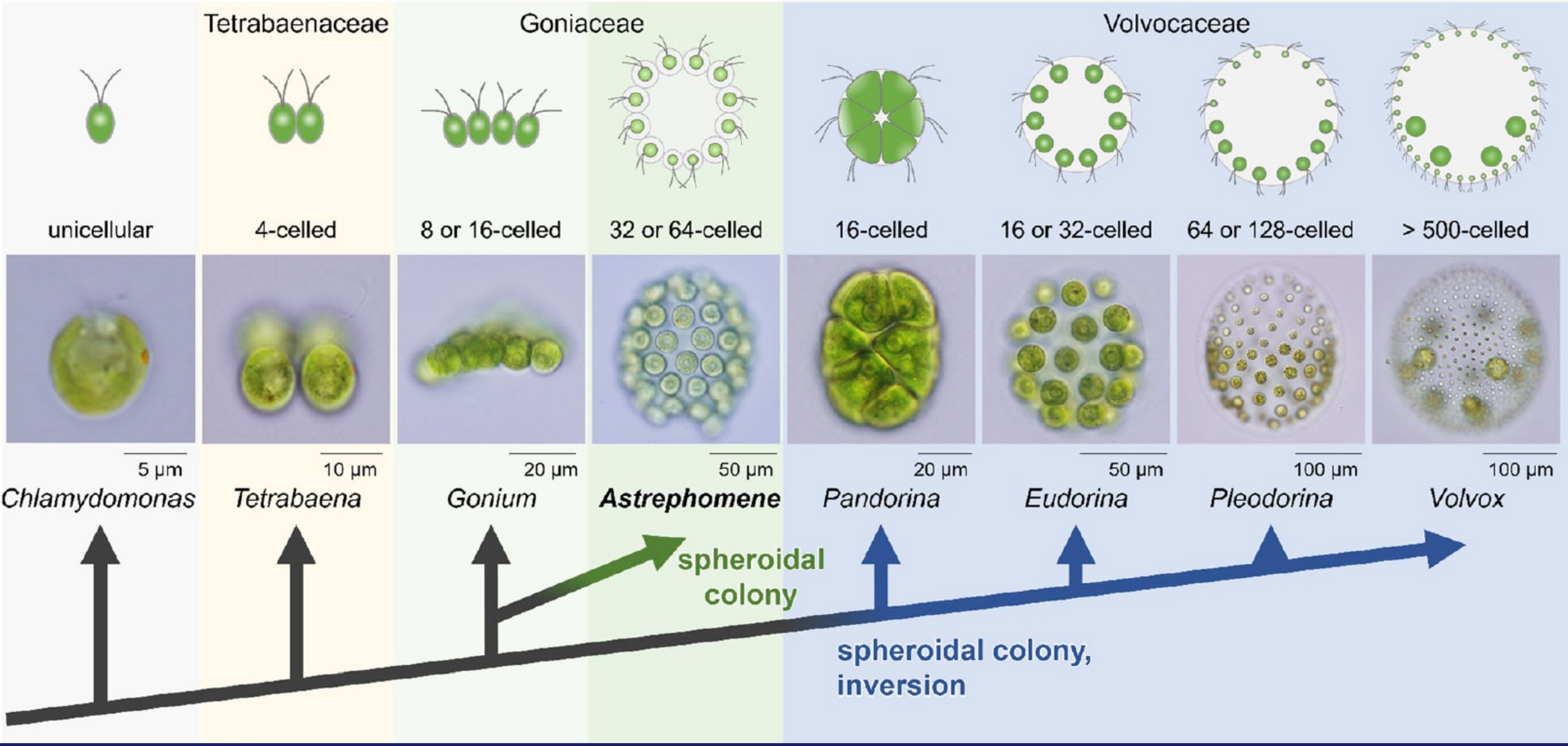
Evolution of multicelularity

The classical “volvocine lineage hypothesis”



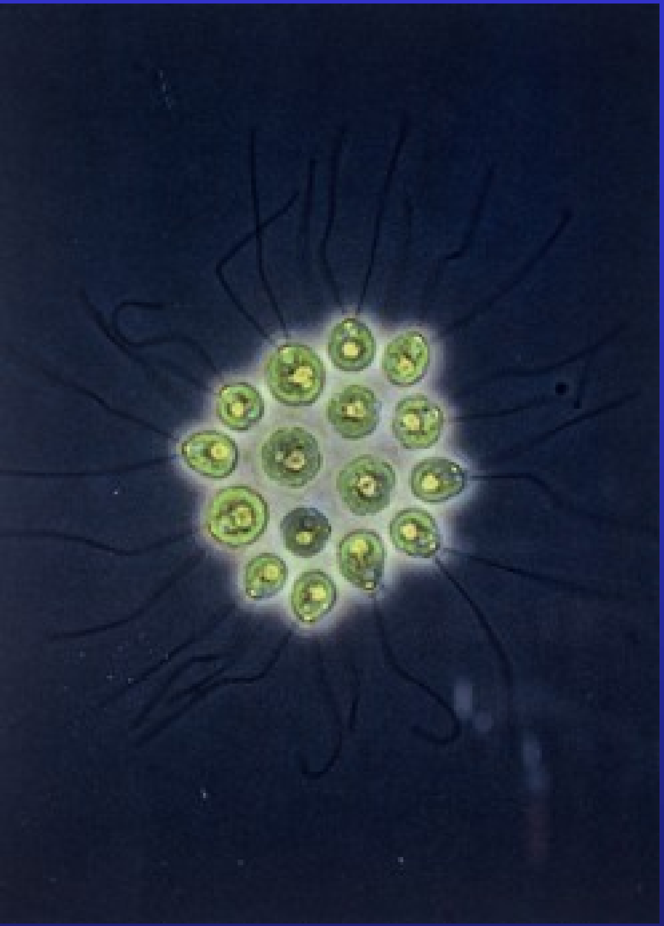
Kirk, 2005

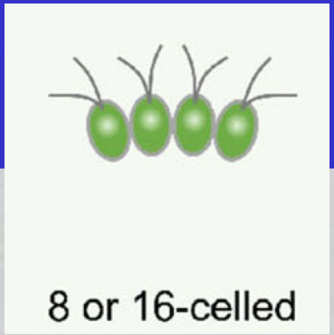
6 genera, gradually diverging (increase in cell number, size, extracellular matrix-to-cell volume ratio, and tendency to form sterile somatic cells).



Yamashita et al. BMC Evolutionary Biology (2016) 16:243
DOI 10.1186/s12862-016-0794-x

Gonium



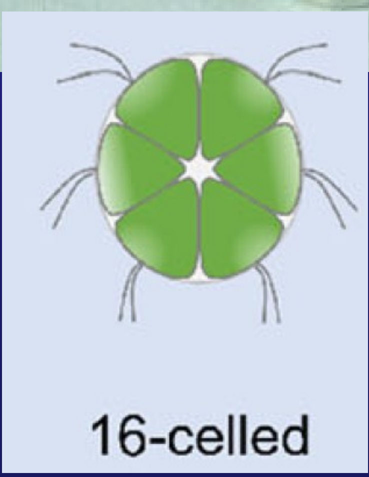


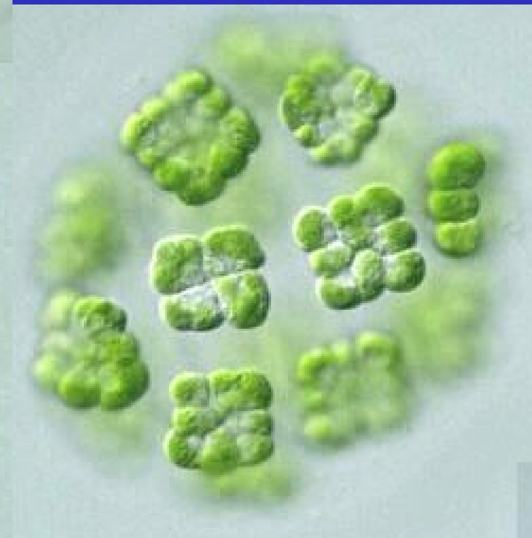
central-to-peripheral polarity

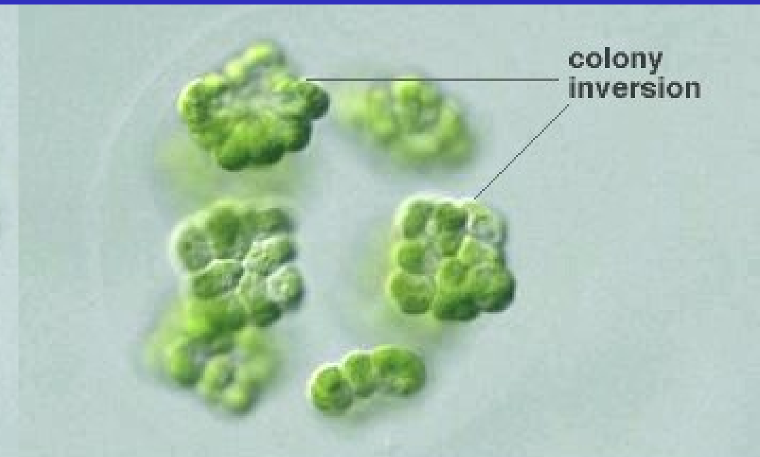
Each reproductive cell or gonidium undergoes successive cell divisions to form a concave-to-cup-shaped embryo composed of a single cell layer

Pandorina

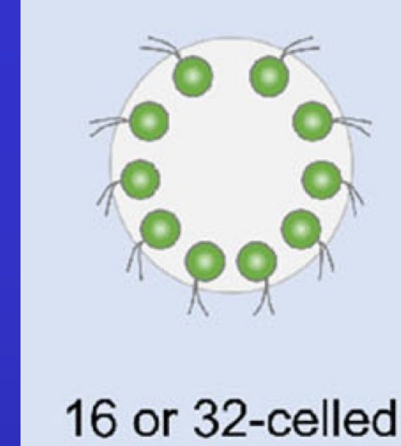
• cenobium ve tvaru koule; anterior-to posterior (AP) polarity, úplná inverze

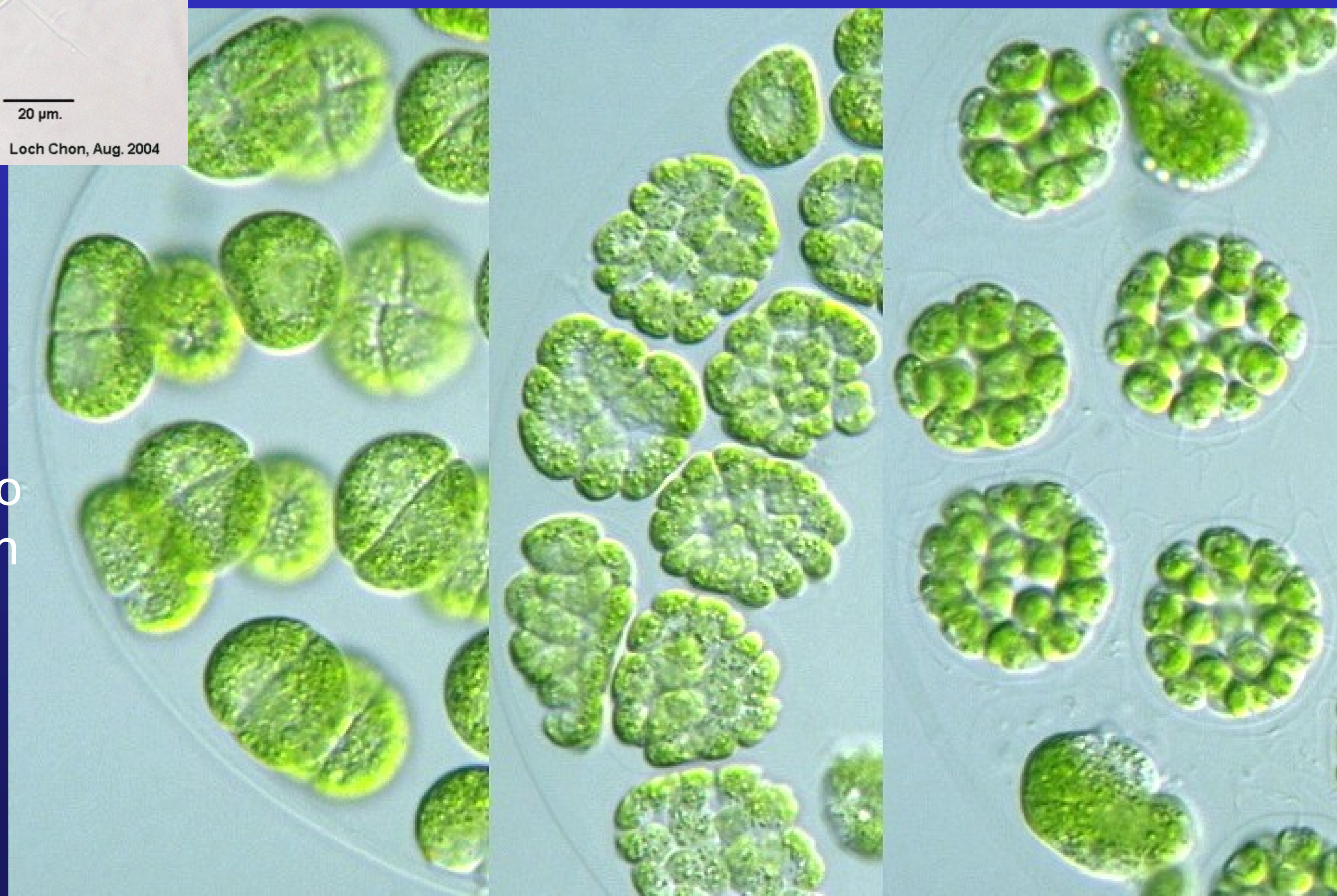






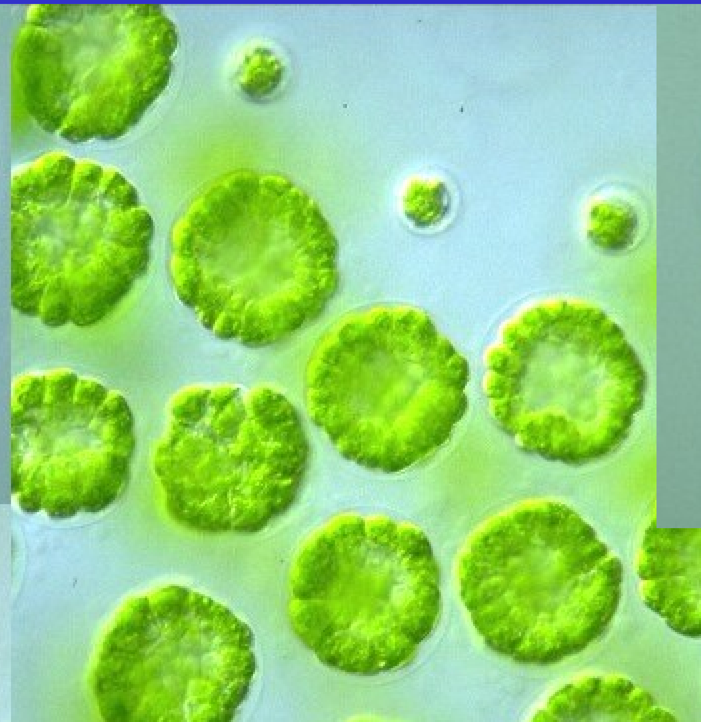
Eudorina

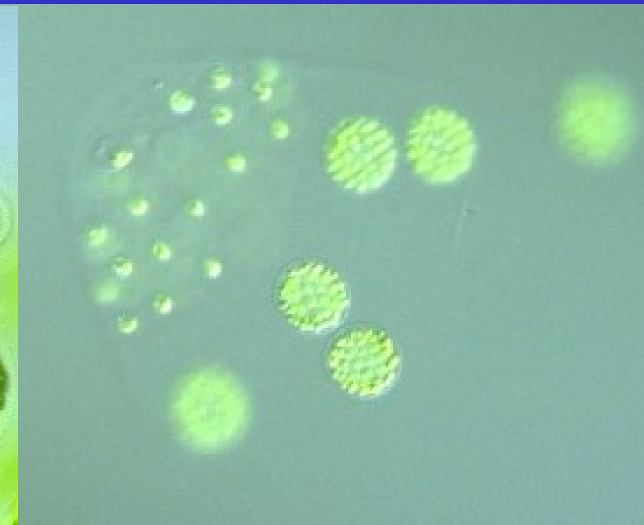


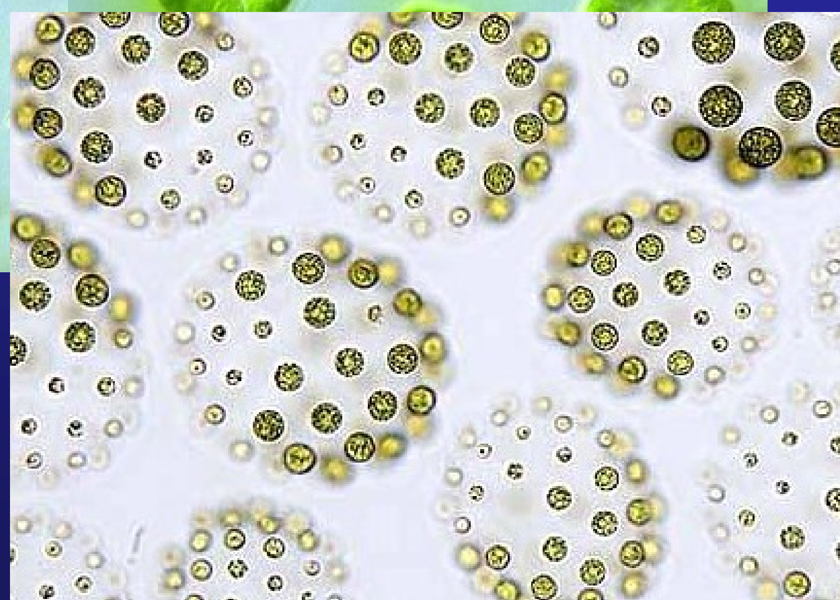


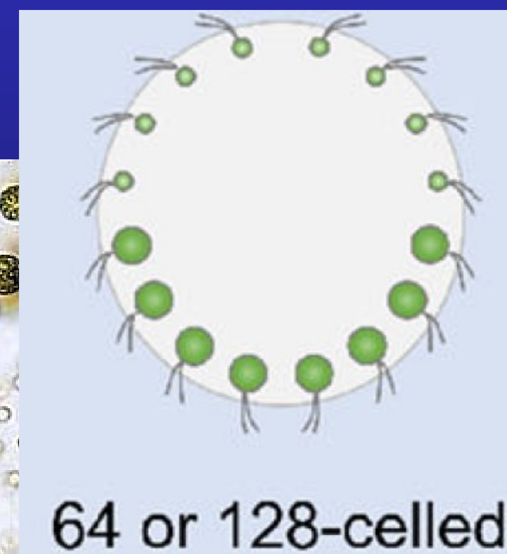
each cell undergoes several rounds of division to form plakeas, which then invert to form daughter colonies

Pleodorina



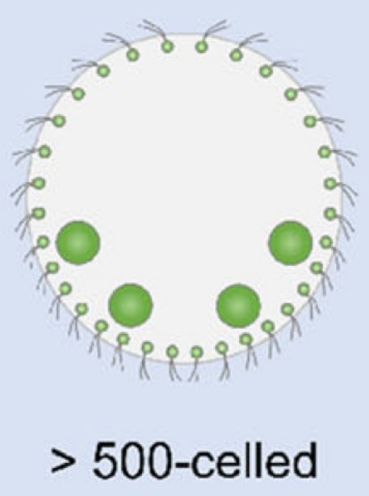




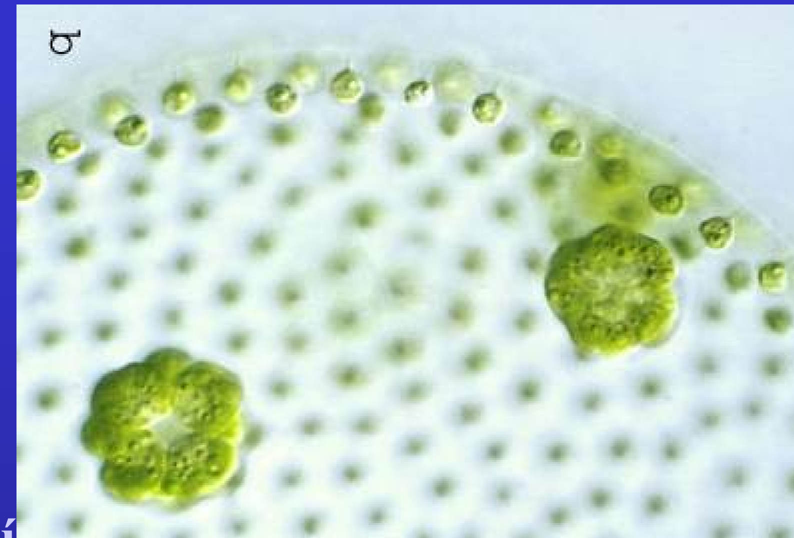


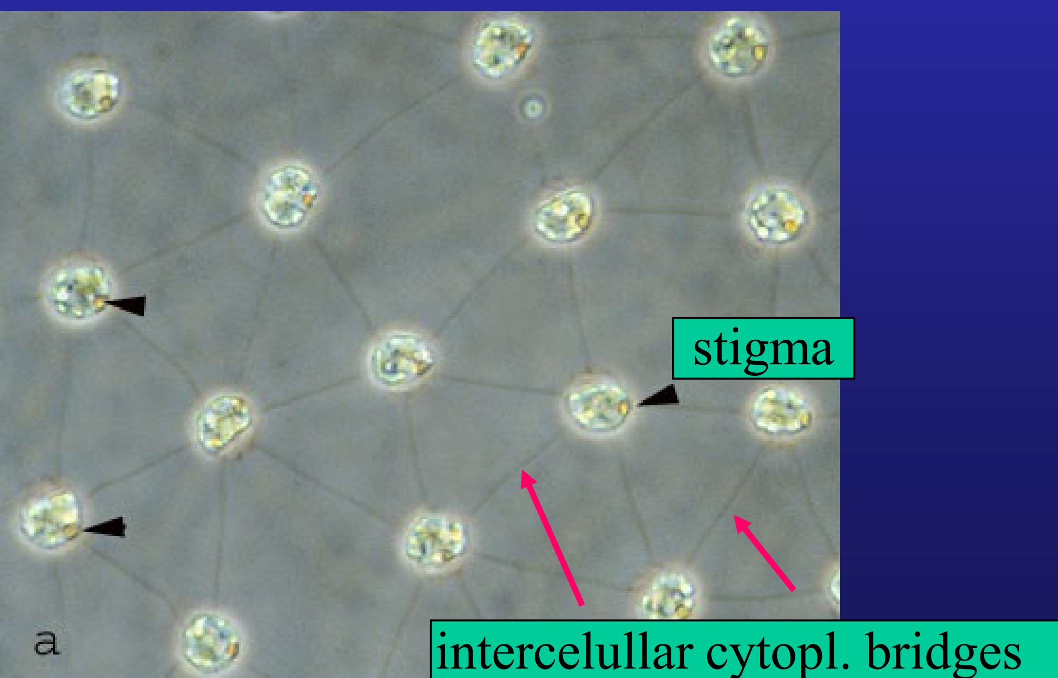
somatické buňky vs. gonidia

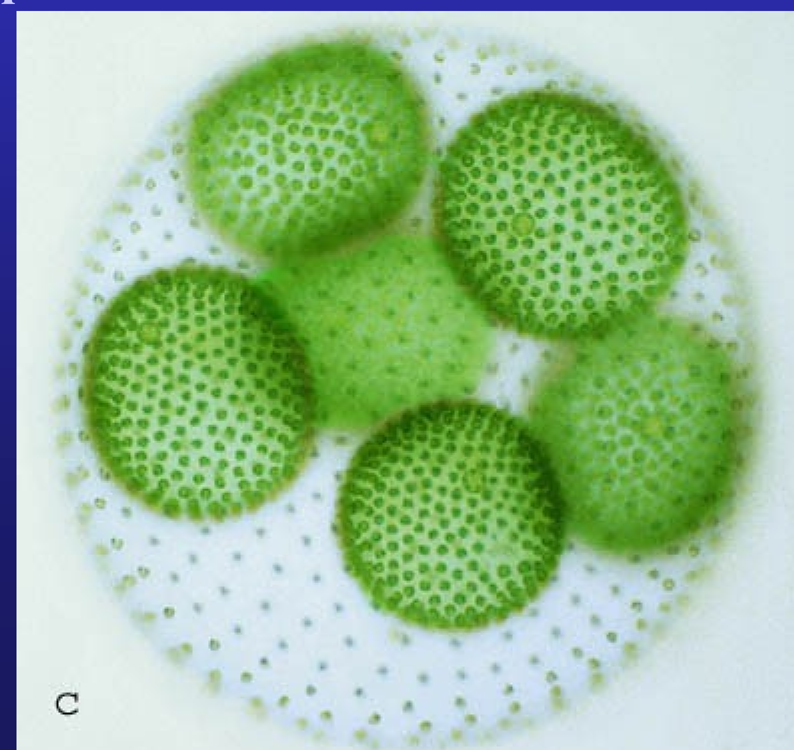
Volvox



Předo-zadní polarita
Syntéza extracelulární matrix







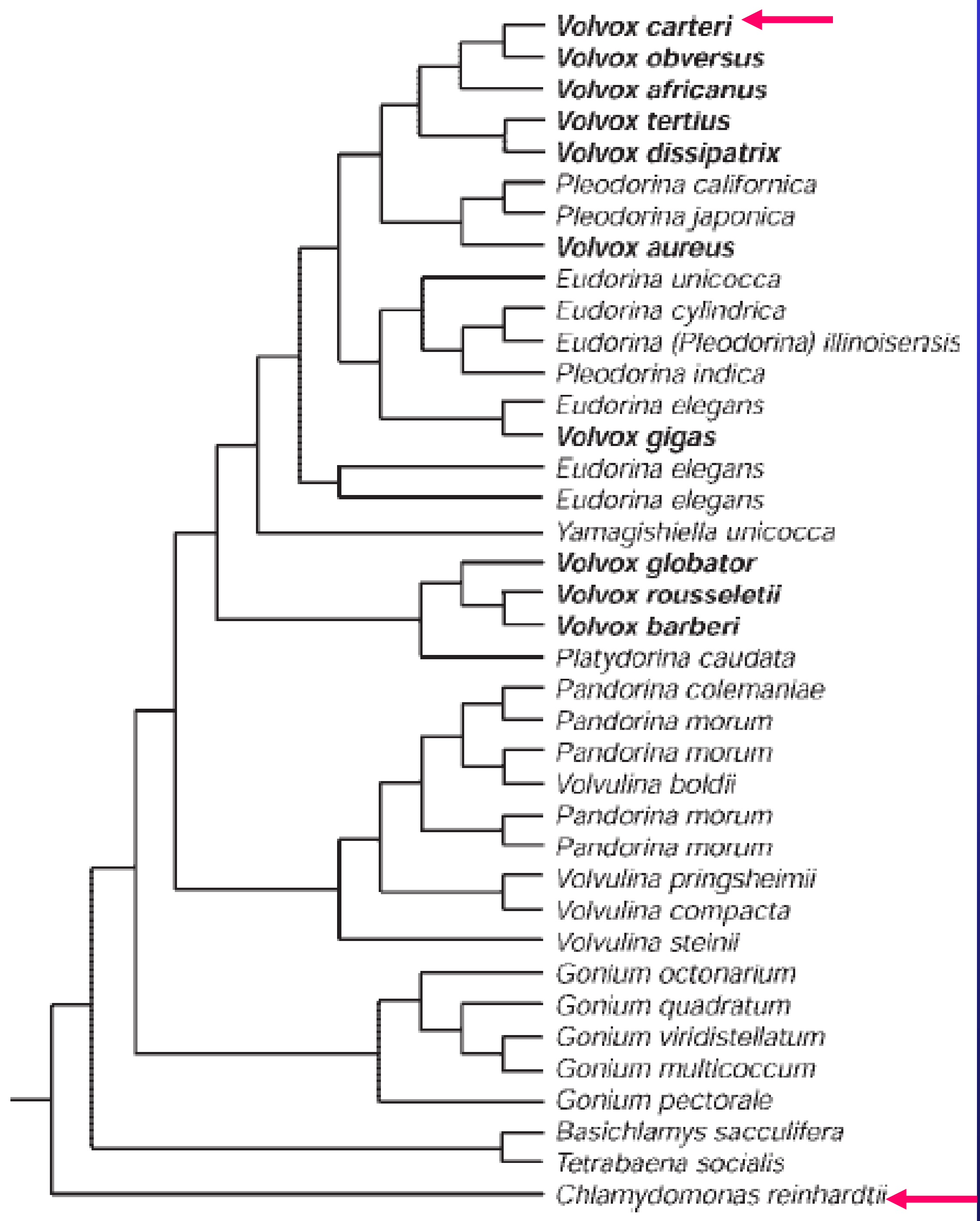
Fylogenetická studie na základě 5 genů

A recent molecular phylogeny of *Chlamydomonas* and its relatives indicates that *C. reinhardtii* shared a common ancestor with *V. carteri*

Společné znaky:

pohl. rozmn. → hypnozygoty

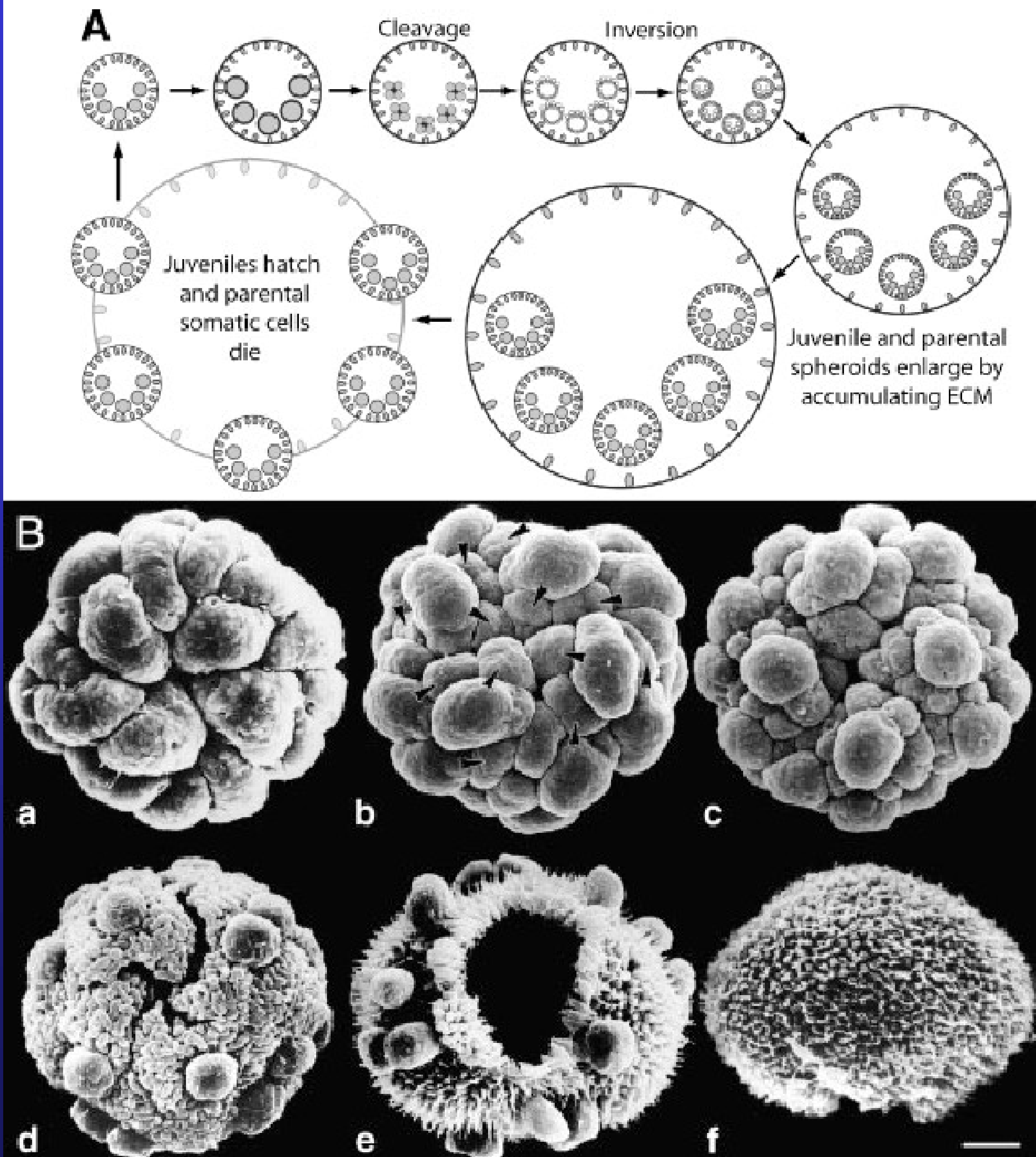
haplontní ž.c.



Volvox carteri

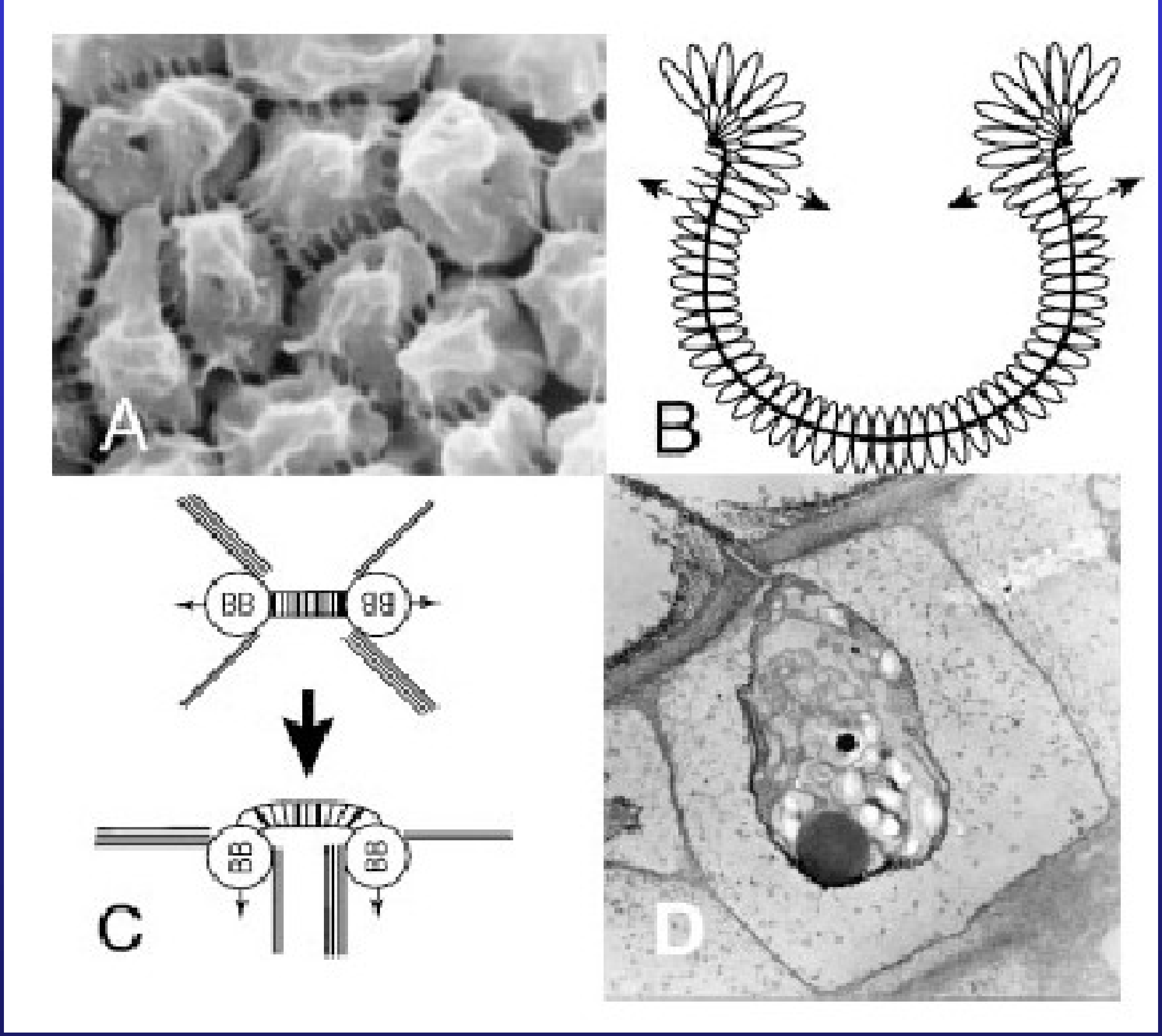
embryogeneze

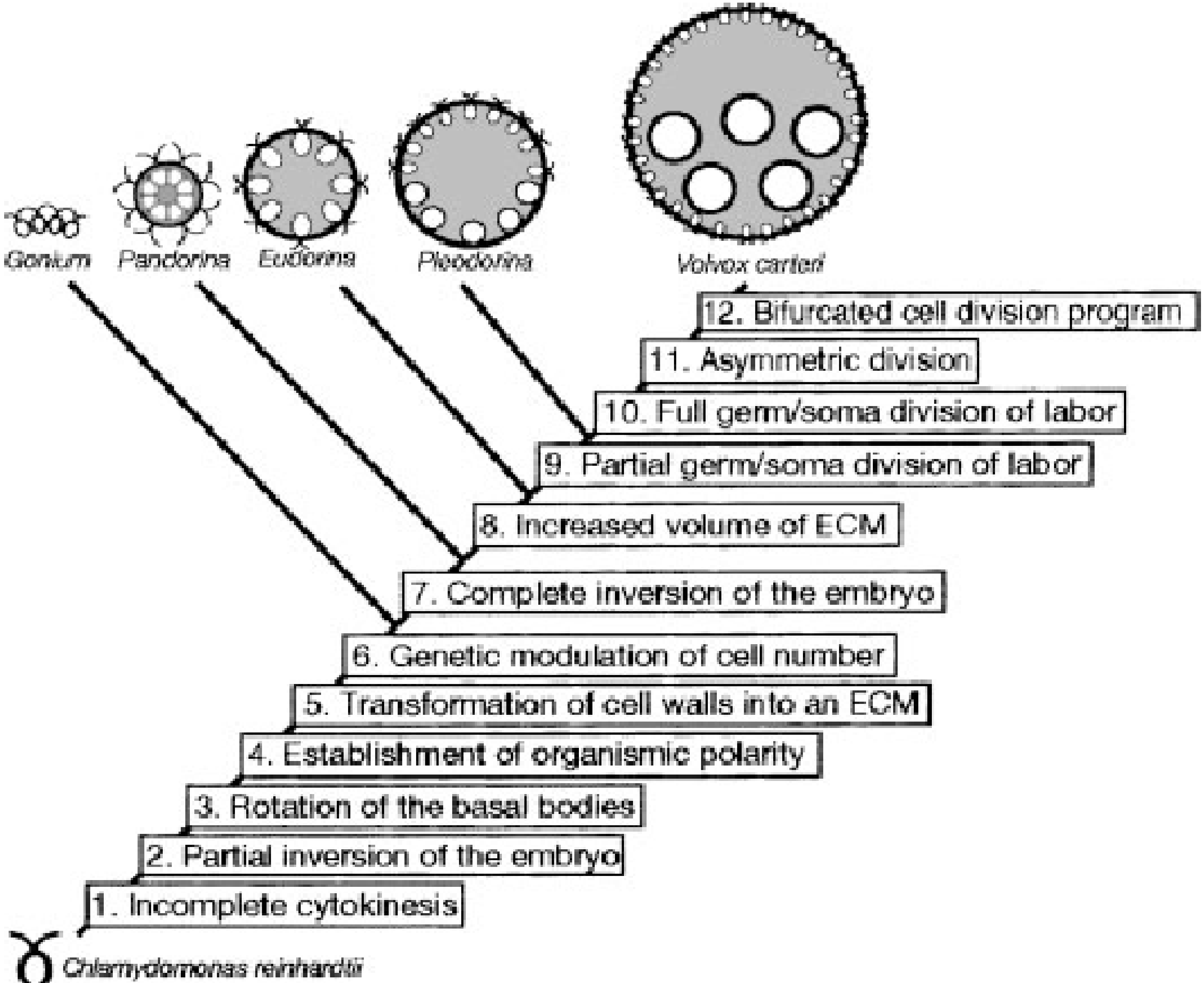
V. carteri asexual reproduction and development, can be compared with the processes of the ancestral development of Chlamydomonas into V. carteri.

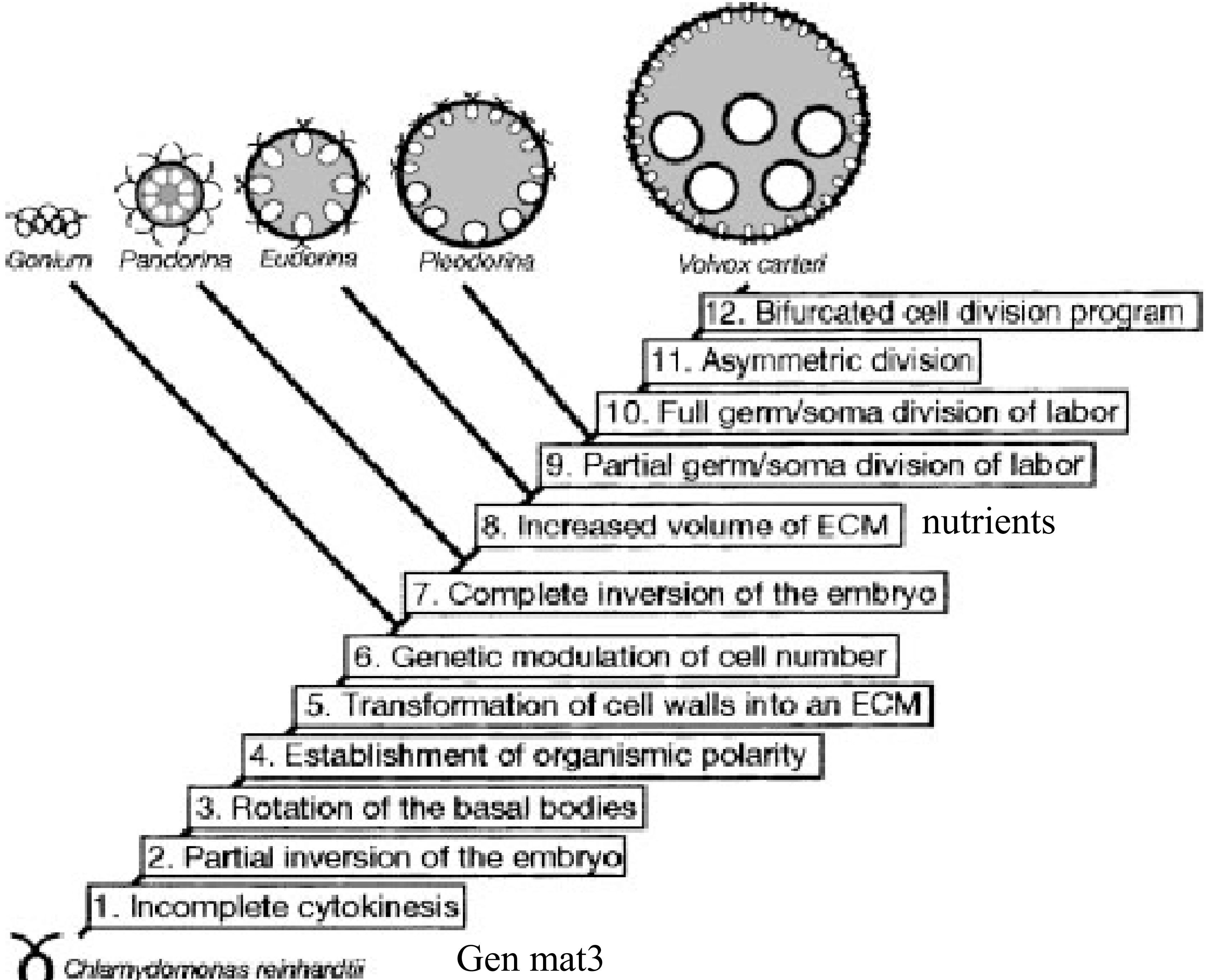


System of cytoplasmatic bridges

Každá buňka je spojena s okolními průměrně 25 můstky
Hnací silou inverze – změna tvaru buněk spojených m.
Rotace bazálních tělísek

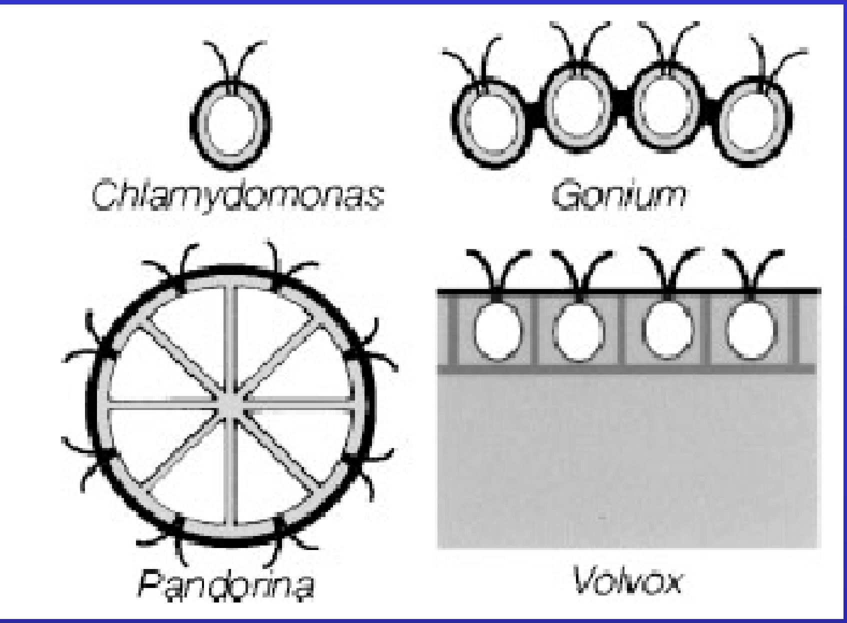


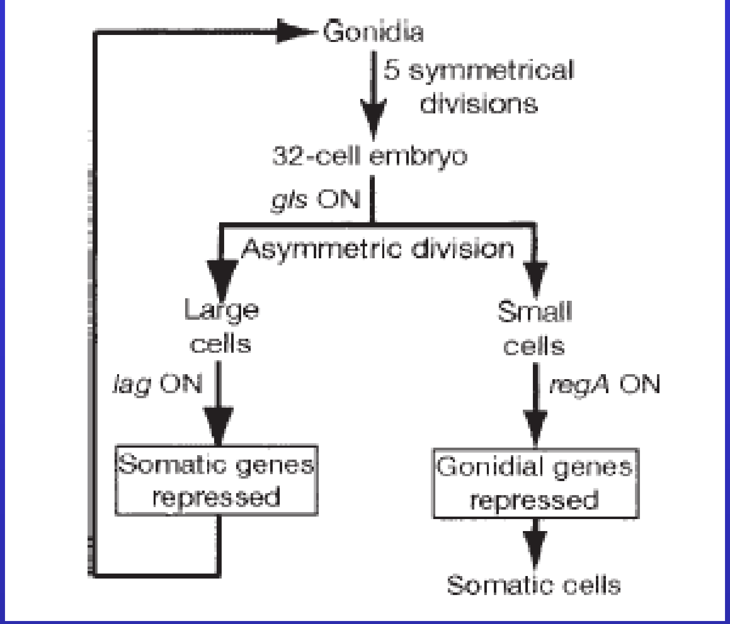

Gonium
Pandorina
Eudorina
Pleodorina
Volvox carteri
12. Bifurcated cell division program
11. Asymmetric division
10. Full germ/soma division of labor
9. Partial germ/soma division of labor
8. Increased volume of ECM
7. Complete inversion of the embryo
6. Genetic modulation of cell number
5. Transformation of cell walls into an ECM
4. Establishment of organismic polarity
3. Rotation of the basal bodies
2. Partial inversion of the embryo
1. Incomplete cytokinesis
Chlamydomonas reinhardtii



nutrients

Gen mat3





Increased volume of extra cellular mathrix (ECM)

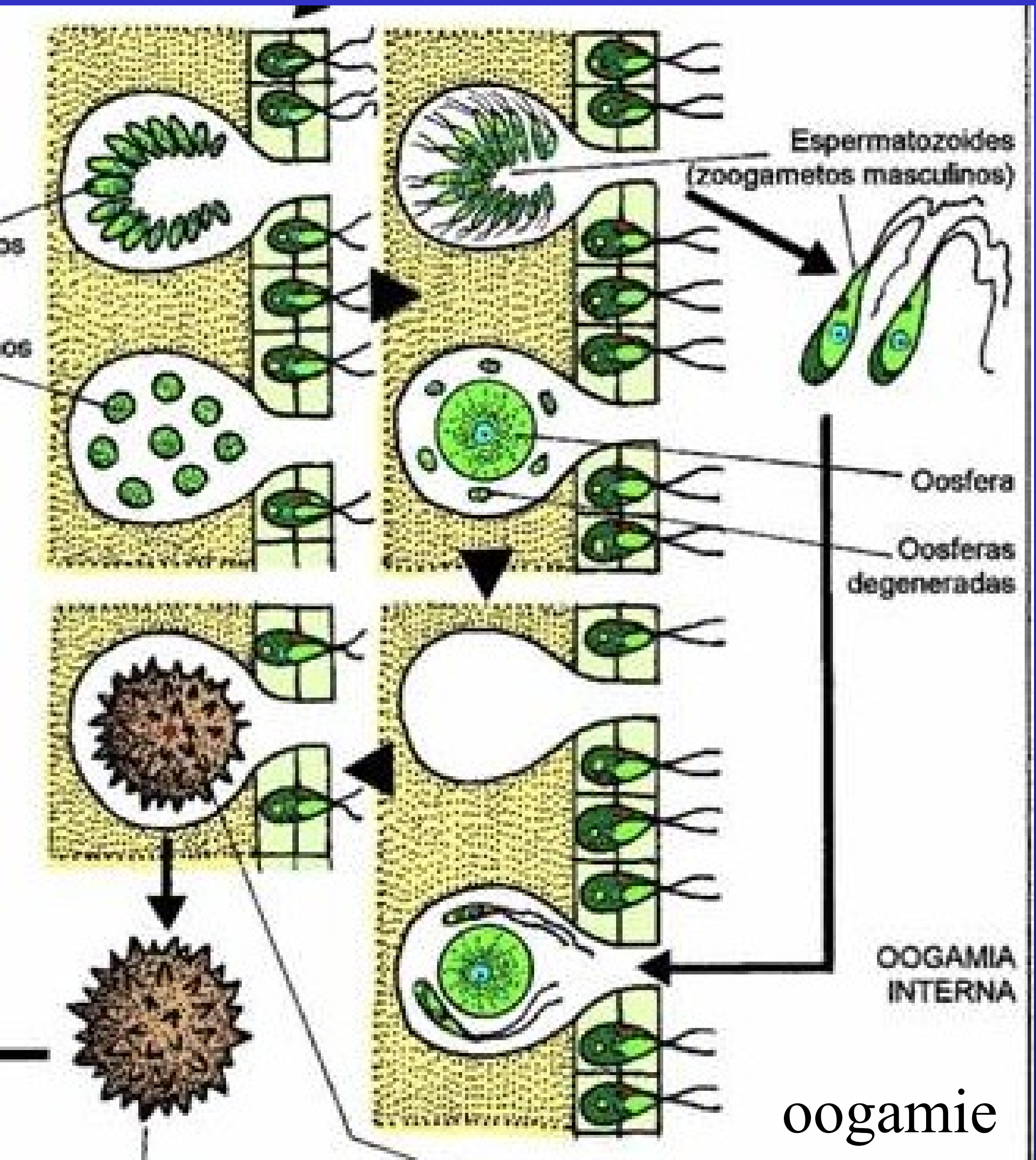
genetic regulation diferenciation to somatic and reproductive cells

C. reihardtii – 2 morfologicky a chemicky odlišné vrstvy BS

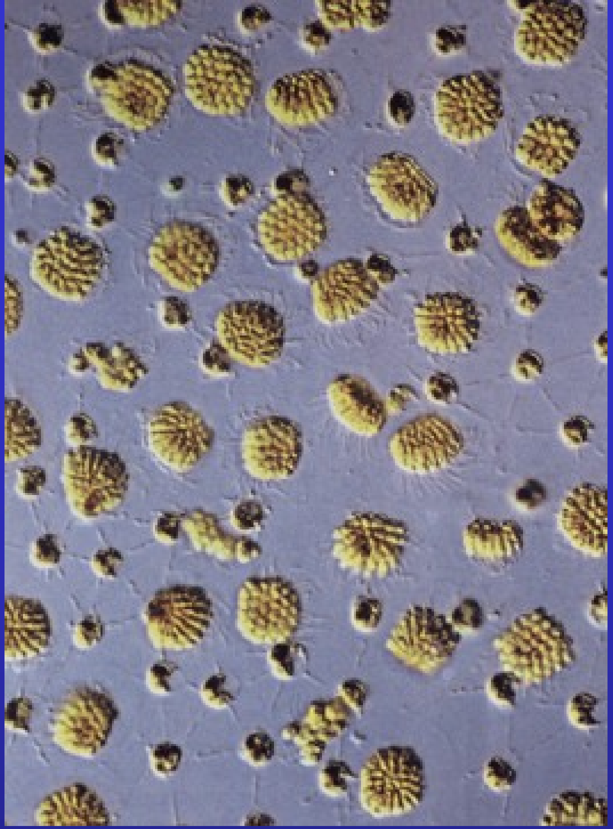
gls geny – způsobují asymetrické dělení. Ve velkých buňkách **lag geny** blokují vývoj somatických znaků (bičíky stigma). V malých buňkách **regA geny** blokují reprodukci) – somatické buňky

Volvox – sexual reproduction

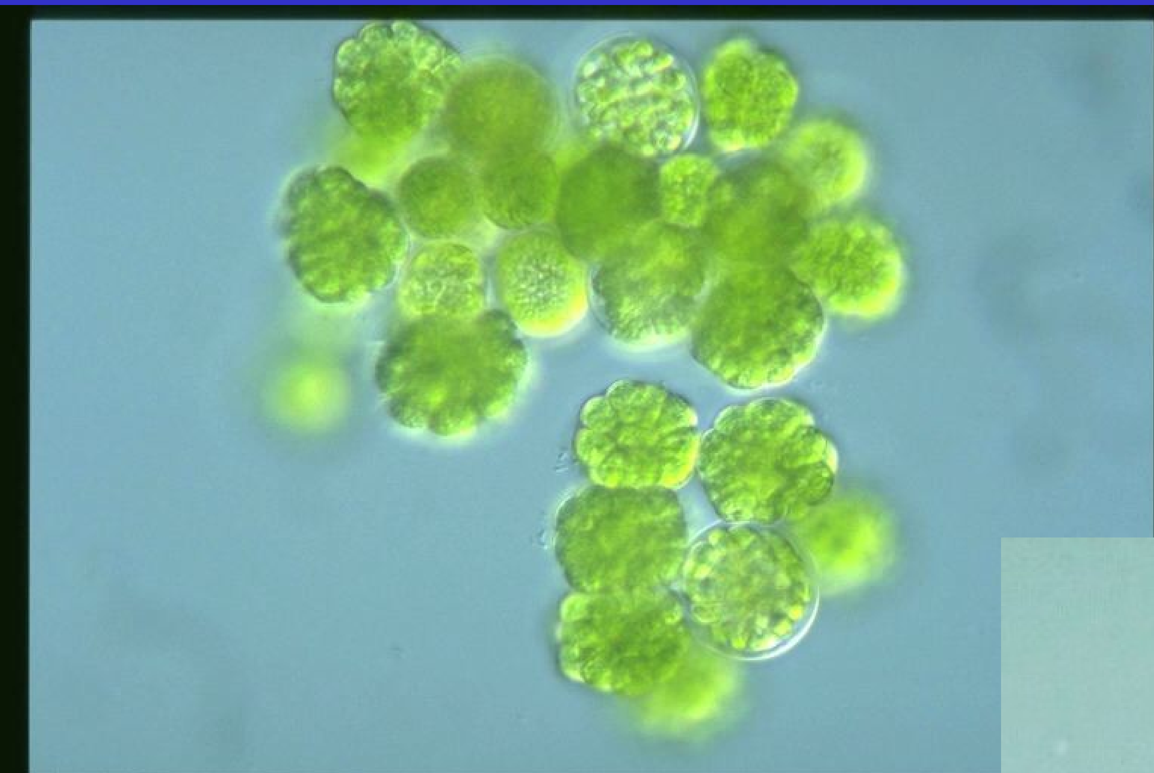
Produkce samčích gamet – heat shock??

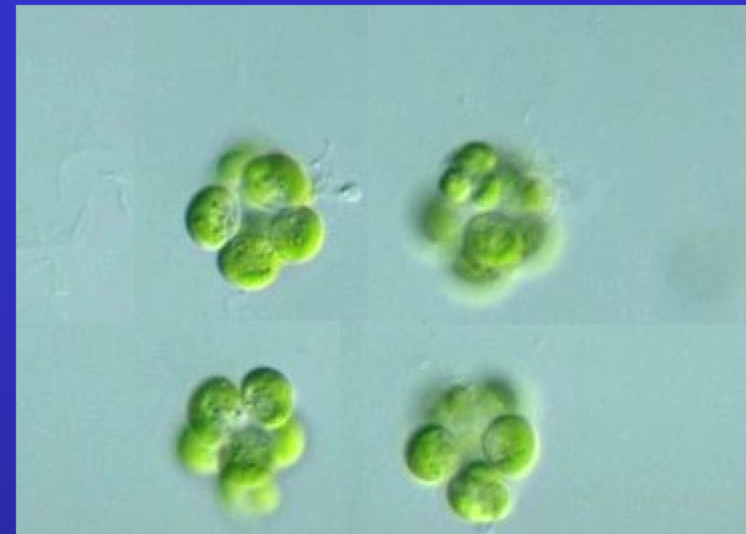


oogamie



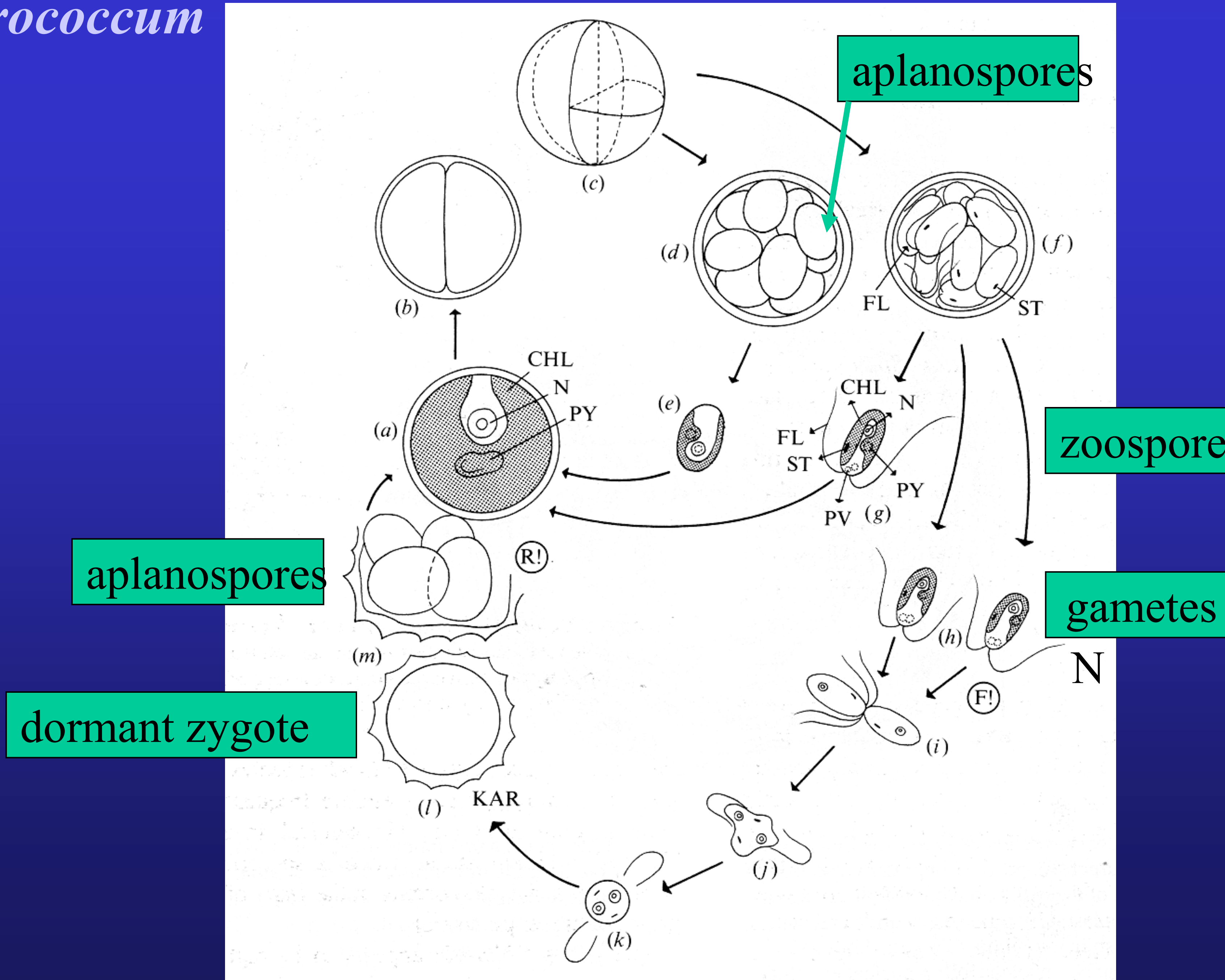
Chlorococcum



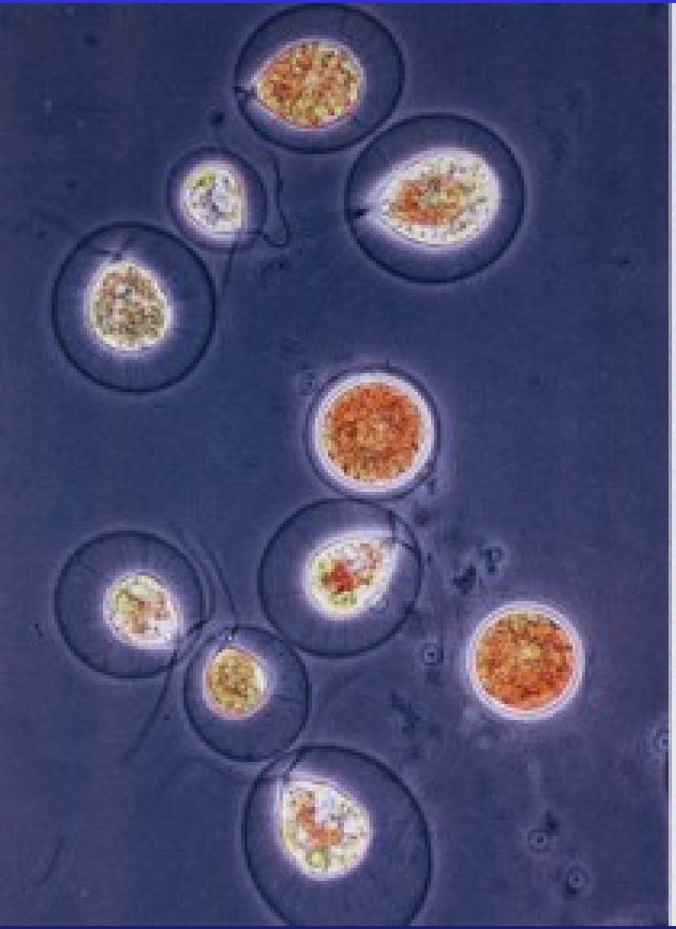


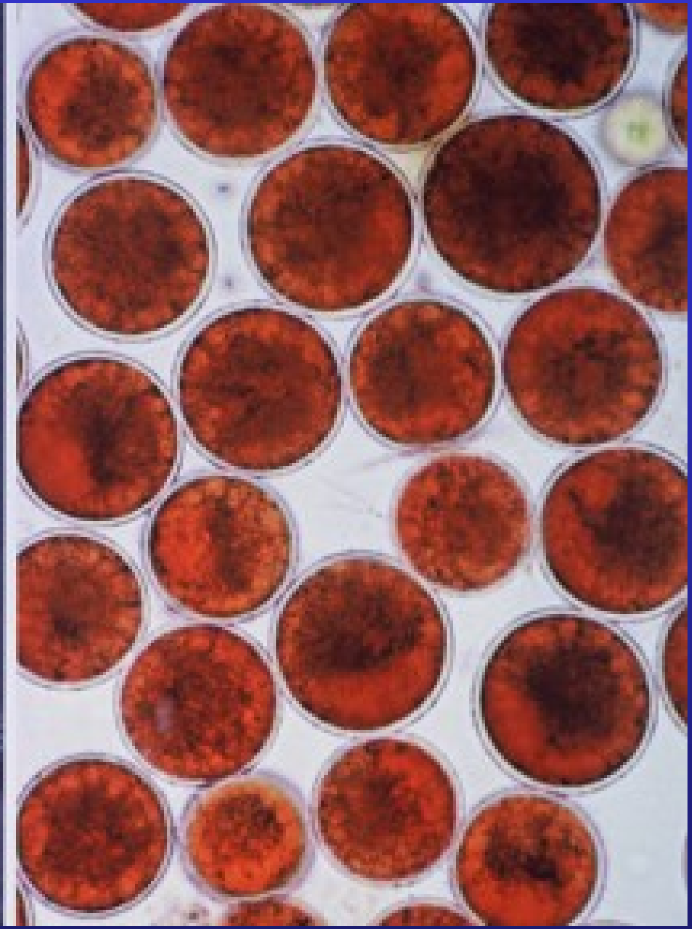
Zoospores, parietal chloroplast with py

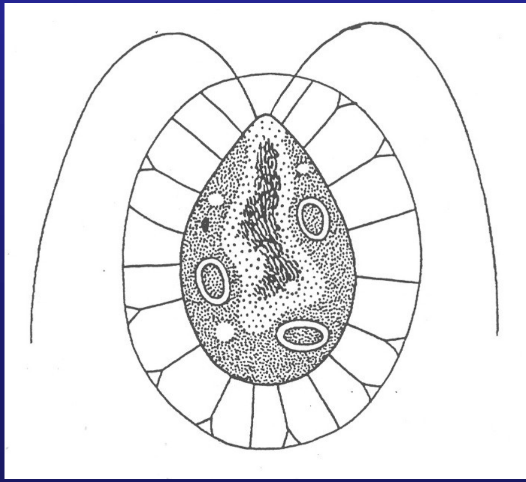
Chlorococcum



Haematococcus







Pioneer alga in shallow ephemeral pools

Haematococcus

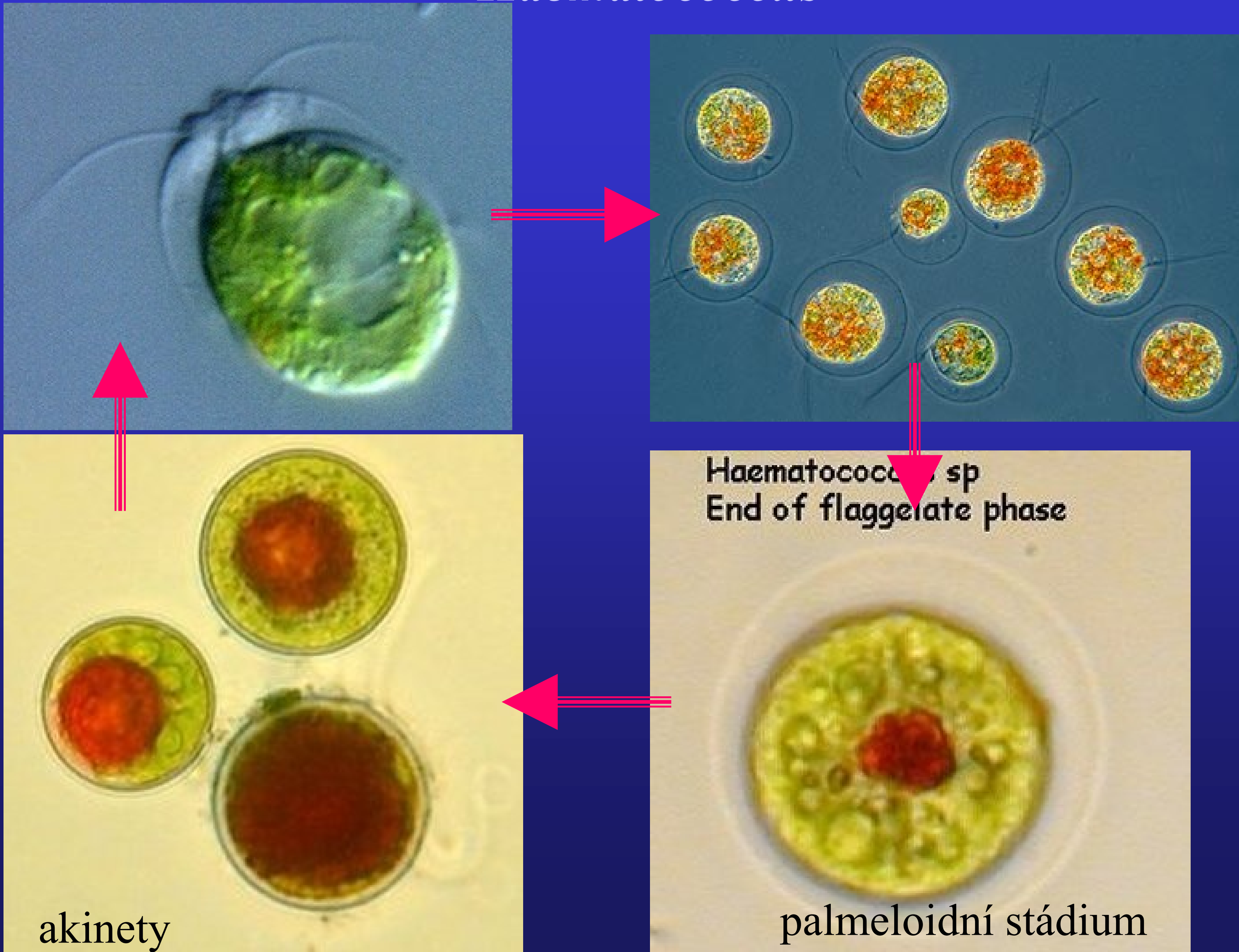
lithotelms

birdbaths

stock and horse tanks

Do you recognize this place?

Haematococcus



Haematococcus

Large-scale cultivation – closed photobioreactors in the Negev Desert.

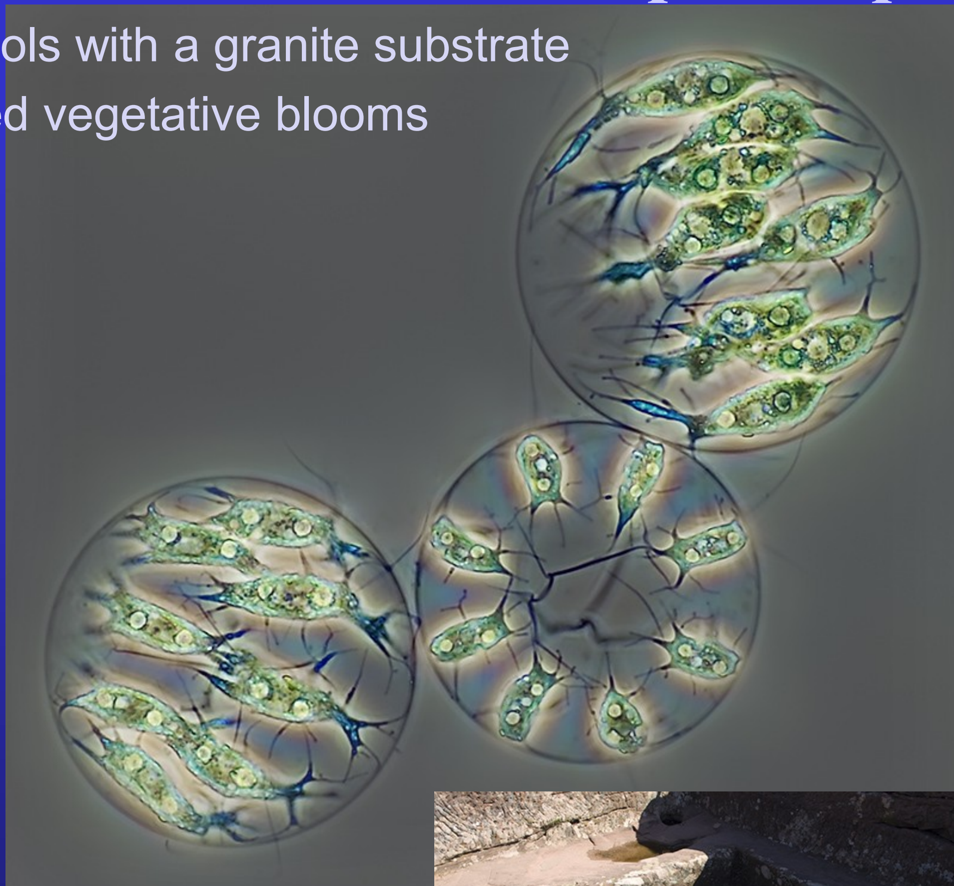
Food suplements

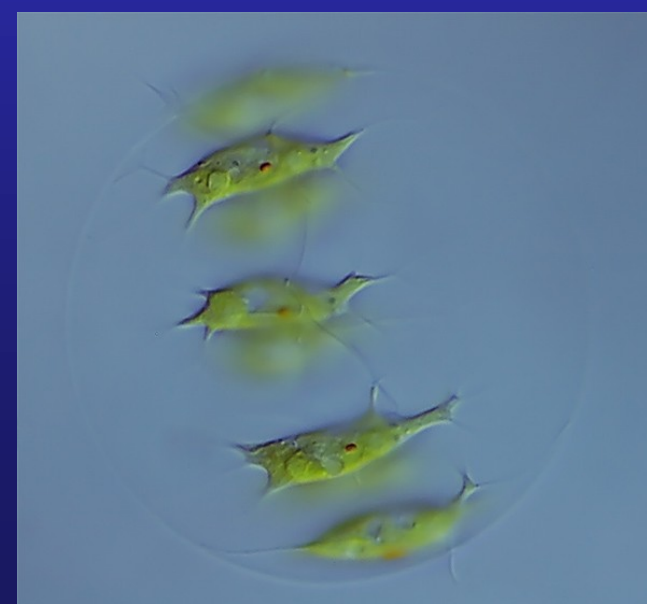
astaxantin

Stephanosphaera

Pools with a granite substrate

Red vegetative blooms





http://www.mikroskopie.de/mikroforum_2/index.php?topic=5659.0

Dunaliella

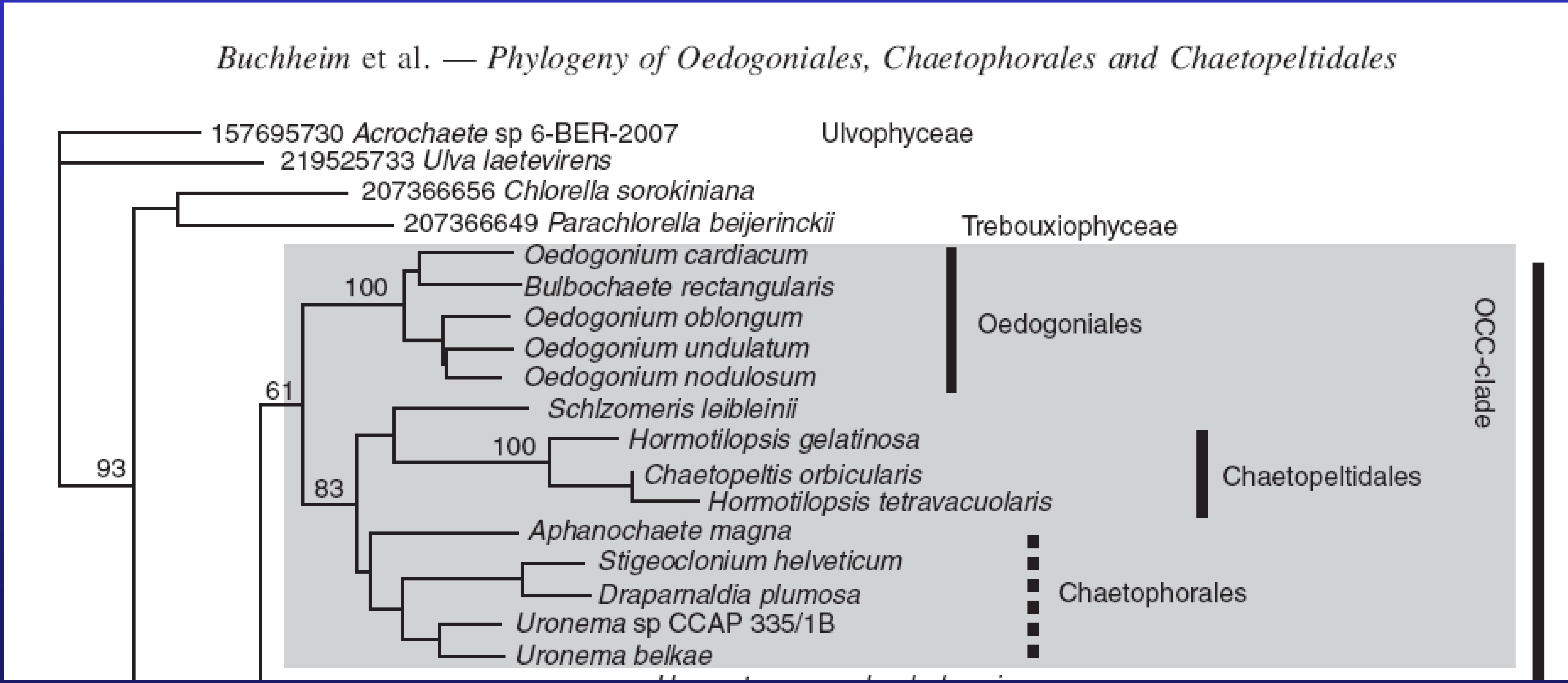
no contractile vacuoles – synthesis and degradation of glycerol

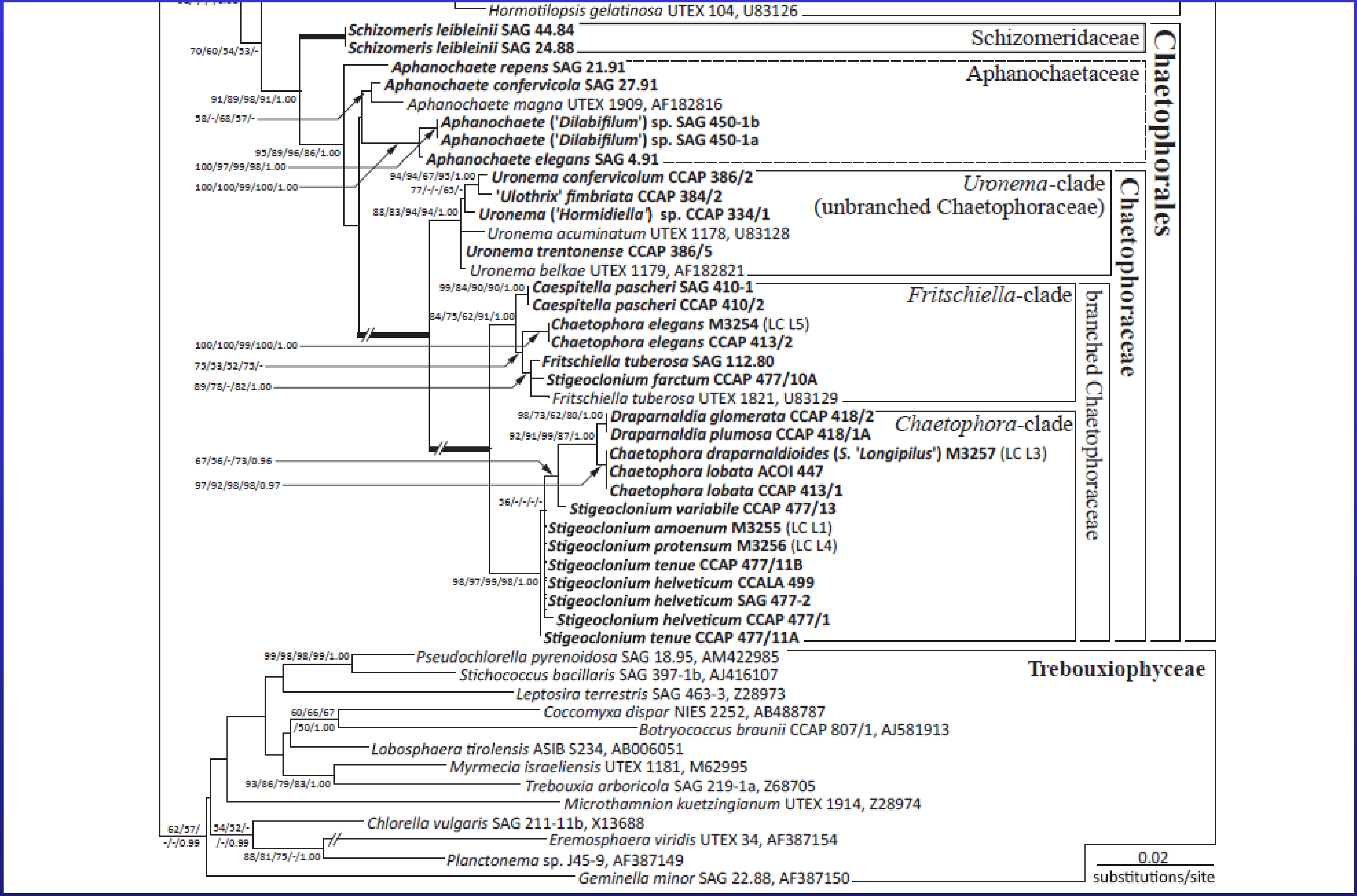
β - carothene production

Pink Lake – hypersaline lake (Australia)

Sea salt salinas with halobacteria and *Dunaliella*, San Francisco Bay, California, 1999

Phylogeny of Oedogoniales, Chaetophorales and Chaetopeltidales (Chlorophyceae): inferences from sequence-structure analysis of ITS2 *Ann Bot (2012) 109(1): 109-116*





Four flagellated zoospores; plasmodesmata in the cell walls

During zoospore release, degradation of the cell wall is mediated by species-specific autolysins.

Caisová et al. 2011

Chaetophora

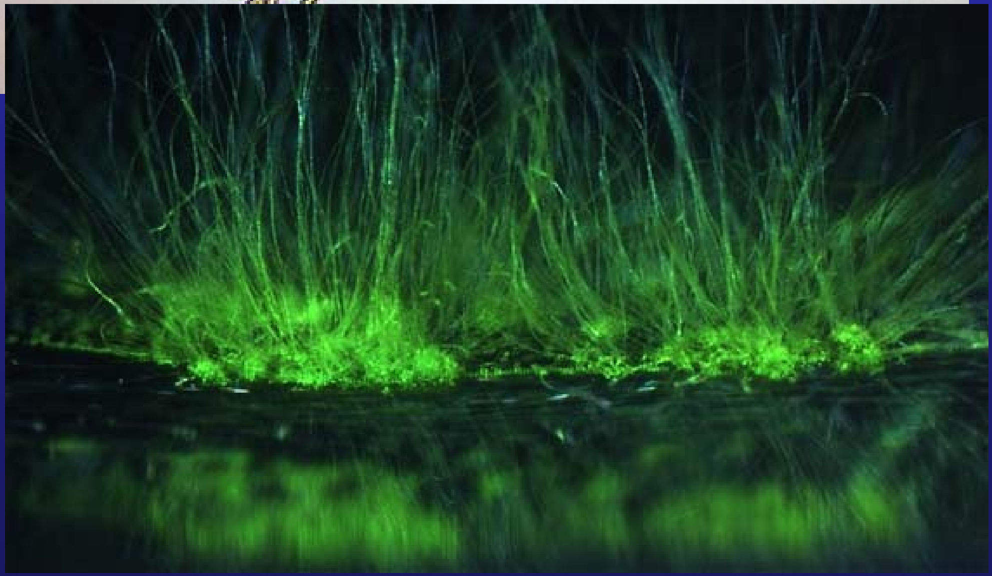
submerged surfaces

Polyphyly
of *Chaetophora* and
Stigeoclonium within
the Chaetophorales
(Chlorophyceae)

the ends of fillaments -
multicellular pointed „hairs“

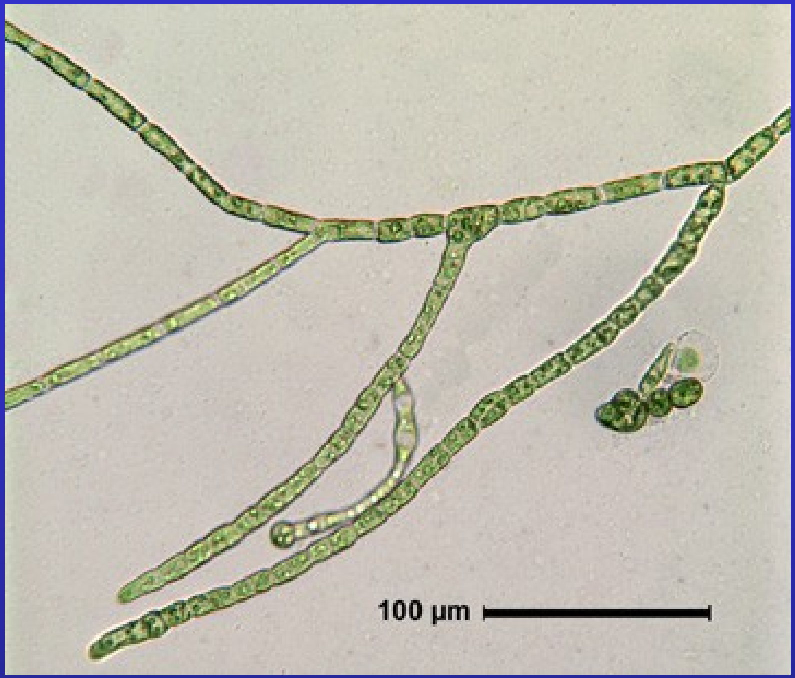
Stigeoclonium

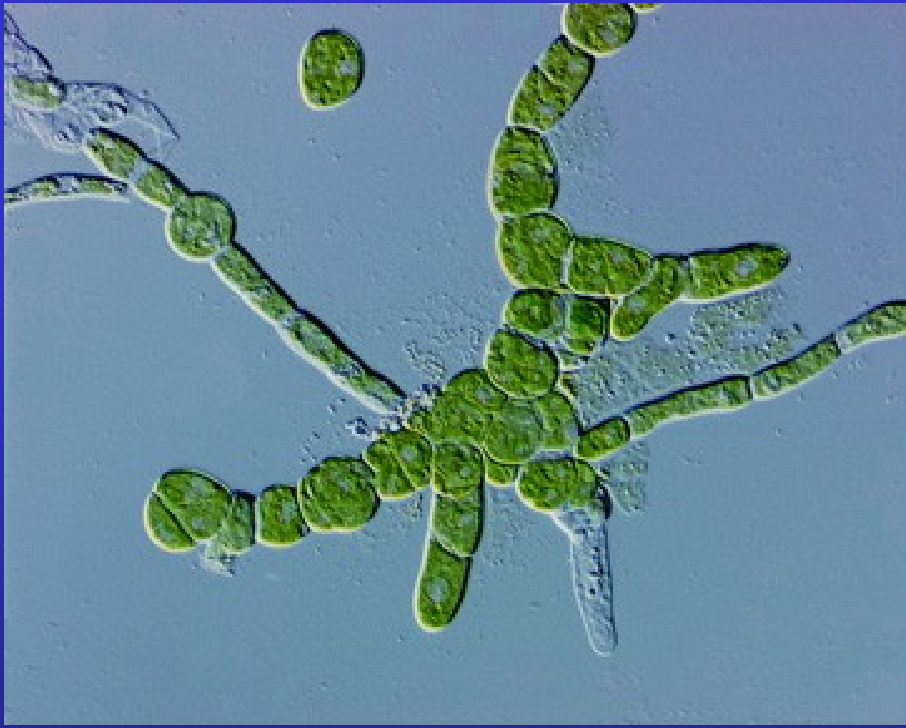
consist of a prostrate system which anchors the plant firmly to rocks or other substrates, and erect branched filaments which are only one cell wide but can be several cm long.



Hans Sluiman: ***Stigeoclonium*** **at night**

Fritschiella





terrestrial alga

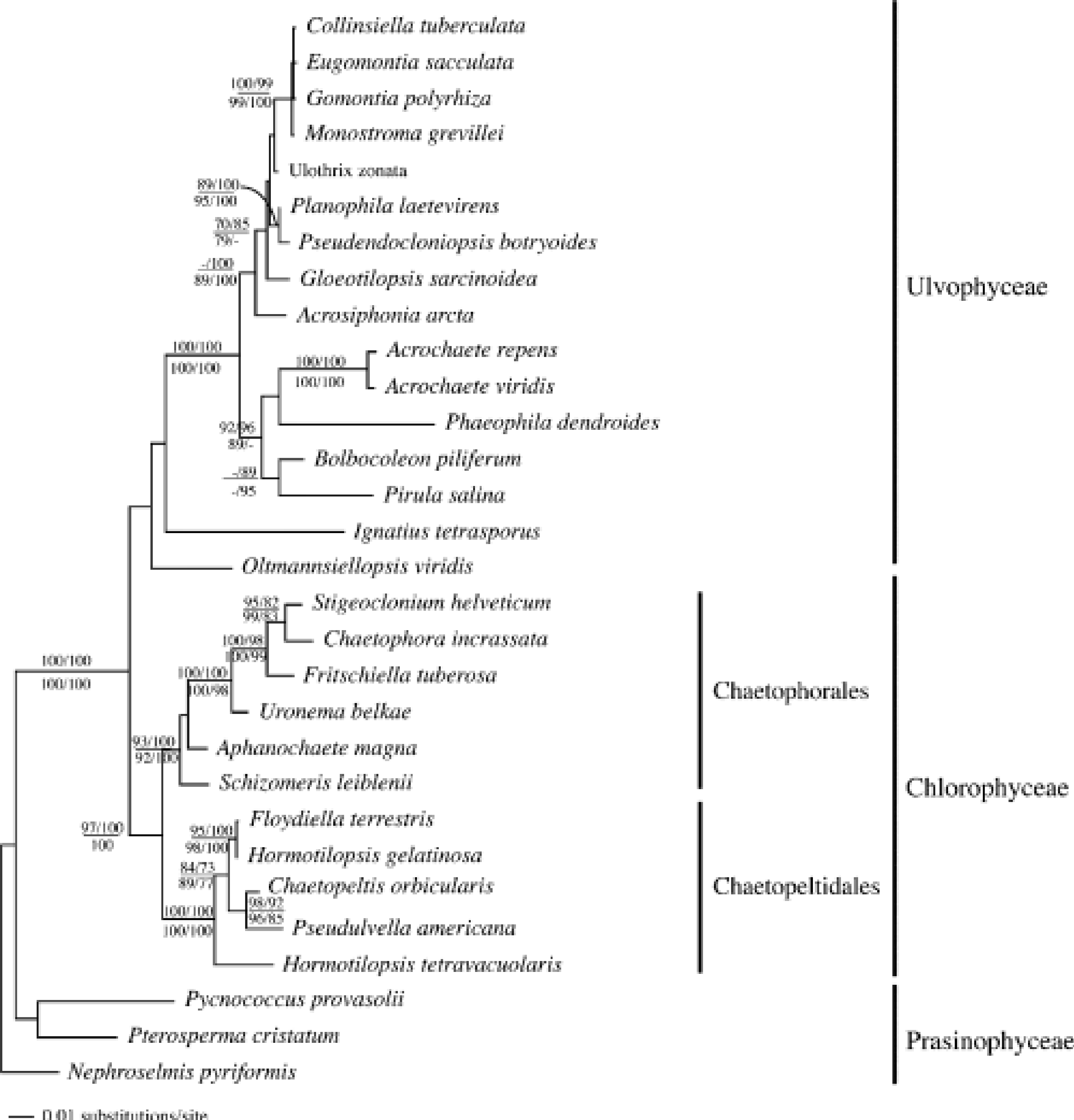
These morphological features are an example of a parallel evolutionary adaptation to terrestrial life with the land plants

Formerly considered an algal ancestor of vascular plants (1970).

Draparnaldia

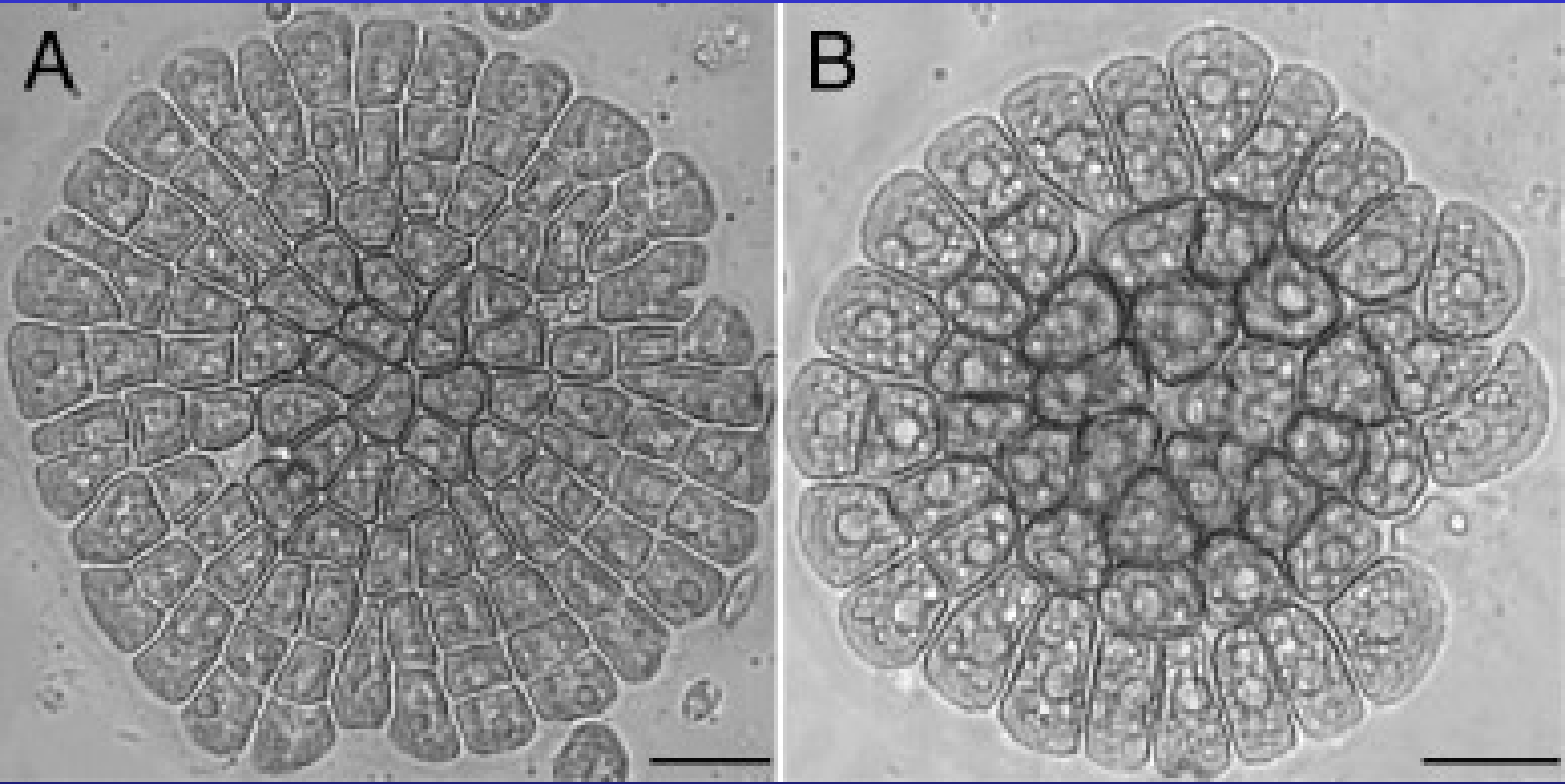
attacherd to rocks in cold running water

Chaetopeltidales



Sanchez-Puerta, et al 2006. Pseudulvella

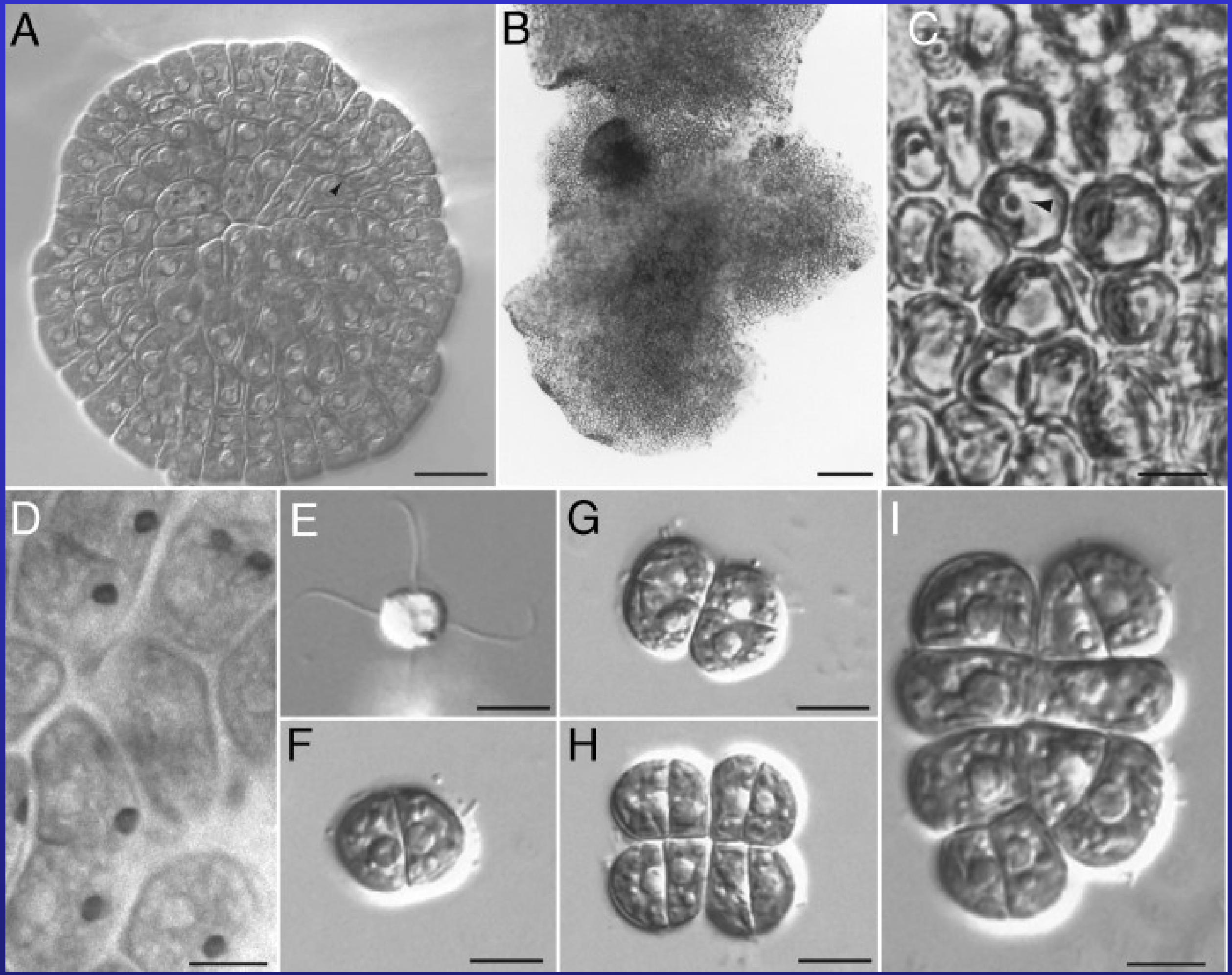
Chaetopeltidales



Disc- shaped thalli from *Pseudulvella americana* (A) *Chaetopeltis orbicularis* (B)

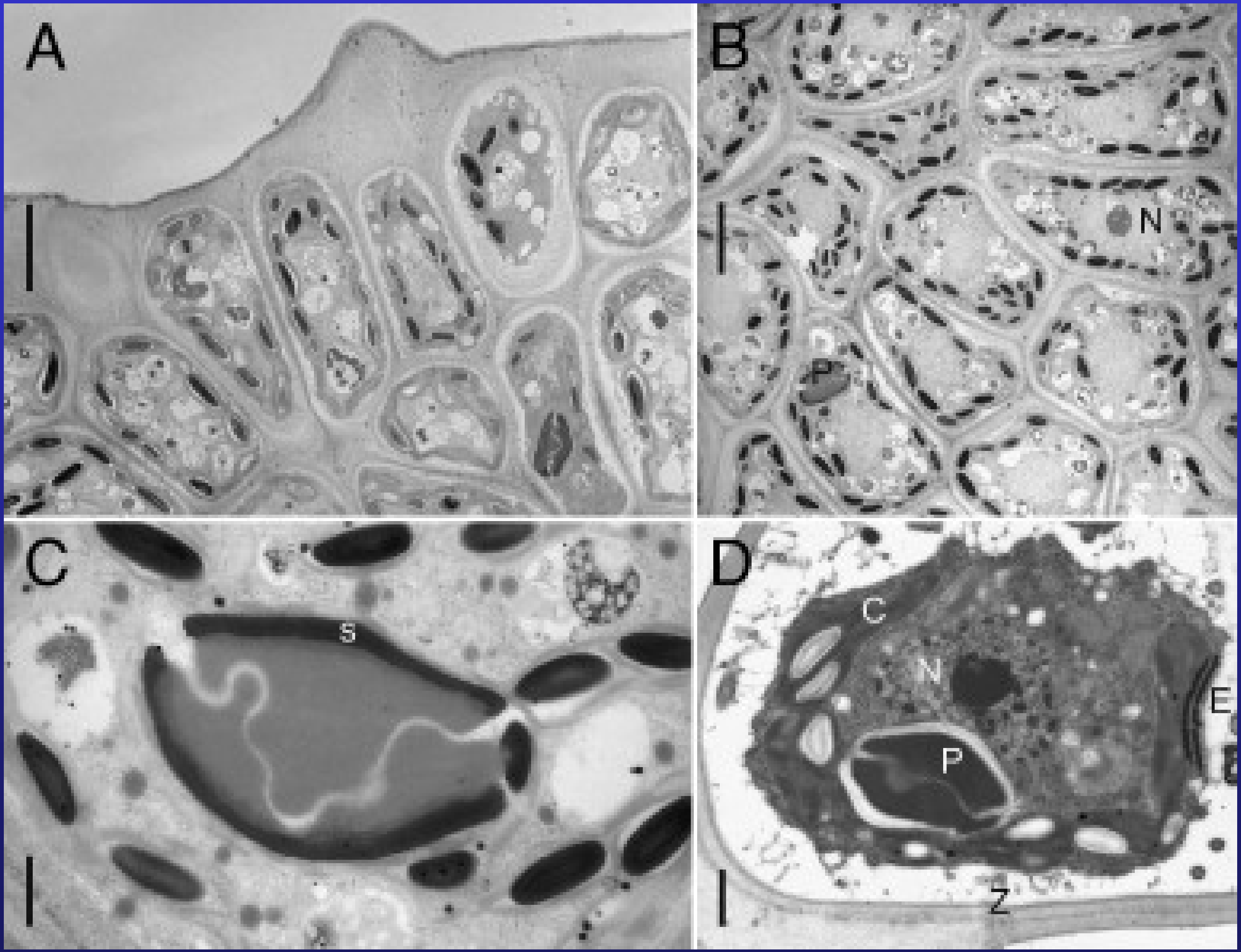
O'Kelly, C.J., Watanabe, S. & Floyd, G.L. (1994).

Pseudulvella



Sanchez-Puerta, Leonardi, O'Kelly, & Caceres, (2006).

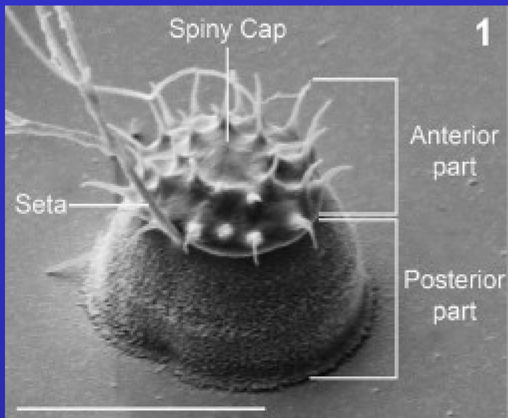
includes epiphytic or epizoic, freshwater, or marine green microalgae py s invaginací cytoplasmy



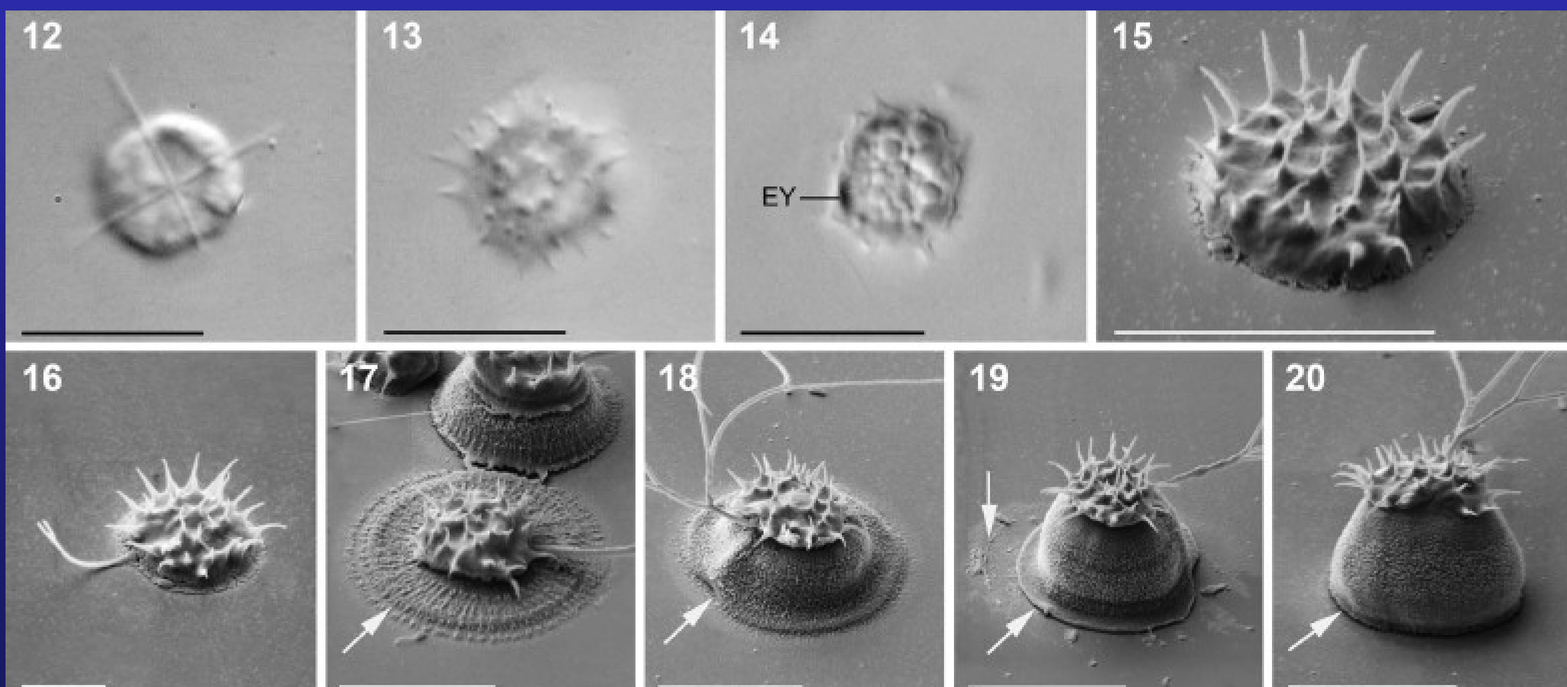
from rivers, lakes, and ponds both as an epiphyte on filamentous algae and twigs, and from the plankton.

When grown in culture, the alga exhibits morphological variations that depend upon the type of substratum on which it is growing

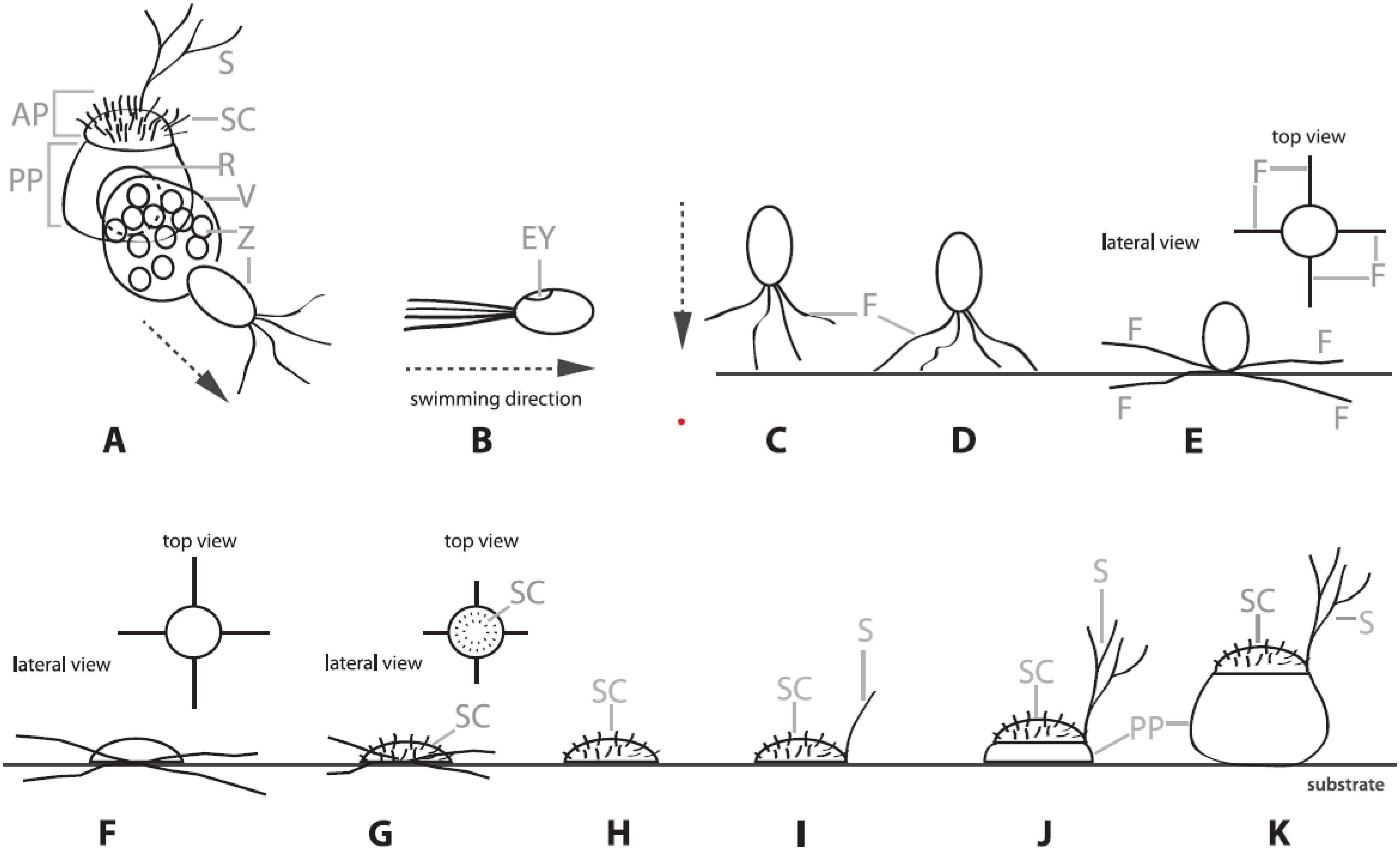
Dicranochaete



Dicranochaete is a green coccoid alga with a spiny cap and a long branched seta, that was described more than 100 yr ago from *Sphagnum* ‘leaves’ in peat bogs,



Caisová 2016


S
AP
SC
PP
R
V
Z
I
EY
swimming direction
F
top view
lateral view
A
B
C
D
E
F
G
H
I
J
K
PP
substrate

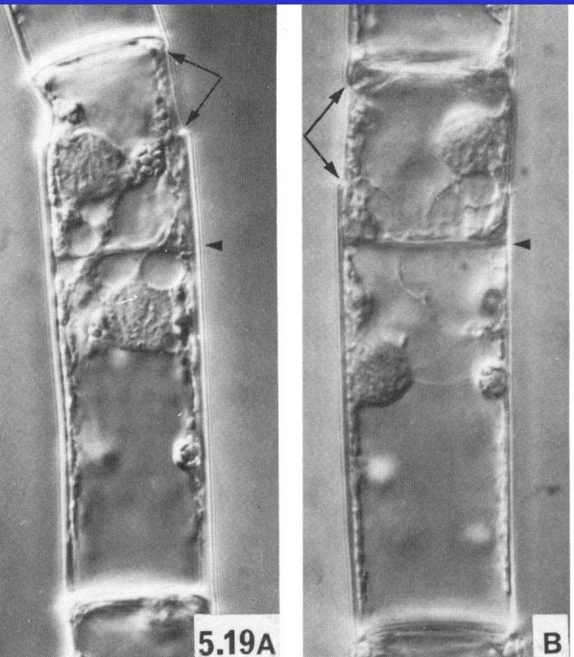
Oedogoniales

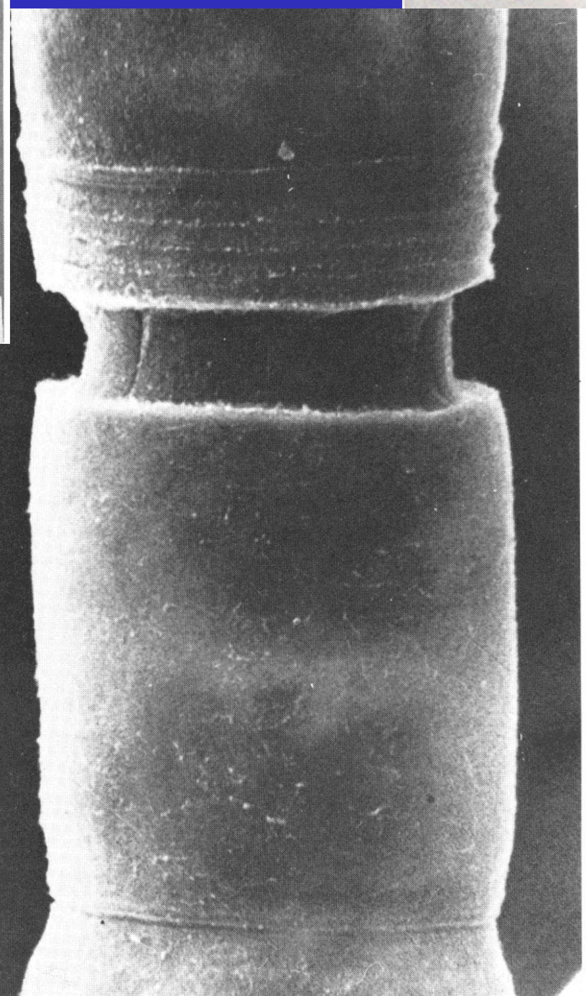
Oedocladium

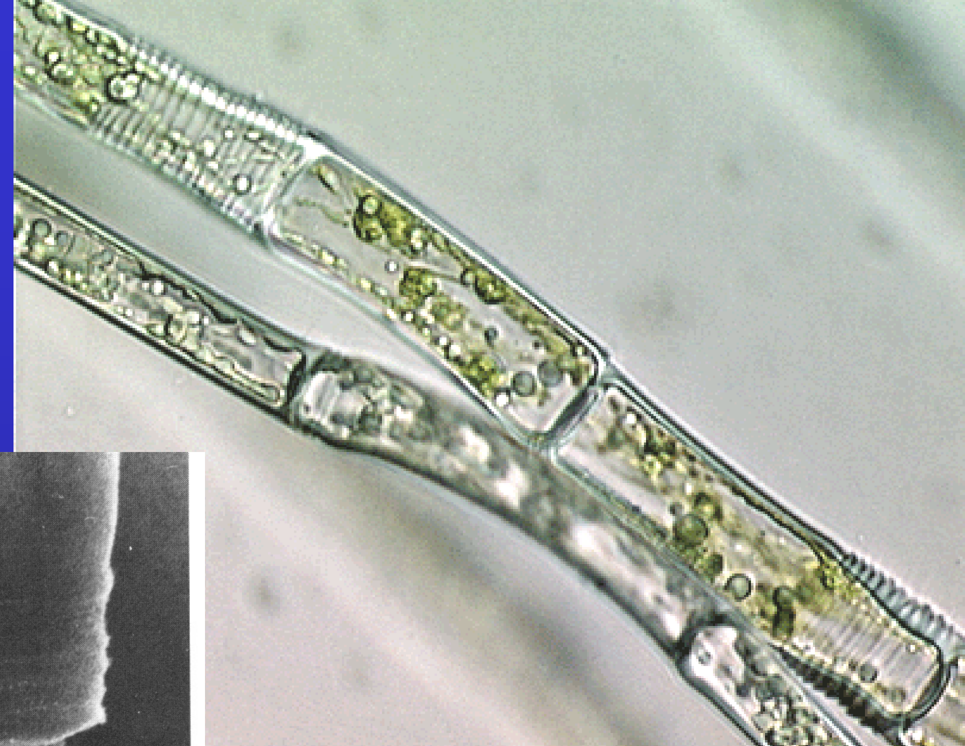
branched filaments

Terrestrial, or occasionally free-floating in freshwater habitats.

Oedogoniales



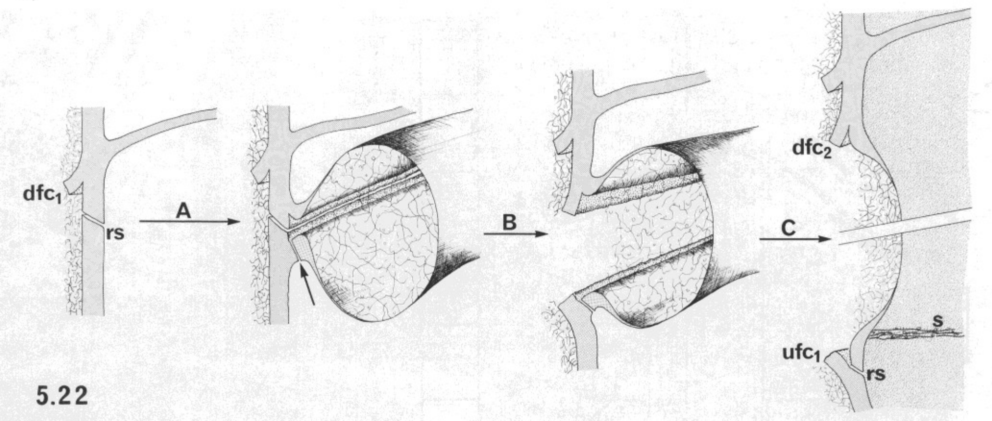




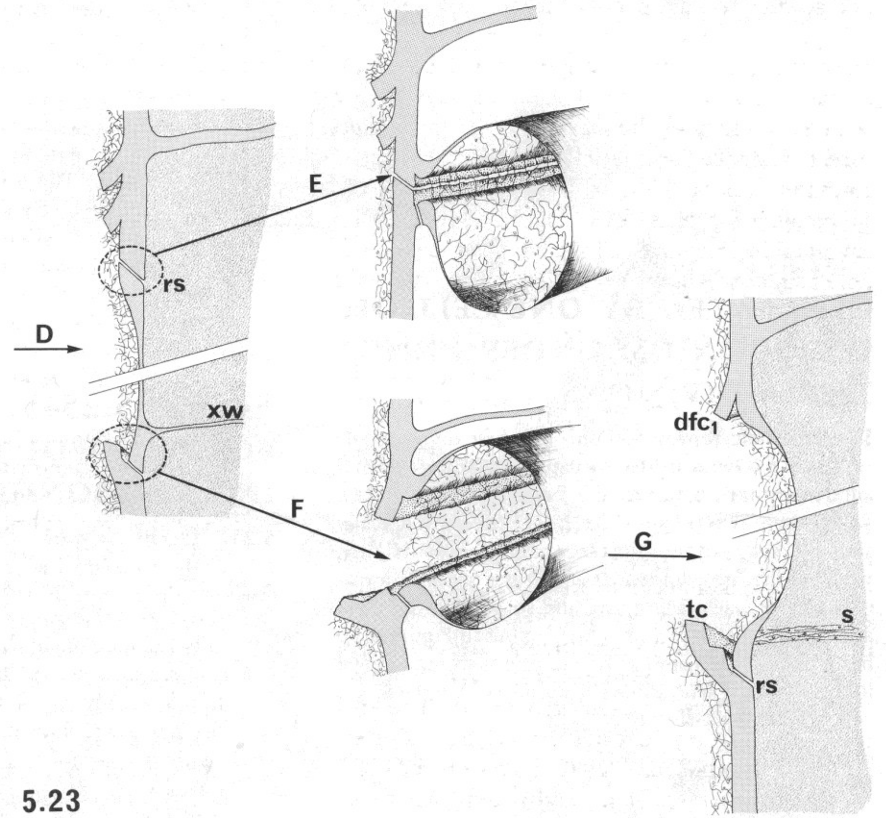
rings

net-like chloroplast, pyrenoids

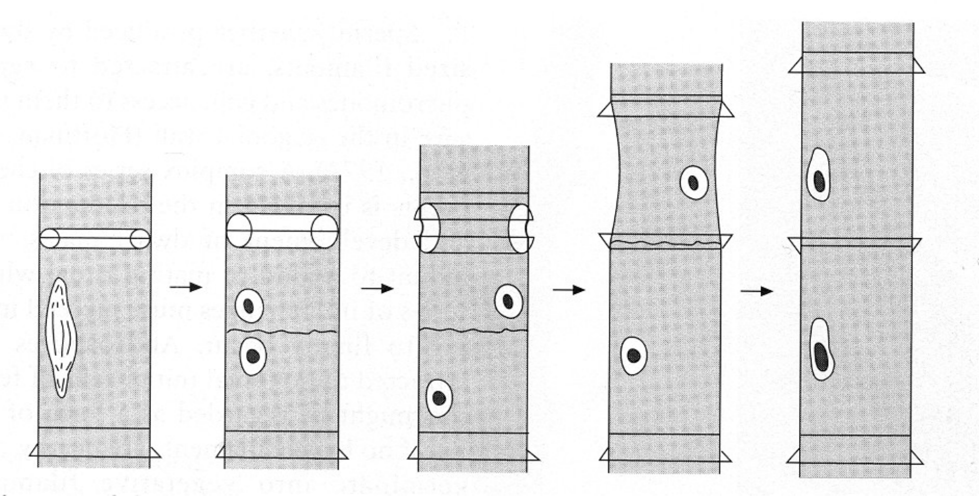
Oedogonium



5.22

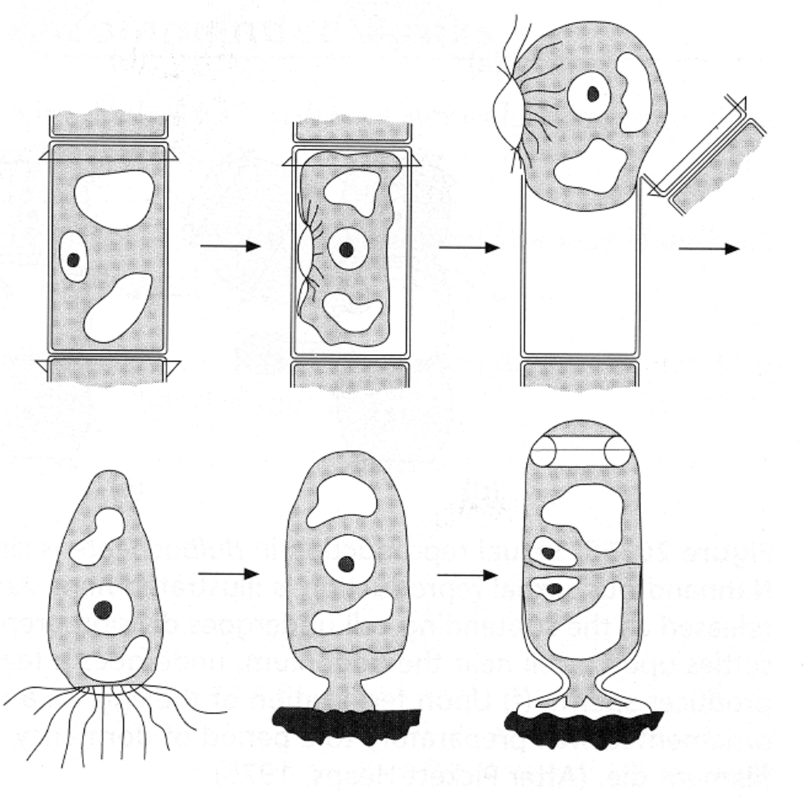


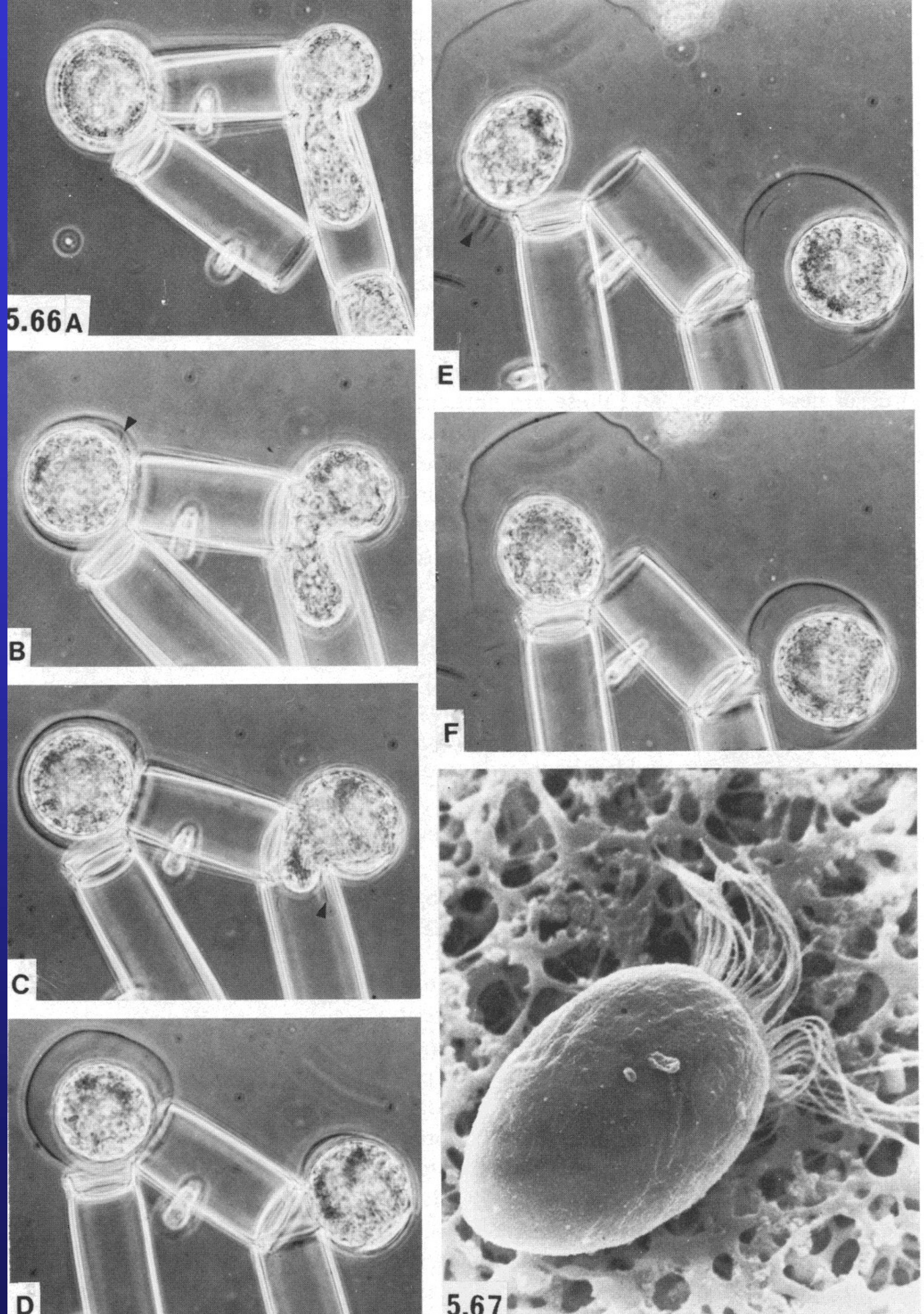
5.23



Each cellular division creates a new ring on the cap cell

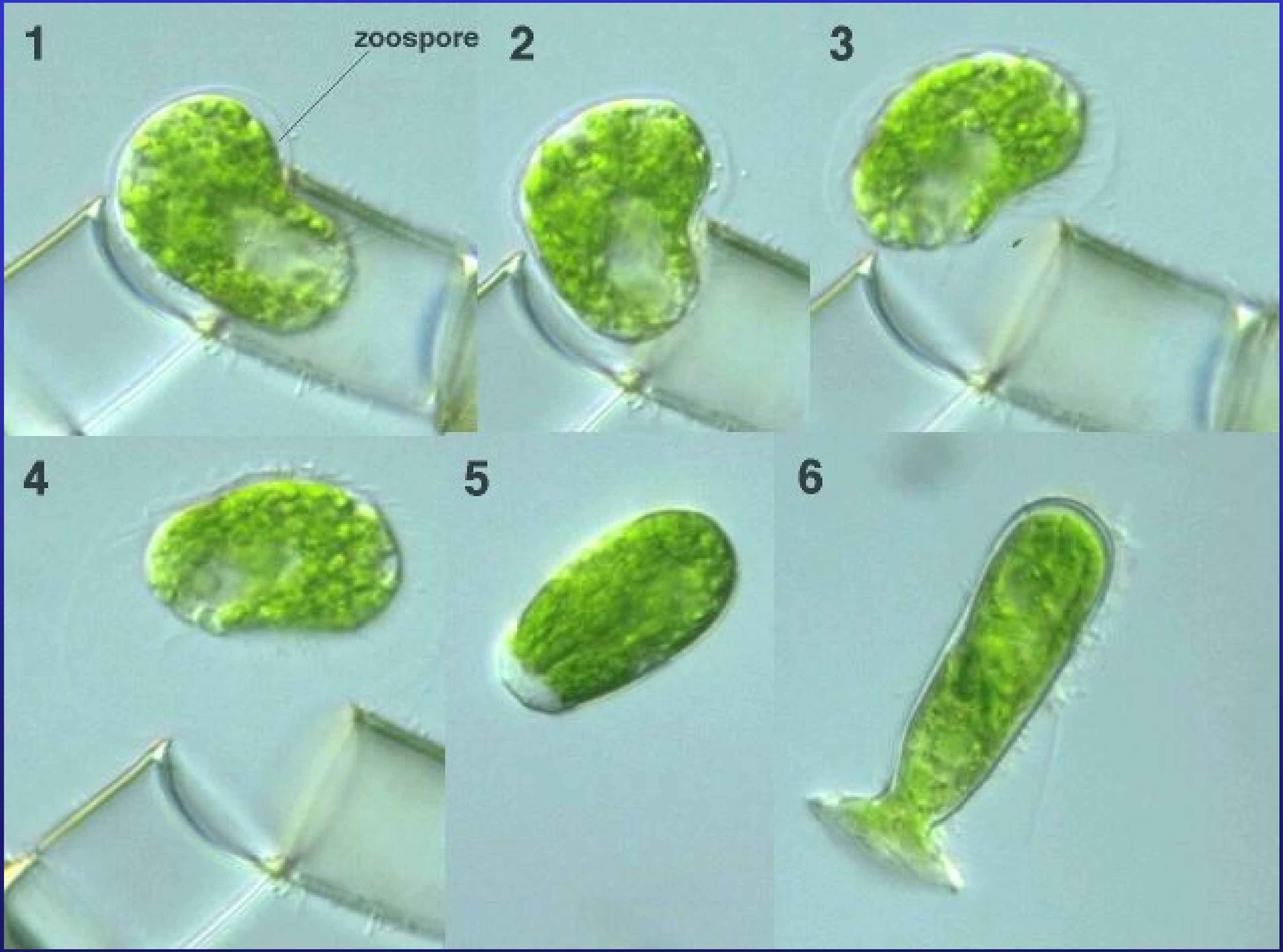
Oedogonium





asexual rproduction – stephanokont zoospores

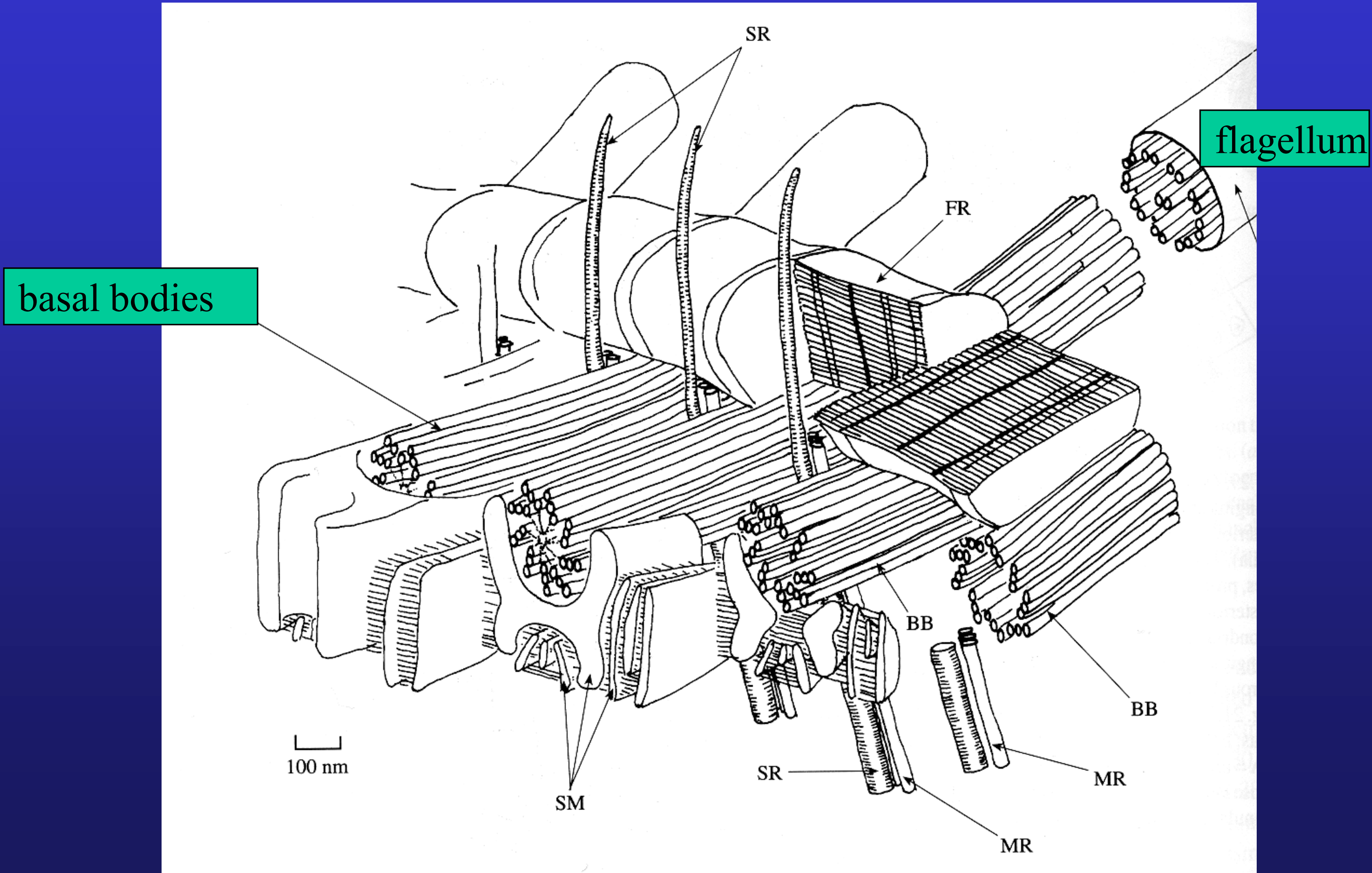
stephanokont zoospores



http://www.youtube.com/watch?v=Oh0E-Afl0_A

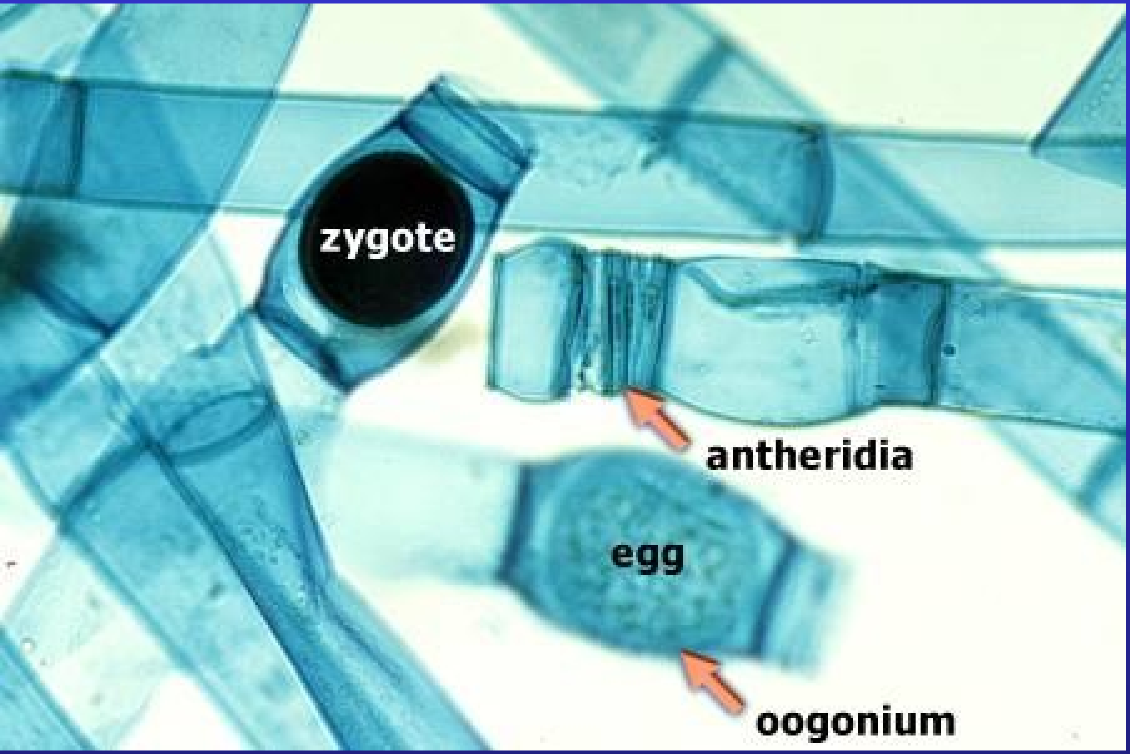
Oedogonium

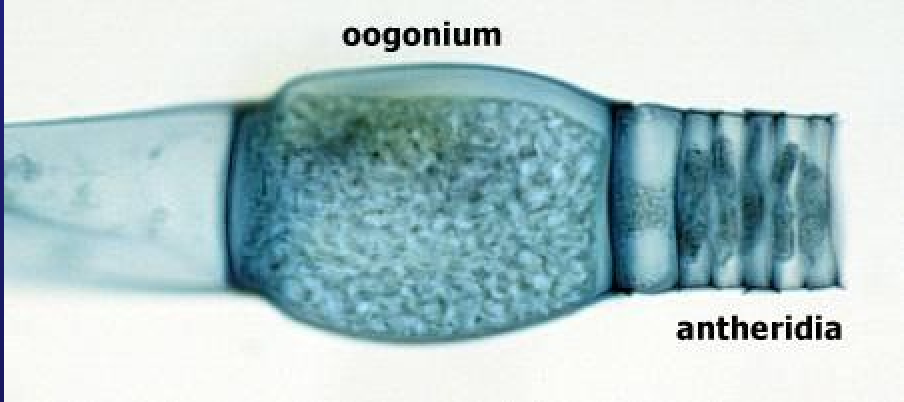
A massive band forms a ring on the surface of the zoospore; it connects the basal bodies of 40 flagella, just beneath the plasma membrane.



Oedogonium

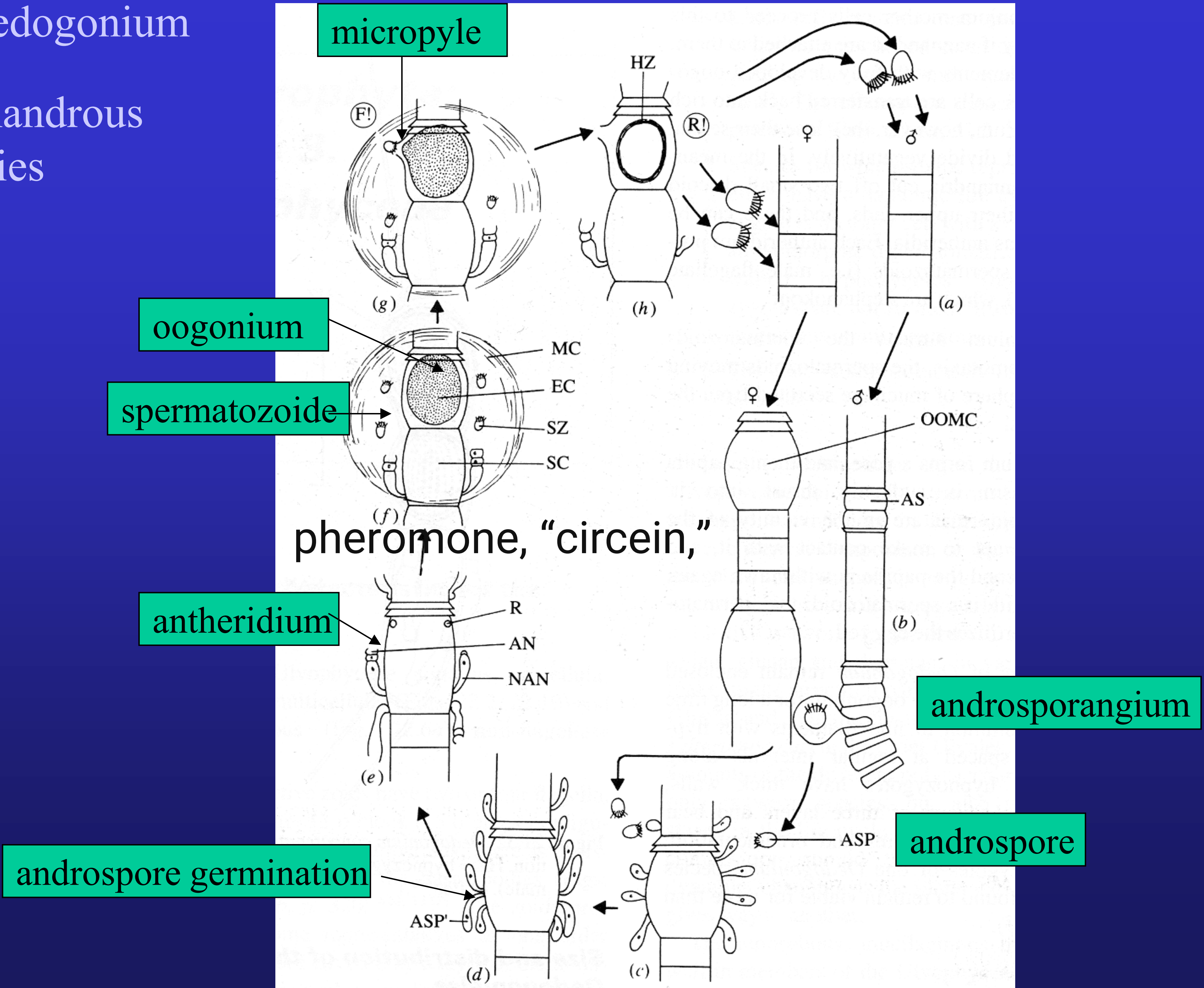
macrandrous species – anteridia directly from vegetative cells



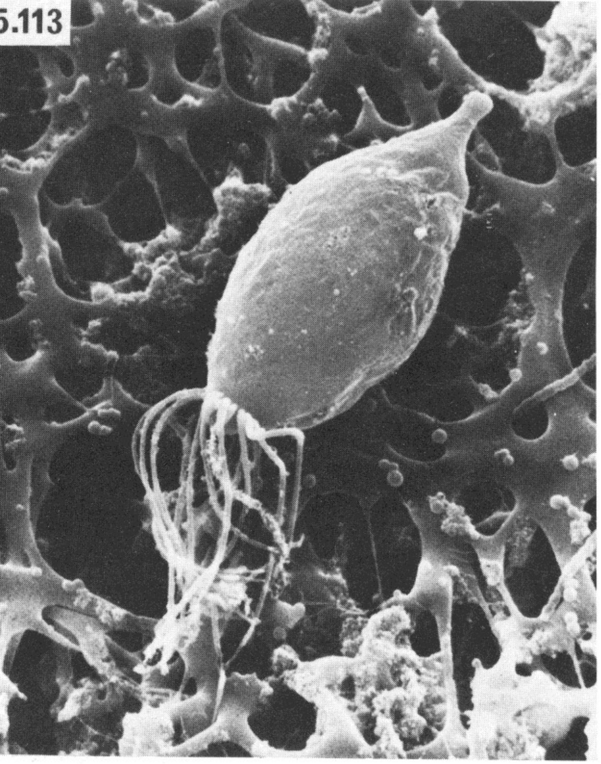


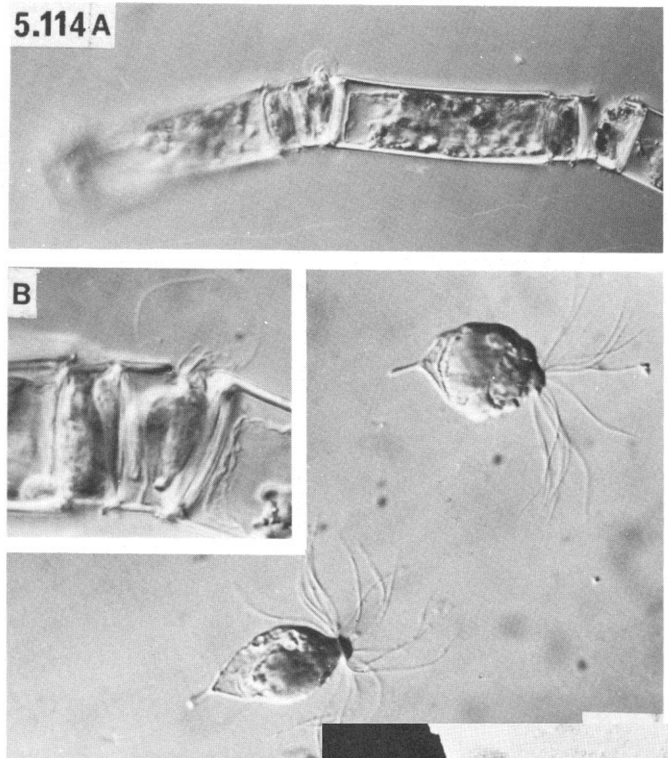
Oedogonium

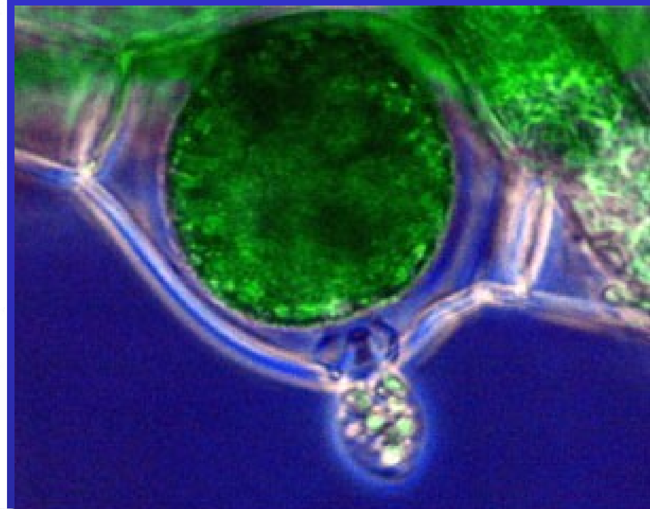
nannandrous species



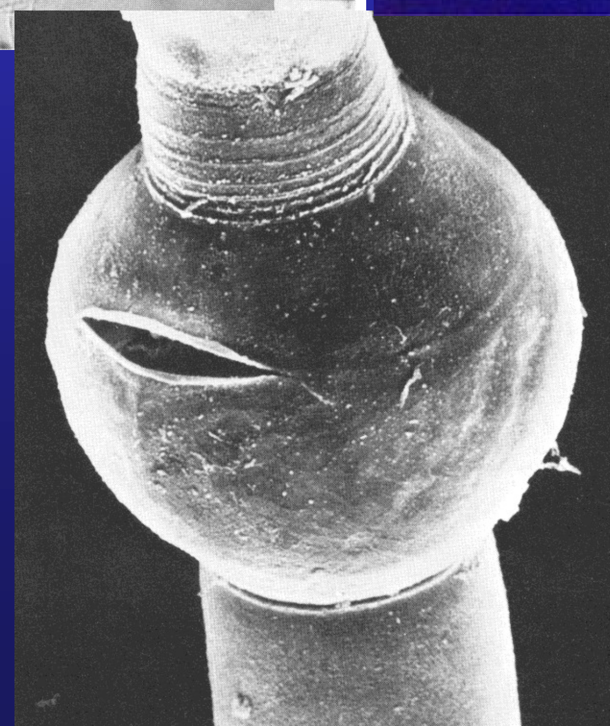
Oedogonium

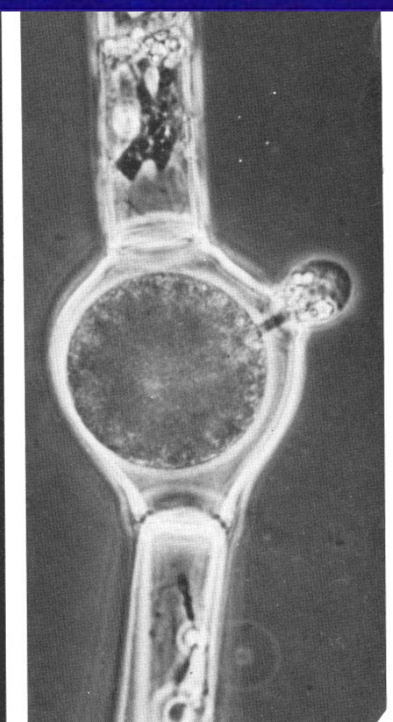






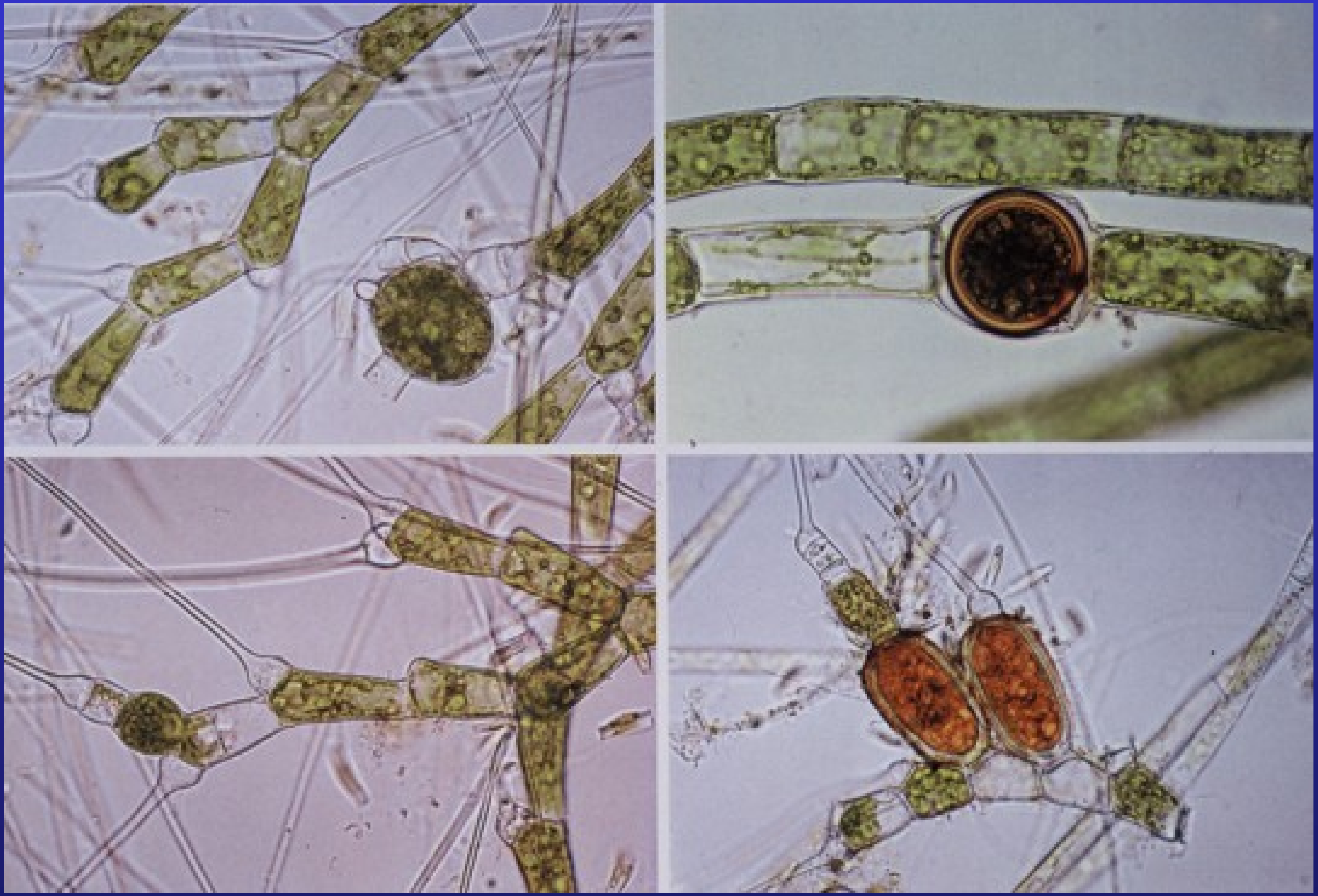
spermatogenesis *O.cardiacum*
macrandrous species



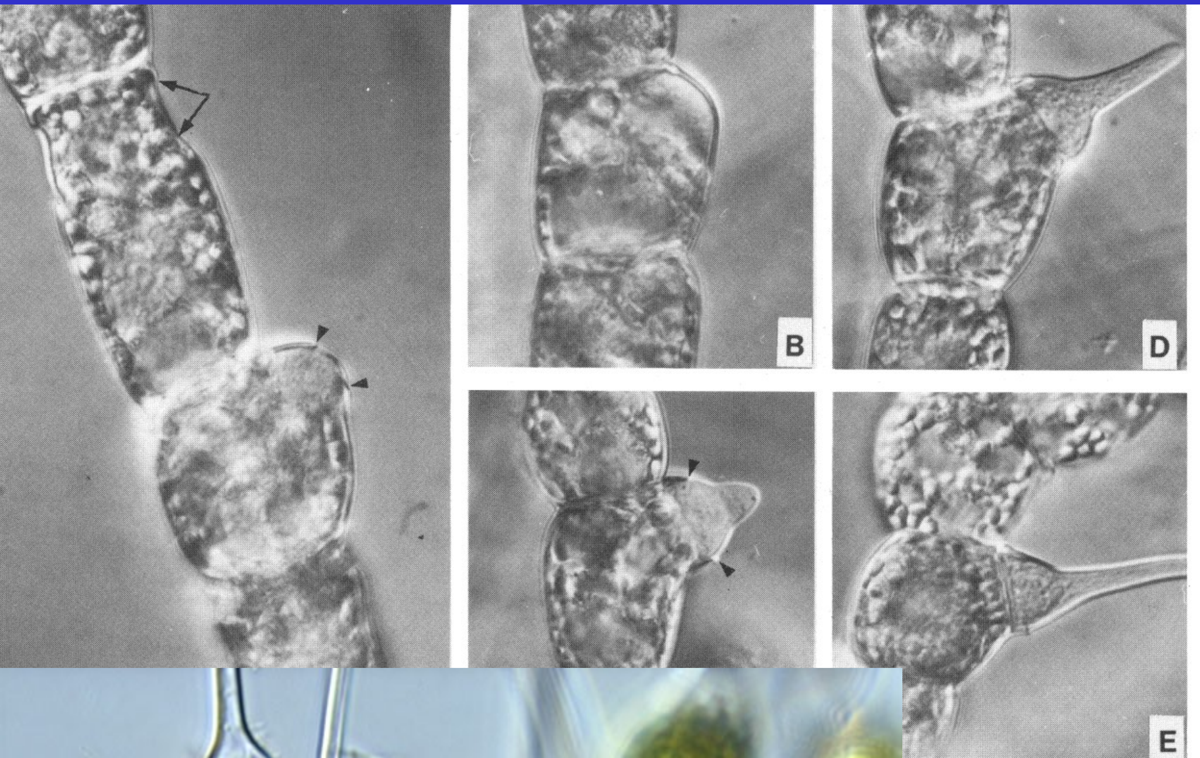


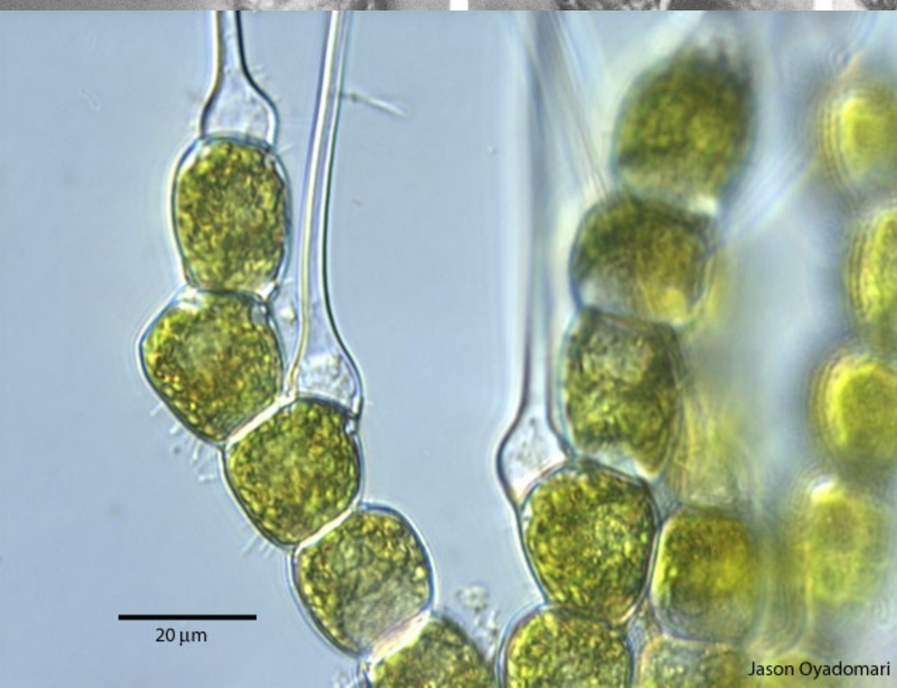
oogonium with a pore in the oogonial wall (microropyle)

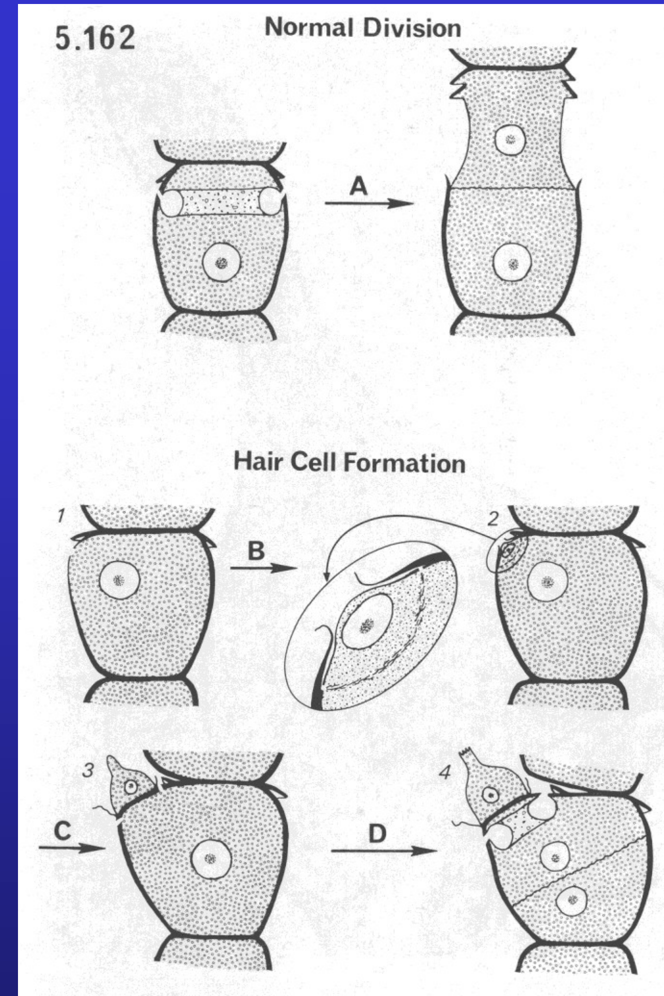
Bulbochaete



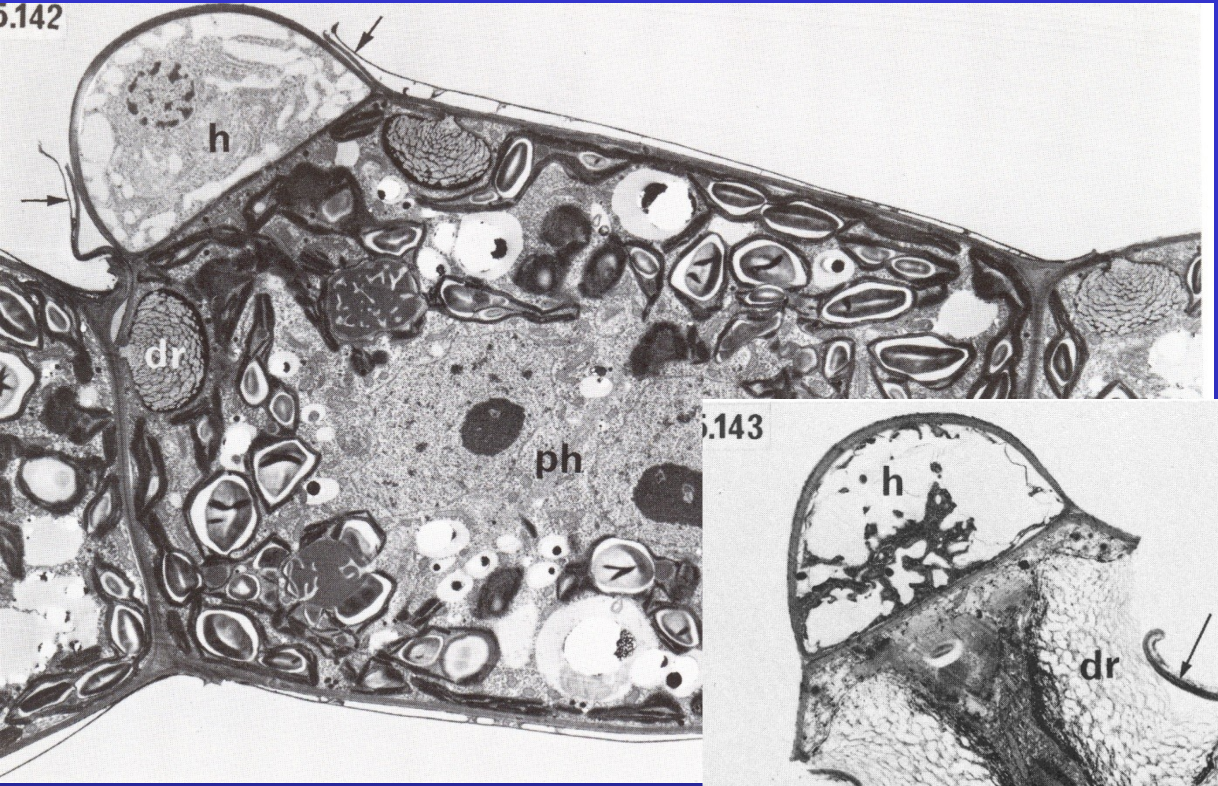
Bulbochaete







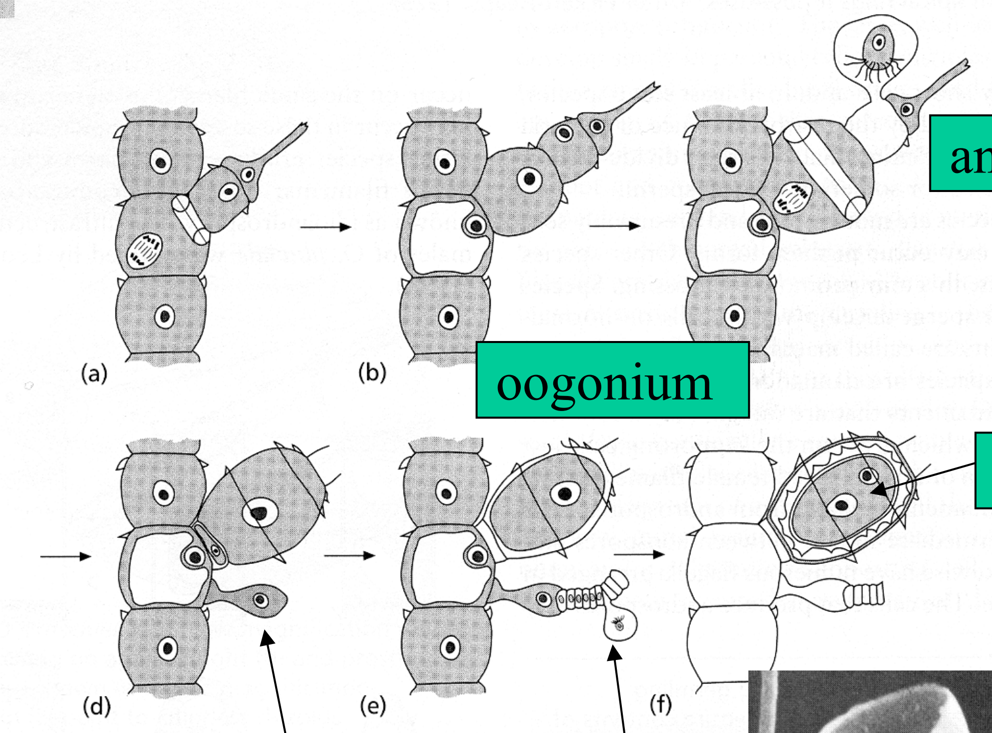
colorless bulbous-based hair cell (setae)

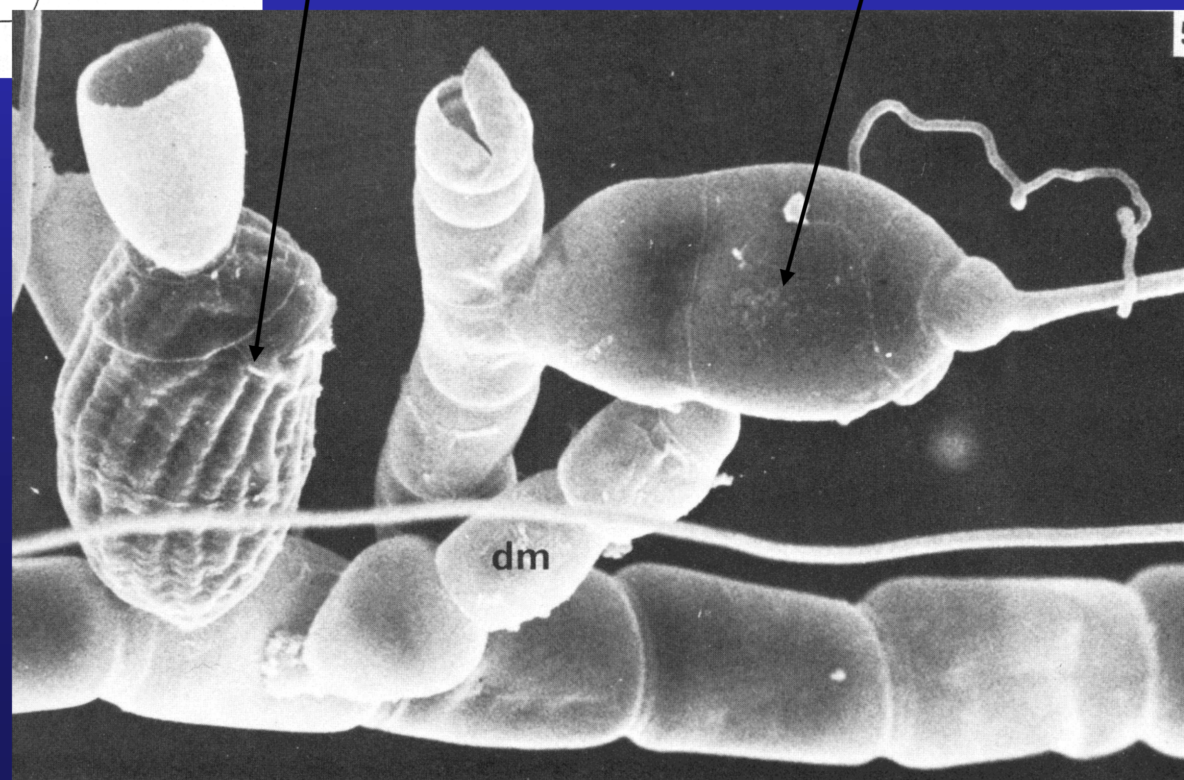


Bulbochaete

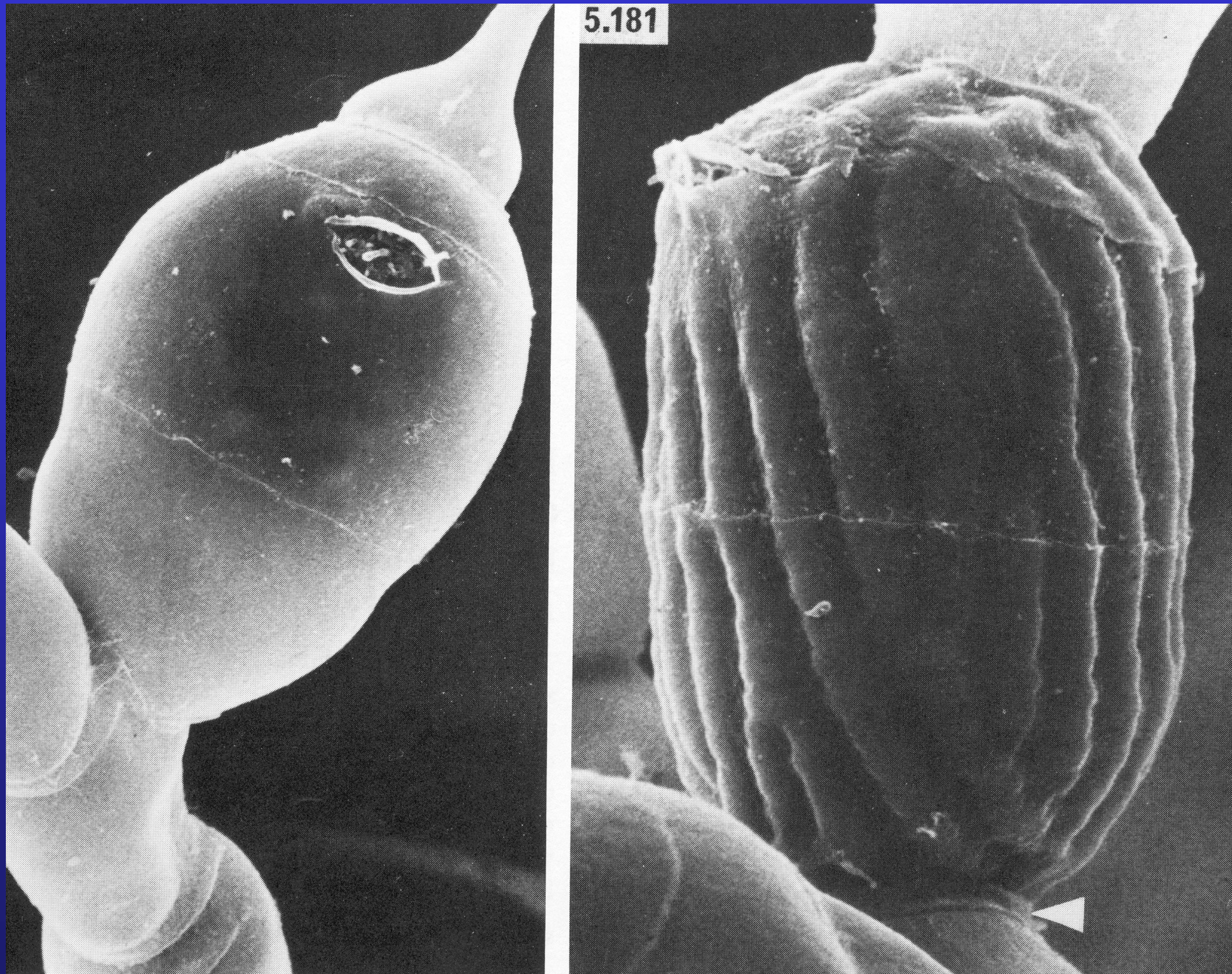
Bulbochaete

nannandrous reproductive process





Bulbochaete



oogonium with micropyle

thick walled oospore