

# Introduction to Cyanobacteria Taxonomy

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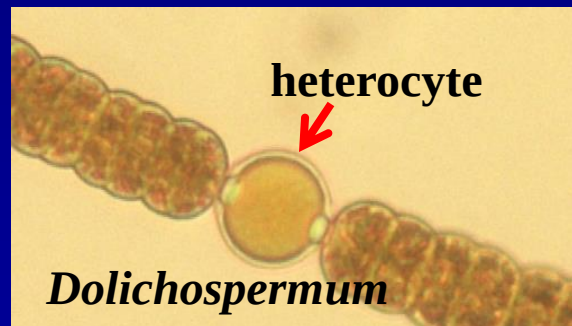
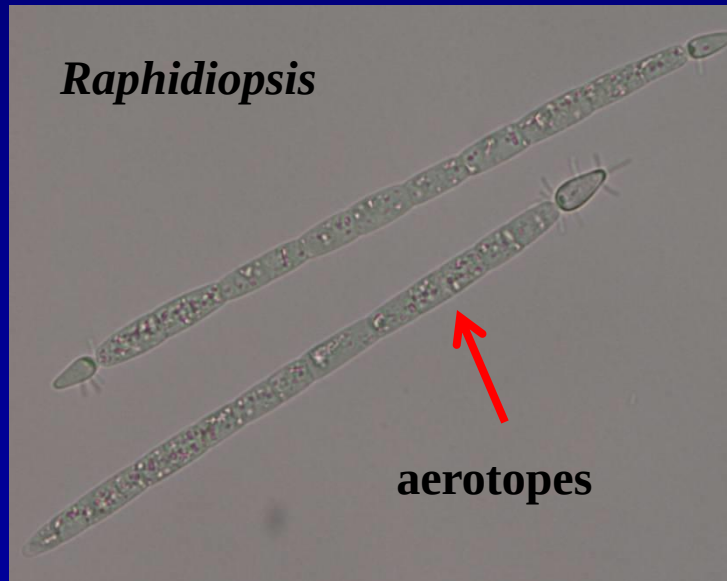
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# Cyanobacteria

- Photosynthetic prokaryotes
- Unicellular, colonial and filamentous forms
- Many cyanobacteria have mucilage associated with them
- Can have a number of specialized structures including aerotopes (gas vacuoles), heterocytes (heterocysts) and akinetes
- Most common in alkaline, nutrient rich waters
- Some can fix atmospheric nitrogen
- Some species can produce taste/odor and/or toxic substances
- Some species can form surface, subsurface or benthic blooms
- Asexual reproduction



# Cyanobacteria: Blue-Green Algae

**Major Pigments:** chl-*a*, phycoerythrin, phycocyanin, allophycocyanin, zeaxanthin

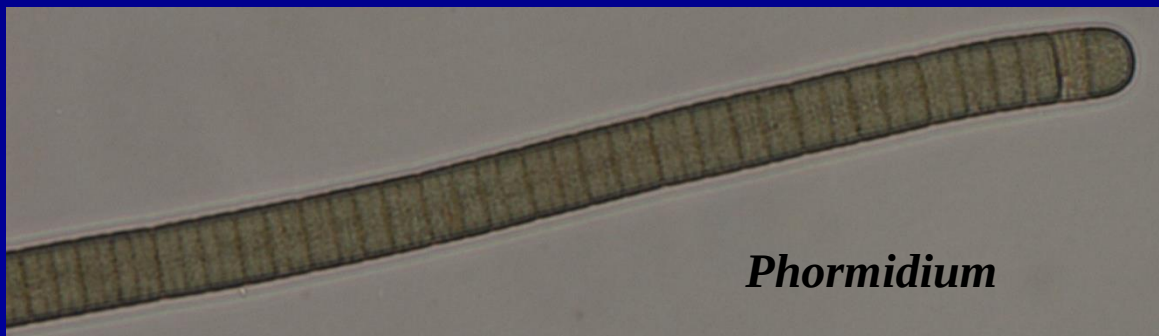
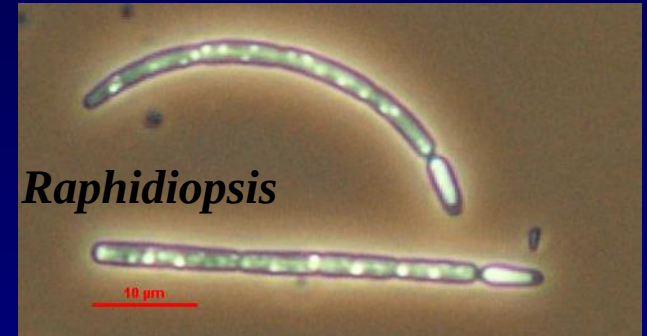
**Chloroplast Outer Membranes:** 0

**Thylakoid Associations:** 0 (not contained in plastids)

**Starch-like Reserve:** cyanophycean starch

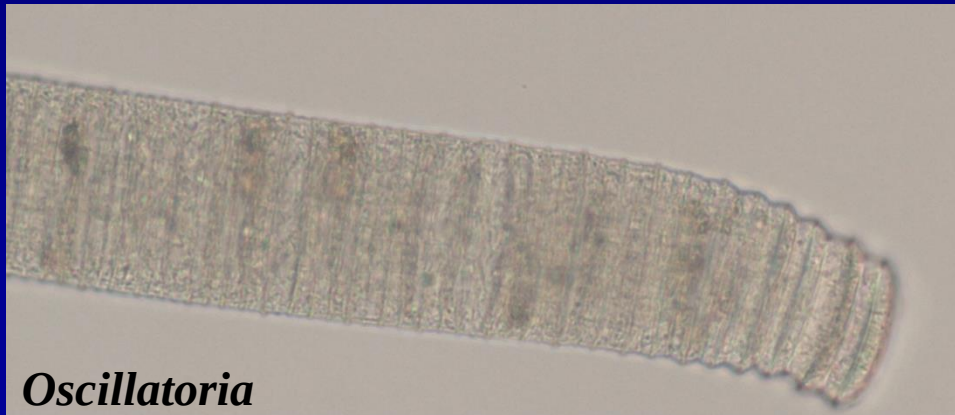
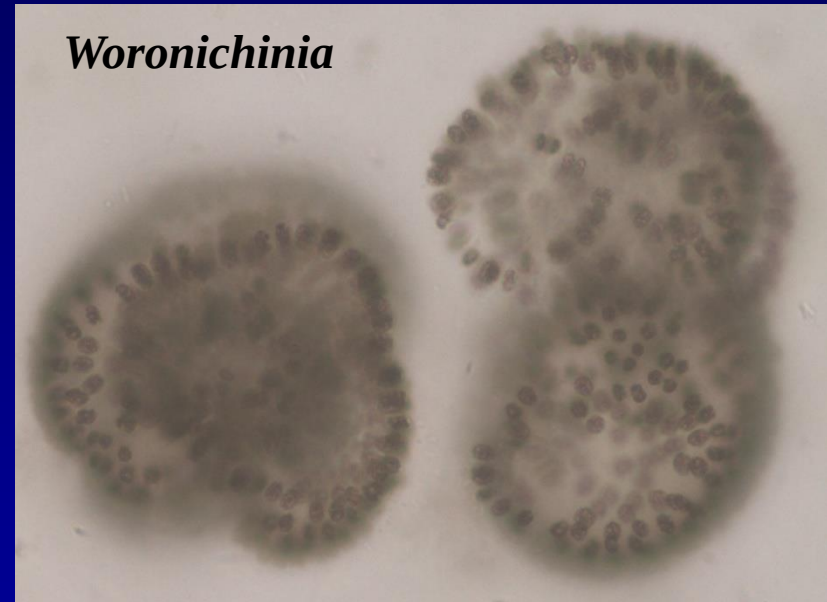
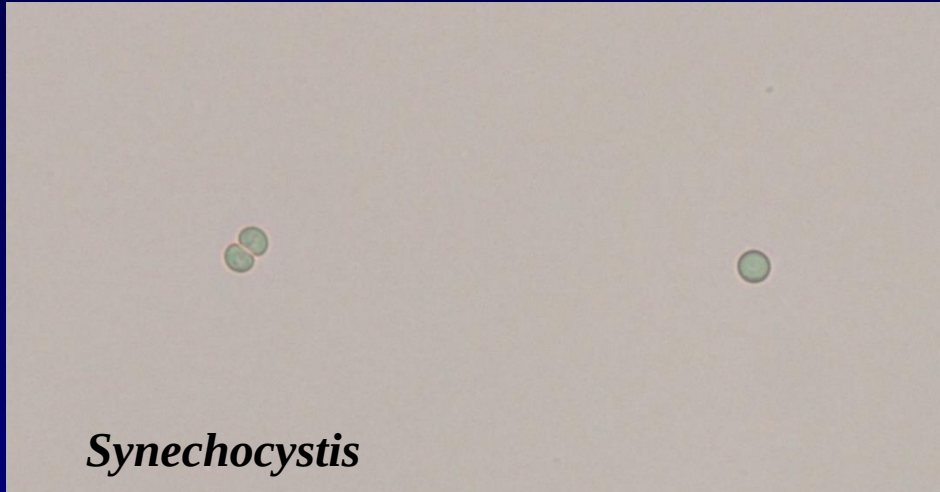
**External Covering:** peptidoglycan matrices or walls

**Flagella:** 0

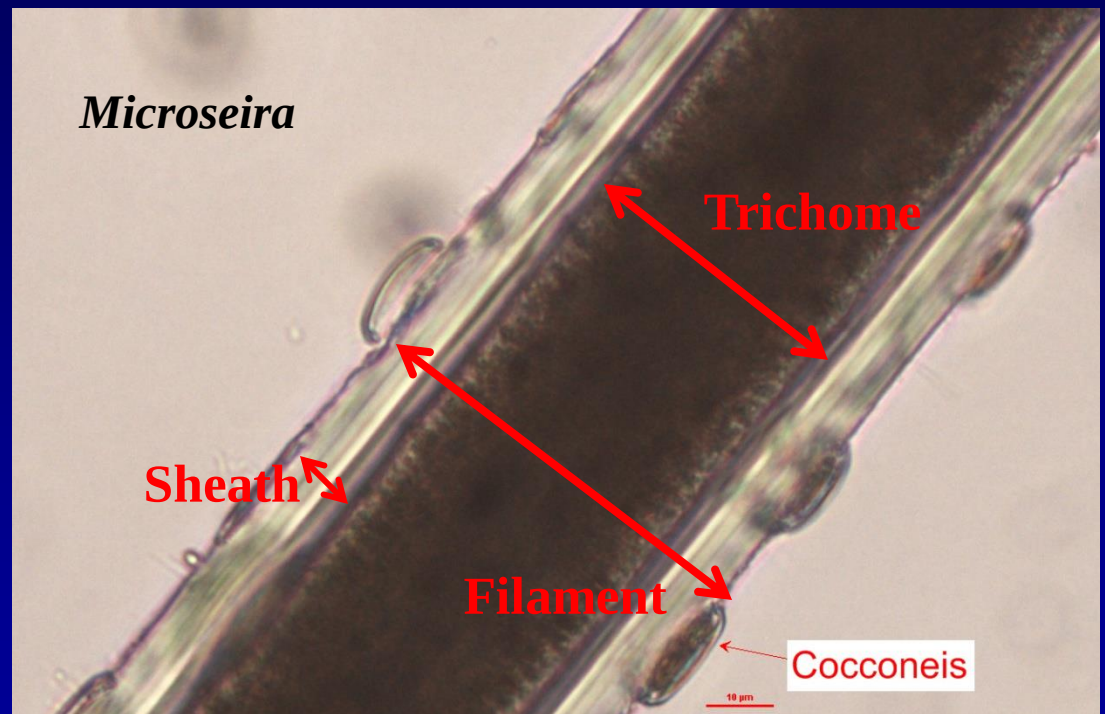


- **Cyanobacteria (blue-green algae) can adversely impact water treatment and supply due to filter clogging, increased operational costs, taste and odor compounds and toxin production.**
- **Because not all cyanobacteria produce taste and odor compounds and/or toxins, proper identification can be critical in making fully informed management decisions.**
- **Generally, for those charged with recognition of cyanobacteria in source waters, identifications will be based on morphological characteristics observed under a light microscope.**
- **Traditionally cyanobacteria have been classified following the International Code of Botanical Nomenclature based primarily on microscopic and cytological characters.**

- Cyanobacteria occur in unicellular, colonial and filamentous forms



- Many cyanobacteria have mucilage associated with them
- Mucilage acts as a microhabitat for bacteria and other algae

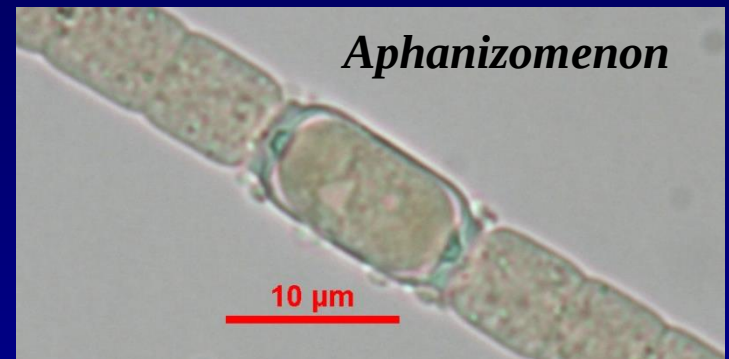


# Specialized Structures in Cyanobacteria

- Aerotopes (gas vacuoles)



- Heterocytes (heterocysts)

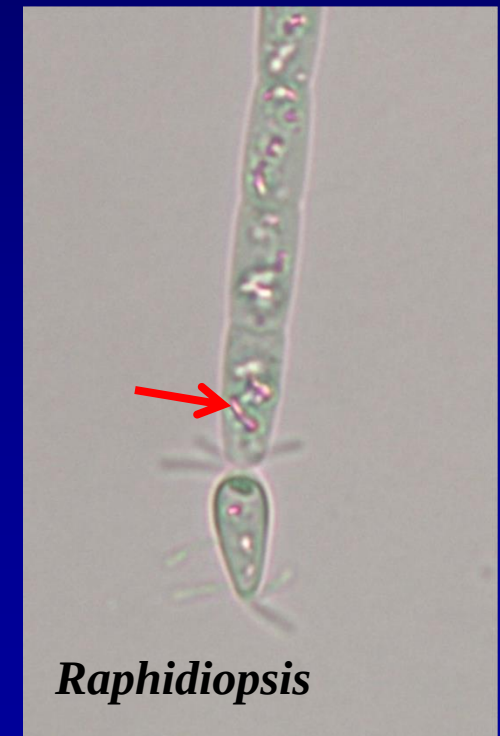


- Akinetes

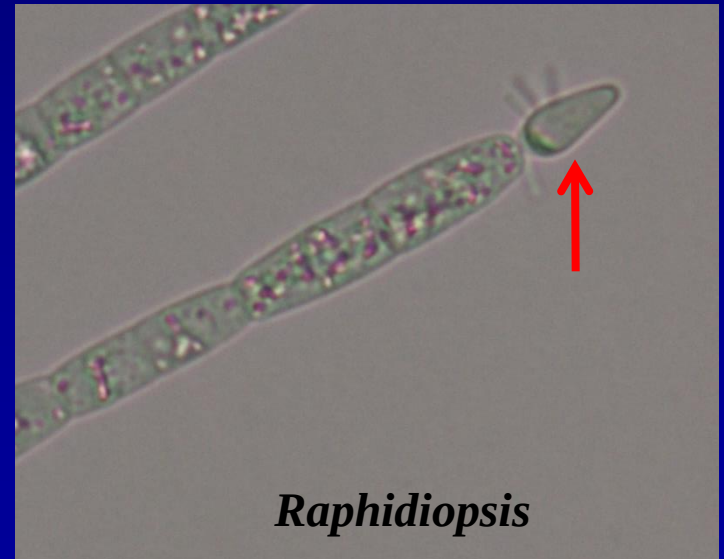
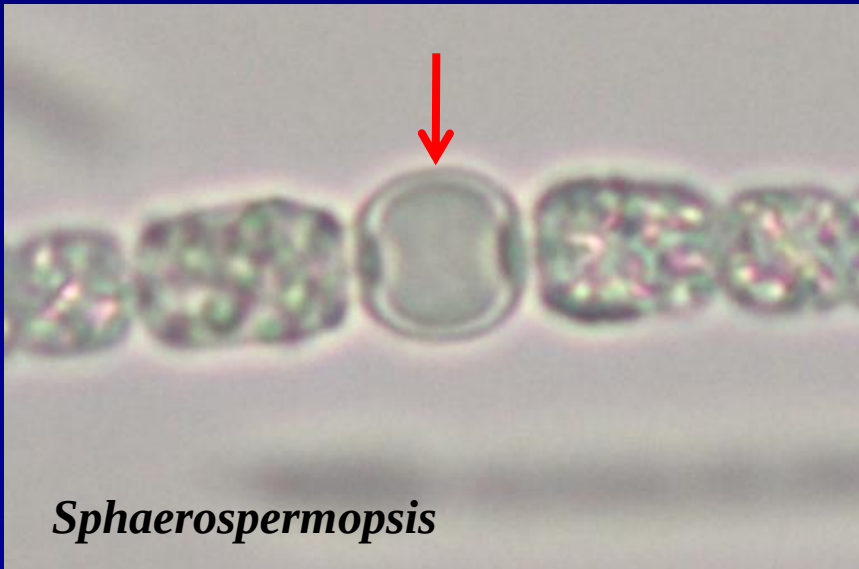


- All are important in cyanobacteria taxonomy

- **Aerotopes are composed of groups of gas vesicles**
- **Allows cells, colonies and filaments to change their position in the water column**
- **Gas vesicles fill or collapse in response to changes in internal turgor pressure due to changes in light level and photosynthesis**



- Heterocytes are morphologically and physiologically distinct cells
- Allow atmospheric nitrogen fixation
- Provide an anaerobic environment in which N-fixation can occur via the enzyme complex nitrogenase
- Yellow-hued transparent appearance and thick cell walls



- **Akinetes are specialized cells that may act as resting stages to survive adverse conditions**
- **Recognized by their larger size, thick cell walls and granular appearance**
- **Germinate when exposed to favorable conditions**

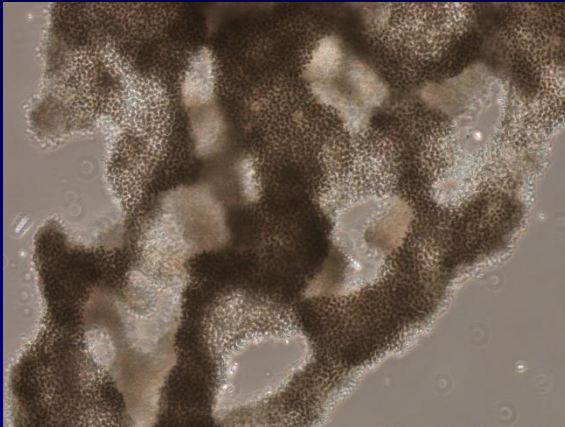


# **Modern Approach to the Classification System of Cyanobacteria**

- **Proposed by Anagnostidis and Komarek in a series of papers from 1985-1990**
- **Follows International Code of Nomenclature for Algae, Fungi and Plants**
- **Monotheic concept of taxa**
- **Polyphasic Approach: Use all currently available data (morphological, physiological, molecular, ecological)**
- **Weighted diacritical features**
- **Small, unambiguously defined genera**
- **Species concept: commonly and repeatedly occurring, ecologically delimited populations in natural biotopes**
- **Komarek et al. 2014. Taxonomic classification of cyanoprokaryotes (cyanobacterial genera) 2014, using a polyphasic approach. Preslia 86: 295-335.**

# Orders of Cyanobacteria Based On Morphological Traits

## Chroococcales



## Oscillatoriales



## Nostocales



## Stigonematales



# Ultrastructural and Chemical Criteria Used In Cyanobacteria Taxonomy

- Thylakoid Arrangement
- Phycobilisomes (shape, structure, diameter, arrangement)
- Cell wall composition, perforations
- Pigment composition, pigment ratios, chromatic adaptation
- Cell inclusions (cyanophycin granules, aerotopes)
- Lipid and protein content
- Polyphosphate bodies

# Genes and Molecular Techniques Used In Cyanobacteria Taxonomy

- **16S rRNA gene**
  - **16S-23S ITS Region (16S-23S rRNA internal transcribed spacer)**
  - **phycocyanin locus (*cpcBA*-IGS)**
  - **spacer region of the ribosomal operon (ITS1)**
  - ***rbcLX* (RubisCO)**
  - ***rpoC1***
  - ***nif* genes**
- 
- **DNA-DNA Reassociation**
  - **Average nucleotide identity (ANI)**
  - **Species genome/pan genome**
  - **DNA-base composition**
  - **Genome size**
  - **Restriction fragment length polymorphism analysis (RFLP)**
  - **Denaturing Gradient Gel Electrophoresis (DGGE)**
  - **BLAST analysis**

# Some Major Findings of Polyphasic Analyses

- Distinction between coccoid and filamentous forms no longer followed at higher taxonomic levels
- Division of higher taxa based on phylogenetic analysis and ultrastructural pattern of thylakoid arrangement
- Heterocytous cyanobacteria unified into one subclass
- Many genera shown not to be monophyletic (e.g. *Anabaena*, *Calothrix*, *Aphanizomenon*, *Nostoc*, *Synechocystis*, *Cynanothece*, *Phormidium*, *Lyngbya*)
- Morphology based species concept for *Microcystis* not supported

# **Modern Systematic Classification of Cyanobacteria**

## **Phylum Cyanobacteria**

### **Class Cyanobacteria**

**Order Gloeobacterales**

**Order Synechococcales**

**Order Spirulinales**

**Order Chroococcales**

**Order Pleurocapsales**

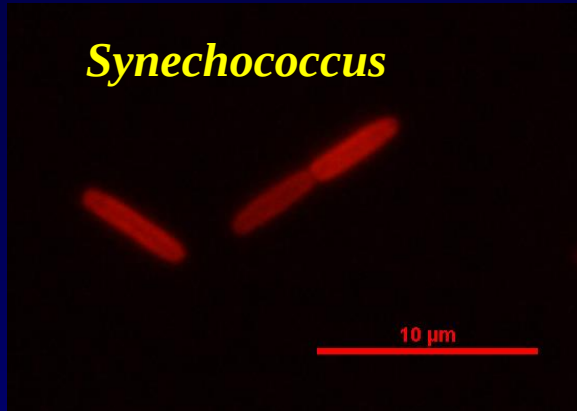
**Order Oscillatoriales**

**Order Chroococciopsidales**

**Order Nostocales**

# Diversity of Synechococcales

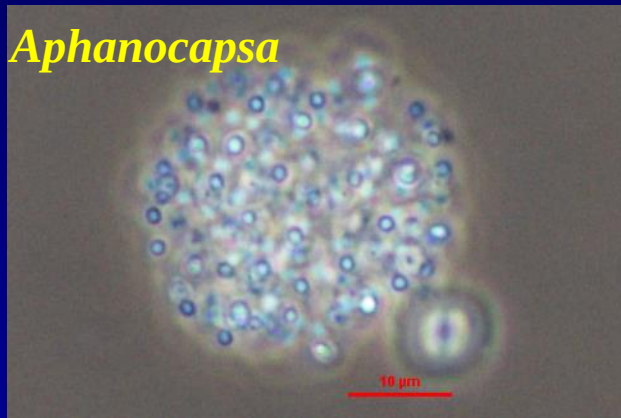
*Synechococcus*



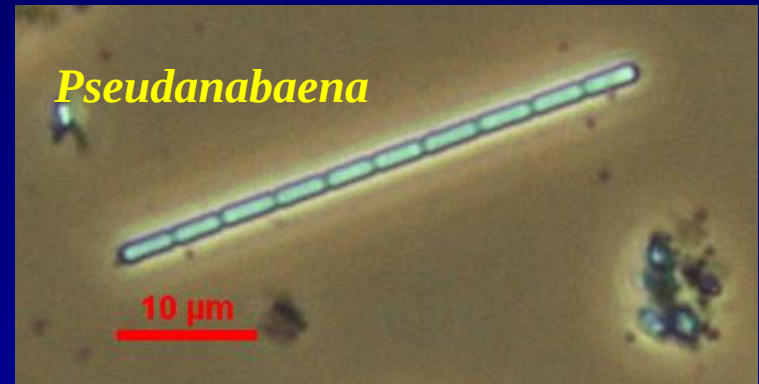
*Planktolyngbya*



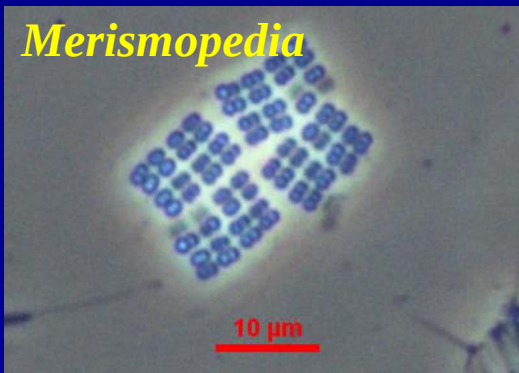
*Aphanocapsa*



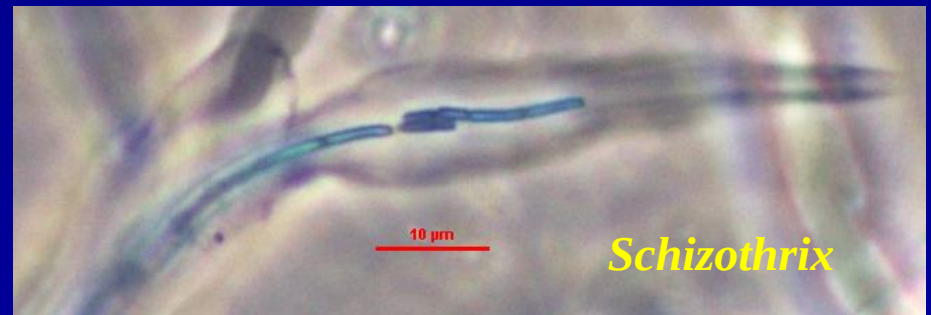
*Pseudanabaena*



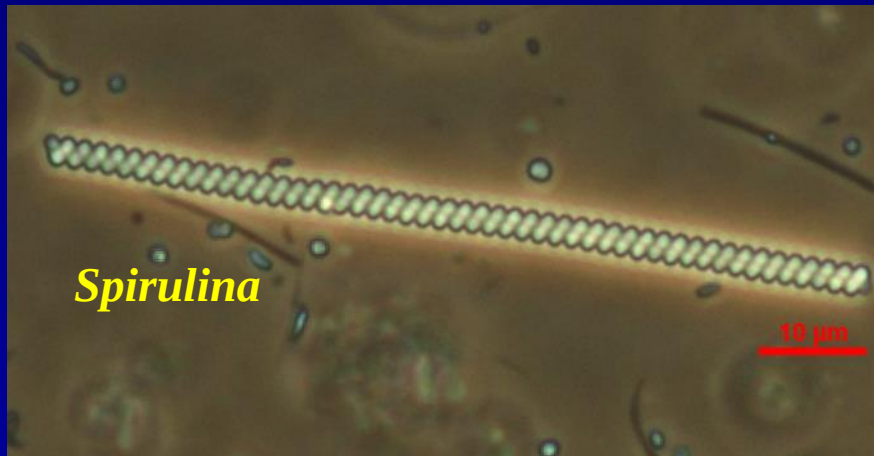
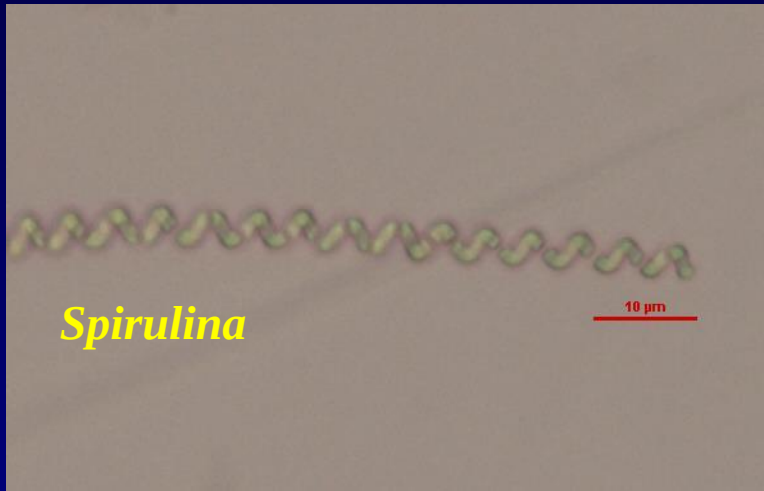
*Merismopedia*



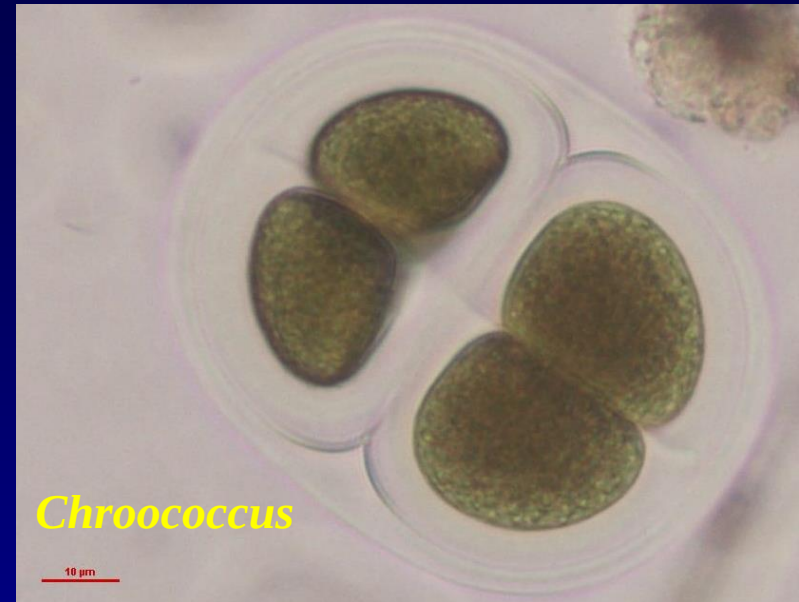
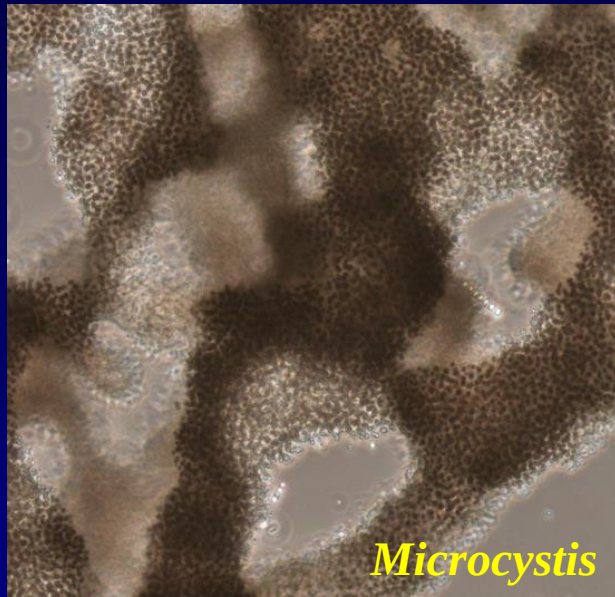
*Schizothrix*



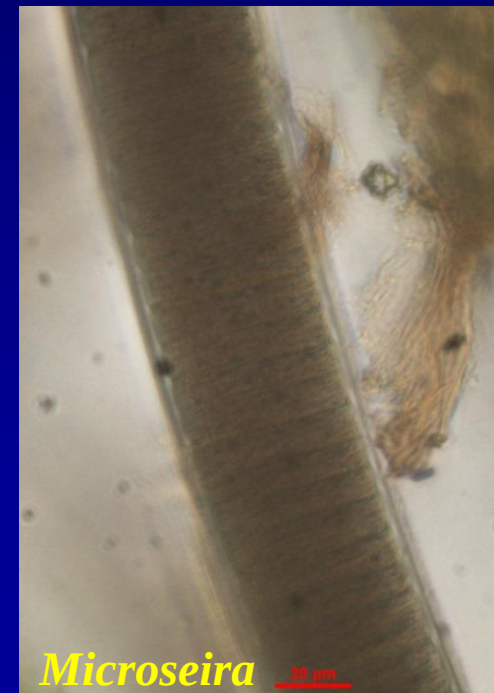
# Diversity of Spirulinales



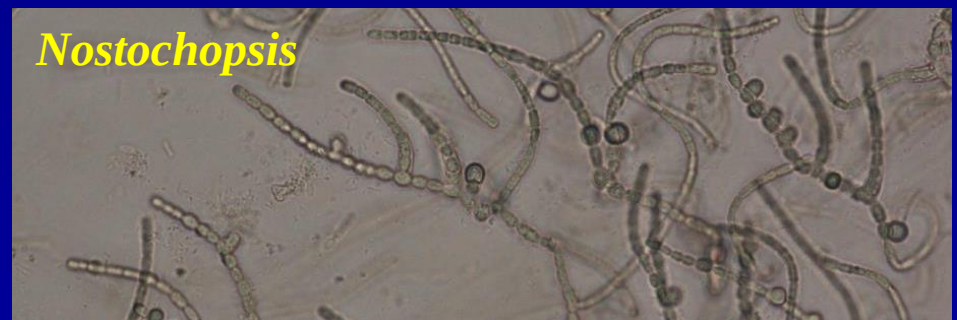
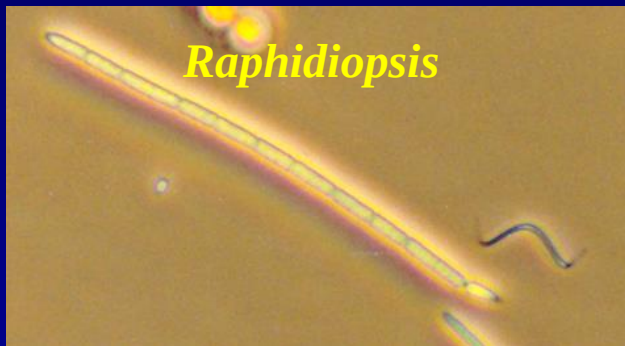
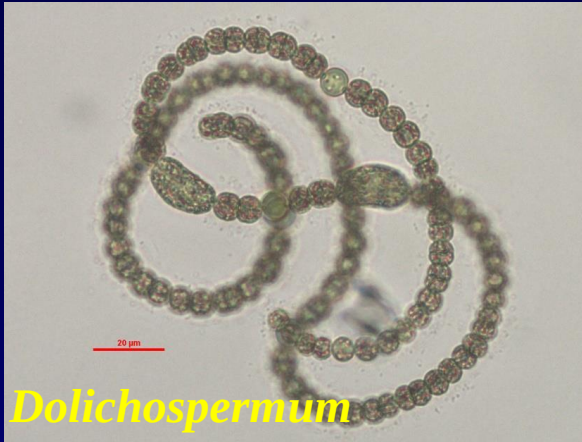
# Diversity of Chroococcales



# Diversity of Oscillatoriales



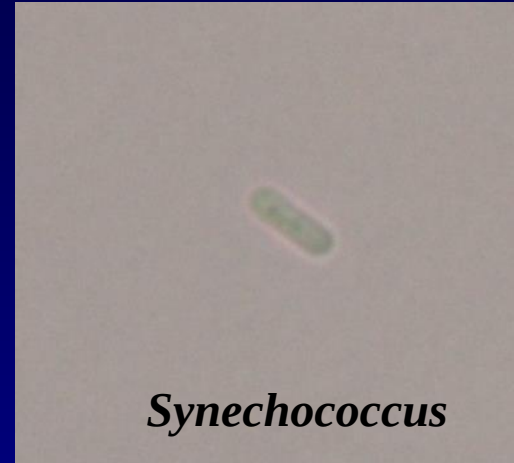
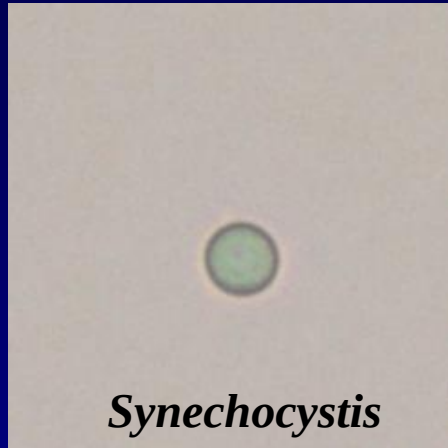
# Diversity of Nostocales



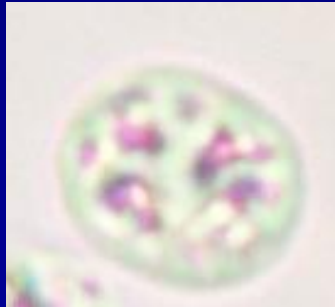
# **Morphological Criteria Used To Identify Cyanobacteria**

# Primary Morphological Criteria Used to ID Unicellular Cyanobacteria Genera

## Cell Shape



## Cell Contents



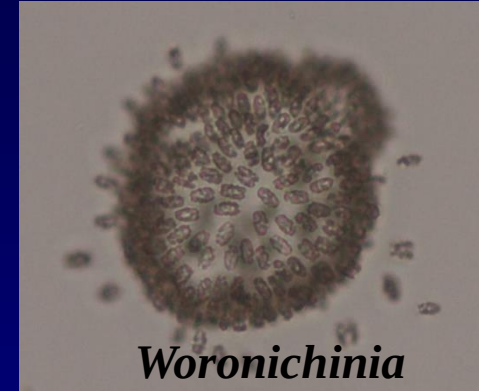
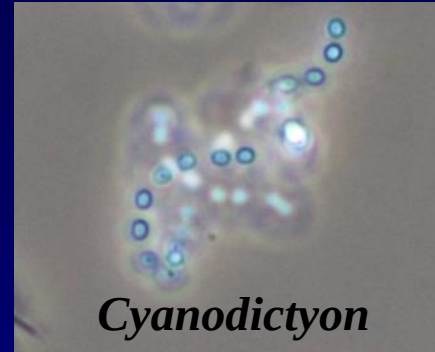
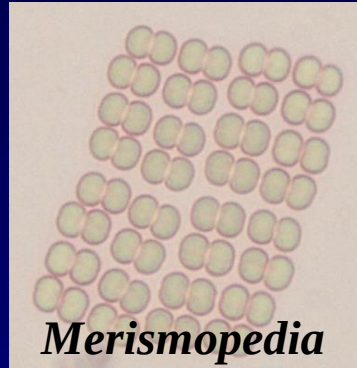
## Keritomy

# Primary Morphological Criteria Used to ID Colonial Cyanobacteria Genera

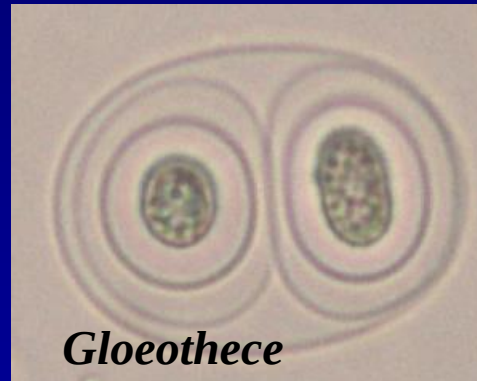
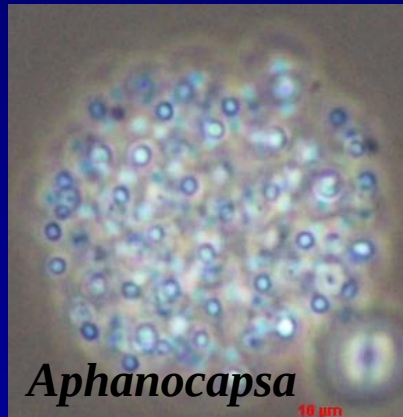
Cell Shape

Cell Arrangement

Colony Shape



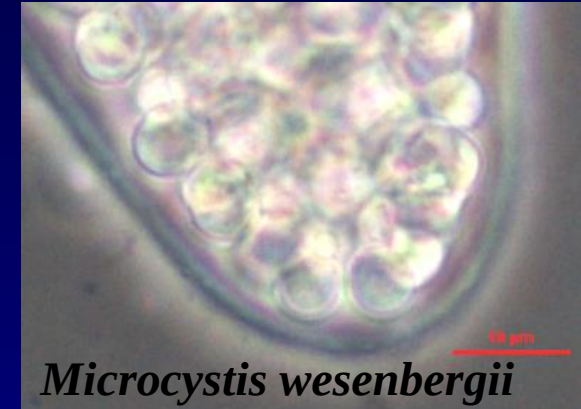
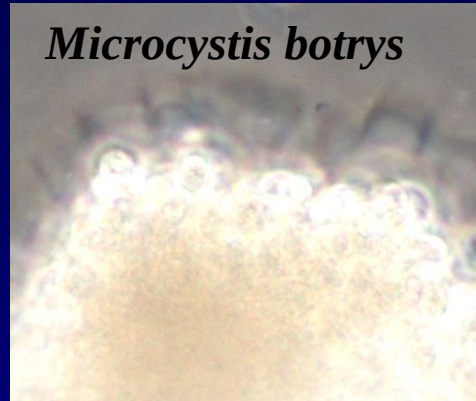
Mucilage



Presence/Absence of Aerotopes

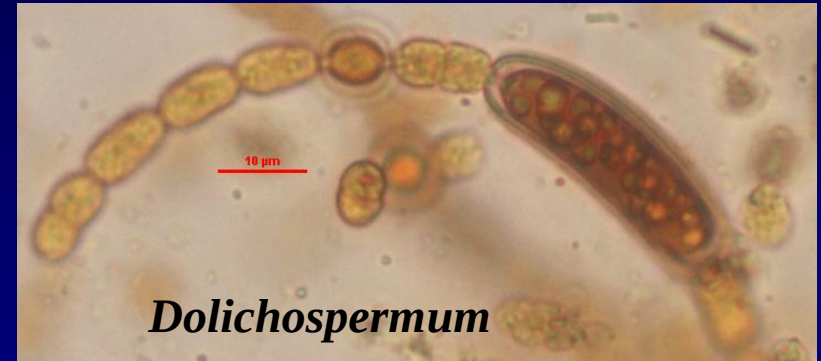
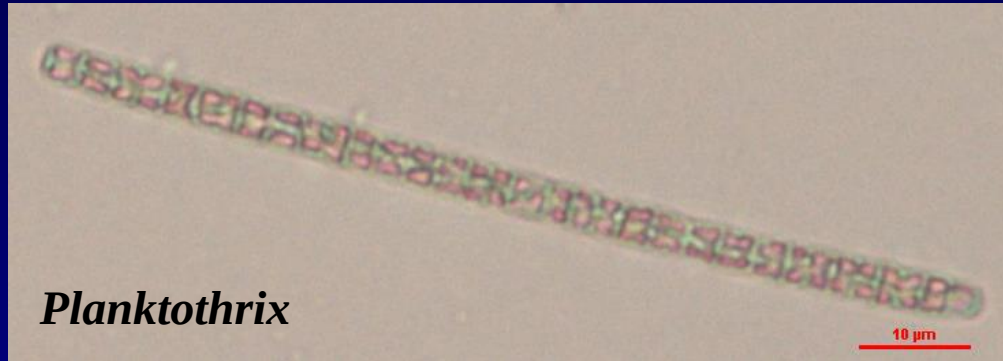
# Primary Morphological Criteria Used to ID Colonial Cyanobacteria Species

- Mucilage characteristics
- Colony Shape
- Cell Shape and Size
- Presence/Absence of Aerotopes
- Color
- Habitat

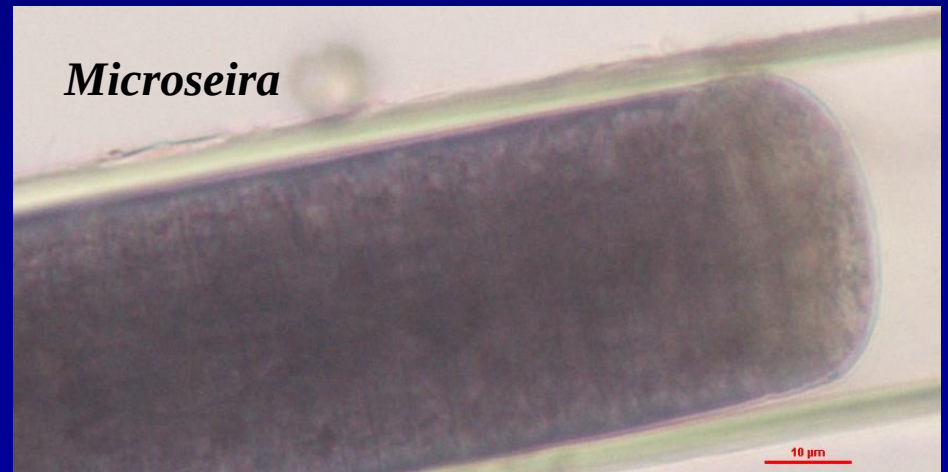
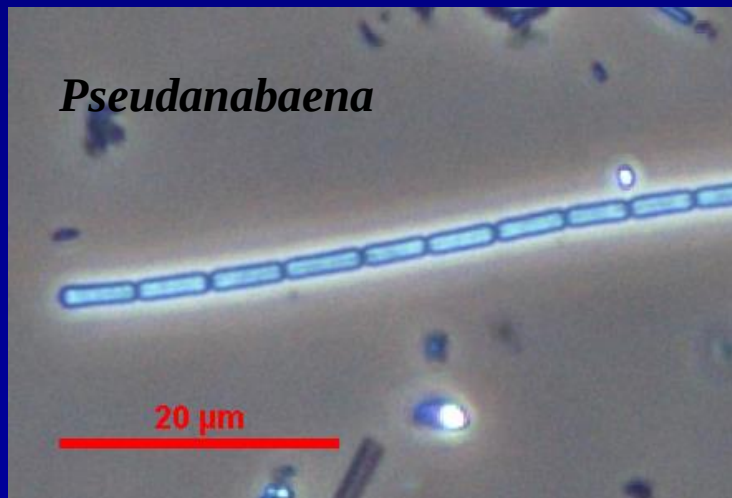


# Primary Morphological Criteria Used to ID Filamentous Cyanobacteria Genera

## Ability to Produce Heterocytes and Akinetes

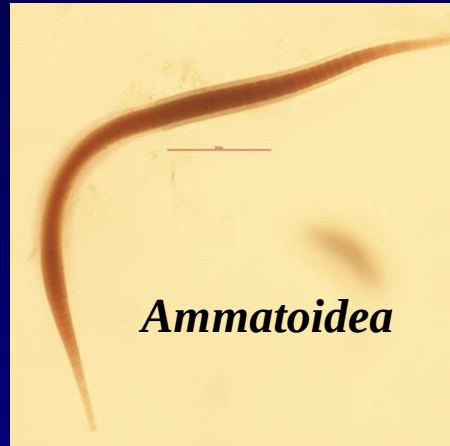


## Trichome Width, Cell Shape, Presence/Absence + Nature of Sheaths



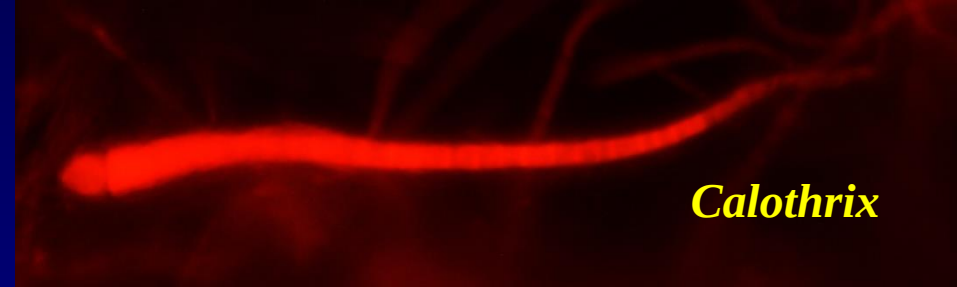
# Primary Morphological Criteria Used to ID Filamentous Cyanobacteria Genera

## Trichome Morphology



*Ammatoidea*

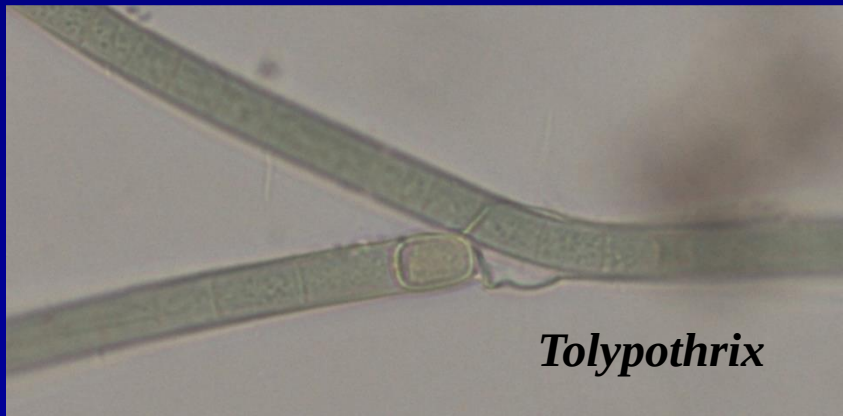
Isopolar



*Calothrix*

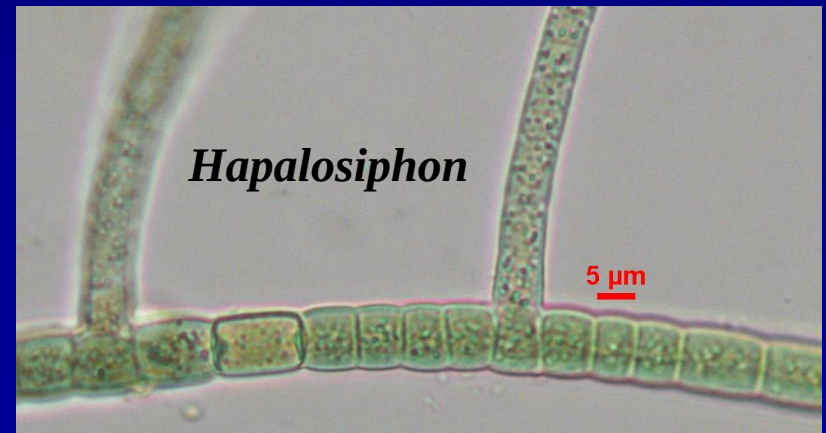
Heteropolar

## Branching



*Tolypothrix*

False Branching



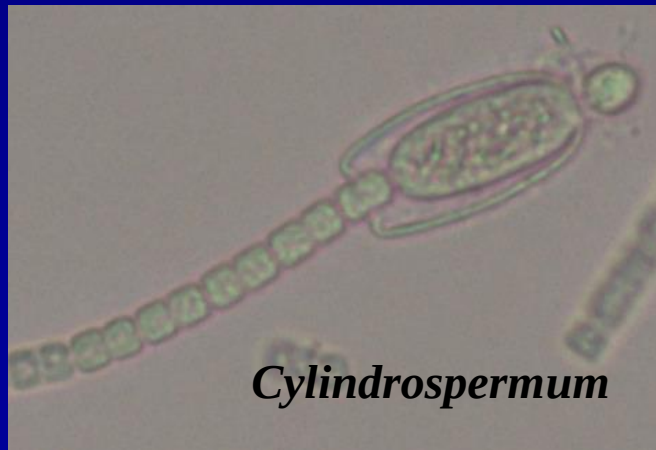
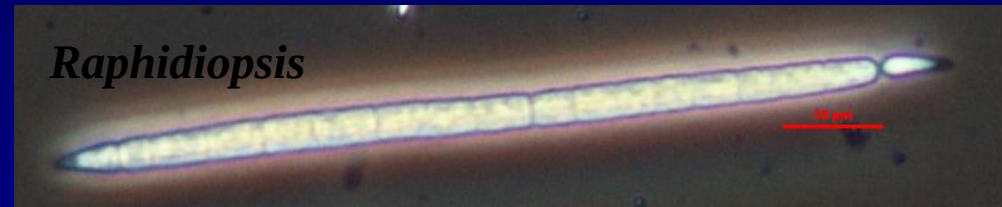
*Hapalosiphon*

True Branching

# Primary Morphological Criteria Used to ID Filamentous Cyanobacteria Genera

**Presence/Absence of Aerotopes**

**Location of Heterocytes and Akinetes on Trichome**



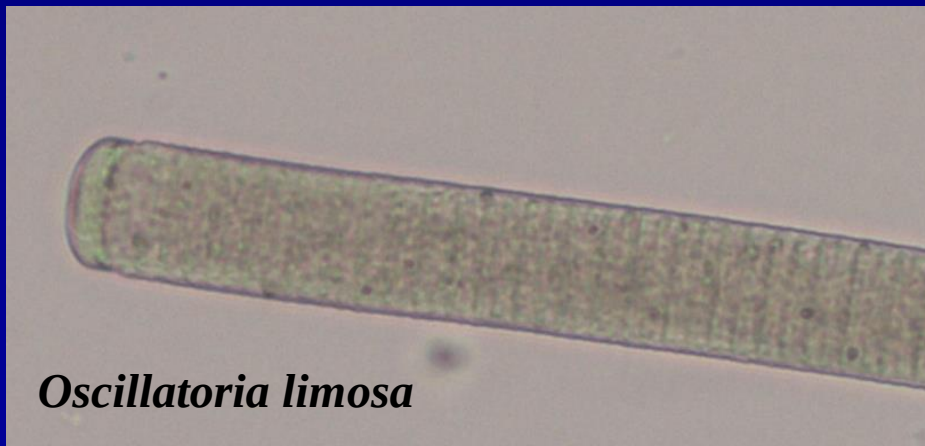
# Primary Morphological Criteria Used to ID Filamentous Cyanobacteria Species

Trichome morphology

Cell shape and Size

Presence/Absence and Nature of Sheath

Presence/Absence of Constrictions at Cross-walls

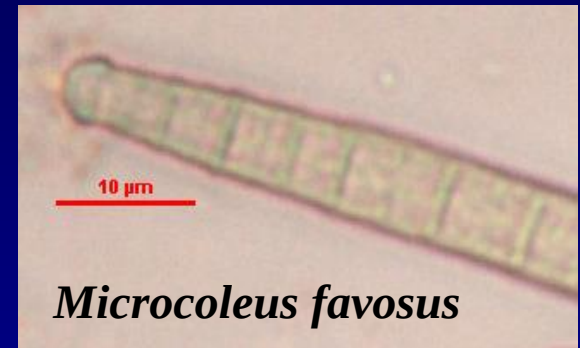
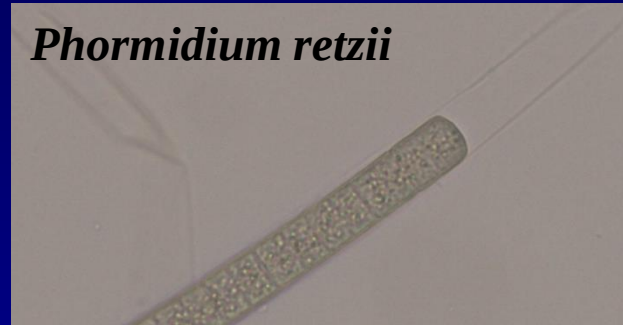


# Primary Morphological Criteria Used to ID Filamentous Cyanobacteria Species

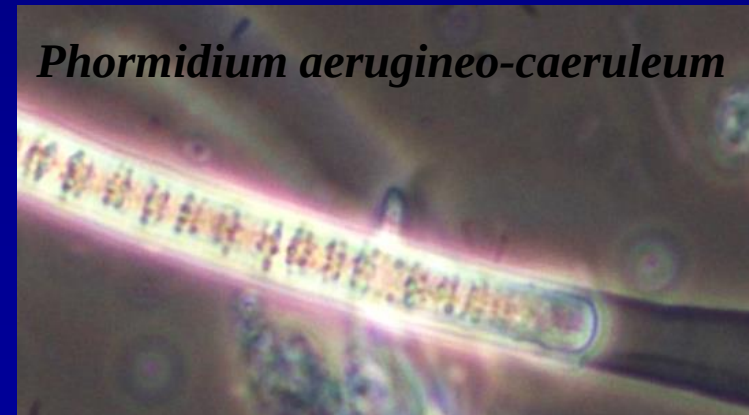
Shape, Size and Location of Heterocytes and Akinetes

Motility

End Cell Shape



Color  
Granulation



Habitat

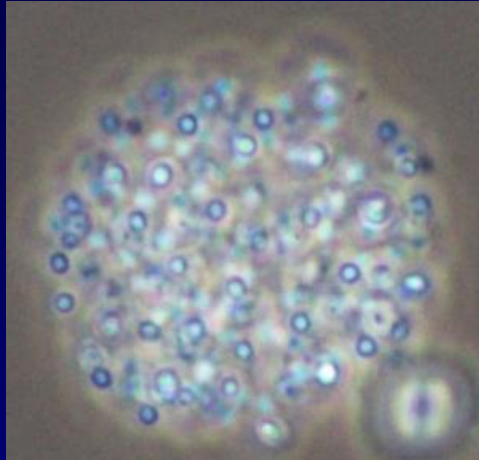
# Unicellular and Colonial Cyanobacteria

- Orders Gloeobacterales, Synechococcales, Chroococcales, Pleurocapsales, Oscillatoriales, Chroococcidiales
- Solitary cells, colonies or pseudoparenchymatic colonies or pseudofilaments; trichome formation lacking
- Heterocytes and akinetes lacking
- Obligatory simple cell division, mainly binary fission
- Facultative formation of exocytes and nanocytes (specialized types of reproductive cells)
- Important criteria used to distinguish genera include cell shape, cell arrangement, colony form, mucilage characteristics and presence/absence of aerotopes
- Genera with known potentially toxigenic species include *Aphanocapsa*, *Cyanobium*, *Microcystis*, *Radiocystis*, *Snowella*, *Synechocystis* and *Woronichinia*.

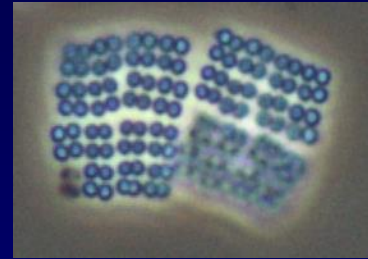
# Diversity of Cyanobacteria: Unicellular and Colonial Forms



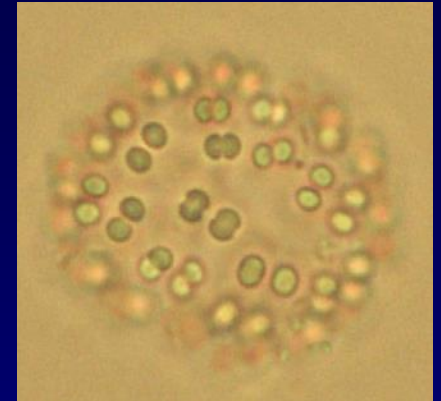
*Synechocystis*



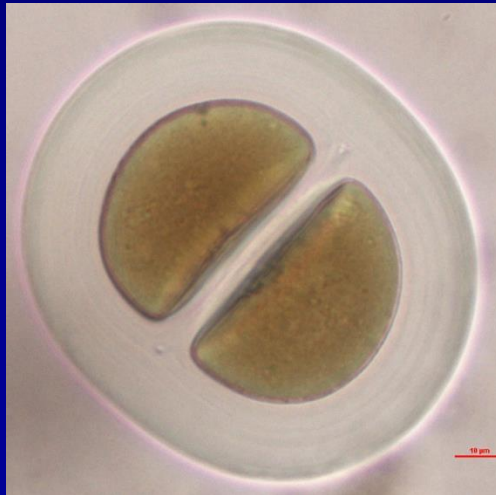
*Aphanocapsa*



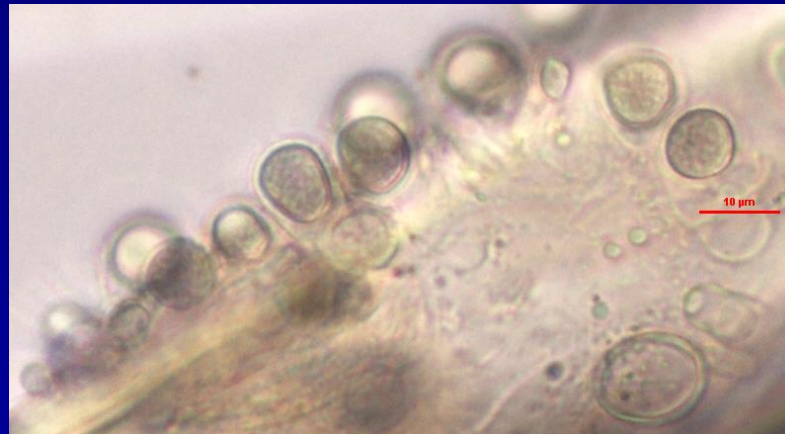
*Merismopedia*



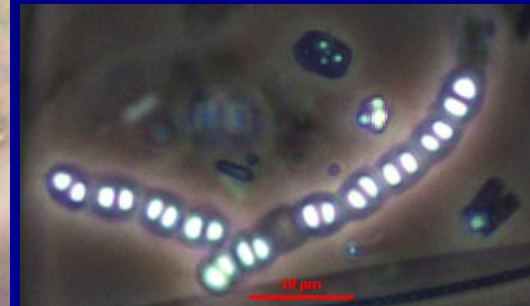
*Snowella*



*Chroococcus*



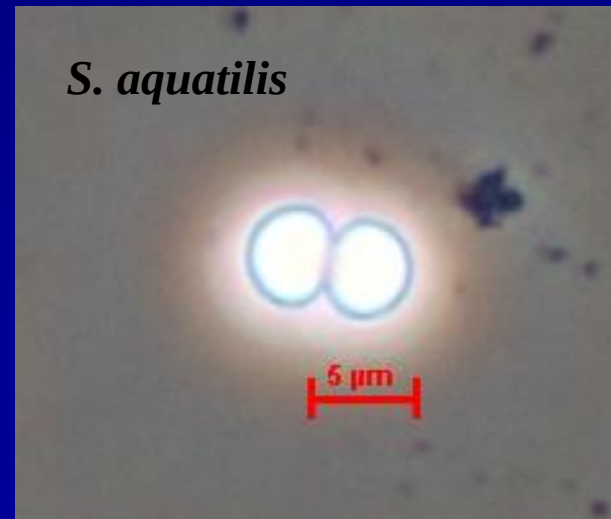
*Xenococcus*



*Johannesbaptistia*

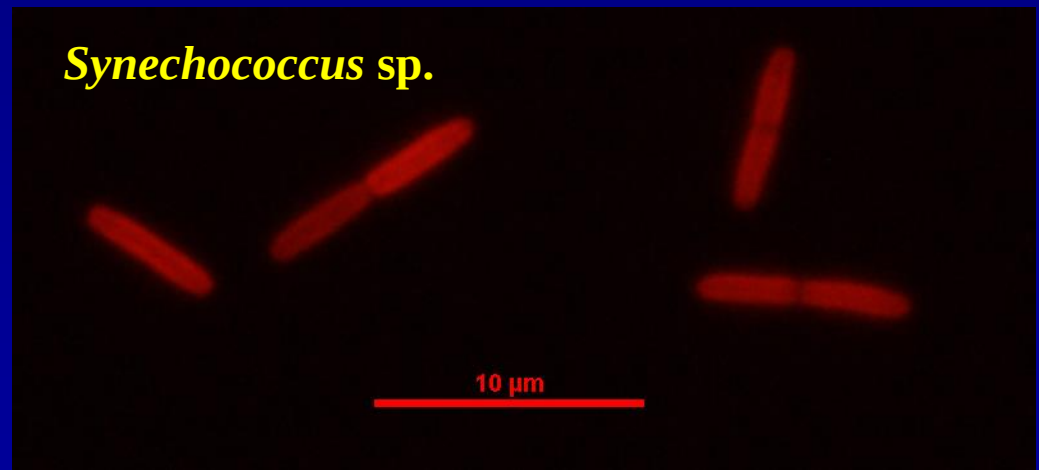
# *Synechocystis*

- Cells spherical (or after division hemispherical) or widely oval
- Cells solitary, after division two together for a short time; never forming colonies
- Without mucilage or (mainly) with narrow, fine colorless and usually diffluent and indistinct mucilaginous envelopes
- Cells divide by binary fission (mainly by pinching) into two hemispherical daughter cells, which reach the original shape before next division
- Cells always divide in two perpendicular planes in successive generations
- Species primarily separated on the basis of cell size, habitat and presence/absence of mucilaginous envelopes.



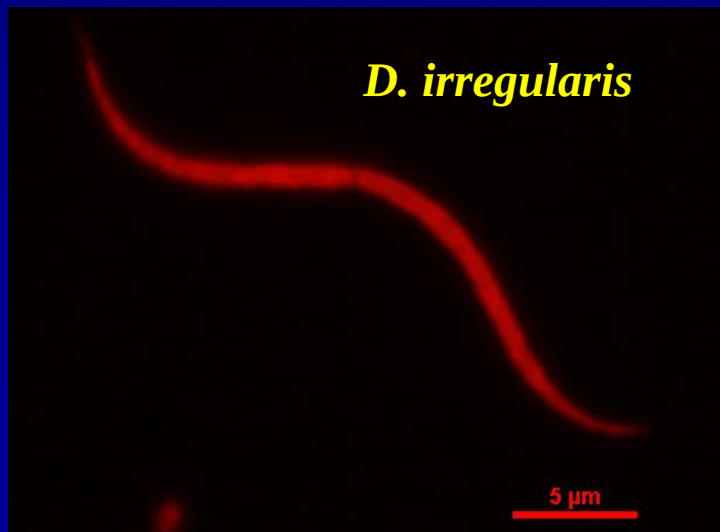
# *Synechococcus*

- Cells long oval or cylindrical, straight, arcuate or sigmoid
- Aerotopes absent
- Cells solitary or grouped in microscopic or macroscopic, irregular clusters, but not forming mucilaginous colonies; cells sometimes in short series of pseudo-filamentous formations
- Mucilage absent or very fine, colorless, homogeneous, diffluent, around single cells
- Cells divide by binary fission, transversely (always in one plane in successive generations perpendicular to the longitudinal axis) into two isomorphic or different daughter cells
- Daughter cells occasionally remain joined for a period of time
- Species primarily separated on the basis of habitat, cell shape, cell size and pigmentation.



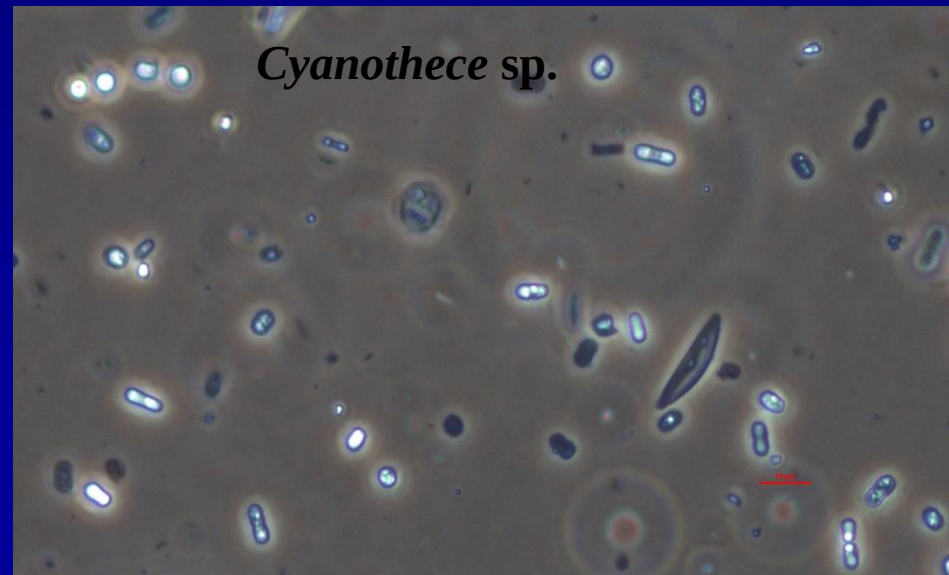
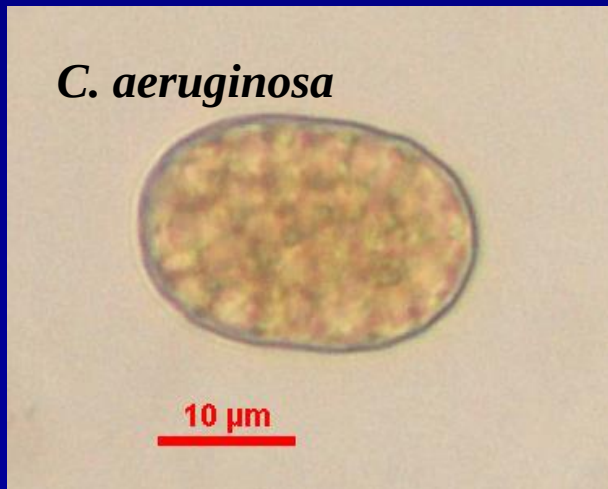
# *Dactylococcopsis*

- Cells cylindrical with sharply pointed ends; straight or sigmoid
- Aerotopes absent
- Cells solitary
- Mucilage absent
- Cells divide by binary fission
- The original type species turned out to be a green alga, so technically the genus name is invalid
- *Dactylococcopsis irregularis* is regarded as a taxonomic synonym of *Monoraphidium irregulare* (a green alga!), but what I see fluoresces like a cyanobacteria
- Appears similar to the chlorophyte genera *Koliella* and *Monoraphidium*
- Species primarily separated on the basis of cell shape.



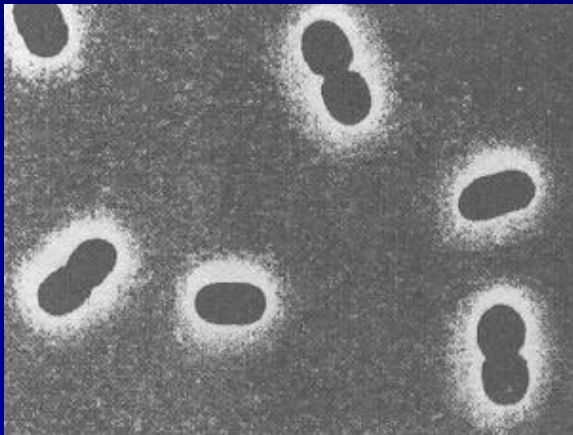
# *Cyanothece*

- Cells widely oval to almost cylindrical, with rounded ends; aerotopes absent
- Cell content with net-like keritomization
- Cells solitary or in twos after division; sometimes aggregated in groups, clusters and mats
- Mucilage absent or very fine, hyaline around single cells
- Cells divide by binary fission, always in one plane in successive generations perpendicular to the longitudinal axis
- Cells grow to original size and shape before division
- Polyphyletic; genetic analyses of “*Cyanothece*” isolates revealed species belonging to *Cyanothece*, *Crocospaera*, *Zehria*, *Rippkaea* and *Gloeothece*
- Species primarily separated on the basis of habitat and cell size.



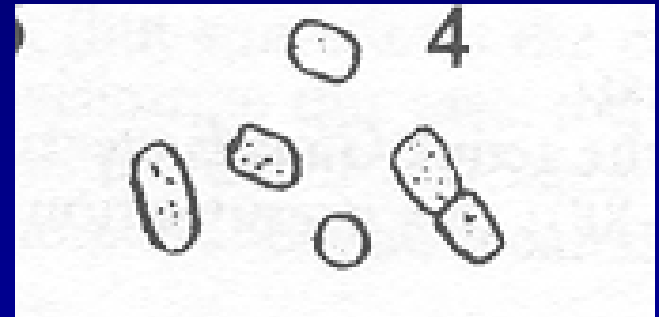
# *Cyanobium*

- Cells oval, ellipsoid to shortly rod-shaped without gelatinous envelopes
  - Cells usually with visible chromatoplasm
  - Aerotopes lacking
  - Cells solitary or in twos after division, not in colonies
  - Cell division by binary fission, transverse to the long axis
  - Cells grow into the original shape and size before next division
- 
- Species primarily separated on the basis of habitat, cell size and pigmentation



*C. stanieri*

(Kom. and Anag. 1998)

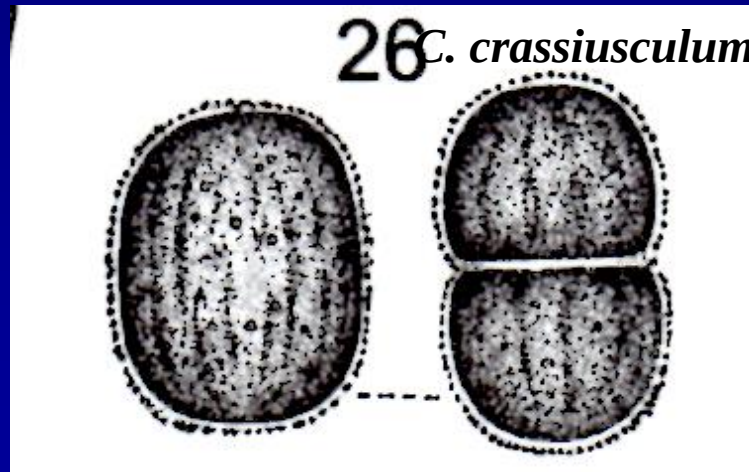


*C. bacillare*

(Kom. and Anag. 1998)

# *Cyanobacterium*

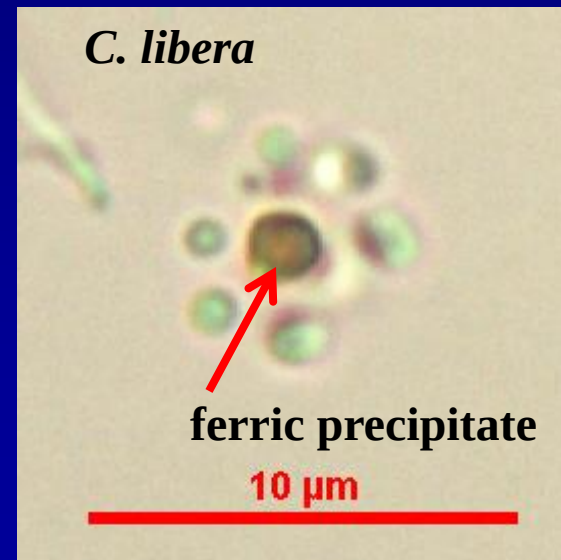
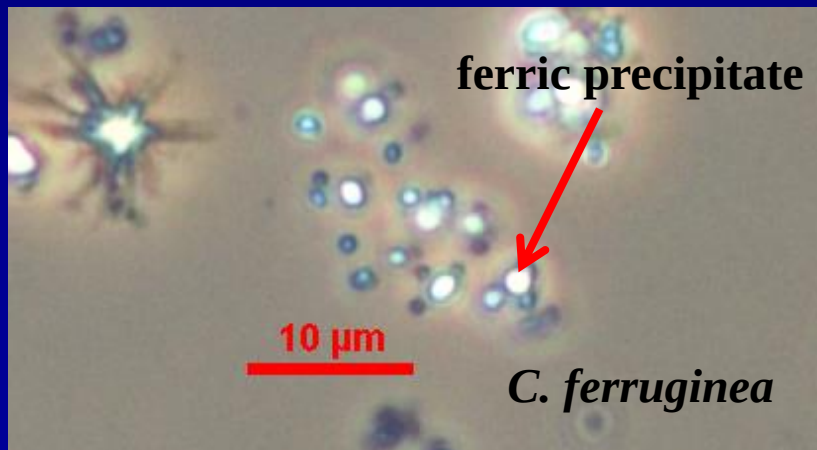
- Cells solitary or in groups of twos after division, sometimes in clusters
- Aerotopes lacking
- Gelatinous envelopes lacking
- Cells cylindrical, rod-shaped or widely oval with rounded ends; straight or slightly arcuate
- Cell content homogeneous, but sometimes with lengthwise striation (keritomy)
- Cell division by binary fission, transversely to the longer cell axis
- Cells grow into the original shape and size before division
- Species primarily separated on the basis of cell shape, cell size, keritomy and habitat



(Kom. and Anag. 1998)

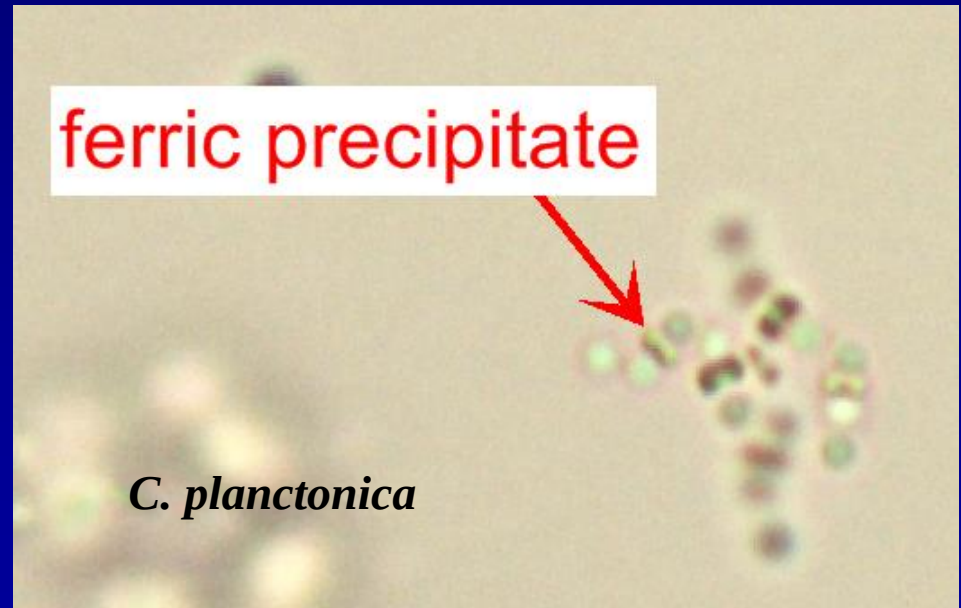
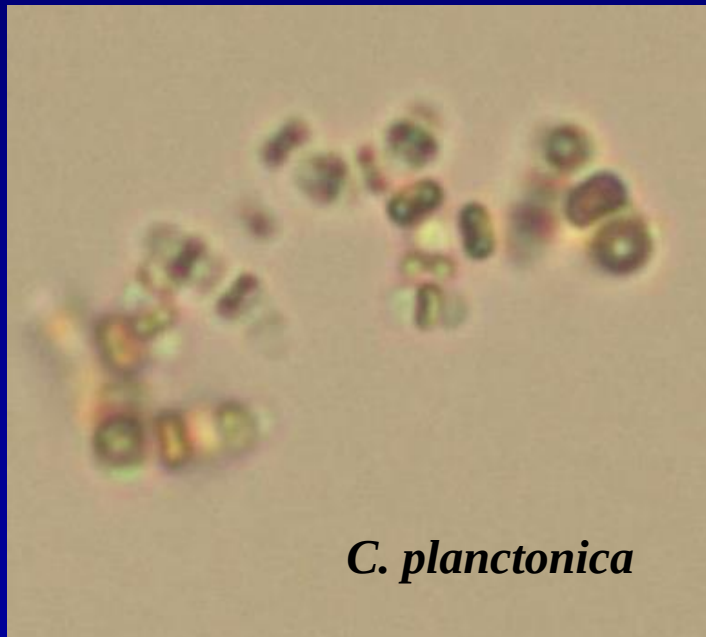
# Cyanogranis

- Cells spherical or subspherical, sometimes widely oval
  - Colonies free-floating; subspherical to irregular in outline
  - Colonies consist of a cluster of irregularly aggregated cells embedded in fine, homogeneous, colorless and diffluent slime
  - Ferric precipitates occur within the colonies
  - Aerotopes lacking
  - Division only in the transverse plane, in successive generations
  - Reproduction by fragmentation of colonies
- Species primarily separated based on cell size, arrangement of cells relative to the ferric precipitates in the colony and habitat..



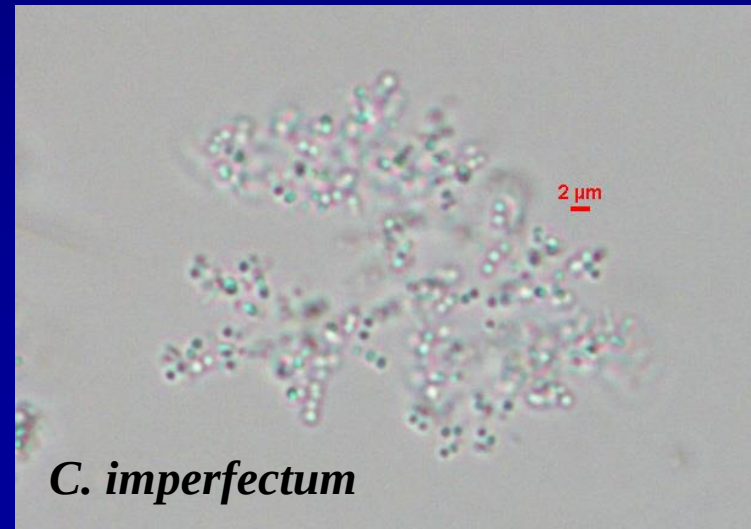
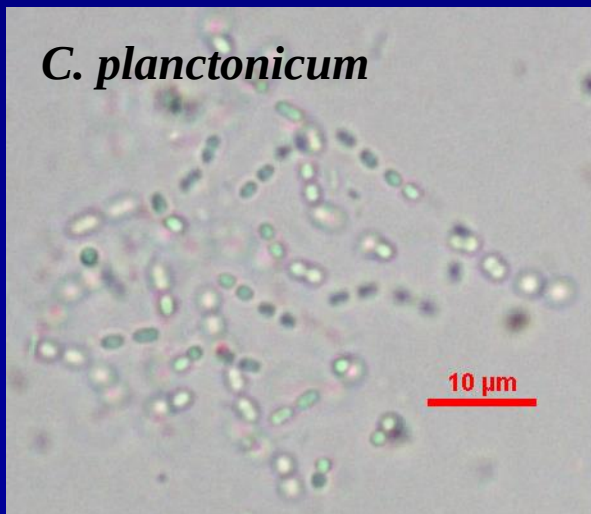
# *Cyanocatena*

- Cells cylindrical, elongate with rounded ends
  - Colonies free-floating; irregular in outline
  - Colonies consist of cells irregularly aggregated in fine, structureless, colorless diffluent mucilage
  - Cells often with brownish or blackish ferric precipitate rings between them
  - Aerotopes lacking
  - Division by binary fission in one plane in successive generations
  - Reproduction by fragmentation of colonies
- Species primarily separated based on cell size and habitat.



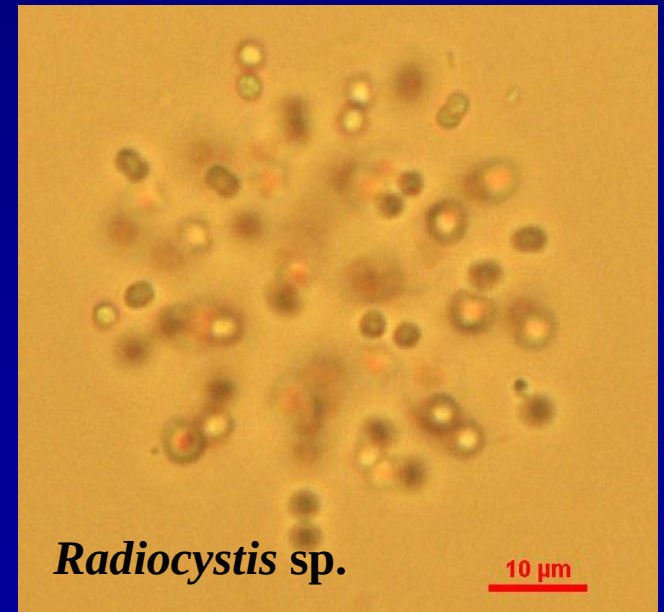
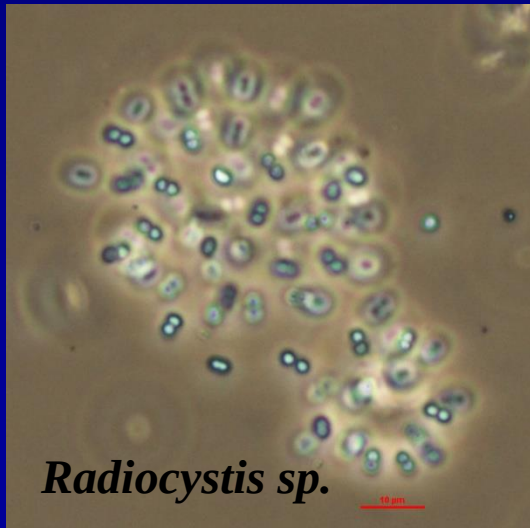
# Cyanodictyon

- Cells spherical, slightly elongate or rod-shaped, aerotopes lacking
- Colonies free floating
- Colonies initially more or less spherical, becoming irregularly reticulate, flat or 3-D, often elongate, composed of gelatinous strands
- Cells in uniseriate or in older stages multiseriate rows
- Mucilage structureless, colorless, usually indistinct and diffluent at the margin
- Cell division always in one plane in successive generations, more or less perpendicularly to the mucilaginous strands
- Hemispherical divided cells grow to the original shape before next division
- Species primarily separated on the basis of cell shape, cell size, form of colony and habitat.



# *Radiocystis*

- Cells widely oval or almost spherical, aerotopes facultative
- Colonies free floating, more or less spherical to irregular, microscopic
- Colonial mucilage fine, colorless and diffluent
- Cells more or less irregularly grouped in the colonial center and radiating in all directions in more or less uniseriate rows
- Cells in radial rows slightly distant from one another or in pairs after division
- Cells divide transversely in one plane in successive generations, in later stages perpendicularly to the radiating rows
- Reproduction by disintegration of mucilaginous colonies
- Species separated primarily on the basis of presence/absence of aerotopes, cell shape and cell size and habitat.



## *Anathece*

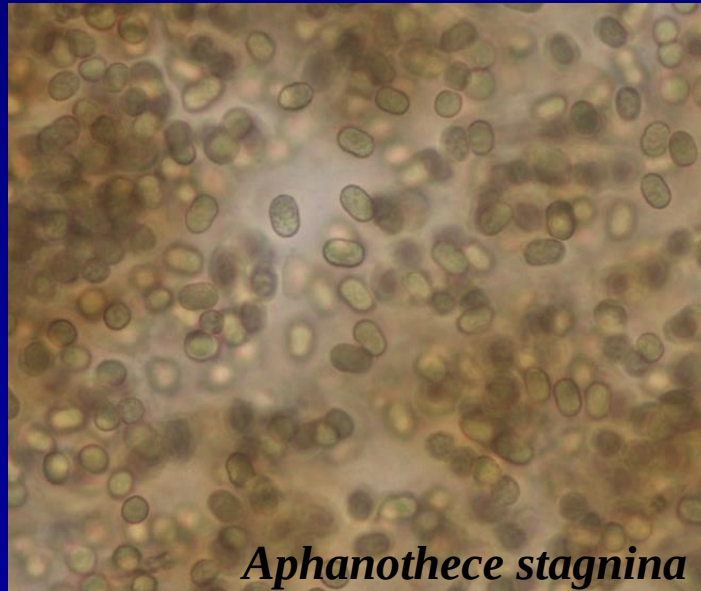
- Colonies irregular in shape; microscopic (rarely macroscopic)
- Cells oval to rod-like, straight or slightly arcuate; individual envelopes lacking
- Cells irregularly arranged; loosely or densely distributed in a common mucilage
- Mucilage fine, colorless, homogeneous and diffluent,
- Mostly planktic, rarely benthic
- Cell division by binary fission in one plane in successive generations, perpendicular to the longitudinal axis
- Species primarily separated based on cell size and shape, size and shape of colony, cell density and habitat.

*Anathece clathrata*



# *Aphanothece*

- Colonies gelatinous, micro- to macroscopic; spherical or usually amorphous shape
  - Cells irregularly arranged; loosely or densely distributed in a common mucilage
  - Cells widely oval to cylindrical, widely rounded ends, straight or slightly arcuate
  - Mucilage distinct, delimited, amorphous, irregular
  - Cells mostly 2.5-5um W x 3-9 um L; marginal cells with their own distinct sheaths
  - Benthic, metaphytic or aerophytic
  - Cell division by binary fission in one plane in successive generations, perpendicular to the longitudinal axis; colonies fragment
- Species primarily separated based on cell size and shape, size and shape of colony, cell density, mucilage characteristics, presence/absence of aerotopes and habitat.

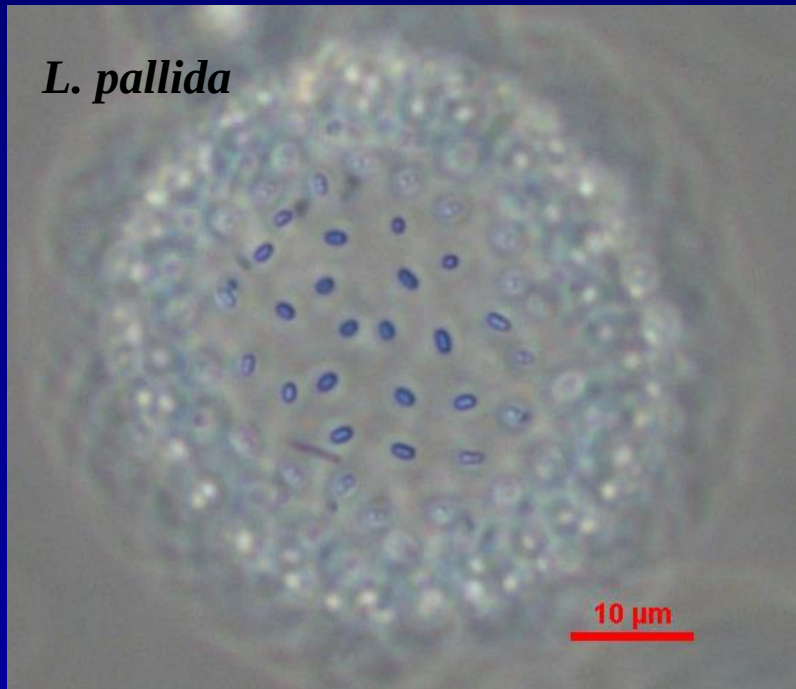


*Aphanothece stagnina*

## *Lemmermaniella*

- Cells oval or rod-shaped, aerotopes absent
- Cells arranged irregularly in one layer just beneath the periphery of colonies
- Colonies in mucilaginous spheres or irregular ovals; simple or compound
- Colonies free floating, microscopic
- Colonial mucilage fine, colorless and homogeneous
- Cells divide by transverse binary fission, in one plane perpendicular to the longer cell axis
- Reproduction by budding of daughter colonies or disintegration of colonies
- Species separated primarily on the basis of cell shape, cell size and habitat.

*L. pallida*



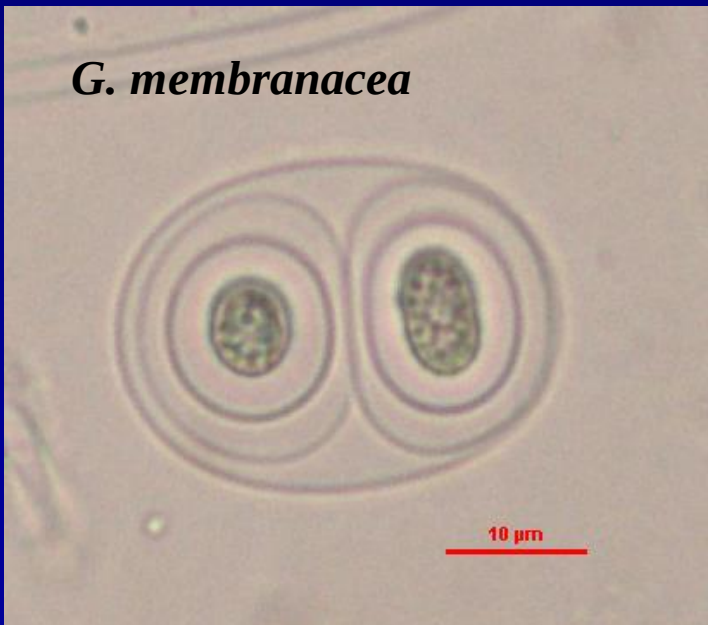
*L. pallida*



# *Gloeotheca*

- Cells widely oval to rod-shaped, rounded at the ends
- Colonies usually small, composed of sheathed cells or groups of cells
- Cells and groups of cells enclosed in delimited, hyaline or concentrically lamellate envelopes
- Aerotopes absent
- Cell division transverse to the longitudinal axis in one plane in successive generations
- Reproduction by disintegration of colonial aggregates or liberation of cells
- Species primarily separated based on color (or lack of color) of envelopes, cell size and shape, presence/absence of lamellation and habitat.

*G. membranacea*

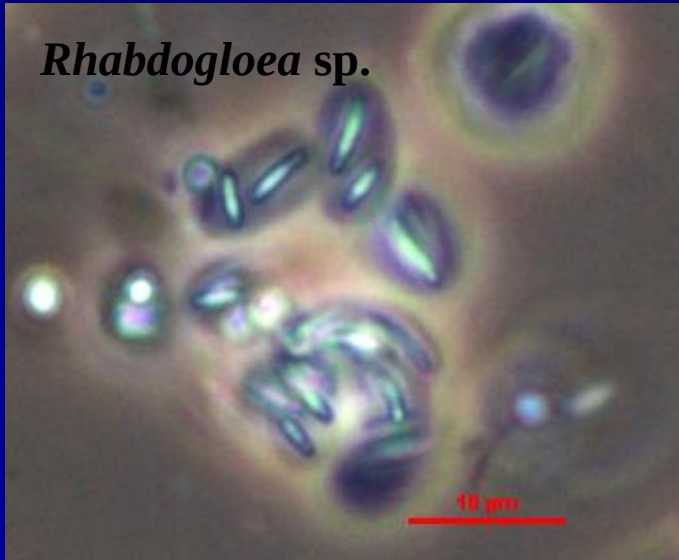


*G. cf. opalotheca*

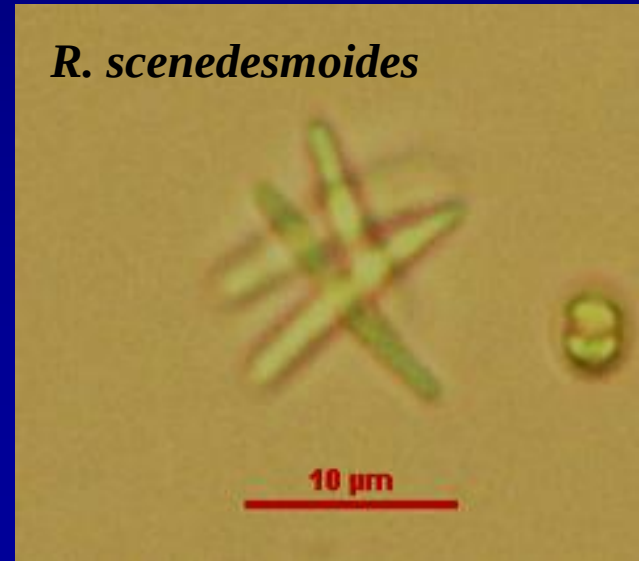
# *Rhabdogloea*

- Cells elongate, narrow, spindle-shaped, ellipsoidal or more or less cylindrical; short attenuate and acute or acute-rounded poles
- Cells straight or slightly arcuate or sigmoidal coiled; aerotopes absent
- Colonies mucilaginous, mostly microscopic, irregular with cells distant from one another
- Cells situated irregularly (more or less parallel in young colonies)
- Colonial mucilage fine, diffluent (rarely delimited), colorless, structureless
- Cell division by binary fission, transverse to the long axis into two more or less identical daughter cells; reproduction by disintegration of colonies
- Species primarily separated on the basis of end shape of cells, symmetry of cells, cell shape and size, cell distribution within a colony and habitat.

*Rhabdogloea* sp.

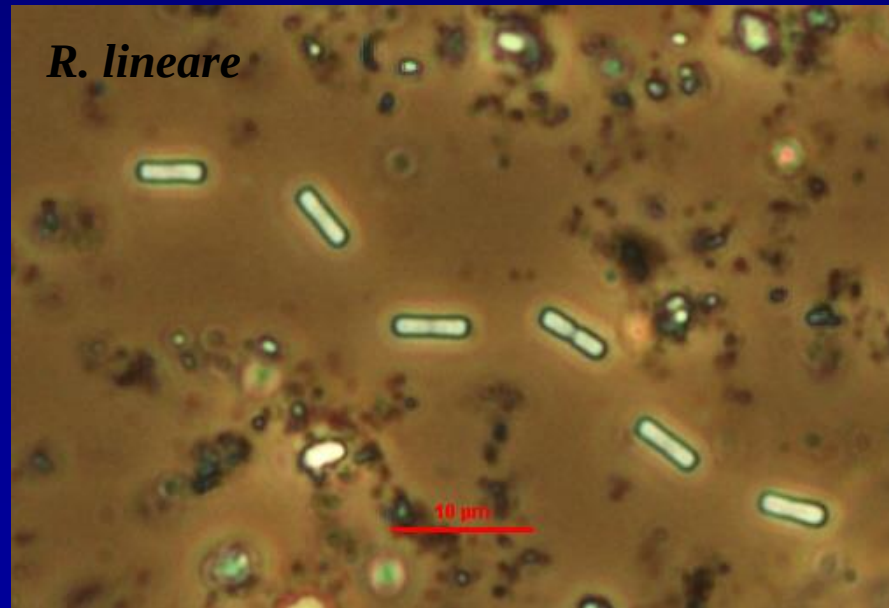


*R. scenedesmoides*



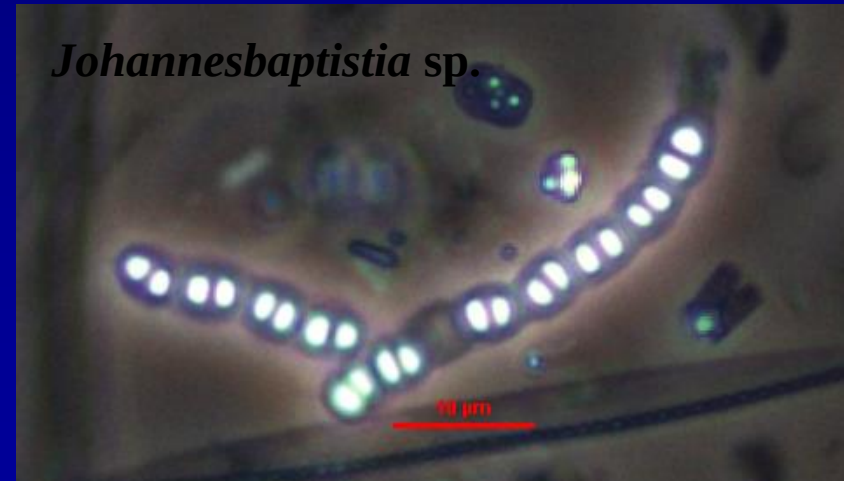
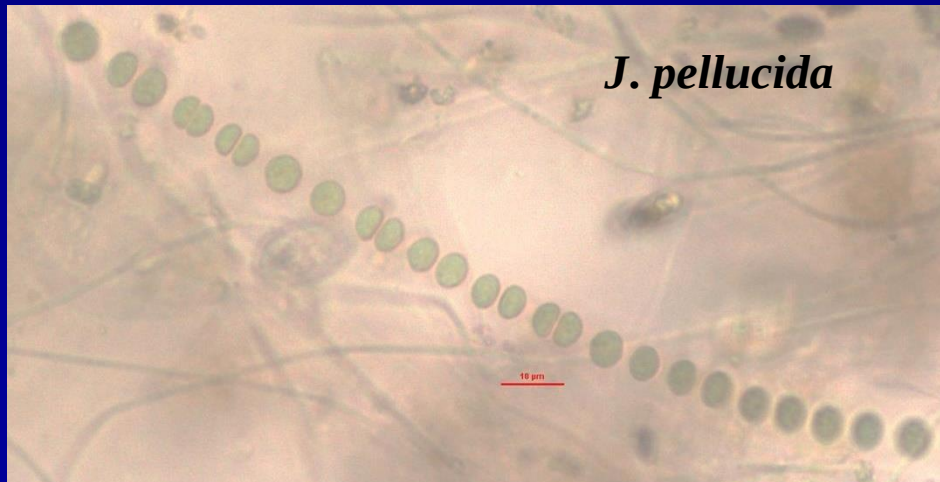
## *Rhabdoderma*

- Cells cylindrical, rod-shaped, straight, arcuate or sigmoid, with rounded ends
- Cells sometimes several times longer than wide
- Colonies microscopic, irregularly oval or elongate-irregular, mucilaginous
- Cells distant from one another or in pseudofilamentous rows; cells often oriented in one direction
- Colonial mucilage fine, colorless, sometimes diffluent, colorless, structureless
- Cell divide transversely to the longer axis, symmetrically asymmetrically; daughter cells sometimes remain joined in short pseudofilaments
- Reproduction by disintegration of colonies
- Species primarily separated on the basis of cell shape and size, habitat and color.



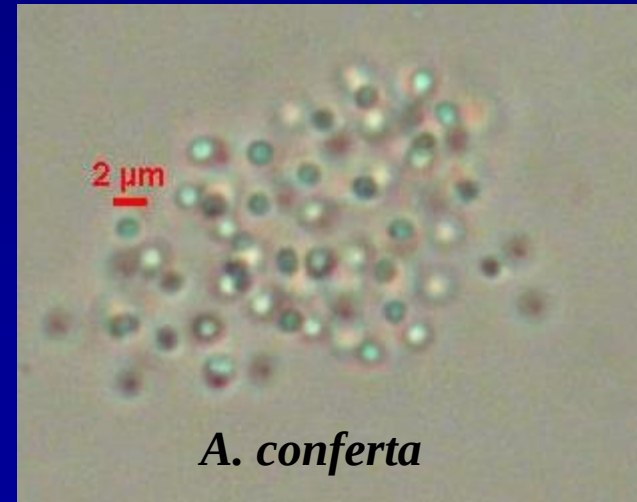
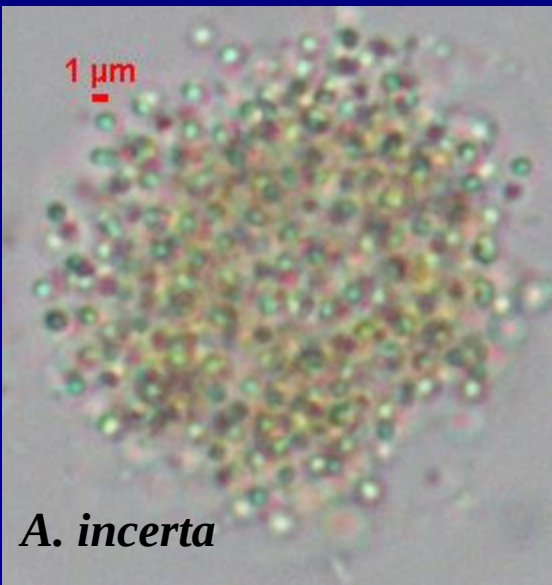
# *Johannesbaptistia*

- Cells discoid or rounded lenticular, aerotopes lacking
- Cells arranged in solitary pseudofilaments; unbranched or rarely laterally or pseudo-dichotomously divaricate
- Mucilaginous envelopes tube-like, colorless; slightly diffluent or distinct at margin
- Clear spaces are visible between cells; daughter cells may remain together for a time
- Colonies benthic and metaphytic; mostly in heliothermal freshwaters or mesohaline to saline waters
- Cell division in one plane, perpendicular to the longitudinal axis of pseudofilaments; reproduction by disintegration of pseudofilaments and facultative liberation of solitary cells
- Species primarily separated on the basis of cell size, nature of pseudobranching and habitat.



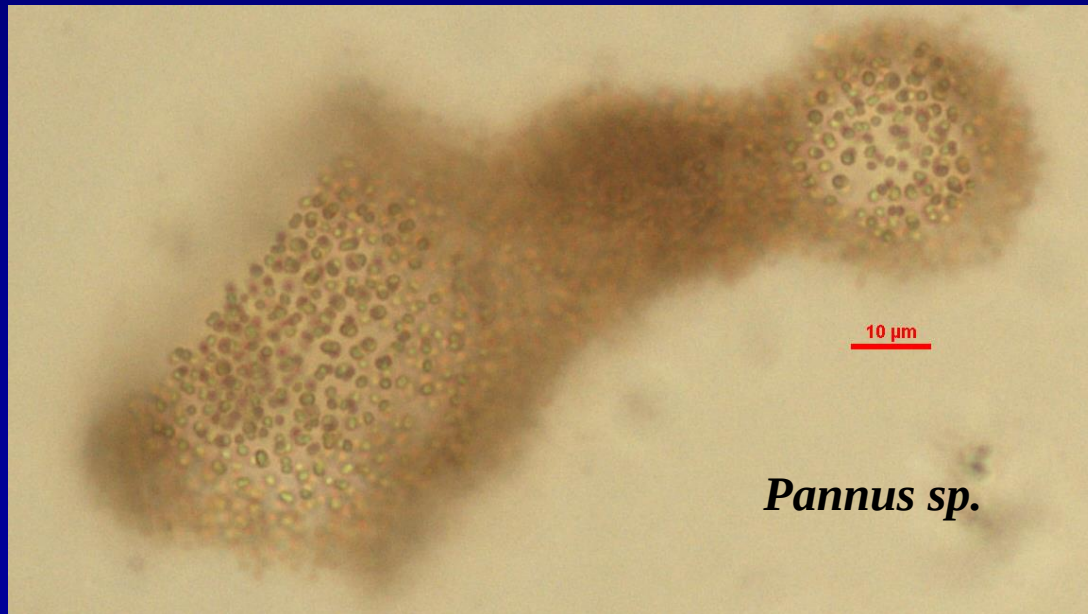
# *Aphanocapsa*

- Cells more or less spherical
- Colonies spherical or irregular
- Colonies consist of numerous, sparsely or densely arranged cells in common mucilage
- Mucilage mainly colorless and diffluent
- Aerotopes lacking
- Division by binary fission in 2 perpendicular planes in successive generations
- Cells sometimes remain in groups of 2 or 4 after division
- Species primarily separated based on cell size, size and shape of colony, cell density, mucilage characteristics and habitat.



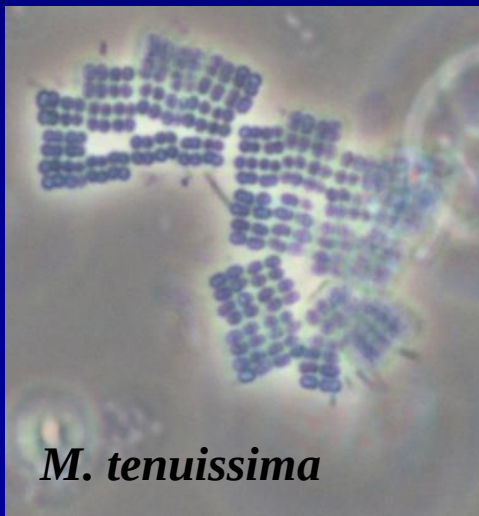
# *Pannus*

- Cells spherical; aerotopes present or absent
- Colonies microscopic, hollow
- Young colonies irregularly spherical with holes; older colonies irregular, flattened, wavy, hemispherical or elongate and lobate, clathrate or made up of sub-colonies
- Mucilage fine, colorless and watery
- Cell division in 2 planes in successive generations perpendicularly to the surface of the colony; reproduction by colony disintegration
- Species primarily separated based on presence/absence of aerotopes, colony shape, clathration, cell size, cell color and habitat.

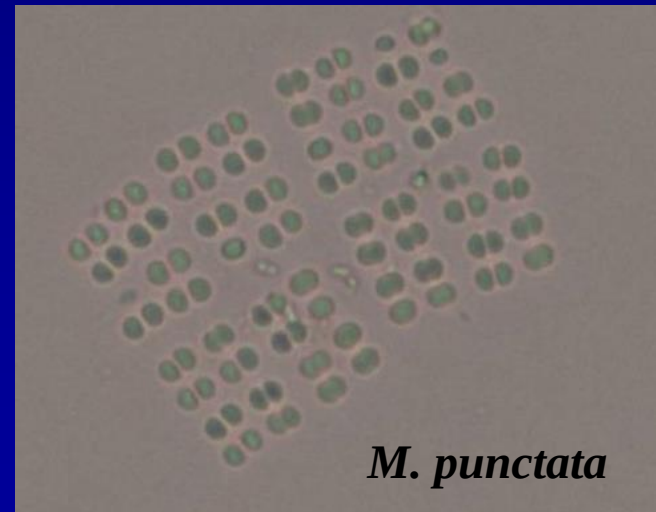


# *Merismopedia*

- Cells spherical, globose or ovate; after division hemispherical; aerotopes in a few species
- Colonies tabular or plate-like, mostly flat but sometimes rolled up at the edges
- Colonies composed of one layer of densely or loosely distributed cells arranged in perpendicular rows
- Colonial mucilage hyaline, fine, usually with indistinct, narrow or wide margin; cells sometimes with individual mucilaginous envelopes
- Cell division by binary fission in two planes, in successive generations, perpendicular to one another and to the plane of the colony
- Species primarily separated based on cell size and shape, size and shape of colony, cell density, presence/absence of aerotopes and habitat.



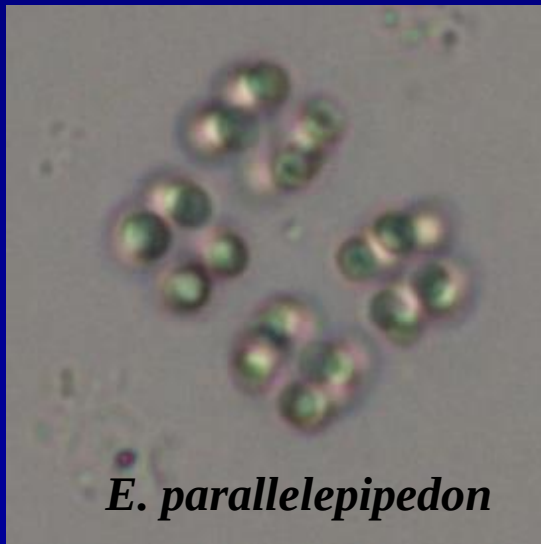
*M. tenuissima*



*M. punctata*

# *Eucapsis*

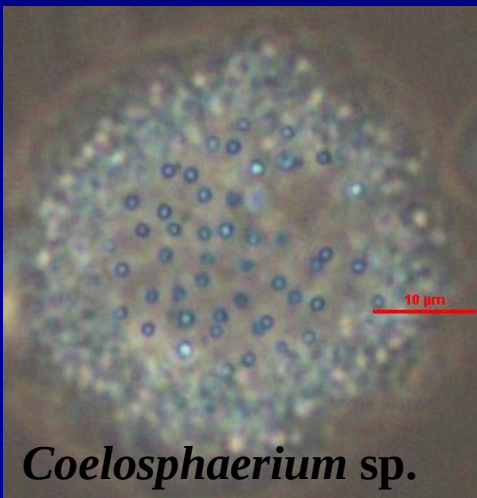
- Cells spherical or widely oval before division
- Colonies cubic with cells arranged three-dimensionally in perpendicular rows
- Colonies small or up 128 cells; large colonies composed of sub-colonies
- Mucilage colorless, hyaline, delimited, rarely diffluent
- Aerotopes absent
- Primarily metaphytic
- Cells division in three perpendicular planes in successive generations without displacement of daughter cells; cells grow into the original spherical form before next division
- Species primarily separated based on cell size, color and habitat.



*E. parallelepipedon*

# *Coelosphaerium*

- Cells spherical
- Cells arranged more or less in one layer at the periphery of colony and normally distant from one another in center of colony
- Colonies spherical or oval (rarely irregular), sometimes composed of sub-colonies
- Colonial mucilage fine, colorless, sometimes indistinct; no gelatinous stalks in colonial center
- Aerotopes present or absent
- Cell division by binary division in two planes in successive generations, perpendicular to one another and more or less to the colony surface
- Species primarily separated based on cell size, size and shape of colony, cell density, mucilage characteristics, presence/absence of aerotopes and habitat.



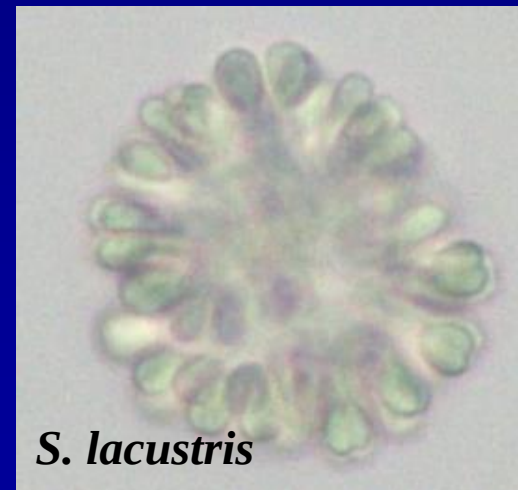
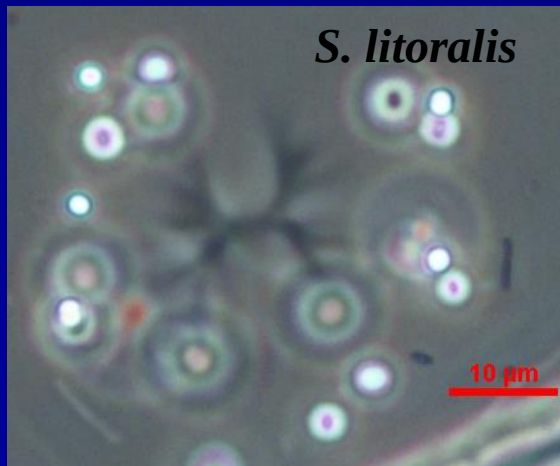
# *Coelomoron*

- Cells slightly elongate, situated more or less radially in the outer layers
- Cells in young colonies randomly or more or less sparsely arranged; in older colonies cells concentrated in the peripheral layer or up to three cells thick
- Colonies more or less spherical, sometimes compound
- Colonial mucilage fine, colorless, diffluent, rarely distinct and delimited; in the center of colonies is a condensed cluster of slime
- Aerotopes present or absent
- Cell division in two planes in successive generations, perpendicular to one another and more or less to the colonial surface
- Species separated primarily based on cell dimensions, colony size and shape, mucilage characteristics, presence/absence of aerotopes and habitat.



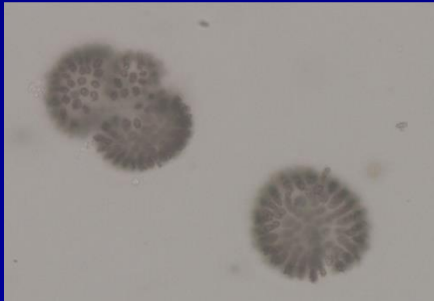
# *Snowella*

- Cells spherical or slightly elongate, distant from one another and joined to the ends of stalks
- Colonies more or less spherical or irregularly oval, with distinct or indistinct, homogeneous, colorless and wide mucilage
- System of fine, thread-like mucilaginous stalks radiating from center of colony
- Cell division by binary fission in two planes in successive generations perpendicular to one another and the colony surface
- Includes some taxa formerly classified as species of *Gomphosphaeria*
- Species primarily separated based on cell size and shape, size and shape of colony, presence of aerotopes/refractive granules, mucilage characteristics and habitat.

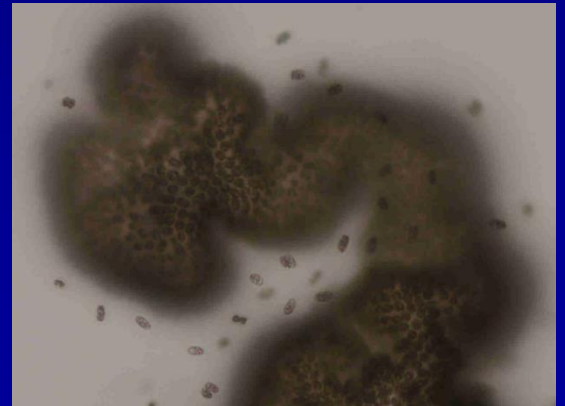
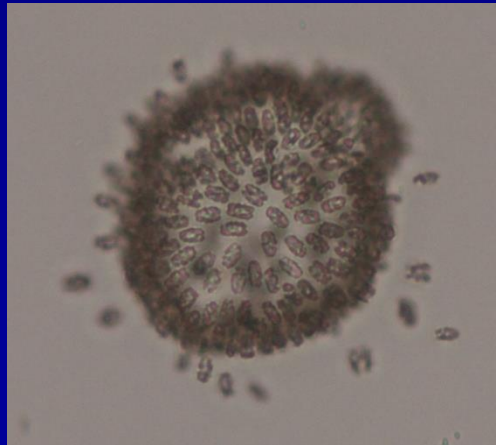


# Woronichinia

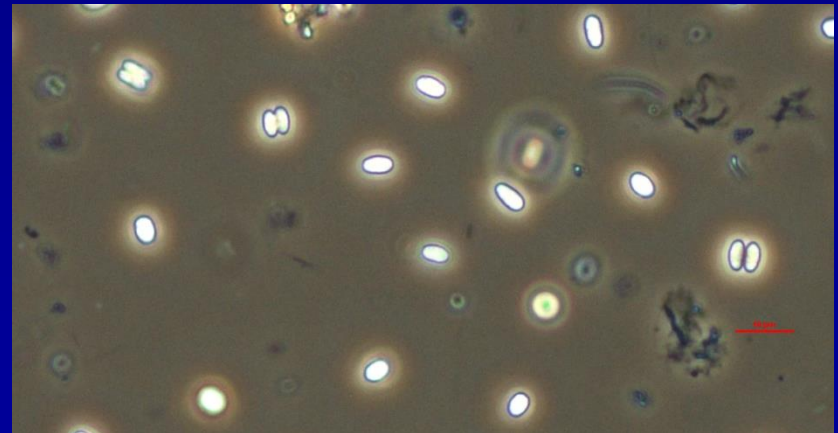
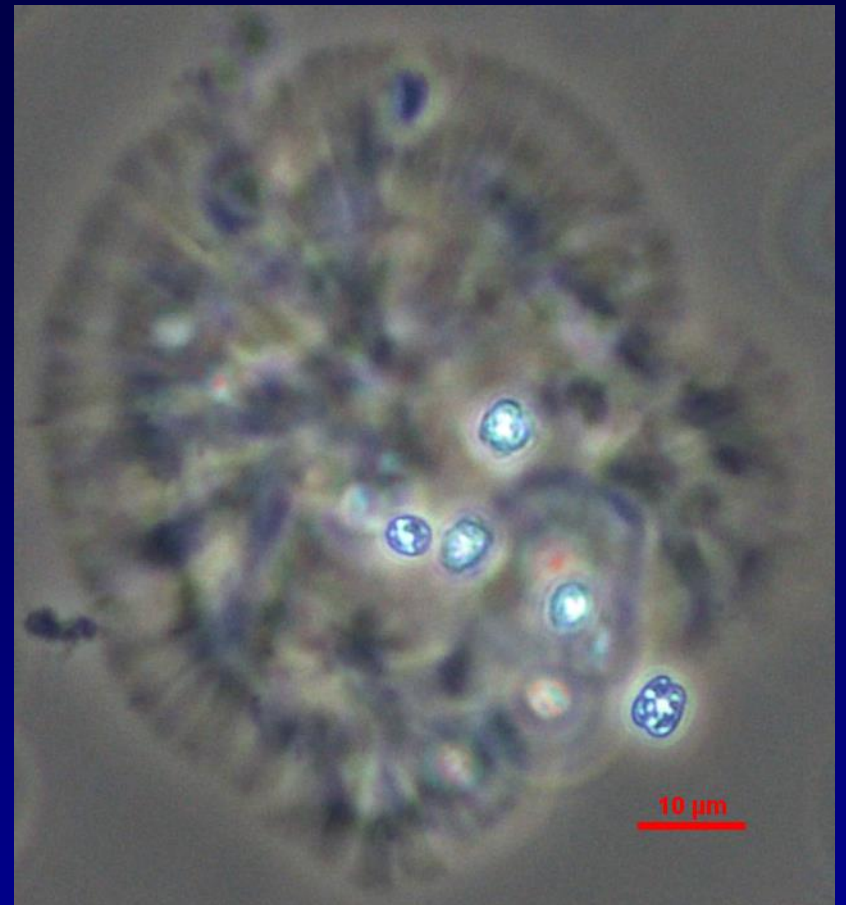
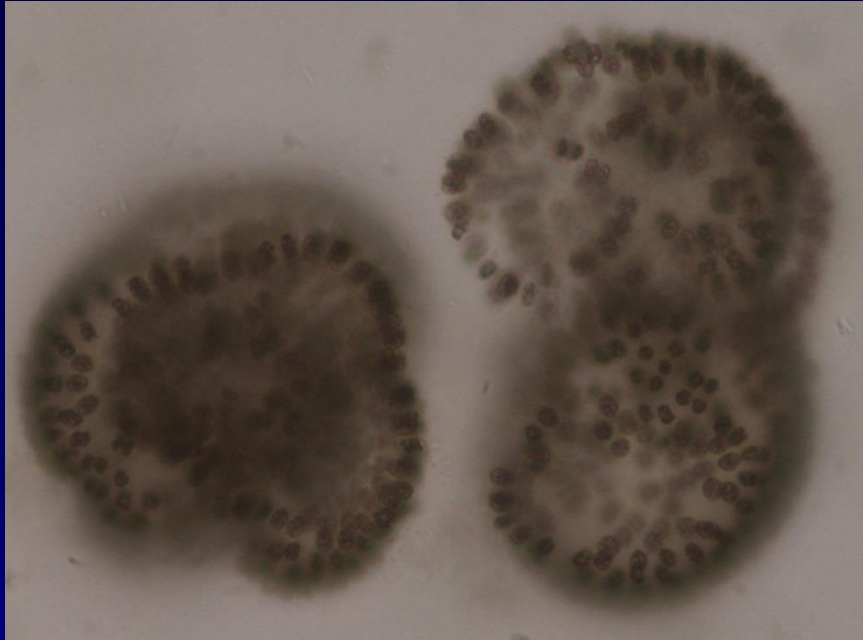
- Cells slightly elongate, widely oval, oval or obovoid; distant from one another in young colonies, but densely and radially aggregated along periphery in older colonies; aerotopes in some species
- Colonies more or less spherical or irregularly oval (sub-colonies common), usually with narrow, colorless mucilaginous envelopes
- Central system of thick, radial and unbranched mucilaginous stalks; generally as wide as the cell width
- Cell division by binary fission in two planes in successive generations perpendicular to one another and to the colony surface
- Includes some taxa formerly classified as species of *Gomphosphaeria* and *Coelosphaerium*
- Species primarily separated based on cell size and shape, size and shape of colony, presence of aerotopes, mucilage characteristics and habitat.



*W. naegeliana*

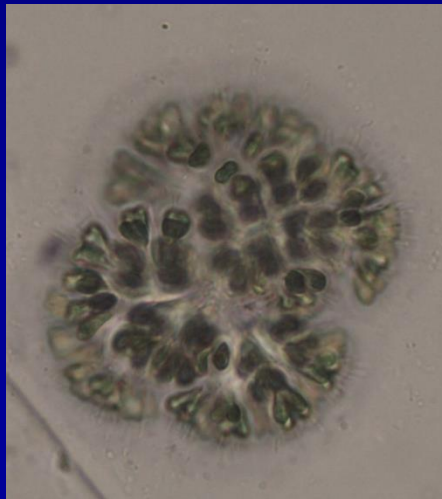


# *Woronichina naegeliana*



# *Gomphosphaeria*

- Cells obovate, club-shaped or cordiform; radially situated at ends of gelatinous stalks
- Cells or pairs of cells slightly distant from one another
- Colonies spherical or irregular, sometimes surrounded by indistinct, fine and diffluent mucilage
- Central system of thick, radial gelatinous stalks; always thinner than cell width, but widen at ends to envelop cells
- Cell division by binary fission in successive generations in two planes perpendicular to one another and the colony surface; cells remain joined together after division for a long part of the life cycle
- Species primarily separated based on cell size and shape, pigmentation, size and shape of colony, mucilage characteristics and habitat.

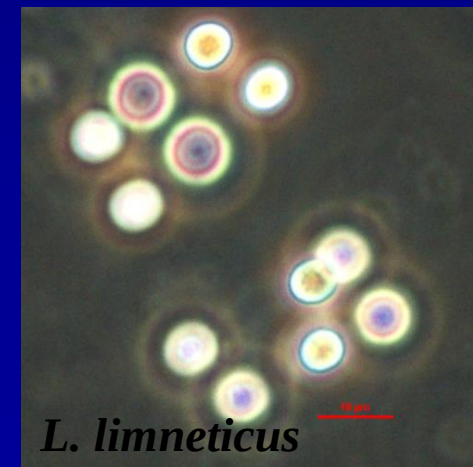
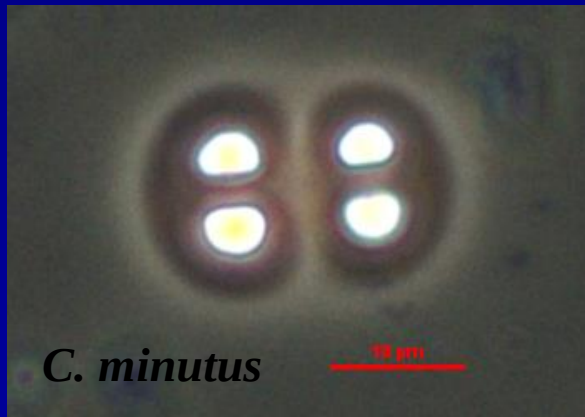


*G. semen-vitis*



# *Chroococcus/Limnococcus*

- Cells at first sub-spherical, widely oval or spherical, later hemispherical (*Chroococcus*) or spherical (*Limnococcus*)
- Groups of cells (rarely solitary) surrounded by mucilaginous envelopes, forming irregular or more or less spherical, gelatinous colonies
- Colonies usually with a small # of cells (2-32); sometimes many-celled
- Mucilage delimited at the margin or homogeneous, hyaline
- Cells often surrounded by narrow individual envelopes
- A few species have facultative aerotopes
- Cell division by binary fission in at least three planes in successive generations
- Species primarily separated based on cell size, whether cells attain a spherical form before next division, size and shape of colony, cell density, mucilage characteristics, presence/absence of aerotopes and habitat.

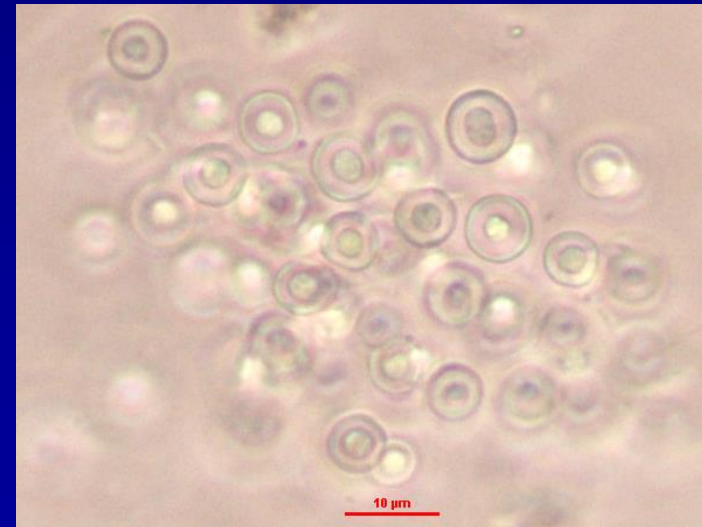


# *Gloeocapsa*

- Cells spherical or rarely indistinctly elongated and oval; after division hemispherical
- Cells in small groups of irregularly arranged cells enveloped by wide, often concentrically lamellate, mucilaginous envelopes
- Mucilage colored in a number of species
- Colonies microscopic or macroscopic; mucilaginous
- Aerotopes in only one species
- Cell division by binary fission in three perpendicular planes in successive generations
- Reproduction by liberation of cells from the colony or colony disintegration; nannocyte production in some species
- Species primarily separated based on color (or lack of color) of mucilaginous envelopes; cell size, presence/absence of lamellation, habit and cell color.

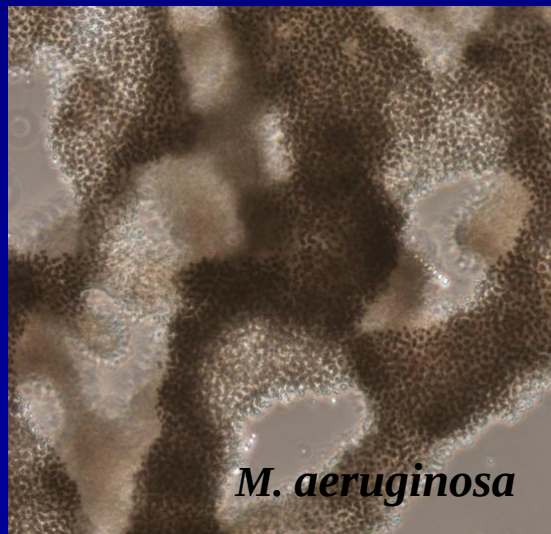


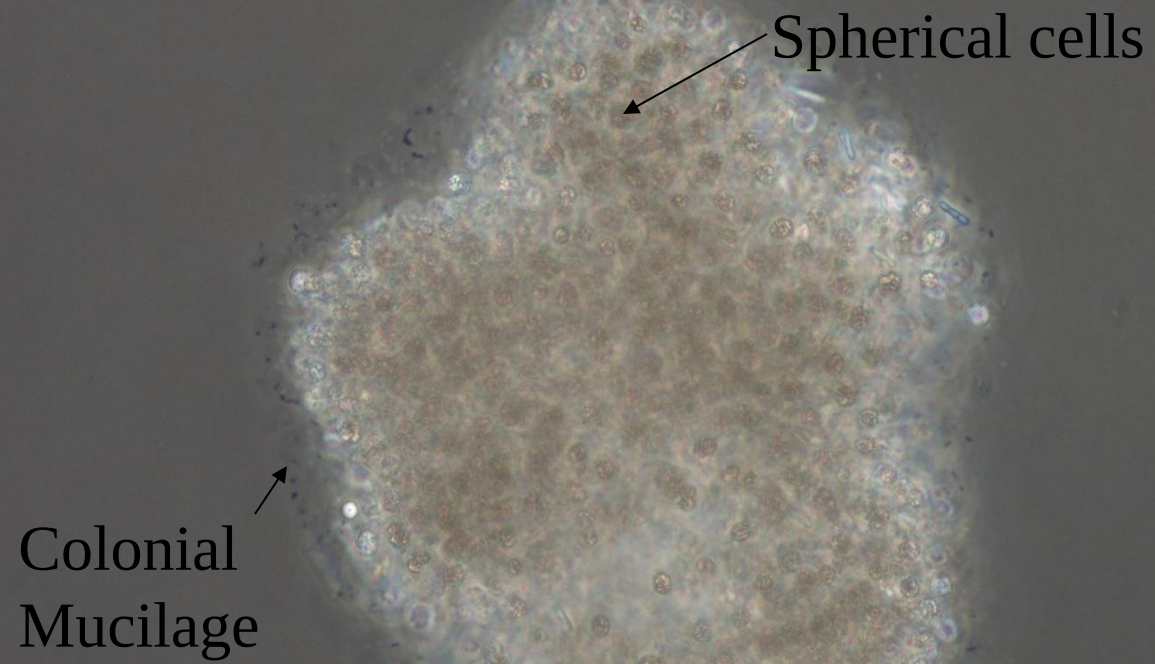
*Gloeocapsa* spp.

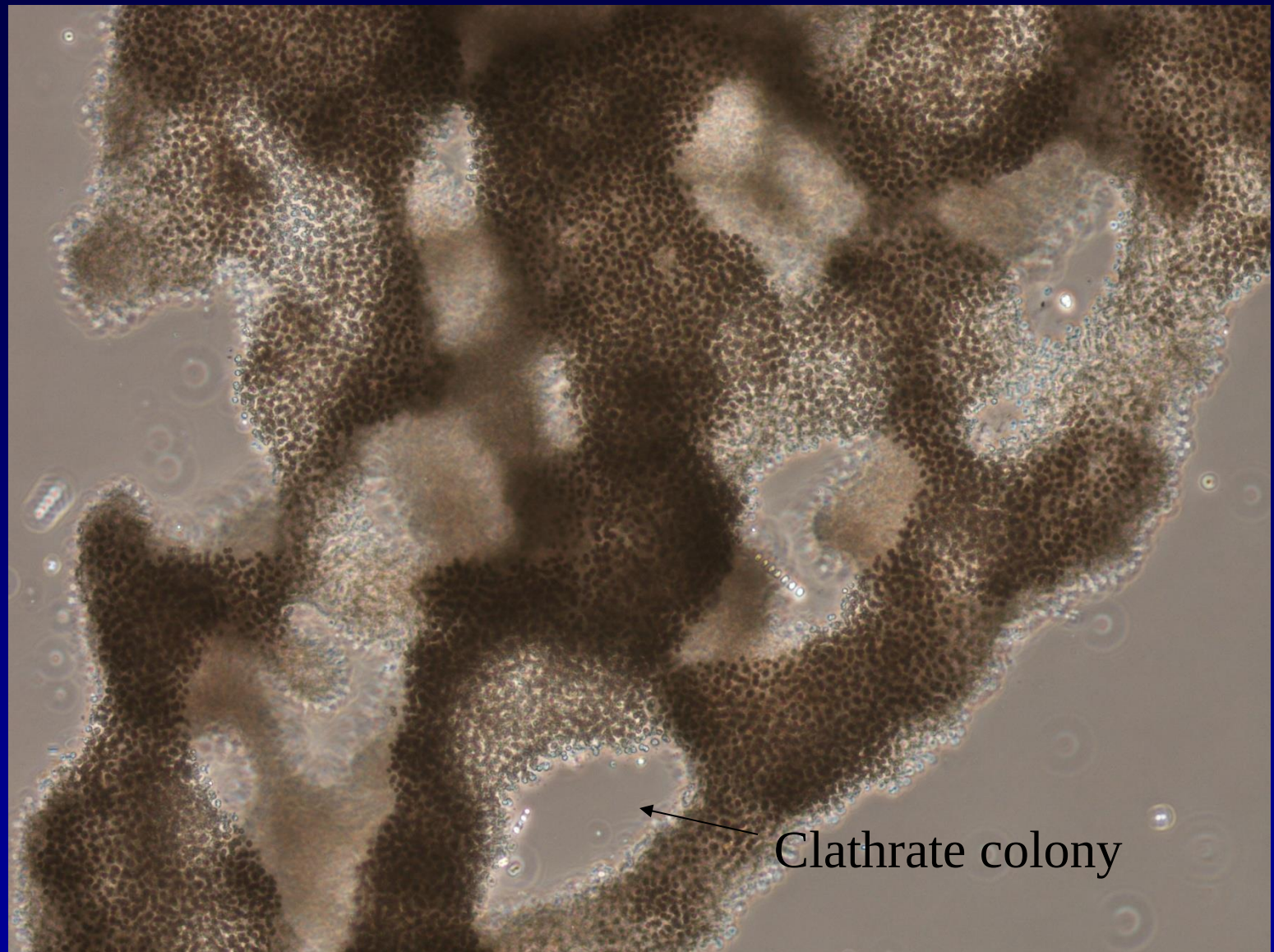


# *Microcystis*

- Cells more or less spherical; aerotopes present
- Colonies spherical, oval, elongate, lobate or irregular, sometimes clathrate; often macroscopic
- Colonies composed of numerous sparsely or usually densely, irregularly arranged cells in common mucilage
- Mucilage fine, colorless, diffuent or distinct and delimited, sometimes with refractive outline
- Division by binary fission in three perpendicular planes in regular (cubic) arrangement; cells grow into original size and shape before next division
- Species primarily separated based on cell size, size and shape of colony, cell density, mucilage characteristics and habitat.







Clathrate colony

# *Microcystis* Taxonomy

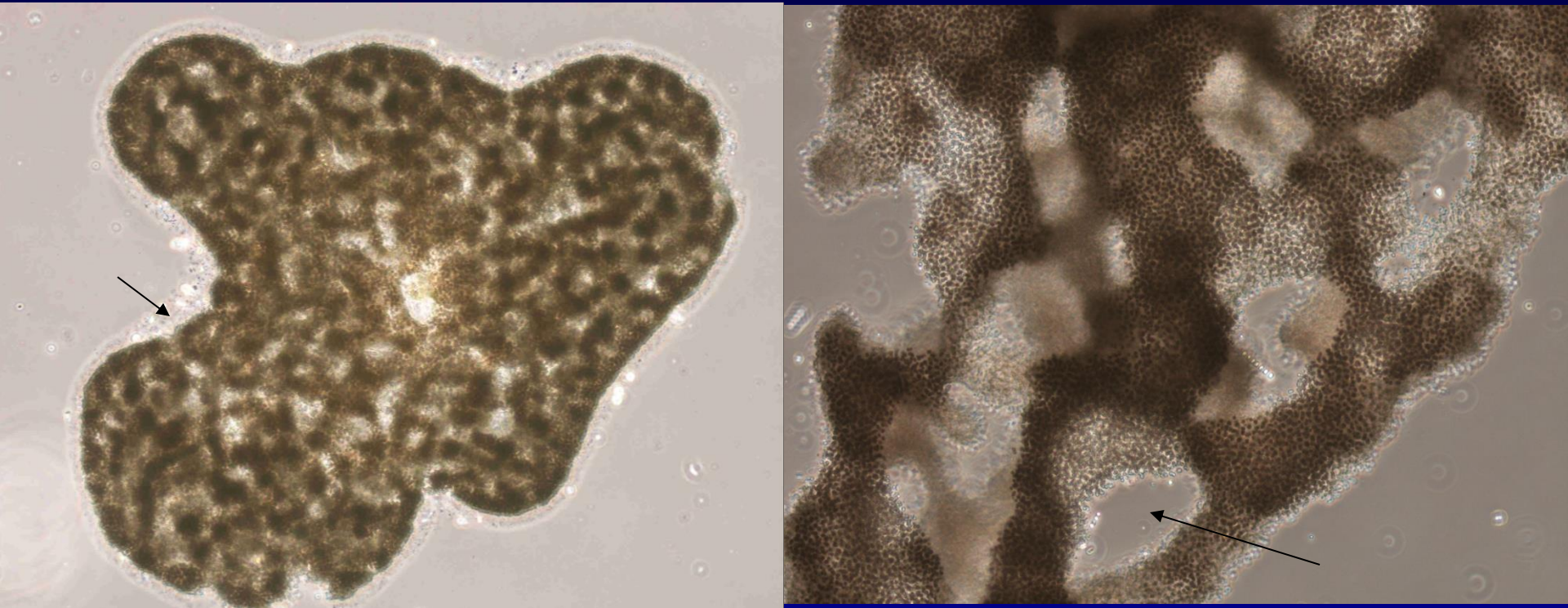
## Classic Cyanobacteria Taxonomy

- Some of the old names used include *Diplocystis*, *Anacystis* and *Polycystis*
- Classic taxonomic approach based on morphological characters observable using light microscopy
- *Microcystis* species primarily separated based on cell size, size and shape of colony, cell density, mucilage characteristics and habitat
- Placed in the order Chroococcales

## Modern Cyanobacteria Taxonomy

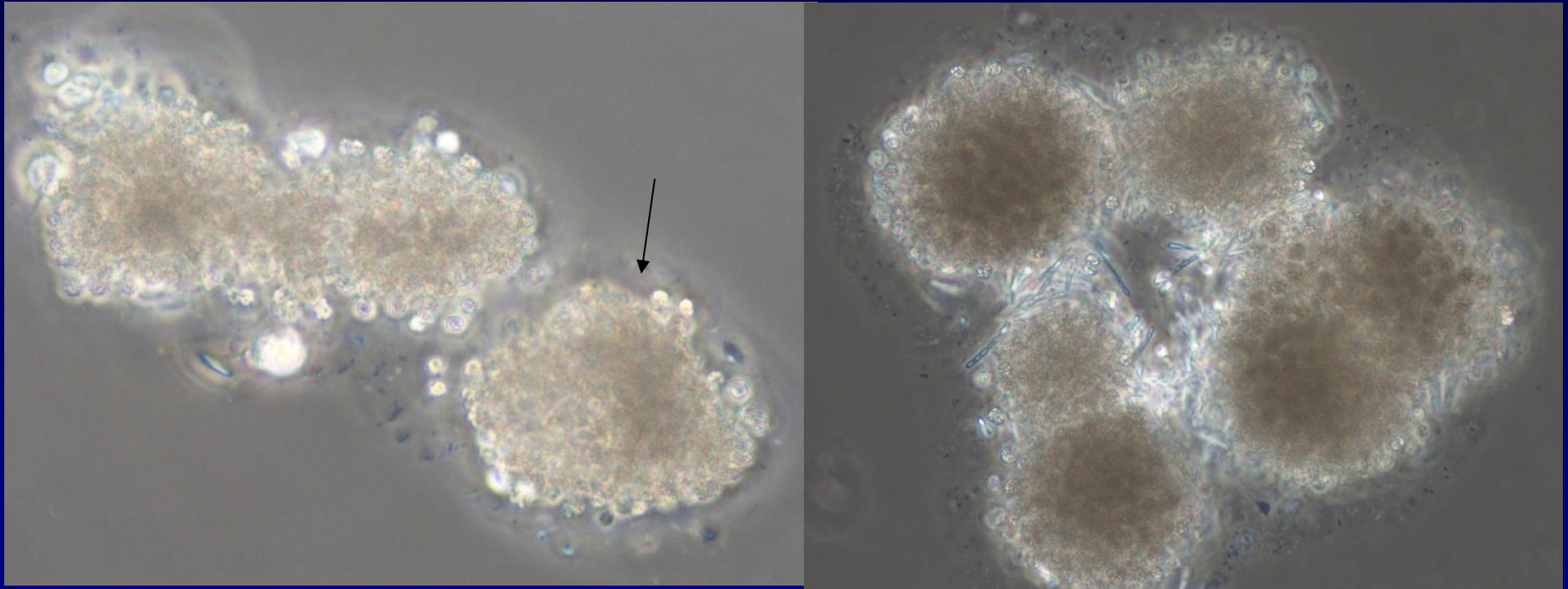
- Modern cyanobacteria taxonomy uses a polyphasic approach
- Polyphasic taxonomic approach uses all currently available data, including morphological, physiological, molecular and ecological
- Morphology based species concept for *Microcystis* not supported
- Otsuka et al. (2001) proposed uniting *M. flos-aquae*, *M. ichthyoblabe*, *M. novacekii*, *M. viridis* and *M. wesenbergii* with *M. aeruginosa*
- Pending more complete analysis, at this time species names preserved as “morphospecies”
- Placed in the Family Microcystaceae in the Order Choococcales

# *Microcystis aeruginosa*



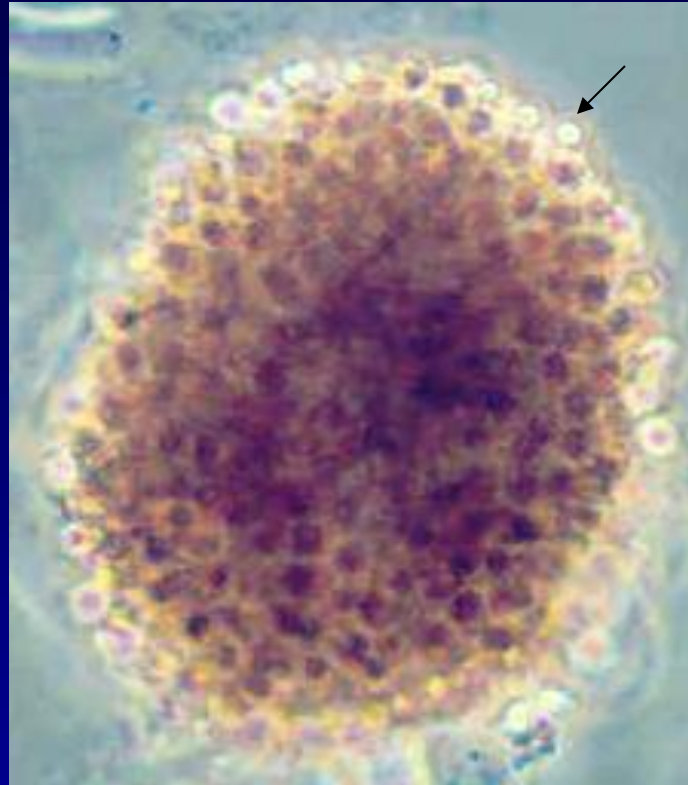
- Colonial mucilage diffluent, extending 5-10  $\mu\text{m}$  past outer cells
- Older colonies macroscopic, clathrate
- Cells irregularly arranged and  $\pm$  densely packed
- Cells mostly 4-6  $\mu\text{m}$  in diameter

# *Microcystis botrys*



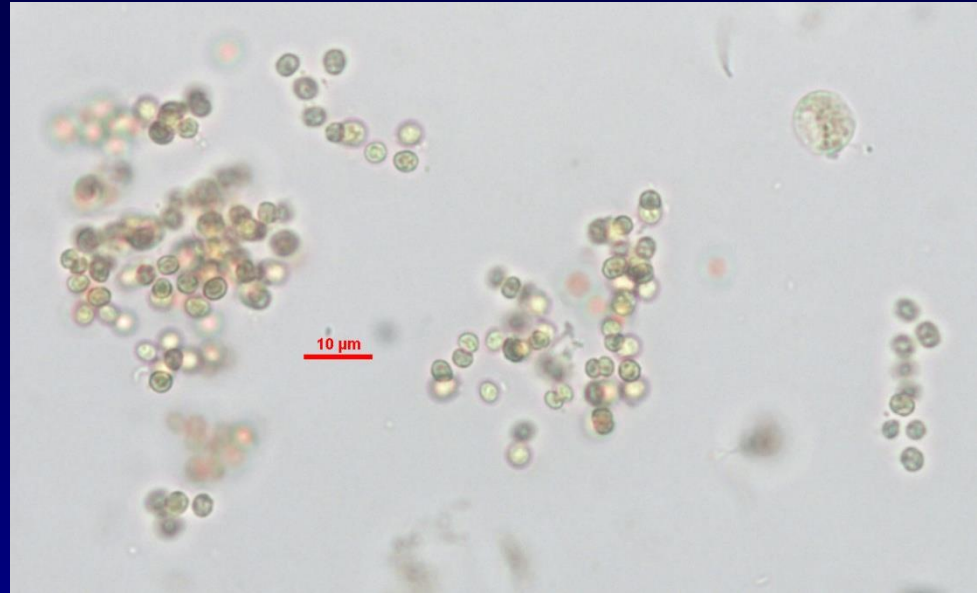
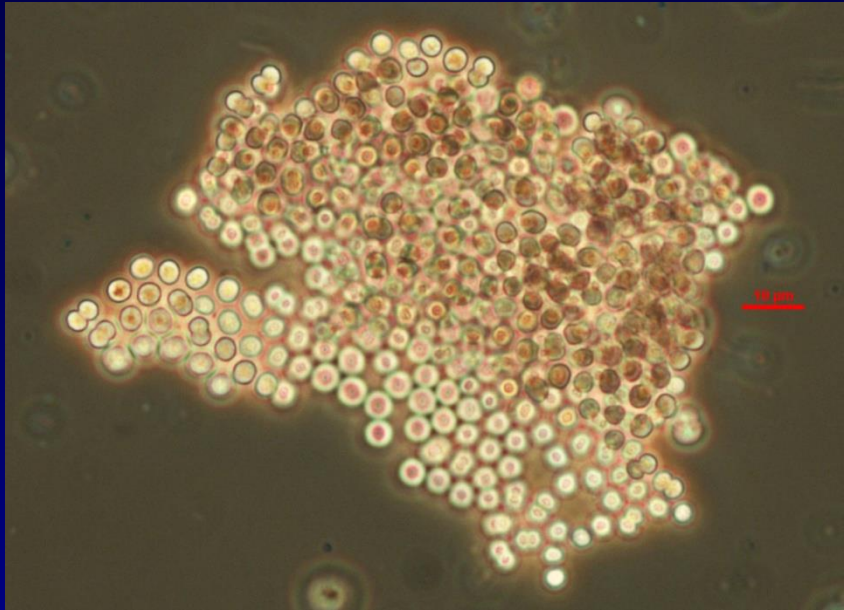
- Colonial mucilage wide, containing gelatinous protuberances
- Often occurring as sub-colonies
- Cells irregularly arranged and densely aggregated
- Cells 5-6  $\mu\text{m}$  in diameter

# *Microcystis flos-aquae*



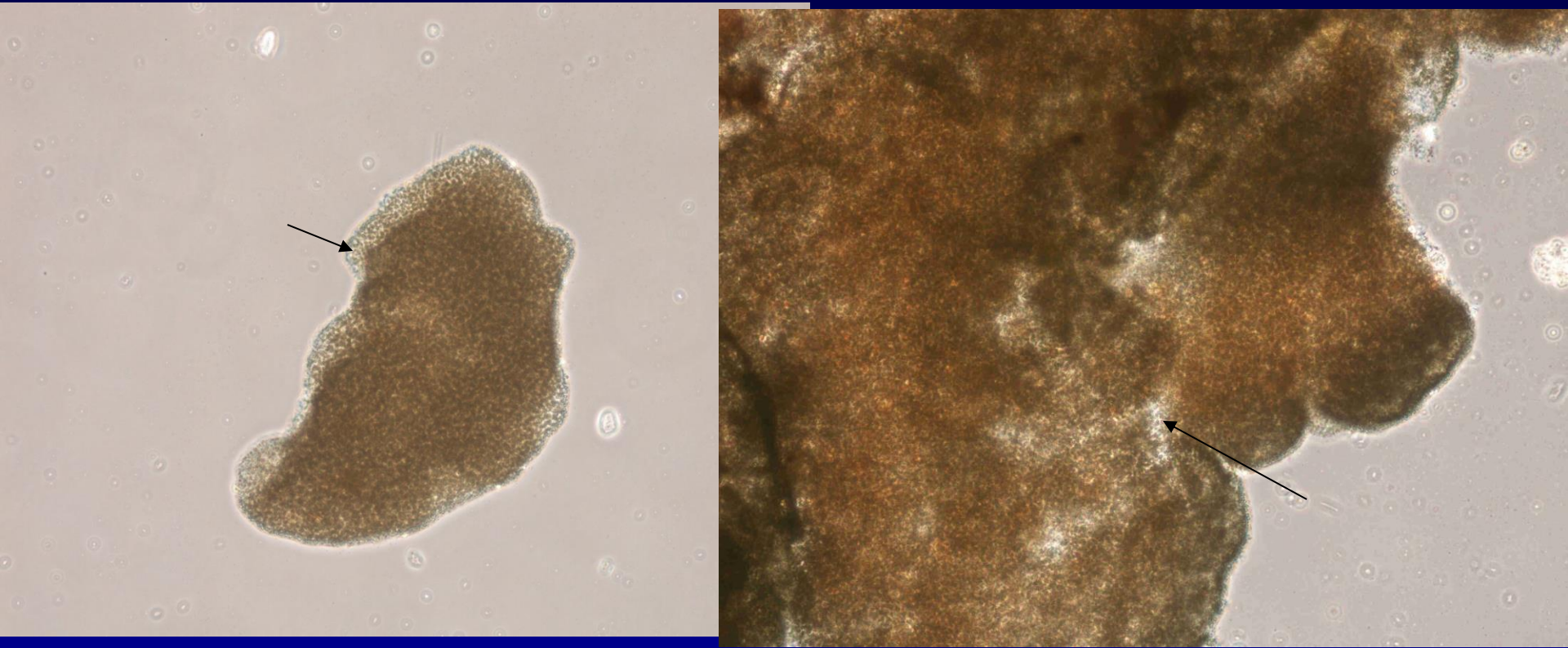
- Colonial mucilage does not distinctly extend past outer cells
- Colonies spherical, not clathrate
- Cells very densely arranged
- Cells 3.5-5  $\mu\text{m}$  in diameter
- Mostly found in temperate waters

# *Microcystis ichthyoblabe*



- Colonial mucilage indistinct, diffuse; irregularly overlapping cells
- Colonies irregular, without holes, often flattened
- Colonies often disintegrate into small groups of cells and unicells
- Cells densely arranged
- Cells mostly 2-3.8 µm in diameter
- Common in temperate zone

# *Microcystis panniformis*



- Colonial mucilage does not distinctly extend past outer cells
- Colonies irregular, sometimes with small holes
- Cells densely arranged
- Cells mostly 3-5  $\mu\text{m}$  in diameter
- Mostly sub-tropical to tropical species

# *Microcystis viridis*



- Colonial mucilage follows outline of outer cells,  $\pm$  refractive
- Cells often arranged in packets or groups of four
- Cells 4-8  $\mu\text{m}$  in diameter

# *Microcystis wesenbergii*



- Colonial mucilage distinctly delimited, refractive
- Colonies lobate with holes; often composed of sub-colonies
- Cells loosely arranged
- Cells 4-8.5  $\mu\text{m}$  in diameter

# **Filamentous Cyanobacteria**

# Simple Filamentous Cyanobacteria



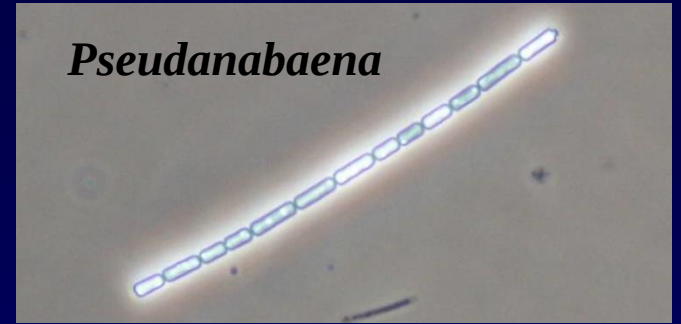
# Simple Filamentous Cyanobacteria

- Orders Synechococcales, Spirulinales, Oscillatoriales
  - Filamentous cyanophytes with true trichomes
  - Trichomes motile or immotile
  - Sheaths, false branching and aerotopes lacking or facultative
  - Heterocytes, akinetes and true branching lacking
  - Division of cells perpendicular to the trichome axis
  - Reproduction mainly by hormogonia or hormocytes
- Important criteria used to distinguish genera include type of cell division, occurrence of aerotopes, motility, ability to form and frequency of false branches, presence of sheaths and number of trichomes in sheaths
- Genera with known potentially toxigenic species include *Arthrospira*, *Anagnostidinema*, *Geitlerinema*, *Hormoscilla*, *Leibleinia*, *Leptolyngbya*, *Limnothrix*, *Lyngbya*, *Microcoleus*, *Microseira*, *Moorea*, *Oscillatoria*, *Phormidium*, *Planktothrix*, *Pseudanabaena*, *Schizothrix*, *Symploca*, *Trichodesmium* and *Tychonema*.

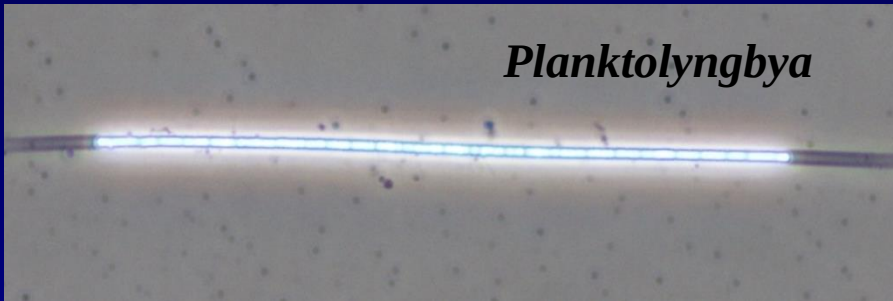
*Arthrospira*



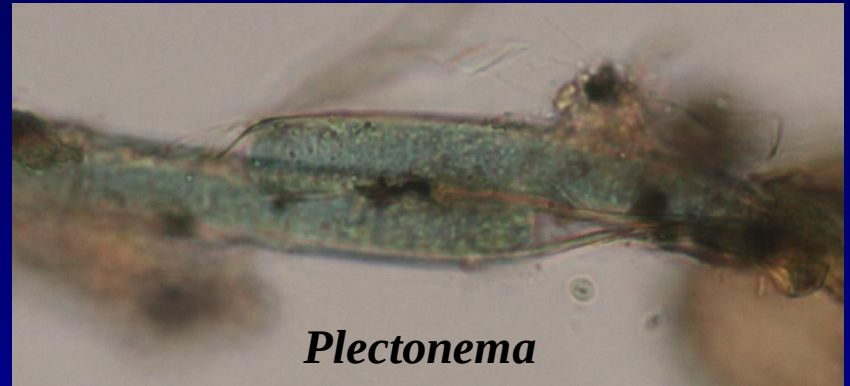
*Pseudanabaena*



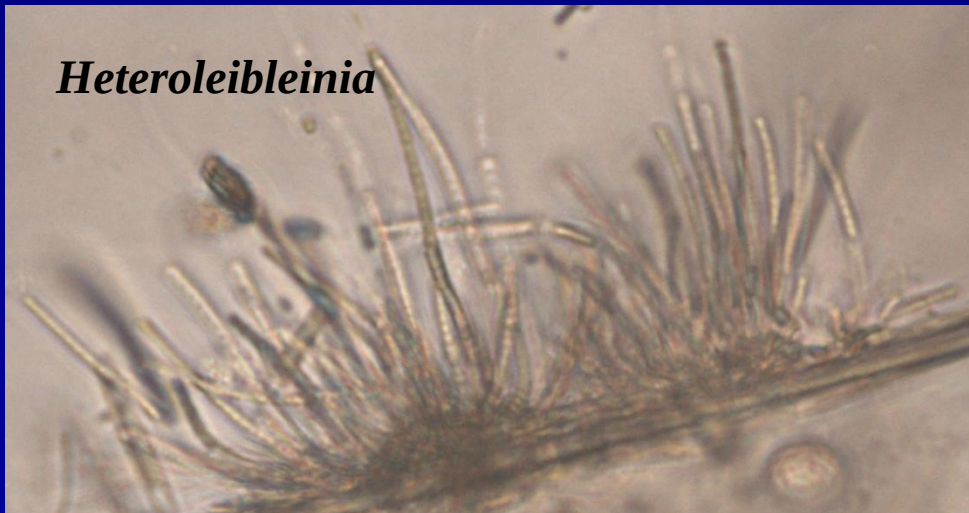
*Planktolyngbya*



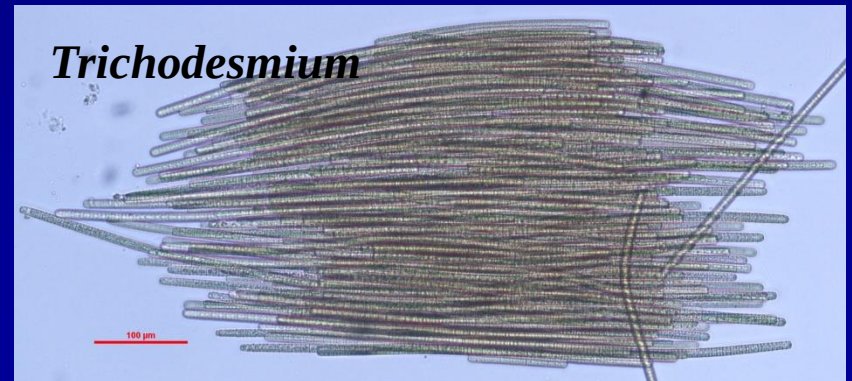
*Plectonema*



*Heteroleibleinia*



*Trichodesmium*



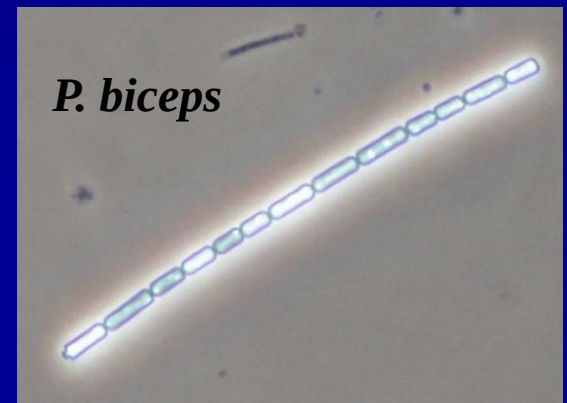
# *Romeria*

- Trichomes solitary or in mucilaginous clusters; planktic, metaphytic, benthic, epiphytic
  - Trichomes thin (up to 3  $\mu\text{m}$  wide), without distinct sheath, but usually with thick, colorless and fine mucilaginous envelope
  - Trichomes usually short; mostly 1- 8 celled
  - Trichomes rarely almost straight, often curved or coiled
  - Cells cylindrical or barrel-shaped, always longer than wide; aerotopes lacking
  - End cells rounded at the apex
  - Ends of adjacent cells are sometimes slightly shifted one to another
  - Motility lacking
  - Reproduction by trichome fragmentation into hormocytes or single cells
- Species primarily separated based on degree of cross-wall constriction, habitat, cell size, trichome morphology and cell shape.



# *Pseudanabaena*

- Trichomes solitary in plankton, metaphytic or in fine mats
- Trichomes thin (<3  $\mu\text{m}$  wide), without evident mucilage
- Trichomes straight, curved or waved
- Cells cylindrical or sometimes almost barrel-shaped, distinctly constricted at the cross walls; cells sometimes appearing disjointed or connected by narrow “bridges”
- End cells not or bluntly attenuated, broadly rounded at tips, occasionally with terminal papillae
- Aerotopes facultative, localized in terminal or central portions of cells
- Motility lacking or facultative (slow gliding)
- Reproduction by one celled or short hormogonia or by trichome fragmentation
- Species primarily separated based on cell shape, trichome width, trichome morphology, manner of cell connection, end cell morphology, presence/absence of aerotopes and habitat.



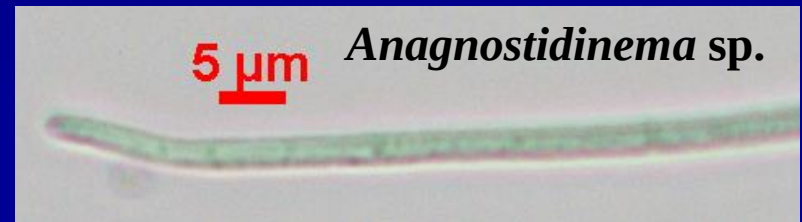
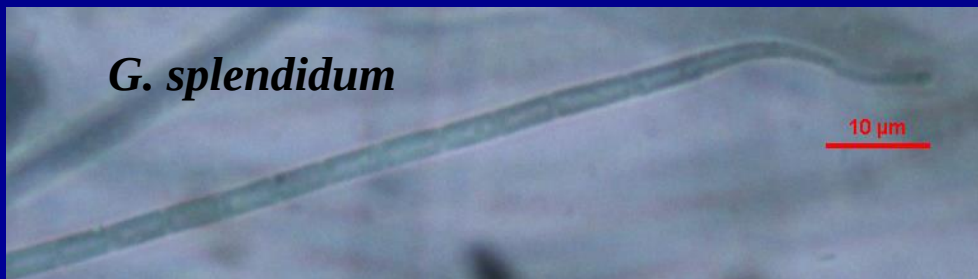
# *Limnothrix*

- Trichomes thin (1-6  $\mu\text{m}$  wide), mostly solitary
- Trichomes straight, curved or waved; without or facultative fine sheaths
- Cells cylindrical, longer than wide; not or slightly constricted at cross walls
- End cells not attenuated, broadly rounded or slightly flattened at tips
- Aerotopes present, localized in apical or central portion of cells
- Immotile or with reduced motility (slight trembling or gliding)
- Reproduction by disintegration of trichomes into immotile hormocytes, without necridic cells
- Includes some species formerly classified in the genus *Oscillatoria*
- Species primarily separated based on trichome width, trichome morphology, cell length, location of aerotopes, degree of cross wall constriction and habitat.



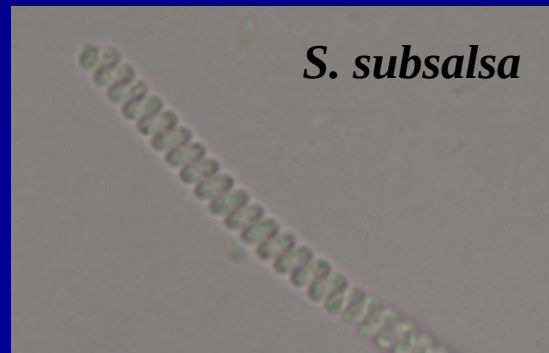
# *Geitlerinema/Anagnostidinema*

- Thallus delicate; forming thin mats (*Geitlerinema*) or dispersed evenly without mat formation (*Anagnostidinema*)
- Trichomes thin, mostly 1-3  $\mu\text{m}$  wide, straight, flexuous or bent screw-like coiled (especially at the ends)
- Trichomes  $\pm$  gradually attenuated and bent or coiled at the ends
- Sheaths absent; mostly not constricted at the cross-walls
- Trichomes motile
- Cells mainly 2-4 times longer than wide; aerotopes absent
- Apical cells in developed trichomes of *Geitlerinema* bent and spherical-capitate and elongated up to 15  $\mu\text{m}$
- Apical cells in developed trichomes of *Anagnostidinema* bent, narrowed and pointed-rounded, never calyptrate or capitate
- Reproduction by disintegration of trichomes into motile hormogonia, no necridic cells
- Very similar to *Jaaginema* which is always immotile and rarely in mats



# *Arthrospira/Spirulina/Glaucospira*

- Trichomes spirally twisted, not or only slightly attenuated at apices
- Spirals loose and lax, or tightly coiled
- Trichomes without evident sheaths
- Cells quadrate or slightly longer than wide; not or slightly constricted at cross walls
- Capable of oscillatory and gliding movement
- Two genera traditionally separated on the basis of presence (*Arthrospira*) or absence (*Spirulina*) of visible cross walls (not valid!)
- Now placed in different subclasses primarily based on thylakoid arrangement and differences in pore and perforation patterns in cell walls (not visible in light microscopy)
- Trichomes of *Arthrospira* tend to be longer than those of *Spirulina*
- Some of the very thin (<3µm) *Spirulina* species have been transferred to *Glaucospira*
- Species primarily separated based on manner of coiling, width of coils, trichome width and habitat.



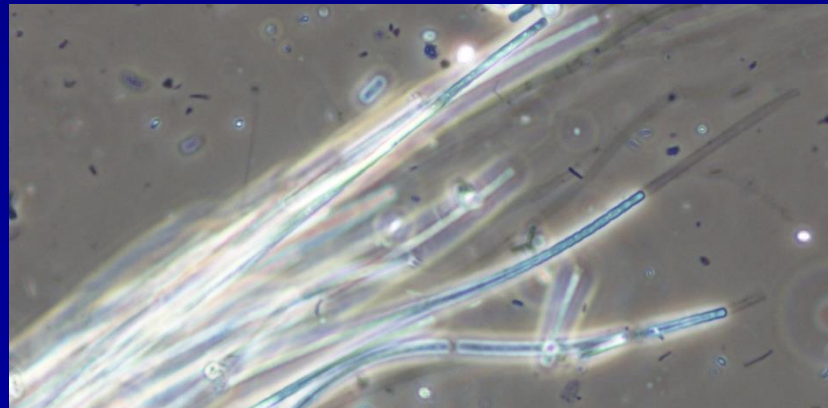
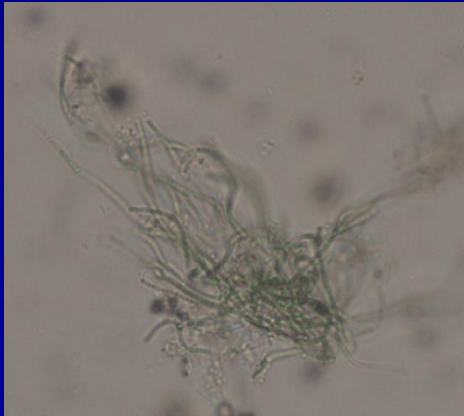
# *Planktolyngbya*

- Trichomes solitary, thin (<3µm wide); straight, waved or coiled
- Firm sheath evident, normally extending past end cells at one or both ends
- Cells cylindrical, quadrate or shorter than wide; with or without constrictions at cross walls
- Not attenuated at apices, end cells broadly rounded or flattened
- Aerotopes absent
- Formerly classified in the genus *Lyngbya*
- Reproduction via trichome fragmentation without necridia
- Species primarily separated based on trichome morphology, trichome width cell length and habitat.



# *Leptolyngbya*

- Filaments rarely solitary, usually in flaky clusters, floating or attached to a substrate; rarely forming compact thalli
  - Filaments  $\pm$  flexuous, finely waved or rarely almost straight; usually not attenuated or capitate at ends
  - Sheaths facultative; thin, hyaline rarely with pseudobranching
  - Trichomes 0.5 to 3.5  $\mu\text{m}$  wide; motile, immotile or with slight trembling
  - Cells cylindrical, isodiametric, longer or shorter than wide; aerotopes absent
  - Thylakoids peripherally arranged
  - Reproduction by trichome fragmentation, with or without necridial cells
  - Polyphyletic; some new genera include *Chamaethrix*, *Haloleptolyngbya*, *Onodrimia* and *Thermoleptolyngbya*
- Species primarily separated based on cell shape, presence/absence of necridial cells, habitat, trichome width, sheath characteristics, cross-wall constriction, color, granulation and presence/absence of pseudobranching.



*Leptolyngbya* spp.

# *Schizothrix*

- Filaments mostly long,  $\pm$  straight or curved, densely aggregated forming soft or hard, fine, membranaceous or thick mats sometimes encrusted with calcium carbonate
- Sheaths rarely thin, usually  $\pm$  thick, widened, soft to firm, often lamellated
- Sheaths colorless or colored
- Sheaths mostly attenuated or pointed at the free ends or conically closed to the apex containing one, several to many trichomes
- Trichomes immotile or motile, slightly to distinctly or not constricted at cross-walls
- Cells usually longer than wide, sometimes isodiametric
- Apical cells rounded, rounded-conical or obtuse to acute-conical; without thickened outer wall or calyptra
- Reproduction by fragmentation of trichomes into motile (?) hormogonia, without necridic cells
- Species primarily separated on the basis of presence/absence of calcium carbonate encrustation, habitat, apical cell morphology, cell size and shape, cell pigmentation, sheath color and degree of cross-wall constriction.



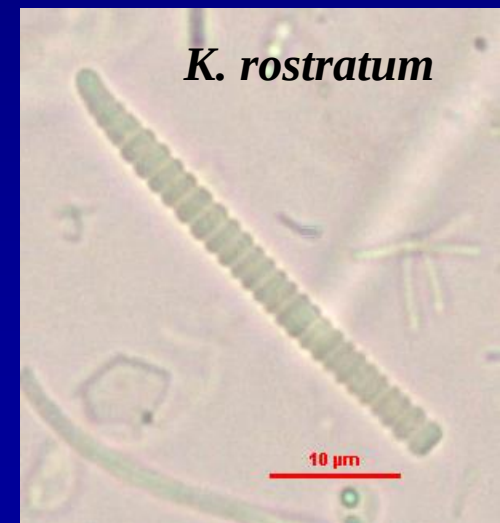
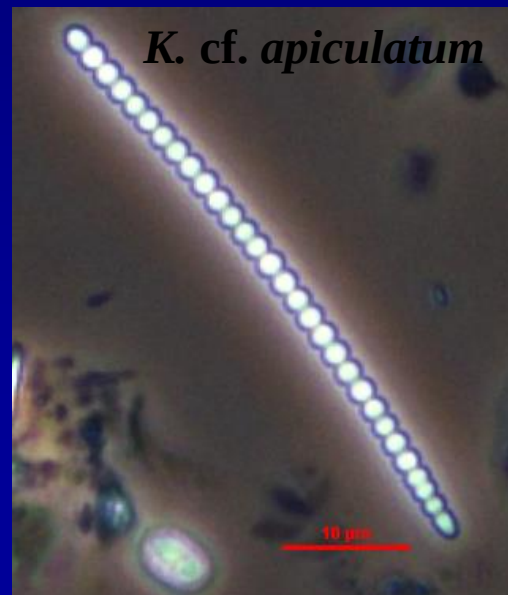
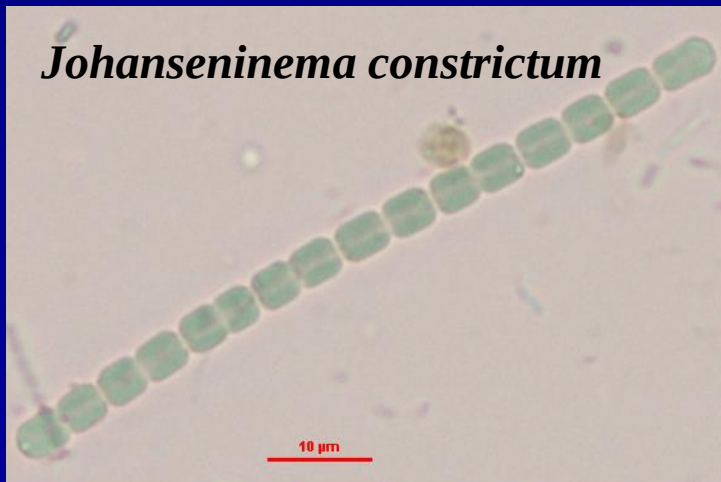
*Schizothrix* sp.

# *Komvophoron*

- Trichomes solitary; straight or slightly flexuous, simple, usually short; without firm sheaths; constricted at cross-walls
- Trichomes motile or immotile
- Cells  $\pm$ spherical, barrel-shaped or discoid, up to 10 $\mu$ m wide
- Aerotopes absent
- Reproduction by fragmentation of trichomes without necridial cells in to immotile hormocytes (rarely motile hormogonia)

*K. constrictum* has been transferred to *Johanseninema* (*J. constrictum*)

- Species primarily separated based on cell shape, motility, trichome width, habitat, and apical cell morphology.



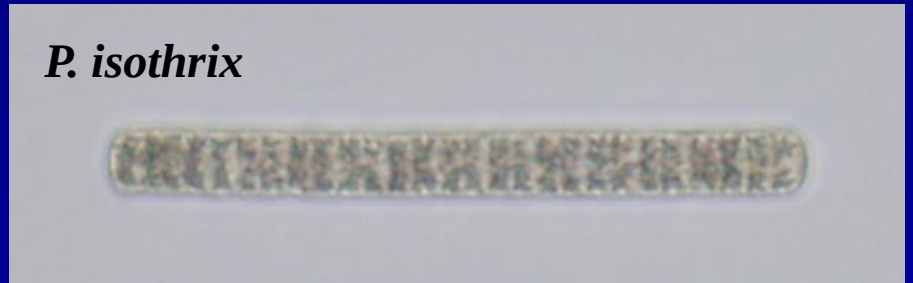
# *Planktothrix*

- Trichomes mostly solitary, planktonic, can form clumps in mass development
  - Trichomes straight or waved; most species without evident sheaths
  - Cells isodiametric or slightly wider or narrower than long; slightly constricted or not constricted at cross walls
  - End cells slightly or not attenuated, often with calyptra or thickened outer wall
  - Aerotopes present, distributed throughout the cell
  - Immotile but occasionally with inconspicuous movement
  - Reproduction by disintegration of trichomes via necridia into immotile hormocytes
  - Includes some species formerly classified in the genus *Oscillatoria*
- Species primarily separated based on trichome morphology, trichome width, end cell morphology, cell length, degree of cross wall constriction and habitat.

*P. agardhii*



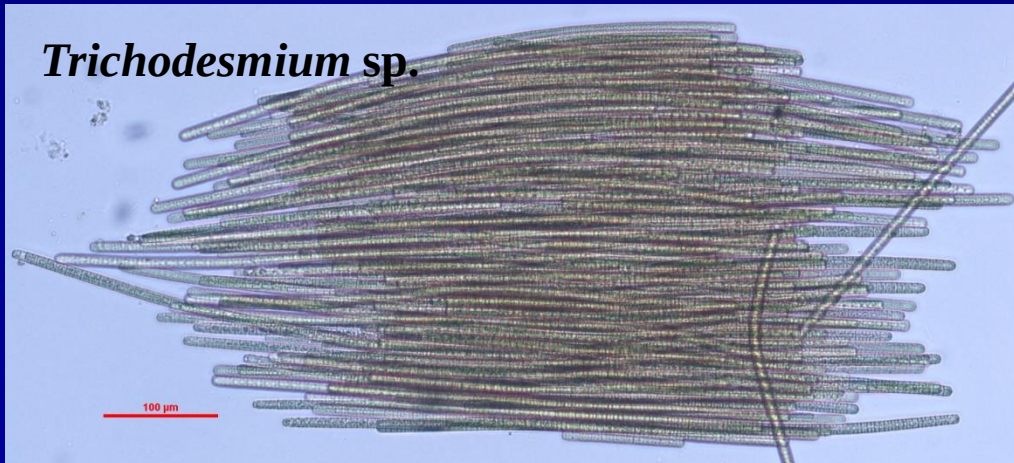
*P. isothrix*



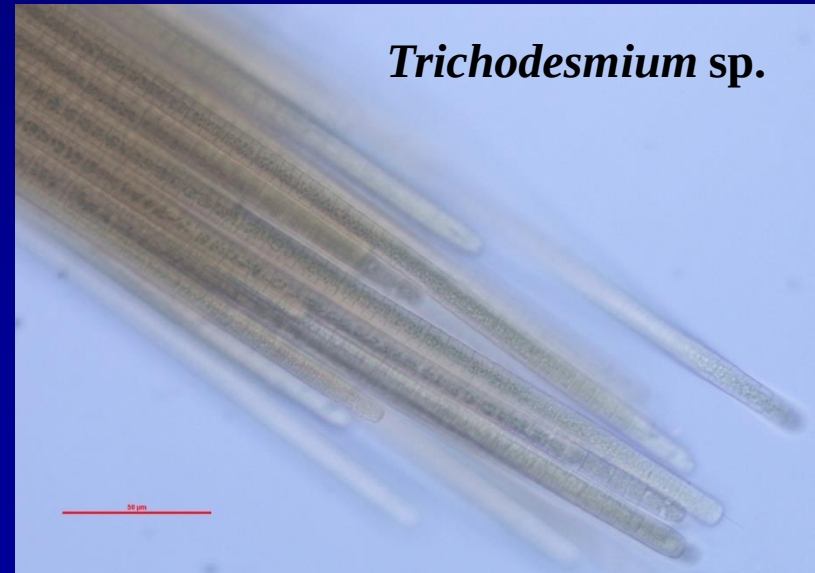
# *Trichodesmium*

- Trichomes planktonic, free-floating, rarely solitary usually forming colonies with parallel or radially arranged fascicles or flocculent masses
  - Colonies fasciculated and spindle-like or scale shaped or disc-like
  - Trichomes without sheaths,  $\pm$  straight or curved, rarely spirally twisted, cylindrical or with slightly tapering ends, constricted or unconstricted at cross-walls
  - Trichomes slightly motile (inconspicuous gliding)
  - Cells  $\pm$  isodiametric or slightly longer or shorter than wide,; aerotopes present
  - Apical cells  $\pm$  straight, rounded or slightly capitate
  - Reproduction by fragmentation or trichomes
- Species primarily separated on the basis of habitat, trichome morphology, colony morphology and degree of cross-wall constriction

*Trichodesmium* sp.



*Trichodesmium* sp.



# *Lyngbya*

- Majority of species benthic or metaphytic, forming wooly or leathery thalli
- Trichomes straight or curved (rarely coiled); trichomes >5 µm wide (most >10 µm) with firm, thick sheaths (sometimes lamellate) extending past end cells
- Cells discoid, mostly not constricted at cross walls
- End cells broadly rounded, not attenuated, with/without thick outer wall or calyptra
- Reproduction by trichome disintegration with necridial cells into motile hormogonia
- *Plectonema* is a very similar genus only differing in the presence of false-branching
- *Lyngbya* (*Plectonema*) *wollei* recently transferred to the genus *Microseira*
- Planktic species with aerotopes transferred to the genus *Limnoraphis*
- Some marine tropical species transferred to the genera *Moorea* and *Tropicmarinus*
- Species primarily separated based on trichome width, cell length, sheath characteristics, end cell morphology, pigmentation and habitat.

*L. aestuarii*

10 µm

*Limnoraphis robusta*

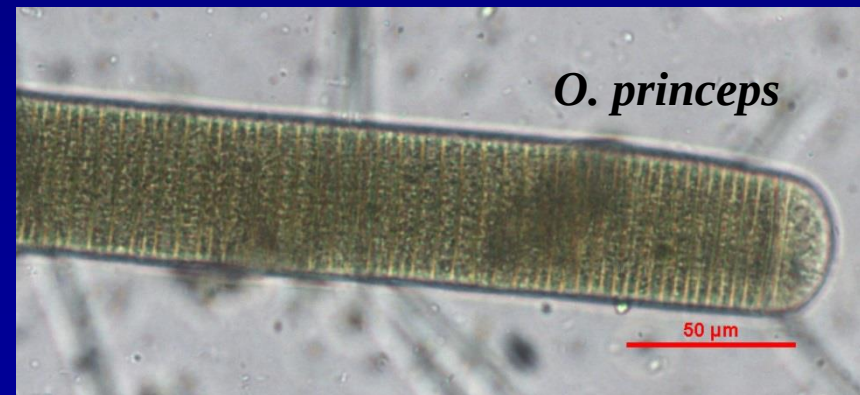
10 µm

*Microseira wollei*

20 µm

# *Oscillatoria*

- Majority of species benthic or metaphytic forming smooth, layered rarely leathery mats (rarely as solitary trichomes)
  - Trichomes straight, curved or waved; sheath absent (can occur under stress)
  - Trichomes generally >6µm wide
  - Cells discoid, various degree of constriction at cross walls; aerotopes absent
  - End cells broadly rounded or attenuated; with or without calyptra
  - Capable of oscillatory and gliding movement
  - Reproduction by disintegration via necridia into motile hormogonia
- 
- Species primarily separated based on trichome width, trichome morphology, cell length, end cell morphology, degree of cross wall constriction, presence of granules at cross walls and habitat.

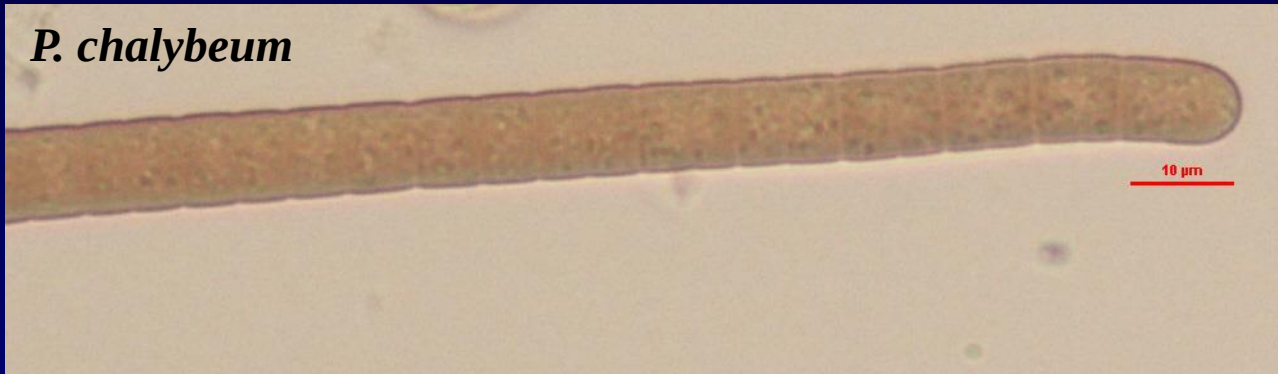


## *Phormidium*

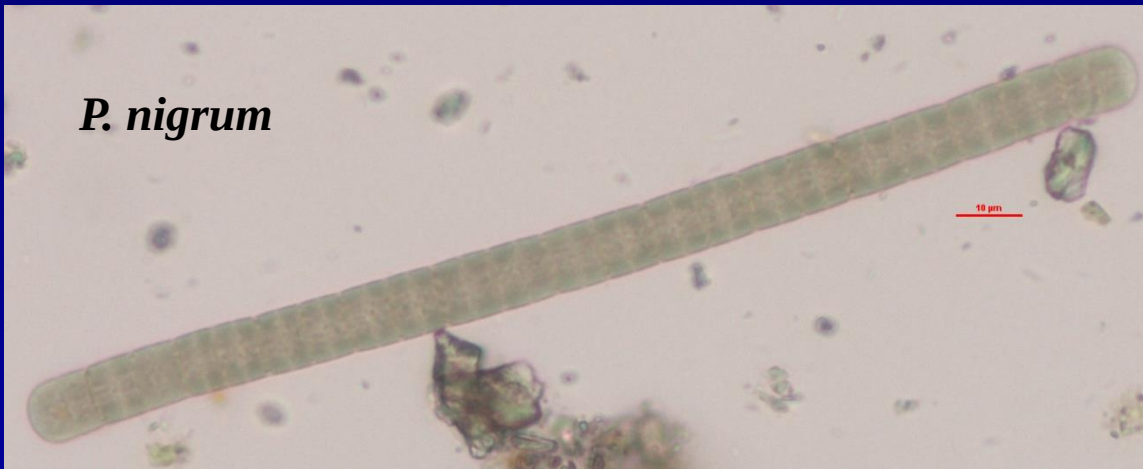
- Majority of species benthic or metaphytic forming fine, thin or cohesive, gelatinous, mucilaginous, felt-like to almost leathery mats (rarely as solitary filaments)
- Trichomes straight, curved, waved or irregularly coiled
- Facultative sheath production; sheaths firm or watery, not lamellate
- Cells more or less isodiametric, or shorter or longer than wide; cells growing to more or less the original size prior to next division
- Cells with various degree of constriction at cross walls; aerotopes absent
- End cells broadly rounded or attenuated; with or without calyptra
- Capable of oscillatory and gliding movement
- Reproduction by disintegration of trichomes into motile hormogonia via necridial cells
- Polyphyletic genus currently undergoing major revision; species transferred to *Kamptonema*, *Microcoleus*, *Oxyliyonema*, *Oxynema*, *Phormidesmis* and *Wilmottia*
- Species primarily separated based on trichome and end cell morphology, trichome width, cell length, degree of cross wall constriction, presence of granules at cross walls and habitat.

# *Phormidium*

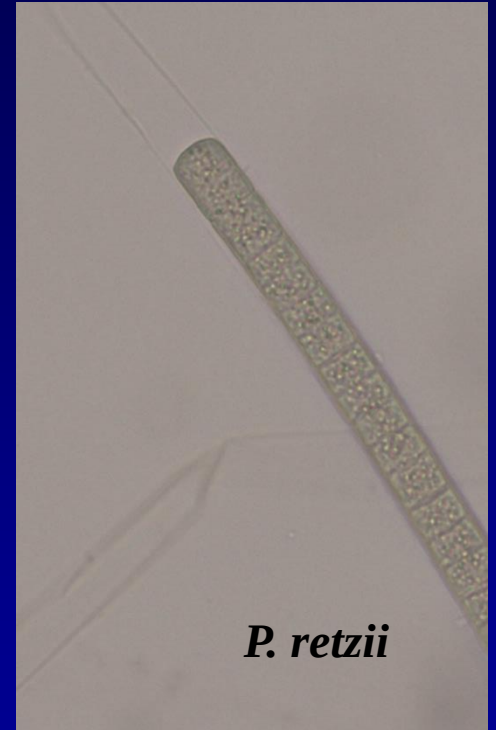
*P. chalybeum*



*P. nigrum*



*P. retzii*



# *Microcoleus*

- Filaments solitary or aggregated in irregular fascicles and forming mats
  - Trichomes uniseriate, isopolar, more or less cylindrical without sheaths or with simple sheaths;
  - Sometimes multiple trichomes in a common sheath, fasciculated with attenuate or cylindrical ends
  - Cells more or less isodiametric, or slightly shorter or longer than wide
  - Cells with various degree of constriction at cross walls; aerotopes absent
  - Apical cells attenuated and rounded; often with distinct calyptra
  - Some capable of oscillatory and gliding movement
  - Reproduction by fragmentation of trichomes via necridic cells
- Species primarily separated based on thallus morphology, trichome width, cell length, degree of cross wall constriction, apical cell morphology, presence of granules at cross walls, color and habitat.

*M. favosus*

10 µm

*M. autumnalis*

10 µm

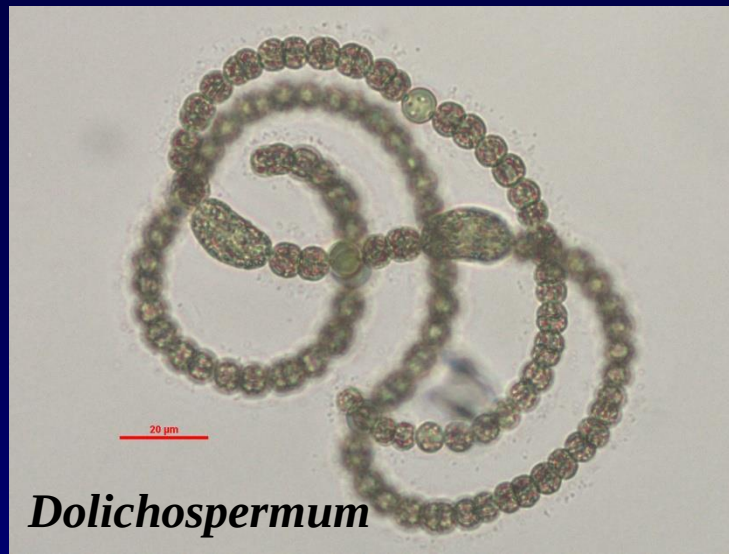
*M. lacustris*

10 µm

# **Order: Nostocales Part I**

# Order: Nostocales Part I

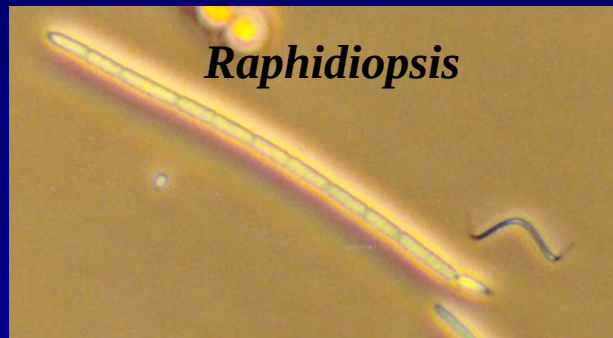
- Filamentous cyanophytes with true trichomes
- Trichomes isopolar or heteropolar, unbranched or with false branching; true branching lacking
- Heterocytes present (facultative in a few species)
- Akinete production facultative
- Cells divide perpendicular to the trichome axis, in one direction in succeeding generations
- Reproduction mainly by hormogonia or hormocytes
- Important criteria used to distinguish genera include heterocyte formation, cell morphology, trichome structure and akinete formation
- Genera with known potentially toxigenic species include *Anabaena*, *Anabaenopsis*, *Aphanizomenon*, *Chrysosporum*, *Cuspidothrix*, *Cylindrospermum*, *Dolichospermum*, *Gloeotrichia*, *Hassalia*, *Iningainema*, *Hormothamnion*, *Nodularia*, *Nostoc*, *Raphidiopsis*, *Rivularia*, *Scytonema*, *Scytonematopsis*, *Sphaerospermopsis*, *Tolypothrix* and *Trichormus*.



*Dolichospermum*



*Aphanizomenon*



*Raphidiopsis*



*Nostoc*



*Tolypothrix*



*Nodularia*

# *Anabaena/Dolichospermum*

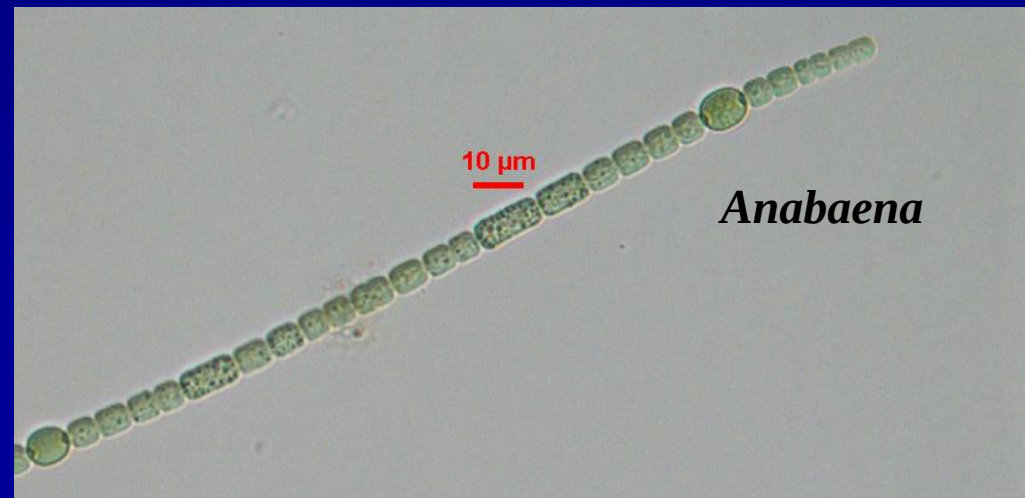
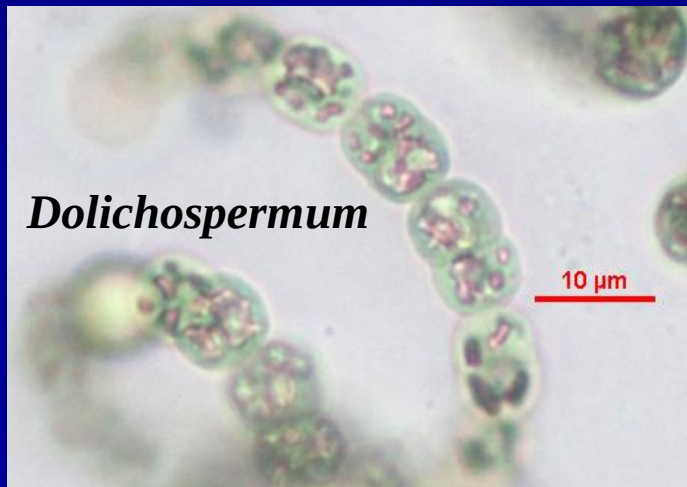
- *Anabaena* with and without aerotopes clearly genetically separated
- *Anabaena oscillarioides*, a benthic species lacking aerotopes, is the type species of *Anabaena*
- New genus needed for “*Anabaena*” with aerotopes:  
*Dolichospermum*
- Type species for *Dolichospermum* is *Dolichospermum flos-aquae*



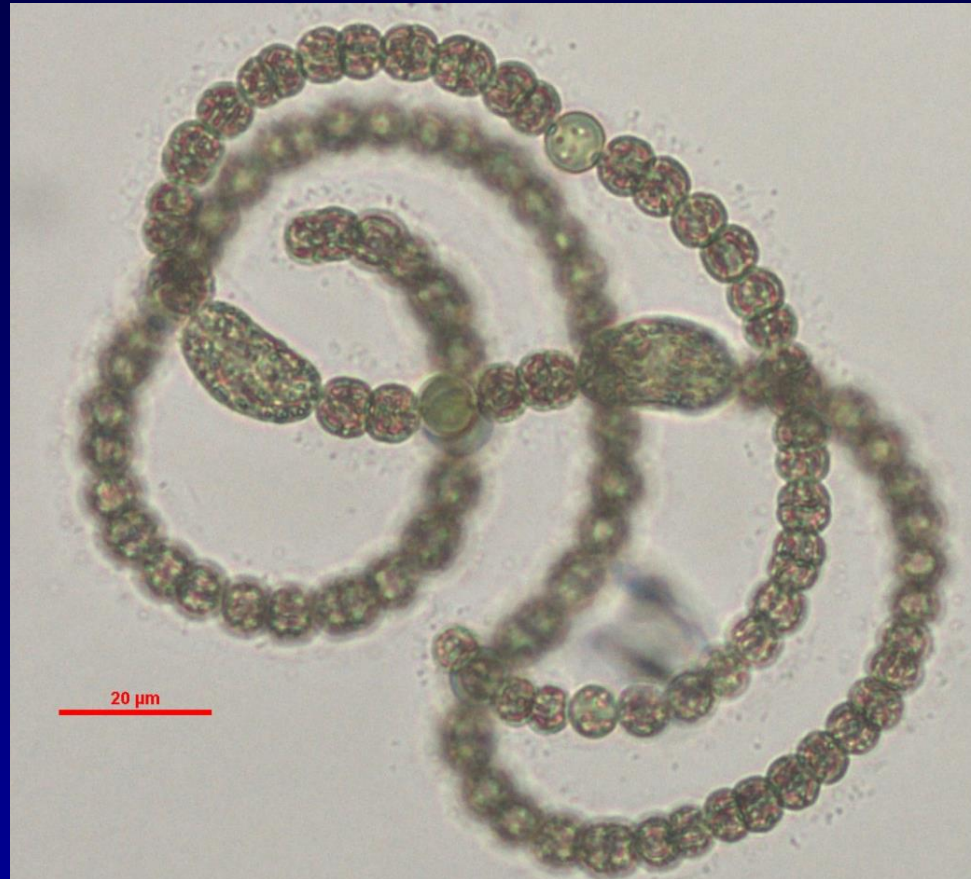
*D. flos-aquae*

# *Anabaena/Dolichospermum*

- Trichomes straight, flexuous or regularly or irregularly coiled
- Trichomes solitary or gregarious; forming clumps of entangled trichomes or bundles of parallel trichomes; trichomes with or without obvious sheaths
- Cells mostly spherical, barrel-shaped or compressed globose; in some species more cylindrical or ellipsoid
- End cells mostly broadly rounded; attenuated or sharply pointed in a few species
- Cells constricted at the cross-walls; aerotopes absent or present
- Heterocytes intercalary; spherical, ovate or cylindrical
- Akinetes solitary, paired or in chains; spherical, ovate, ellipsoid, cylindrical, or reniform; positioned adjacent to, near or remote from heterocytes
- *Anabaena* species with aerotopes have been transferred to *Dolichospermum*
- Species primarily separated based on akinete shape, location and size, trichome morphology, trichome width, size and shape of vegetative cells, end cell shape and habitat.



# *Dolichospermum flos-aquae* (*Anabaena flos-aquae*)



- Spherical cells; 2.5-8.3 µm
- Mostly irregular coils
- Akinetes mostly kidney shaped, distant from heterocytes; 5-14 µm wide x 12-35 µm long

# *Dolichospermum crassum* (*Anabaena crassa*)



**Cells spherical to barrel shaped; 10-15 μm wide**

**Regular coils**

**Akinetes oval to cylindrical; remote from heterocytes**

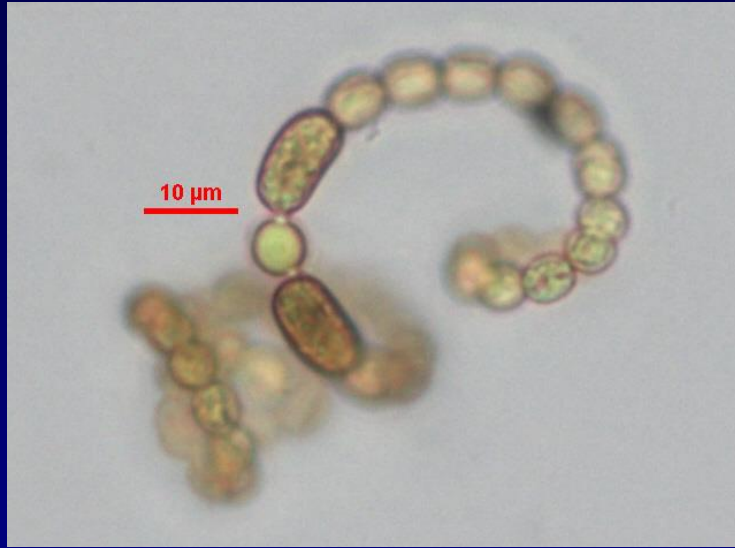
**Akinetes 13-15 μm wide x 15-42 μm long**

# *Dolichospermum circinale* (*Anabaena circinalis*)

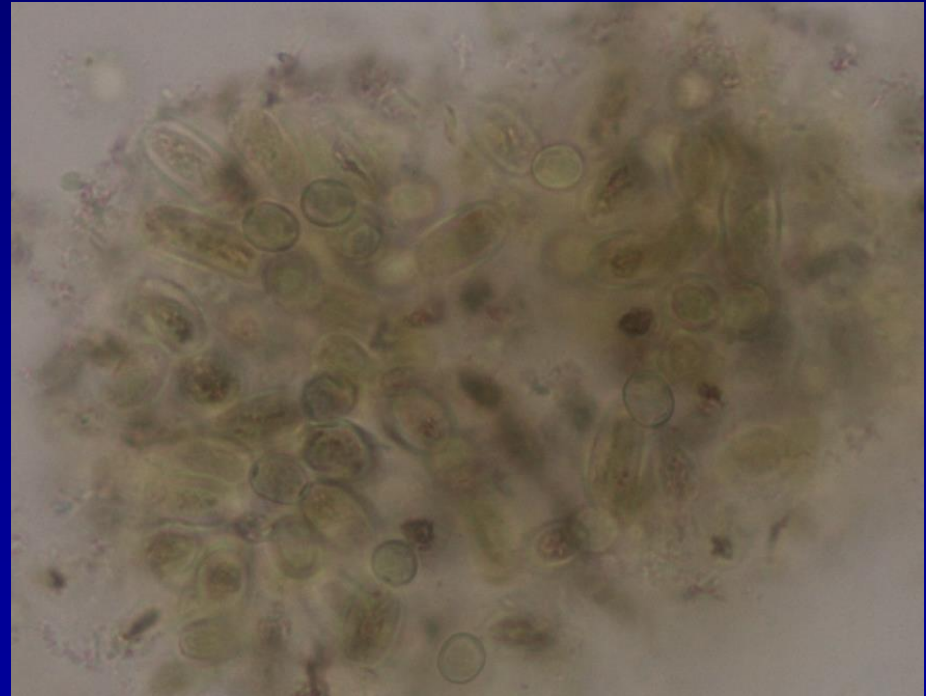


- Spherical cells; 7-11 µm
- Mostly regular coils
- Akinetes oval, distant from heterocytes
- Akinetes 9-21 µm wide x 12.5-42 µm long

# *Dolichospermum lemmermannii* (*Anabaena lemmermannii*)



- Cells barrel-shaped; 2.5-6.9 µm wide
- Irregular coils forming clumps
- Akinetes kidney shaped, at both sides of heterocytes; 6.3-11 µm wide x 13-25.6 µm long



# *Dolichospermum mendotae* (*Anabaena mendotae*)



Cells cylindrical; 2.5-5 µm wide

Irregularly coiled, forming clumps

Akinetes cylindrical; 4.5-7.8 µm wide x 13.5-30 µm long,  
remote from heterocytes

Similar to *Dolichospermum sigmoideum*

# *Dolichospermum planctonicum* (*Anabaena planctonica*)



- Cells shortly barrel-shaped; 7.7-15 μm wide
- Trichomes straight
- Akinetes oval to wide cylindrical; distant from heterocytes
- Akinetes 9-21 μm wide and 15-37 μm long

# *Aphanizomenon*

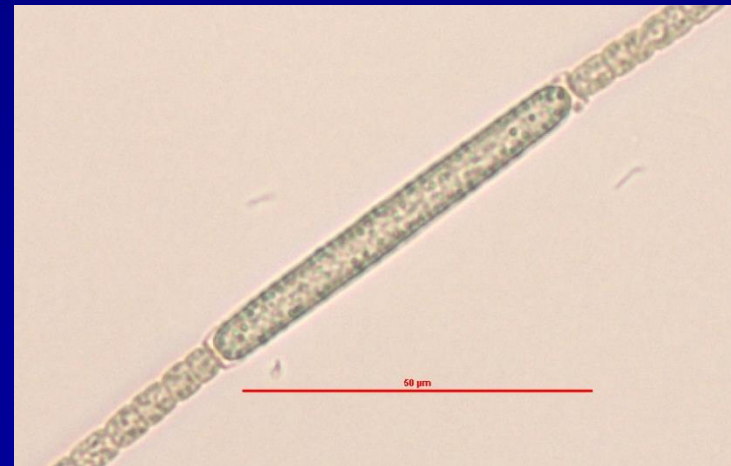
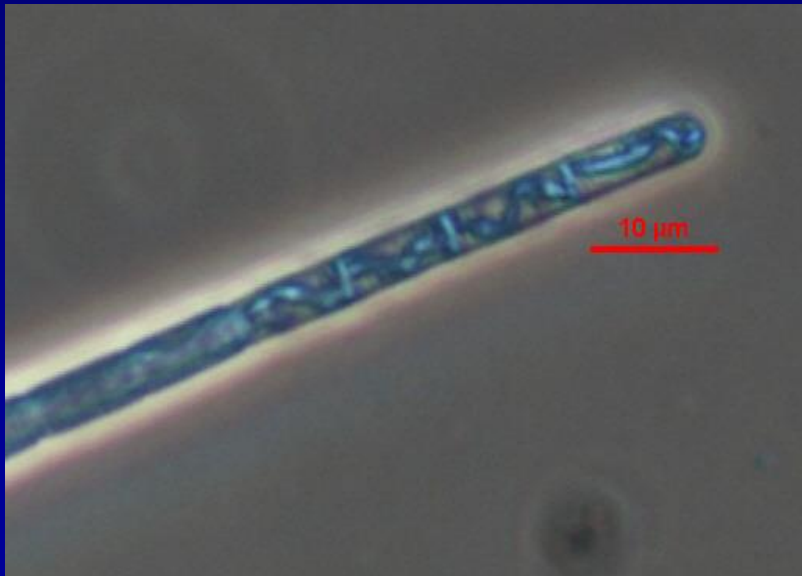
- Trichomes straight, bent or curved
- Trichomes solitary or united in parallel bundles (fascicles); without obvious sheaths
- Cells mostly cylindrical, occasionally barrel-shaped; constricted at cross walls
- End cells generally elongate, rounded or with slightly swollen tips
- Aerotopes commonly present
- Heterocytes intercalary, mostly 1-3 per trichome; cylindrical, ellipsoid or spherical
- Akinetes solitary, paired or in chains; spherical, ovate, ellipsoid or cylindrical; positioned adjacent to, near or remote from heterocytes
- Species primarily separated based on akinete shape, location and size, trichome morphology, trichome width, size and shape of vegetative cells, end cell morphology and habitat.





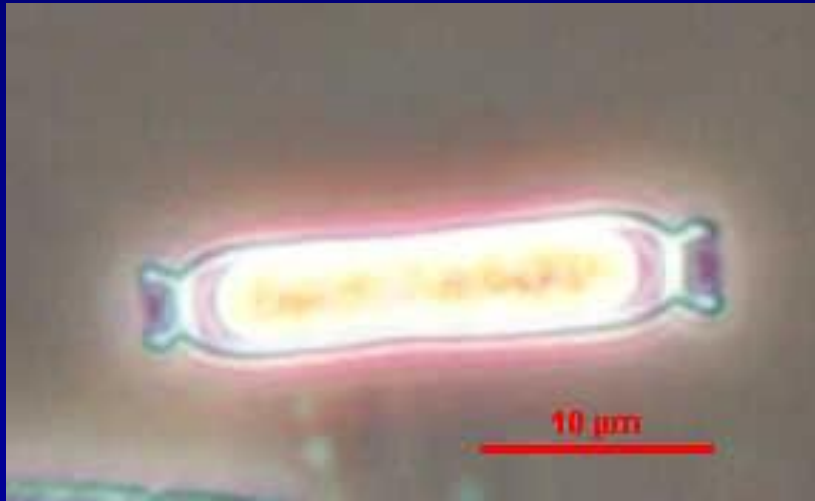
## *Aphanizomenon flos-aquae*

- Trichomes 4.5-8  $\mu\text{m}$  wide
- Forms fascicles
- Cells cylindrical
- End cells elongated and hyaline
- Akinetes cylindrical 6-10.8  $\mu\text{m}$  wide x 40-220  $\mu\text{m}$  long
- Akinetes distant from heterocytes



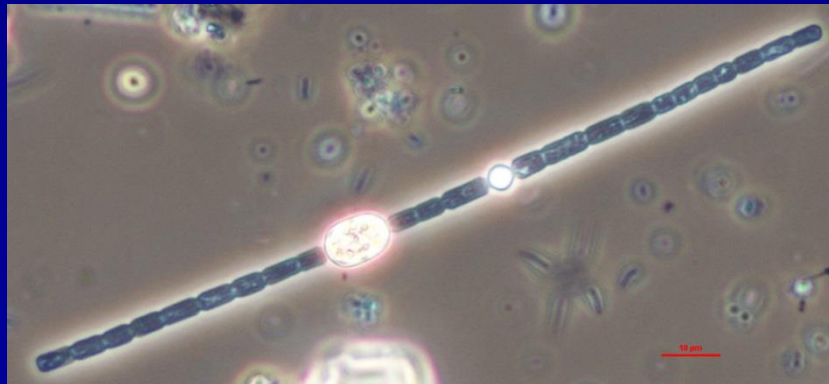
## *Aphanizomenon gracile*

- Trichomes 2.5-5.5  $\mu\text{m}$  wide
- Filaments solitary
- Cells quadrate to rectangular
- End cells often club-shaped
- Akinetes cylindrical, often with collar-like extensions; sometimes pinched in middle
- Akinetes 2.9-6.4  $\mu\text{m}$  wide x 12.5-50  $\mu\text{m}$  long
- Akinetes mostly distant from heterocytes



# Chrysosporum

- Trichomes free-floating, planktic, solitary
  - Trichomes straight or slightly curved and flexuous
  - Slightly or distinctly constricted at cross-walls; mostly without sheaths
  - Cells barrel-shaped or +isodiametric
  - Well developed trichomes always  $\pm$  narrowed towards ends
  - Apical cells usually slightly elongated, conical rounded
  - Aerotopes obligate or facultative
  - Heterocytes intercalary, usually solitary, +spherical, oval or barrel-shaped
  - Akinetes solitary or in pairs (rarely more); cylindrical or oval (rarely almost spherical)
  - Akinetes located adjacent to or remote from heterocytes
  - Epispore usually brownish or yellow-brown
  - Previously described as species of *Anabaena* and *Aphanizomenon*
- Species primarily separated based on akinete location, size and shape of vegetative cells, trichome width, akinete size and shape, end cell morphology and habitat.



*C. ovalisporum*

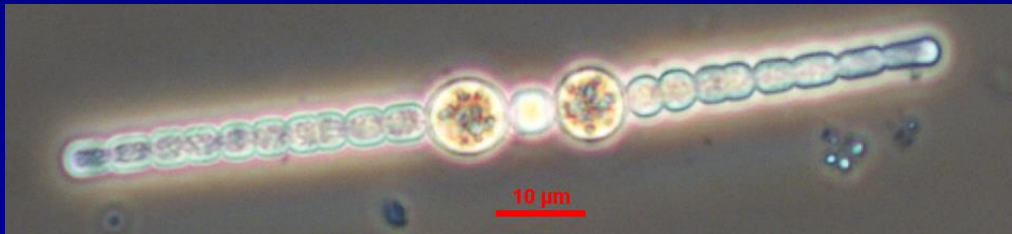
# *Chrysoosporum ovalisporum*



- Trichomes 2-5 µm wide
- Trichomes solitary
- Cells cylindrical to barrel-shaped
- Akinetes oval; mostly distant from heterocytes
- Akinetes 5-14 µm wide x 7-20 µm long

# *Sphaerospermopsis*

- Trichomes free-floating, planktic, solitary; aerotopes present
  - Trichomes straight or coiled; with or without mucilaginous sheaths
  - Cells spherical, barrel-shaped or cylindrical, more or less constricted at cross walls
  - Well developed end cells usually slightly elongated and tapered towards ends
  - Heterocytes intercalary, solitary,  $\pm$ spherical
  - Akinetes intercalary; always spherical or widely oval; developing on both sides of the heterocyte
  - Previously described as species of *Anabaena*
- 
- Species primarily separated based on trichome morphology, akinete size, trichome width, size and shape of vegetative cells, end cell morphology and habitat.



*S. aphanizomenoides*



*S. torques-reginae*

# *Cuspidothrix*

- Trichomes free-floating, planktic, solitary
  - Trichomes straight or curved; less frequently irregularly coiled
  - Constricted or not constricted at cross-walls; mostly without mucilage
  - Cells cylindrical, or with slightly convex sides
  - Well developed trichomes distinctly narrowed and always pointed (sharply or bluntly) at the ends
  - Apical cells elongated, mainly hyaline, attenuated and pointed
  - Aerotopes facultative
  - Heterocytes intercalary, solitary, cylindrical or ellipsoidal
  - Akinetes solitary or in pairs;  $\pm$  cylindrical (almost spherical in one species)
  - Akinetes located adjacent to or remote from heterocytes
  - Previously described as species of *Aphanizomenon*
- Species primarily separated based on trichome morphology, akinete size and shape, trichome width, size and shape of vegetative cells, end cell morphology and habitat.



*C. issatschenkoi*

# *Cuspidothrix issatschenkoi*

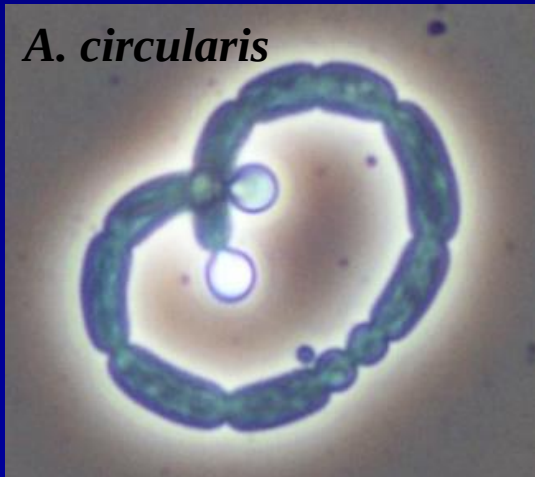


- Trichomes 2.5-5  $\mu\text{m}$  wide; solitary
- Cells cylindrical
- Cells step-wise attenuated at one or both ends; end cell long
- Akinetes cylindrical
- Akinetes 3-5  $\mu\text{m}$  wide x 7.5-25  $\mu\text{m}$  long

# *Anabaenopsis*

- Trichomes spirally coiled, curved or straight; aerotopes present or absent
  - Trichomes solitary, with or without evident mucilaginous envelopes
  - Cells compressed spherical, barrel-shaped or cylindrical; with or without constrictions at the cross walls
  - Intercalary development of heterocyte pairs; trichome fragmentation between heterocytes results in their terminal position
  - Heterocytes spherical, oval or ellipsoid
  - Akinetes solitary, paired or in short chains; ovate, ellipsoid, cylindrical or reniform; adjacent to or remote (more common) from heterocytes
  - Recently described genus *Cronbergia* is morphologically similar to *Anabaenopsis*
- Species primarily separated based on akinete shape, location and size, trichome morphology, trichome width, size and shape of vegetative cells, heterocyte shape and habitat.

*A. circularis*



*A. elenkinii*



*A. cunningtonii*



*Cronbergia* sp.

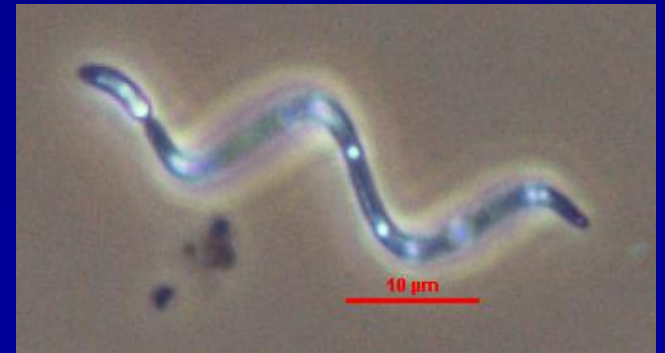
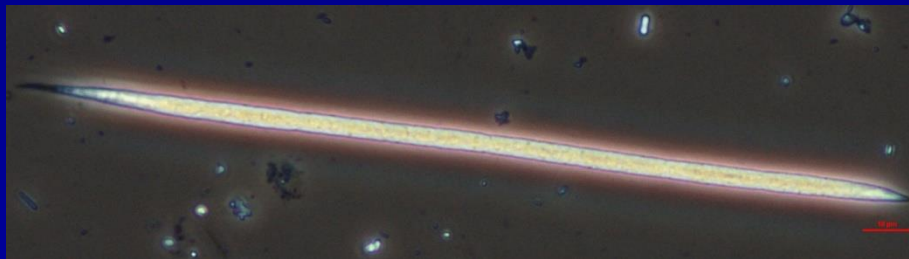
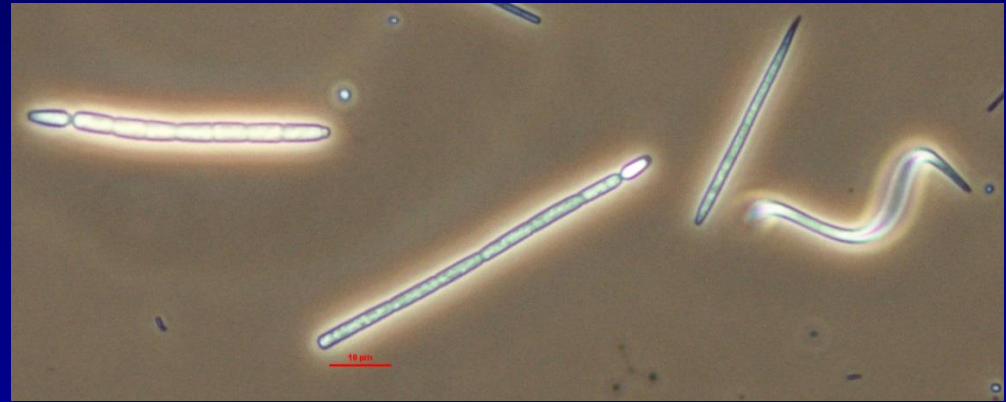
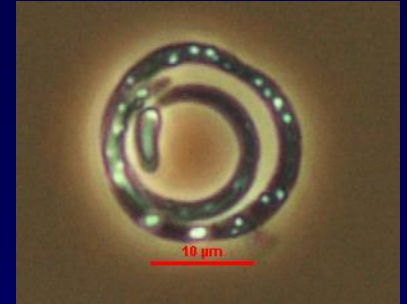
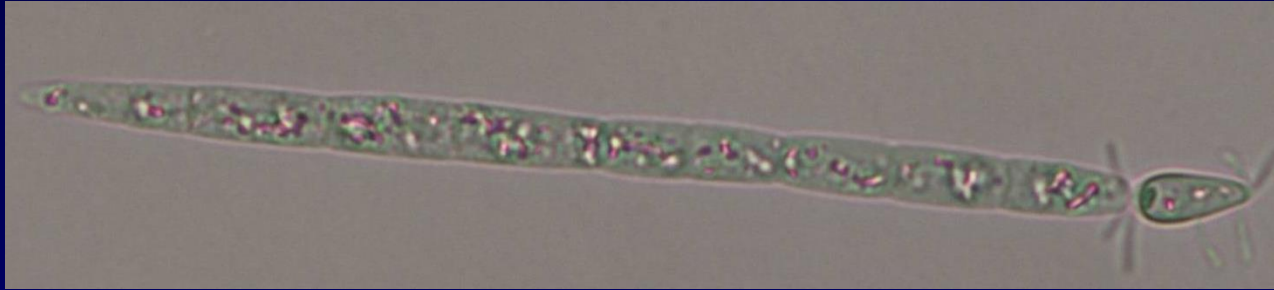


# *Raphidiopsis*

- Trichomes straight, curved, undulate or spirally coiled
- Trichomes solitary; fine colorless sheaths occur sporadically
- Cells cylindrical, constrictions at cross walls absent (common) or present
- End cells (when present) attenuated, tips pointed or broadly rounded
- Aerotopes present or absent
- Heterocytes, when present, develop in terminal position, at one or both ends of trichomes, mostly tear drop shaped, with sharply pointed or rounded tips; often curved on coiled trichomes
- Akinetes solitary, in pairs or short chains; mostly 1-3 cells from heterocyte, occasionally adjacent; cylindrical (curved on coiled trichomes)
- *Cylindrospermopsis* recently transferred to *Raphidiopsis*
- Reproduction via trichome fragmentation and akinete germination
- Species primarily separated based on trichome width, akinete shape, trichome morphology, heterocyte morphology and habitat.



# Morphological Variation in *R. raciborskii*



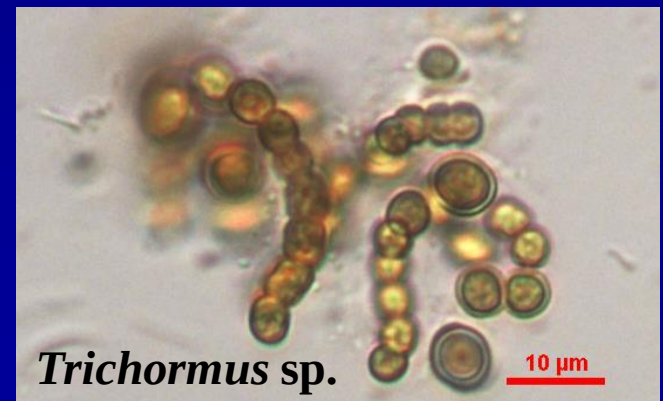
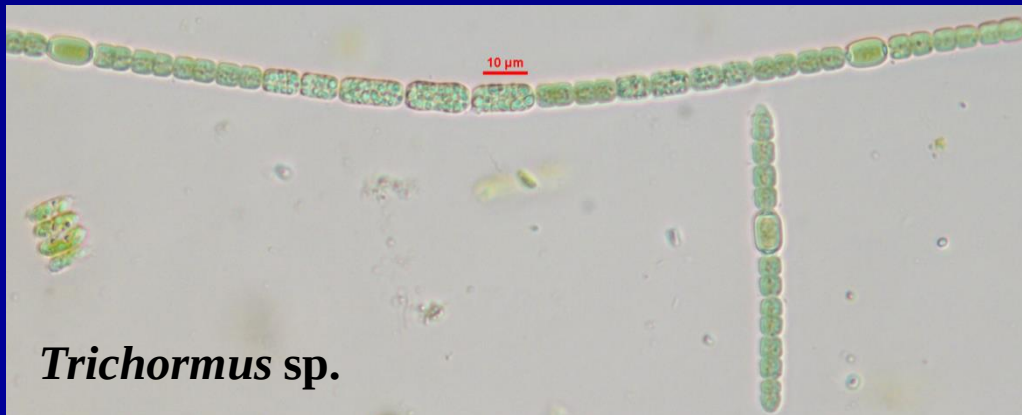
# *Nostoc*

- Mainly benthic, occurring in many epiphytic, epipelic and epilithic habitats
- Thalli are microscopic or macroscopic, spherical or irregular gelatinous mats
- Filaments are typically coiled, forming irregular, loose or dense clusters within the often firm, wide colonial mucilage
- Cells are barrel-shaped or spherical
- Heterocytes are barrel-shaped or spherical, solitary, intercalary or terminal
- Akinetes are ellipsoidal, arising in rows between heterocytes
- Reproduction is by motile hormogonia, by akinete germination or filament disintegration
- *Nostoc* has been shown to be polyphyletic; new genera established include *Aliinostoc*, *Desikacharya*, *Desmonostoc*, *Halotia* and *Mojavia*
- Species are primarily separated on the basis of habitat, nature of colonial mucilage, cell size and shape, akinete size and shape, heterocyte size and shape and trichome density.



# *Trichormus*

- Majority of species colonize soils or mud; some are periphytic or endophytic
- Thalli occur as macroscopic mats or in clusters
- Trichomes straight, bent or coiled; constricted at the cross-walls
- Firm sheaths absent, but slimy envelopes are sometimes present
- Cells are barrel-shaped to cylindrical; aerotopes absent
- End cells often conical
- Heterocytes are spherical to ellipsoidal, intercalary in metameric configuration
- Akinetes are oval to barrel-shaped, rarely almost cylindrical and develop in rows apoheterocytically between two heterocytes; one vegetative cell becomes one akinete
- Reproduction occurs via hormogonia and by akinete germination
- Species are primarily separated based on shape and size of akinetes, heterocytes and vegetative cells, trichome morphology, thallus structure and habitat.



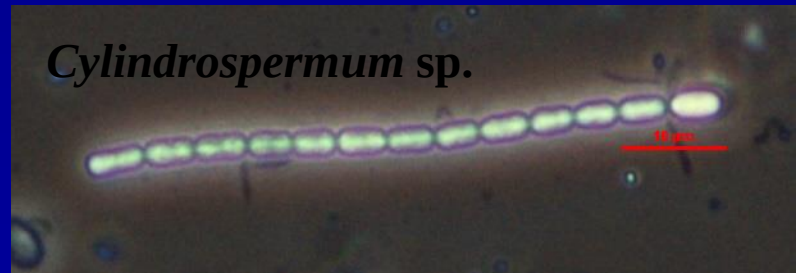
# *Cylindrospermum*

- Most species are benthic, epiphytic or epilithic
  - Thallus composed of fine of compact mucilaginous mats
  - Filaments are slightly curved or irregularly coiled
  - Trichomes are without a firm sheath, but have a fine, colorless, homogeneous and diffuse mucilaginous envelope
  - Trichomes are symmetrical, usually constricted at the cross-walls
  - Cells are cylindrical,  $\pm$  isodiametric; aerotopes lacking
  - Heterocytes are terminal (at one or both ends) and are ellipsoidal, ovoid or conical
  - Akinetes are adjacent to heterocytes and are ellipsoidal, rarely spherical; solitary or in rows (up to seven); often with sculptured episporium
  - Reproduction occurs via akinete germination and fragmentation of trichomes into hormogonia
- 
- Species are primarily separated based on akinete distribution (solitary or rows), size and shape of akinetes, akinete episporium (smooth, sculptured), trichome diameter and habitat.

*C. licheniforme*

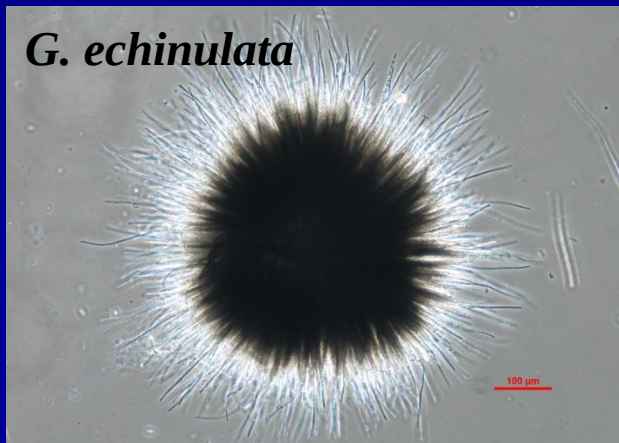


*Cylindrospermum* sp.



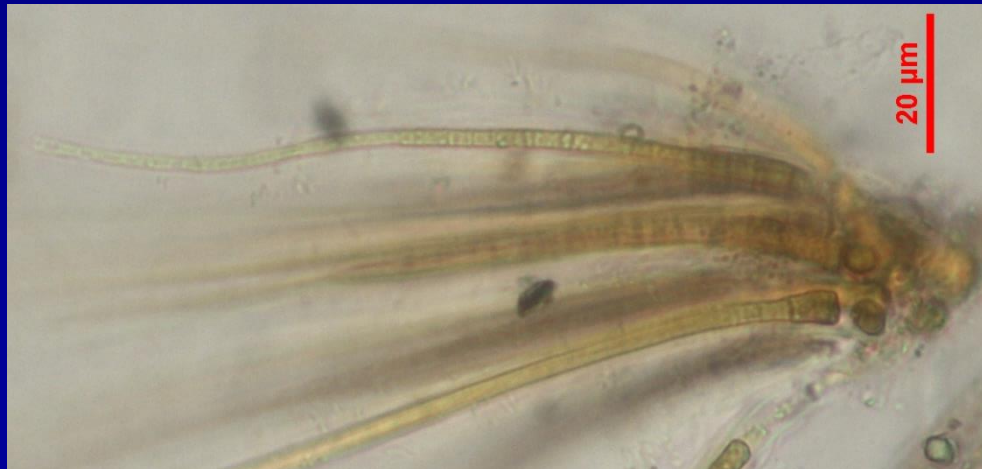
# *Gloeotrichia*

- Macroscopic, hemispherical or globose colonies of radiating trichomes; colonies attached or free-floating
- Trichomes heteropolar, sharply attenuated at one end
- Colonial mucilage soft or firm
- Cells spherical, barrel-shaped or cylindrical; cell shape often changes along length of trichome; aerotopes present or absent
- Heterocytes globose to oval; terminal at one end of trichome (rarely also intercalary; basal position in colony)
- Akinetes cylindrical, positioned adjacent to heterocyte; usually solitary
- Reproduction via trichome disintegration, hormogonia and akinete germination
- *Gloeotrichia* and *Rivularia* are very similar in appearance
- Species primarily separated based on habitat, colony shape, cell size and shape, akinete size and presence/absence of aerotopes.



# *Calothrix*

- Thallus consists of bristle-like groups or thin mats of filaments; primarily epiphytic and epilithic
  - Filaments are heteropolar, with wider basal part and narrow (hair-like) apical end
  - Firm sheaths always present, sometimes lamellate or enlarged at the end
  - False-branching occurs occasionally
  - Cell shape varies on location in trichome; barrel-shaped, cylindrical or hair-like
  - Aerotopes absent (but may be present in hormogonia)
  - Heterocytes ellipsoidal, spherical to hemispherical; mainly basal but sometimes intercalary (especially near false-branches)
  - Akinetes (when present) ellipsoidal to cylindrical, located above basal heterocyte
  - Calothrix* is polyphyletic and currently undergoing revision (i.e. *Macrochaete*)
- 
- Species primarily separated based on trichome morphology, presence of akinetes, akinete size, presence of intercalary heterocytes, trichome width and habitat.



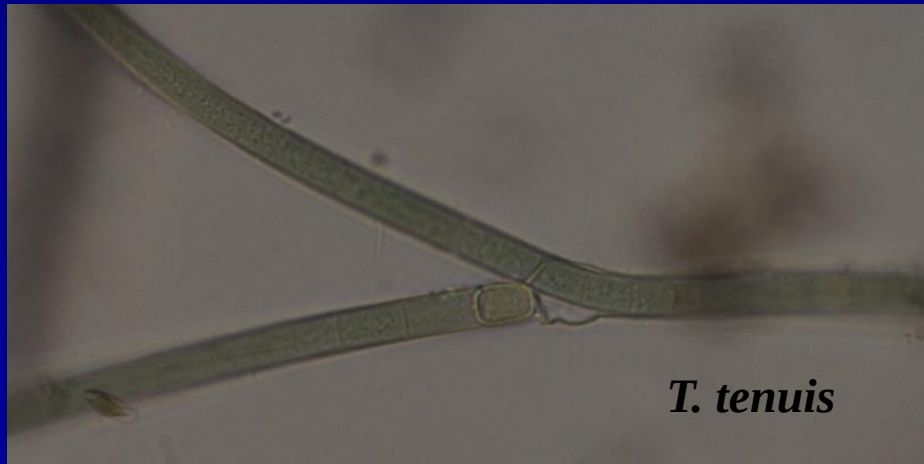
# *Scytonema*

- Mainly aerial or subaerial, some species found in periphyton/metaphyton
  - Filaments forming wooly mats or irregular clusters
  - False branching is simple, usually two branches (rarely in one branch); branching often occurs after formation of necridic cells
  - Trichomes are isopolar, constricted or not constricted at cross-walls
  - Sheaths are firm sometimes lamellated, sometimes wide, often yellow-brown in color
  - Cells are cylindrical to barrel-shaped, apical cells are rounded
  - Heterocytes are solitary and intercalary
  - Akinetes have been occasionally reported
  - Reproduction occurs by hormogonia
- Species are primarily separated on the basis of sheath character, filament width, cell size and shape, heterocyte shape and habitat.



# *Tolypothrix*

- Thalli form woolly mats, tufts or caespitose colonies; benthic, epiphytic, epilithic or subaerial
- False branching begins next to the heterocyte, diverging singly or doubly
- Trichomes are uniseriate, with one or more heterocytes at the base; constricted or unconstricted at cross-walls
- Cells are long cylindrical to short barrel-shaped
- Heterocytes are spherical, cylindrical or discoid; intercalary, singly or in pairs
- Akinetes rarely seen
- Reproduction mainly by hormogonia
- Species are primarily separated on the basis of sheath character, trichome width, cell size and shape and habitat.



# *Nodularia*

- Trichomes solitary or forming loose gelatinous expansions or tufts
- Trichomes straight, curved or rarely coiled; surrounded by a gelatinous sheath
- Cells discoid or compressed spherical; constricted at the cross walls
- Trichomes not attenuated, end cells identical to intercalary cells
- Aerotopes present or absent
- Heterocytes intercalary; discoid or compressed spherical, generally slightly broader than vegetative cells
- Akinetes globose, discoid or compressed spherical; solitary or often in chains
- More common in brackish waters
- Reproduction via hormogonia, trichome disintegration and akinetes
- Species primarily separated based on trichome width, cell length and shape, size and shape of akinetes and habitat.



## **Order: Nostocales Part II**

## Order Nostocales Part II

- Formerly Order Stigonematales
- Filamentous, true branching always present (at least in part of a life cycle)
- Facultative false branching; thallus heteropolar or isopolar
- Heterocytes mostly present, akinetes only rarely
- Cells divide perpendicularly to the trichome axis and/or irregularly in more directions
- Cells arranged in uniseriate, biseriate or multiseriate rows connected by transverse and longitudinal cell walls
- Reproduction by hormogonia, hormocytes, akinetes, nanocytes, planocytes and monocytes
- Important criteria used to distinguish genera include pattern of branching, presence/absence of multiseriate branches, false branching, reproductive structures, heterocyte formation and location, ability to form akinetes and presence of terminal hairs.
- Genera with known potentially toxigenic species include *Aetokthonous*, *Fischerella*, *Hapalosiphon* and *Umezakia*.

*Stigonema*



*Nostochopsis*



*Aetokthonous hydrillicola*

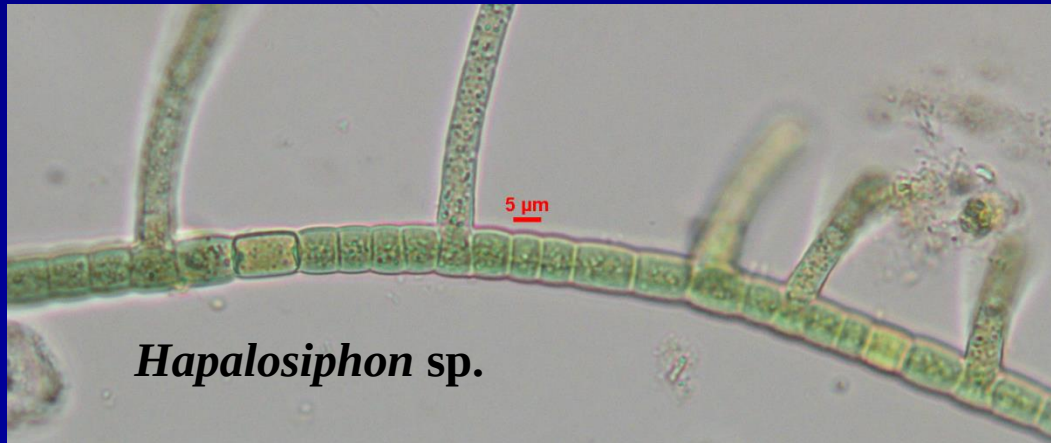


*Hapalosiphon*



# *Hapalosiphon*

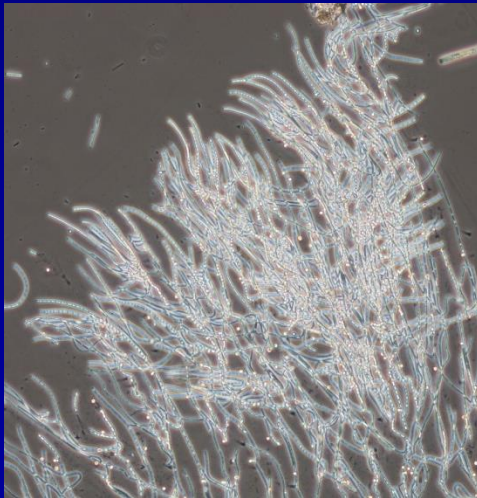
- Most species occur in littoral metaphyton, usually with macrophytes
- Thallus is filamentous
- Filaments are irregularly curved with uniseriate trichomes, only rarely with some longitudinally dividing cells
- True branching is usually lateral (T—type) with no morphological differentiation in the main and lateral trichomes
- Sheaths are colorless, thin, firm (rarely indistinctly lamellated)
- Heterocytes are intercalary
- Cells divide horizontally without meristematic zones
- Reproduction occurs via hormogonia separated by necridic cells, usually at ends of trichomes
- Species are primarily separated on the basis of pattern of branching, trichome width, heterocyte shape and habitat.



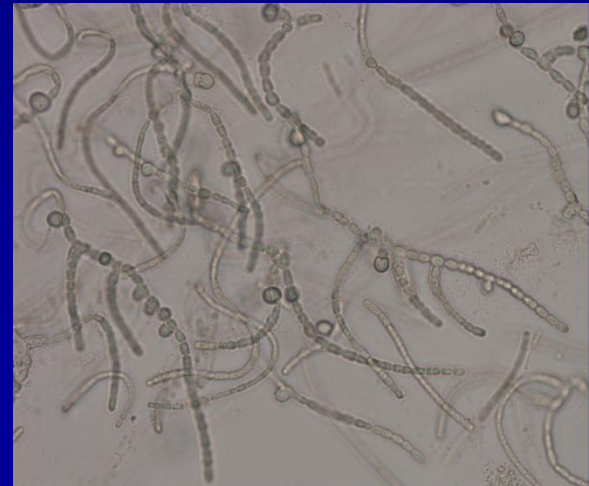
*Hapalosiphon* sp.

# *Nostochopsis*

- Thallus is gelatinous; irregularly spherical or lobed
  - Attached to submerged substrates (wood, stones, moss) in creeks and streams
  - Filamentous are relatively radially arranged in thallus
  - Filaments are irregularly curved or coiled with uniseriate trichomes
  - Cells are isodiametric, barrel-shaped or elongated ellipsoid
  - True branching is lateral (T or V type); long , cylindrical multicelled branches with rounded apical cells or very short branches terminated by apical heterocytes
  - Sheaths are fine, gelatinous and diffuse; colorless
  - Heterocytes always present; intercalary, lateral or terminal; akinetes unknown
  - Cells divide horizontally, primarily in apical regions of trichomes
  - Reproduction occurs via hormogonia with short barrel-shaped cells
- Only one species of freshwater *Nostochopsis* is known (*N. lobata*)

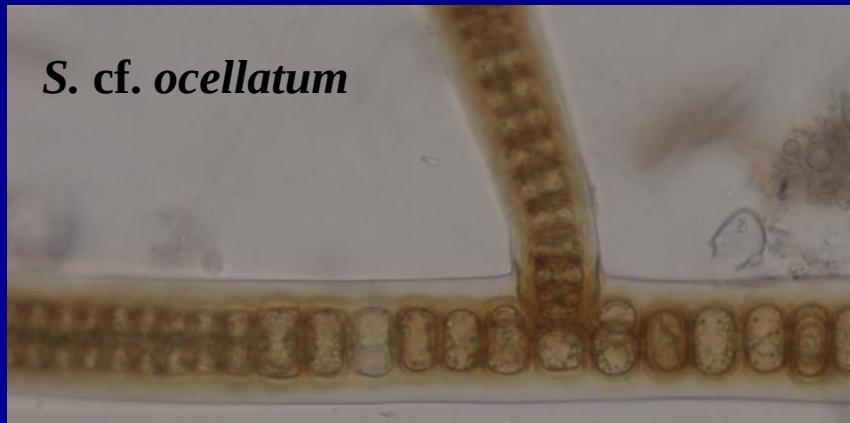


*N. lobata*



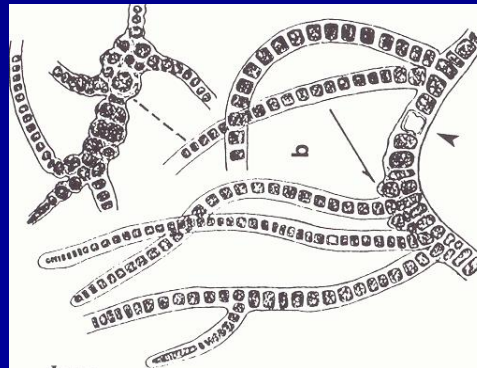
# *Stigonema*

- Thallus is filamentous, woolly or crusty; usually attached to a substrate
- Thalli composed of free, coiled, true branched filaments
- Trichomes may be uniseriate or multiseriate
- Branches are thick, irregularly lateral, narrowed towards ends, but with apical cells often larger than other cells
- Sheaths are thin or thick; often lamellate and colored with age
- Cells barrel-shaped or irregularly rounded, usually connected by one pore
- Heterocytes are intercalary, solitary, occasionally lateral; akinetes are unknown
- Cell division occurs in all planes
- Reproduction occurs via hormogonia released from trichome ends; hormogonia sometimes with aerotopes
- Species primarily separated based on numbers of cell rows, filament width, sheath characteristics, hormogonia characteristics and habitat.



# *Fischerella*

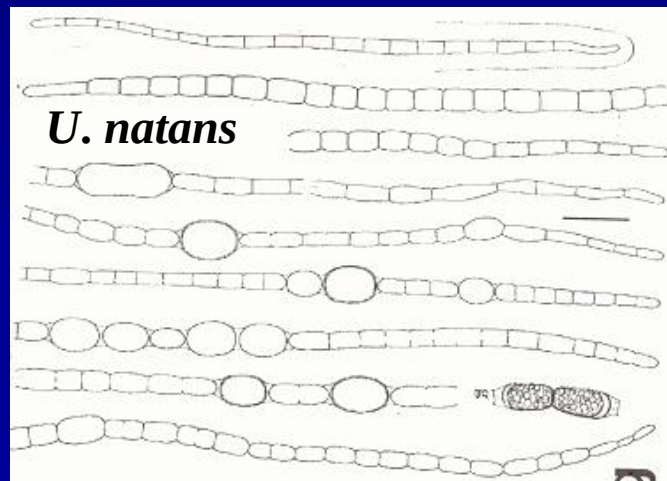
- Mainly subaerial, growing on wet soils and rocks, some submerged; form felt-like, rarely compact mats
- Thallus composed of morphologically diverse uniseriate or multiseriate, usually creeping filaments and more or less erect uniseriate branches
- Trichomes enveloped by thick, colored sheaths
- T-type true branching
- Cells generally cylindrical, elongated
- Heterocytes are intercalary, subspherical or cylindrical
- Akinetes known only in a few species
- Cell division occurs mainly by horizontal perpendicular fission
- Reproduction occurs by hormogonia separating from ends of branches
- Species are primarily separated on the basis of whether basal filament is mainly uniseriate or multiseriate, sheath character, cell size and shape, habitat and akinete production.



*F. ambigua*

# Umezakia

- To date only recorded in Japan (discovered in Lake Mikata)
  - Filaments consist of a single row of cells, sometimes with true branching
  - Branches are initiated from longitudinal division of the parental cells
  - Trichomes are attenuated at ends, slightly constricted at the cross-walls
  - Cells are cylindrical to barrel-shaped
  - Sheaths are hyaline and watery
  - Heterocytes and akinetes are intercalary
  - Heterocytes are spherical to elongate
  - Akinetes are ellipsoidal and appear singly or in series
- 
- Umezakia natans* is the only species reported to date



# Taste and Odor Producing Cyanobacteria

## Geosmin

*Aphanizomenon*  
*Dolichospermum*  
*Geitlerinema*  
*Leibleinia*  
*Microcoleus*  
*Phormidium*  
*Planktothrix*  
*Pseudanabaena*  
*Tychonema*

## MIB Producers

*Jaaginema*  
*Lyngbya*  
*Microcoleus*  
*Oscillatoria*  
*Phormidium*  
*Planktothrix*  
*Pseudanabaena*  
*Tychonema*

## Sulfur Compounds

*Microcystis*  
*Synechococcus*

# Anatoxin Producers

*Anabaena lapponica*

*Aphanizomenon flos-aquae* (?)

*Arthrospira fusiformis*

*Cuspidothrix issatschenkoi*

*Dolichospermum circinale*

*Dolichospermum crassum*

*Dolichospermum flos-aquae*

*Dolichospermum lemmermannii*

*Dolichospermum macrosporum*

*Dolichospermum mendotae*

*Dolichospermum planctonicum*

*Dolichospermum spiroides*

*Microcoleus amoenus*

*Microcoleus autumnalis*

*Microcoleus favosus*

*Phormidium formosum*

*Planktothrix agardhii*

*Planktothrix isothrix*

*Planktothrix rubescens*

*Pseudanabaena catenata*

*Raphidiopsis mediterranea*

*Raphidiopsis raciborskii*

*Sphaerospermopsis oumiana*

*Synechocystis* spp.

*Trichormus variabilis*

*Tychonema bourrellyi*

# Microcystin Producers

*Anabaena subcylindrica*

*Anabaenopsis arnoldii*

*Anabaenopsis milleri*

*Aphanocapsa cumulus*

*Arthrospira fusiformis*

*Cyanobium bacillare*

*Dolichospermum circinale*

*Dolichospermum flos-aquae*

*Dolichospermum lemmermannii*

*Dolichospermum planctonicum* (?)

*Geitlerinema splendidum*

*Gloeotrichia echinulata*

*Hapalosiphon hibernicus*

*Leptolyngbya boryana*

*Limnothrix redekei*

*Microcystis aeruginosa*

*Microcystis botrys*

*Microcystis ichthyoblabe*

*Microcystis panniformis*

*Microcystis smithii*

*Microcystis viridis*

*Microcystis wesenbergii*

*Nostoc linkia*

*Nostoc muscorum*

*Nostoc paludosum*

*Nostoc spongiforme*

*Nostoc zetterstedtii*

*Oscillatoria limosa*

*Oscillatoria perornata*

*Oscillatoria tenuis*

*Phormidium corium*

*Phormidium willei*

*Planktothrix agardhii*

*Planktothrix isoethrix*

*Planktothrix rubescens*

*Pseudanabaena galeata*

*Pseudanabaena mucicola*

*Pseudanabaena limnetica*

*Radiocystis fernandoi*

*Rivularia biasoletiana*

*Rivularia haematites*

*Snowella lacustris*

*Synechocystis aquatilis*

*Tolypothrix distorta*

*Trichormus variabilis*

*Woronichinia naegeliana*

## Saxitoxin/PST Producers

*Anagnostidinema amphibium*

*Anagnostidinema lemmermannii*

*Aphanizomenon favaloroi*

*Aphanizomenon gracile*

*Cylindrospermum stagnale*

*Cuspidothrix issatschenkoi*

*Dolichospermum circinale*

*Dolichospermum lemmermannii*

*Microseira wollei* (syn. *Lyngbya wollei*)

*Phormidium uncinatum*

*Raphidiopsis brookii*

*Raphidiopsis raciborskii*

*Scytonema cf. crispum*

## Cylindrospermopsin Producers

*Anabaena lapponica*

*Aphanizomenon flos-aquae*

*Aphanizomenon gracile*

*Chrysosporum bergii*

*Chrysosporum ovalisporum*

*Hormoscilla pringsheimii*

*Microseira wollei*

*Phormidium ambiguum*

*Raphidiopsis curvata*

*Raphidiopsis raciborskii*

*Umezakia natans*

# Dermatotoxin Producers

*Leibleinia gracilis*

*Moorea producens*

*Nostoc muscorum*

*Phormidium nigroviride*

*Schizothrix calcicola*

*Scytonematopsis crustacea*

*Symploca muscorum*

## Nodularin Producers

*Iningainema pulvinus*

*Nodularia sphaerocarpa*

*Nodularia spumigena*

*Nostoc* sp. (cycad endosymbiont)