

## Algal classes and their signature pigments

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# Overview



1. Algal classification systems
2. Origins of microalgal plastid diversity
3. Biological characteristics of microalgal classes
  - \* Prokaryotes
  - \* Eukaryotes
    - Glaucocystophyta
    - Red radiation
    - Green radiation
4. Pigment characteristics of microalgal classes
5. Selected pigments for CHEMTAX analysis  
(individual genera and class discrimination)
6. Where to now? – Are pigments past their usefulness in phytoplankton oceanography / ecology ?

# Algal classification – the protist perspective



Super-groups	First rank	Second rank (examples of photosynthetic eukaryotes)
Rhizaria	Cercozoa	Chlorarachniophyta
Archaeplastida	Glaucophyta	Glaucophyceae
	Rhodophyceae	Subdivisions uncertain
	Chloroplastida	Charophyta*, Chlorophyta, <i>Mesostigma</i> , Prasinophytae
Chromalveolata	Cryptophyceae	Cryptomonadales
	Haptophyta	Pavlovophyceae, Prymnesiophyceae
	Stramenopiles	Bacillariophyta, <i>Bolidomonas</i> , Chrysophyceae, Dictyochophyceae, Eustigmatales, Pelagophyceae, Phaeophyceae*, Phaeothamniophyceae, Pinguichrysidales, Raphidiophyceae, Synurales, Xanthophyceae
		Alveolata
Excavata	Euglenozoa	Euglenida

\* Clades with multicellular groups.

# The photosynthetic perspective (part 1)



Algal Division	Class	Common Name	Microplankton >20 $\mu$ m	Nanoplankton 2-20 $\mu$ m	Picoplankton 0.2-2 $\mu$ m
<i>PROKARYOTES</i>					
<b>Division :</b>	<b>Cyanophyta</b>				
Class :	Cyanophyceae, includes	cyanophyte, cyanobacteria	+	+	+
Class :	Prochlorophyceae	(blue-green algae), prochlorophyte	-	+	+
<i>EUKARYOTES</i>					
<b>Division :</b>	<b>Glaucocystophyta</b>				
Class :	Glaucocystophyceae	glaucocystophyte	+	+	-
<b>Division :</b>	<b>Rhodophyta</b>				
Class :	Rhodophyceae*	red algae	macrophyte	+	-
<b>Division :</b>	<b>Heterokontophyta (<math>\equiv</math> Chromista, Chromophyta, Stramenopiles)</b>				
Class :	Bacillariophyceae	diatom	+	+	-
Class :	Bolidophyceae	bolidophyte	-	-	+
Class :	Chrysophyceae	golden-brown algae	-	+	+
Class :	Dictyochophyceae	silicoflagellate	+	-	-
Class :	Eustigmatophyceae	eustigmatophyte	-	+	-
Class :	Pelagophyceae	pelagophyte	-	+	+
Class :	Phaeothamniophyceae	phaeothamniophyte	-	+	-
Class :	Pinguiophyceae	pinguiophyte	+	+	-
Class :	Raphidophyceae	raphidophyte	+	+	-
Class :	Synurophyceae	synurophyte	+	-	-
Class :	Xanthophyceae	xanthophyte	+	+	-

\* Includes macrophytes

continued on next slide

# The photosynthetic perspective (part 2)



Algal Division		Class	Common Name	Microplankton >20µm	Nanoplankton 2-20µm	Picoplankton 0.2-2µm
<b>Division :</b>	<b>Haptophyta</b>					
		Pavlovophyceae	golden-brown algae	-	+	+
Class :		Prymnesiophyceae (≡Coccolithophyceae <sup>1</sup> )				
			golden-brown algae (coccolithophorid)	-	+	+
				+	+	-
<b>Division :</b>	<b>Cryptophyta</b>					
Class :		Cryptophyceae	cryptomonad	-	+	-
<b>Division :</b>	<b>Dinophyta</b>					
Class :		Dinophyceae	dinoflagellate	+	+	-
<b>Division :</b>	<b>Euglenophyta</b>					
Class :		Euglenophyceae	euglenophyte	+	+	-
<b>Division :</b>	<b>Chlorarachniophyta</b>					
Class :		Chlorarachniophyceae	chlorarachniophyte	+	-	-
<b>Division :</b>	<b>Chlorophyta</b>					
Class :		Chlorophyceae	green algae	-	+	-
Class :		Prasinophyceae	prasinophyte	-	+	+
Class :		Trebouxiophyceae	green algae/lichen algae	+	+	-
<b>Division :</b>	<b>Streptophyta</b>					
Class :		Mesostigmatophyceae	mesostigmatophyte	-	+	-
<b>Division :</b>	<b>Unknown</b>					
Class :		Unknown (1)	'picobiliphytes' <sup>2</sup>	-	+	+
		Unknown (2)	Chlorophyll <i>d</i> -containing <sup>3</sup>	Unknown taxa		

<sup>1</sup> Silver *et al.* (2007)

<sup>2</sup> Not yet formally described (Not *et al.* 2007);

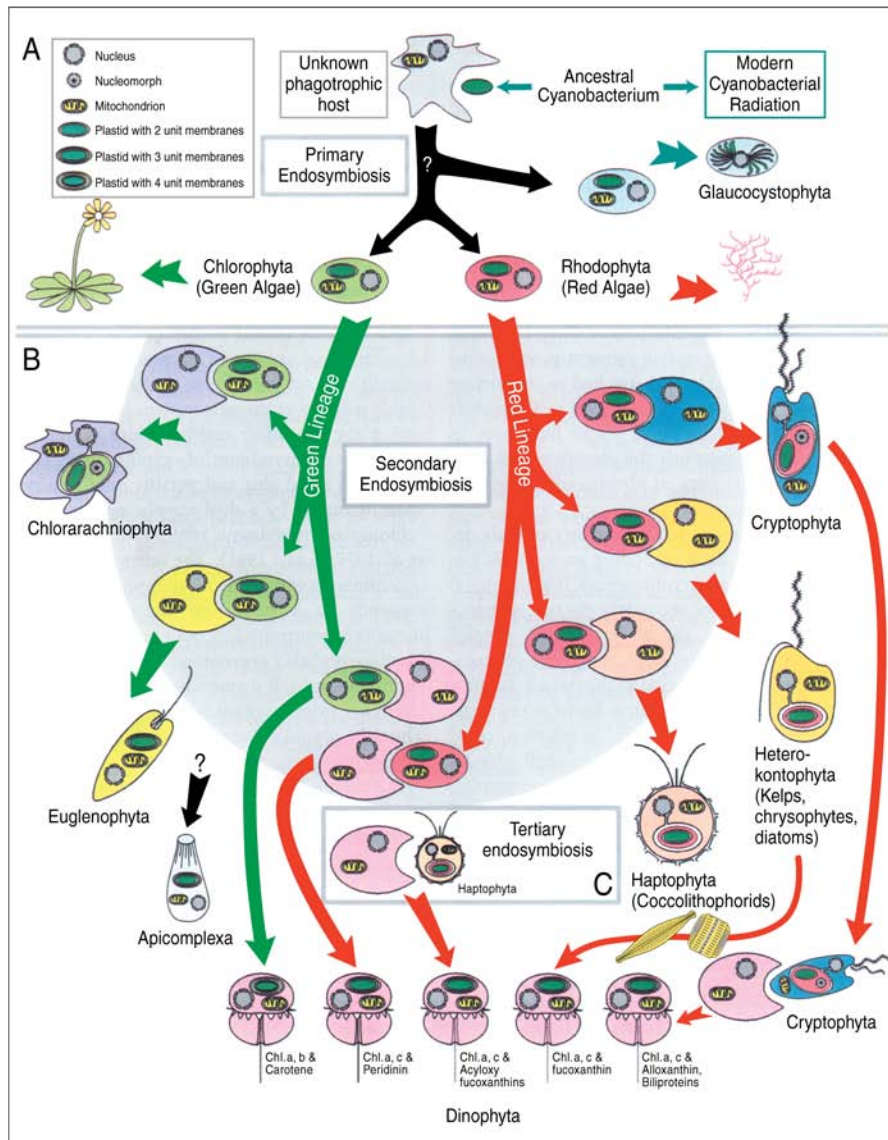
<sup>3</sup> Kashiyama *et al.* (2008)

# Distinguishing features - then (1997) and now



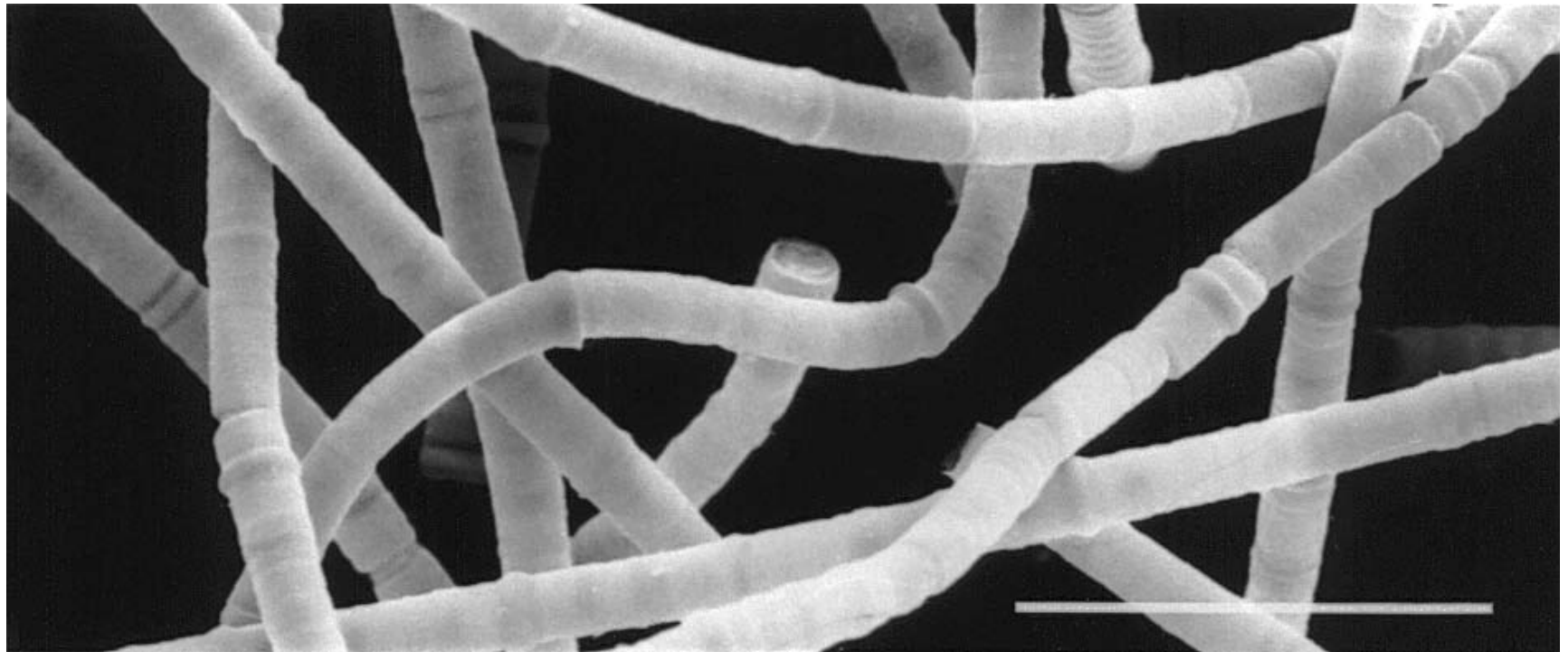
<b>Jeffrey and Vesk (1997)</b>		<b>Jeffrey, Wright and Mantoura (now)</b>	
Divisions/Classes	12	Divisions	11
		Classes	25
<b>PIGMENTS</b>			
Chlorophylls	9		12
Carotenes	5		5
Xanthophylls	25		52
Biliprotein - types	3		3

# Hypothetical evolution of plastid diversity via serial endosymbiosis



(modified from Delwiche, 1999)

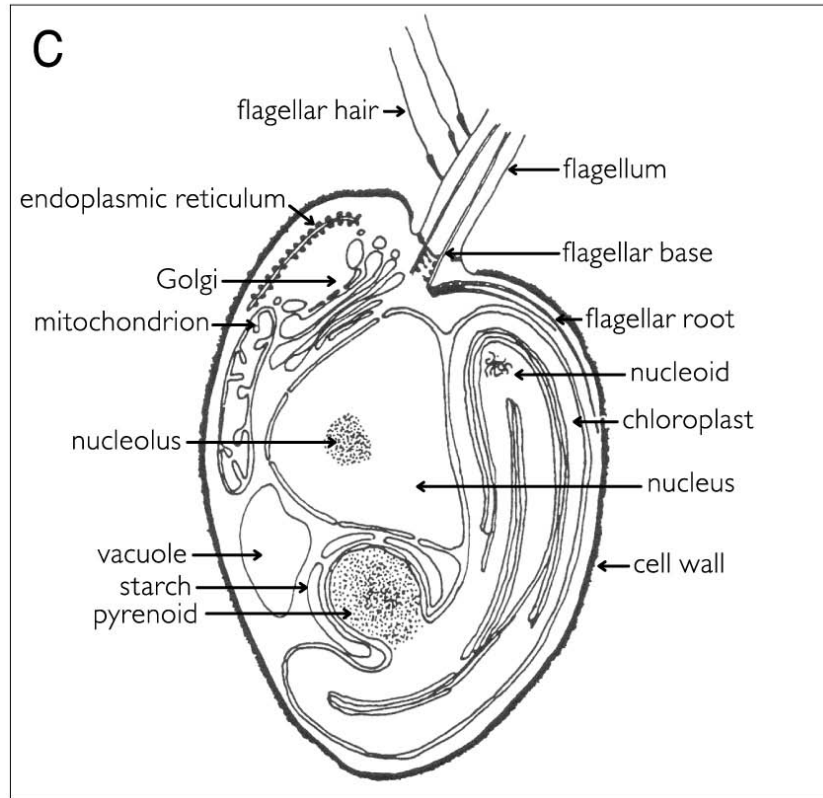
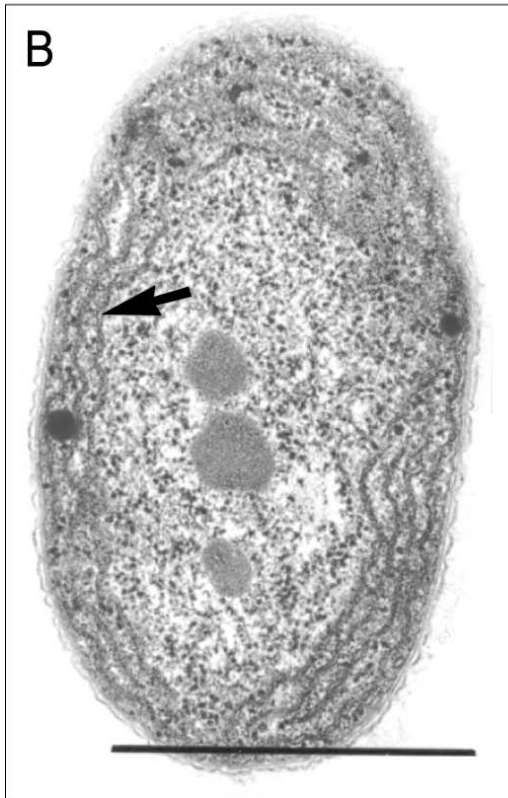
# SEM of a filamentous toxic cyanobacterium, *Nodularia spumigena*



(scale bar = 50  $\mu\text{m}$ )

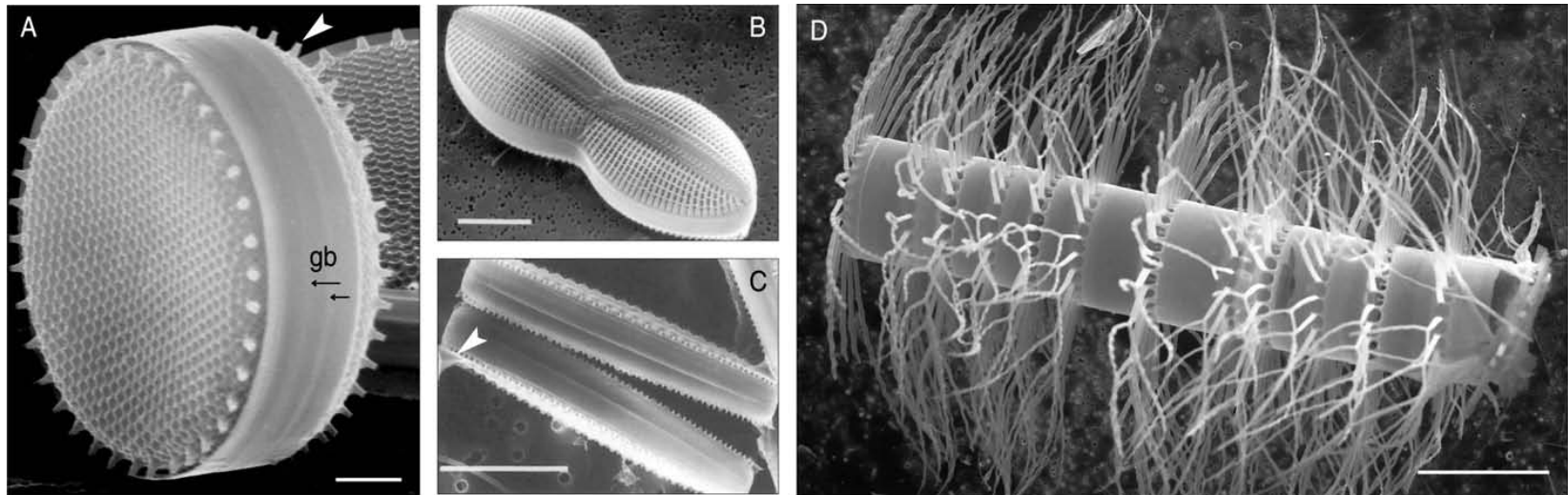


# Prokaryotes/Eukaryotes



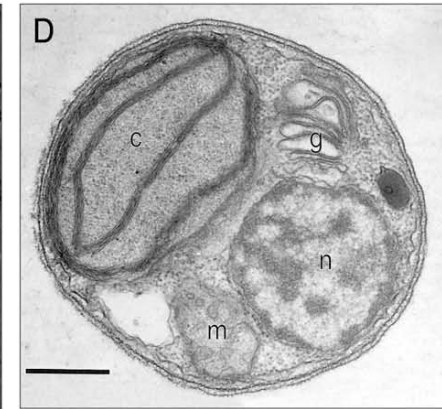
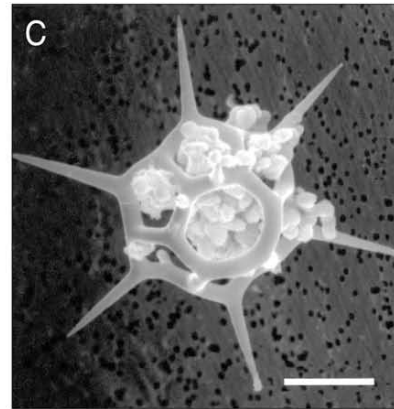
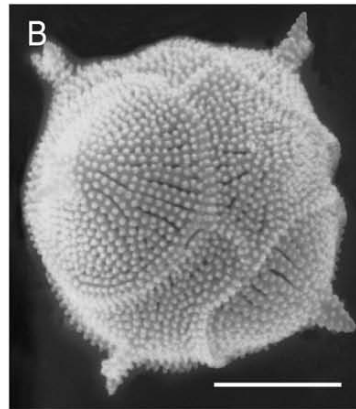
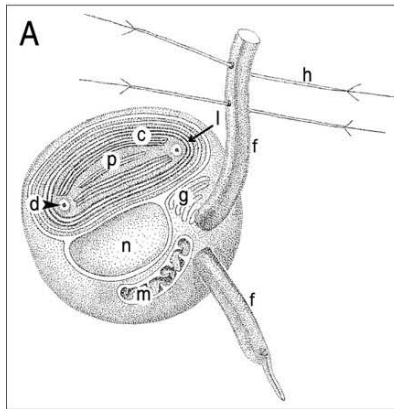
Profiles of (B) a prokaryotic cell, *Synechococcus* sp., showing single thylakoids in the cytoplasm (arrow), and (C) a diagram of a hypothetical eukaryotic cell, showing organelles often present.

# SEMs of diatoms showing valve morphology



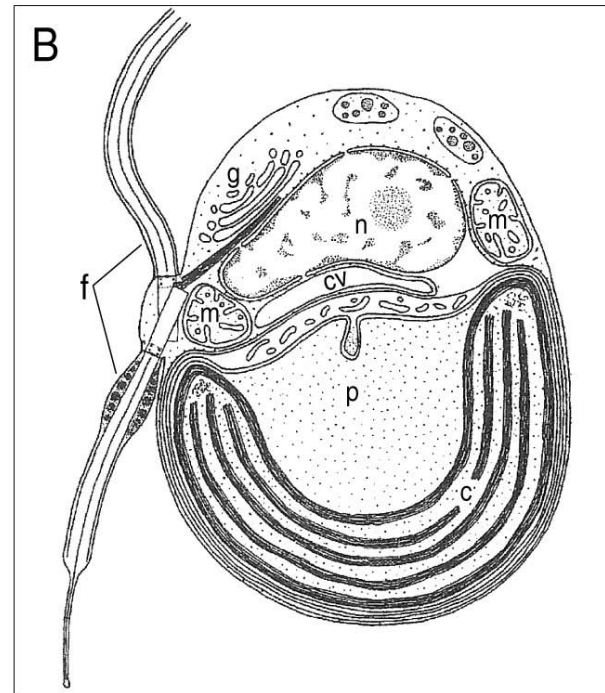
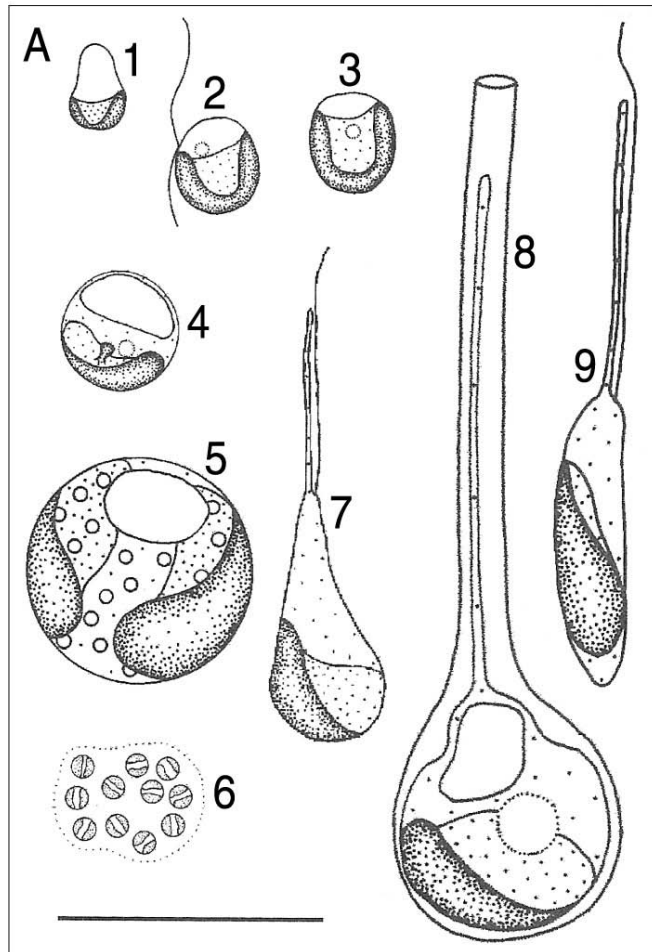
SEMs of diatoms showing valve morphology: (A) *Thalassiosira pacifica*; (B) *Diploneis* sp. (C) *Thalassionema* sp., (D) the tropical diatom *Bacteriastrium* sp.

# Various chrysophyte microalgae



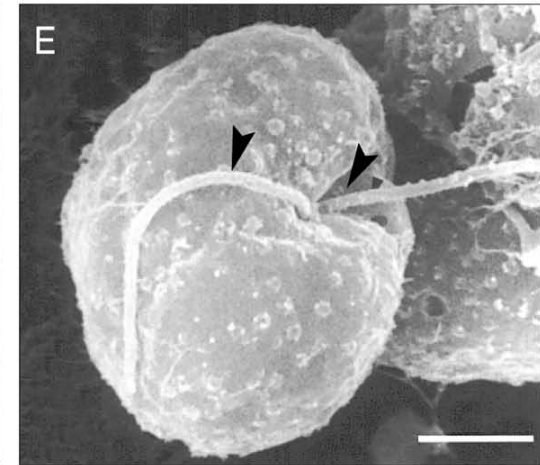
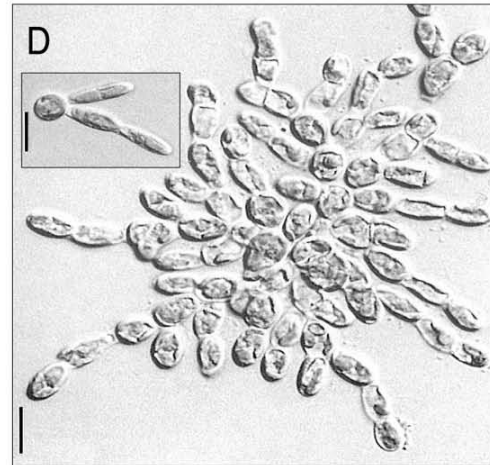
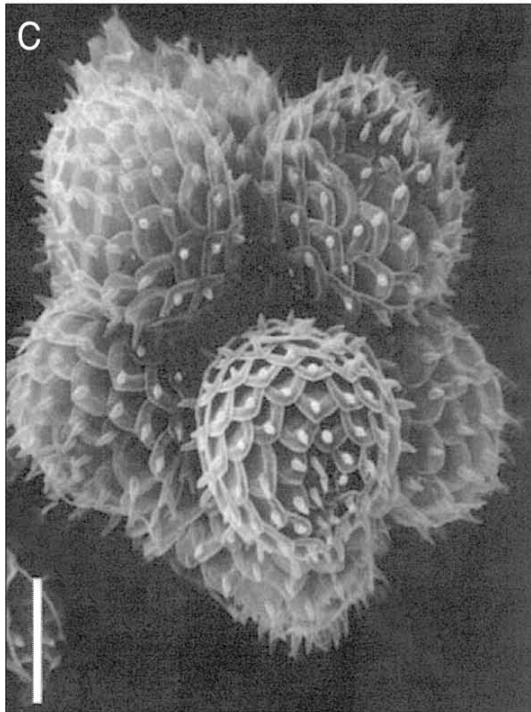
Various chrysophyte microalgae (A) *Bolidomonas*; (B) *Tetraparma* (Parmales); (C) Silicoflagellate, *Distephanum* sp., (D) *Pelagococcus subviridis* (scale bars 1, 10 and 1 $\mu$ m).

# Pinguiphytes



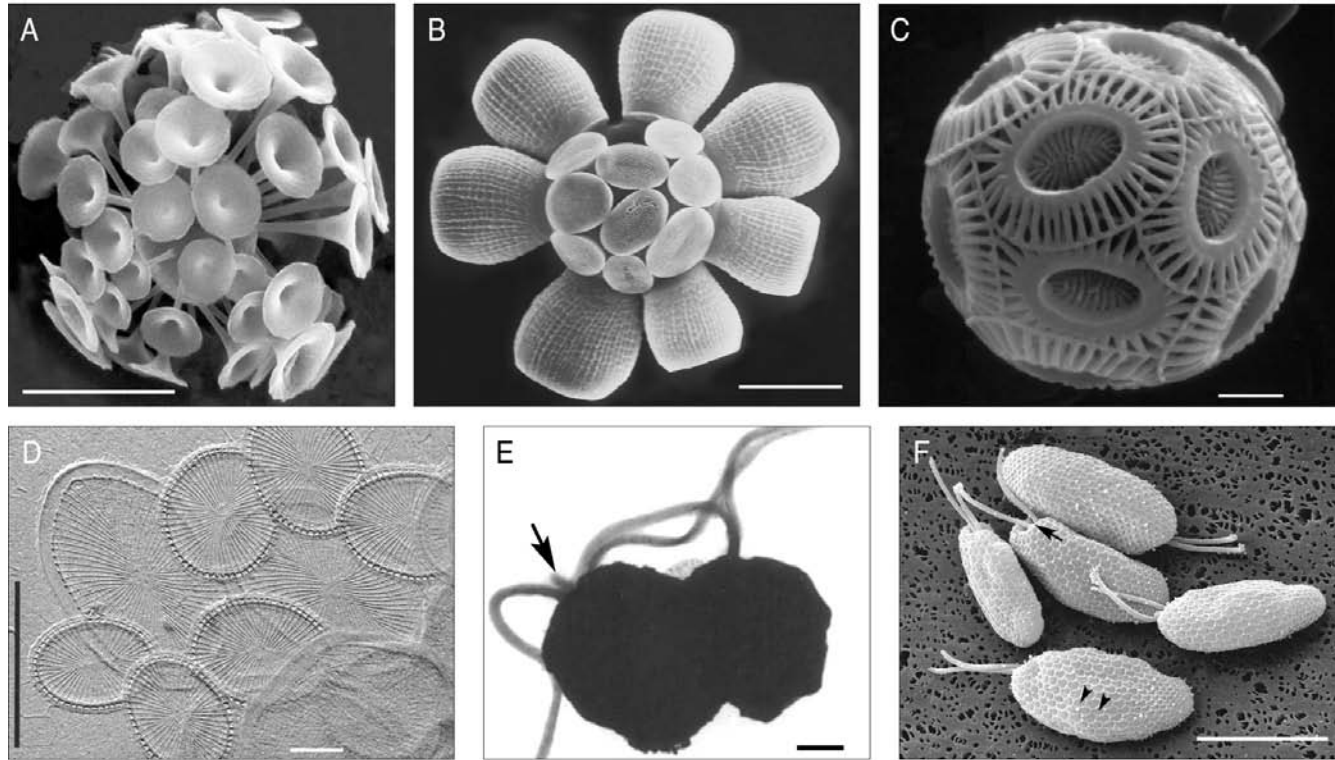
Diagrams of various Pinguiphytes (e.g. *Pinguiochrysis* sp.)

# Examples of Heterokontophyta



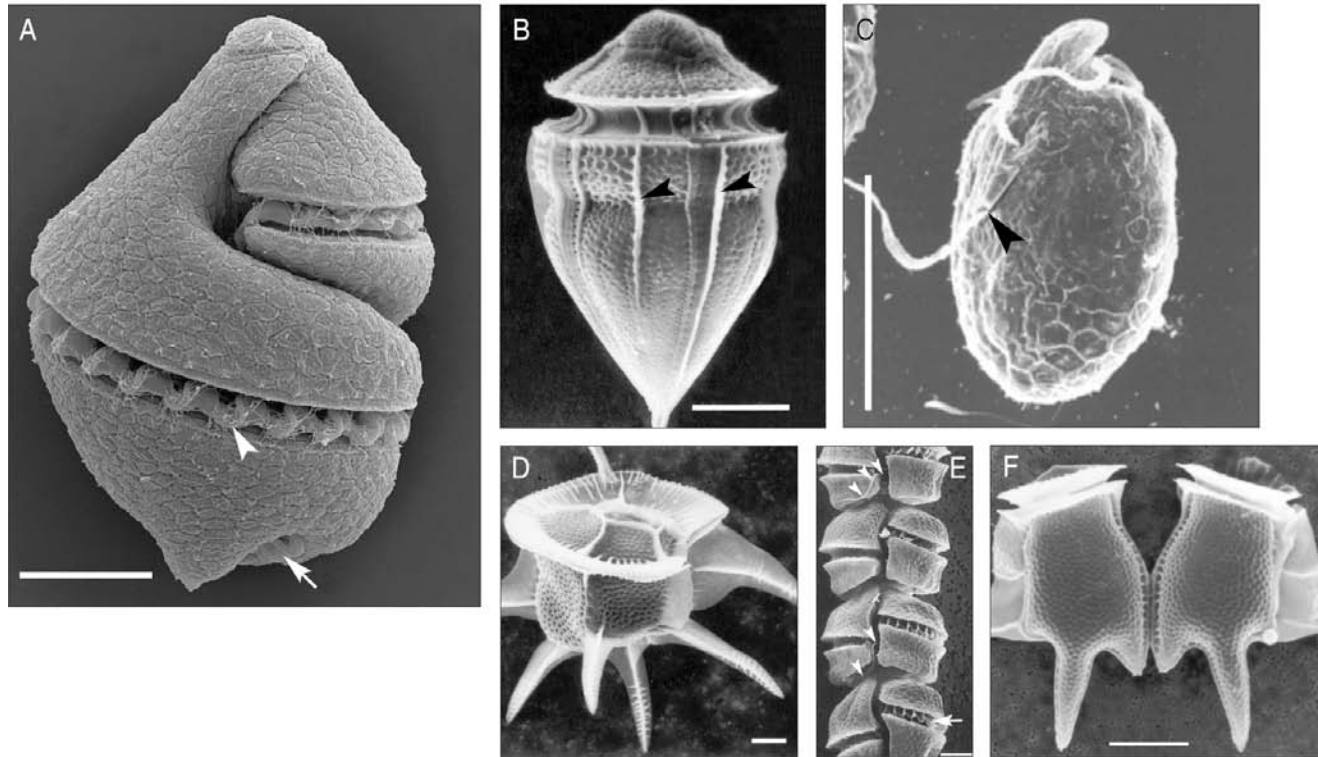
Examples of (C) a Synurophyte;  
(D) a Phaeothamniophyte; and (E) a Raphidophyte

# Examples of nanoplanktonic Haptophyta



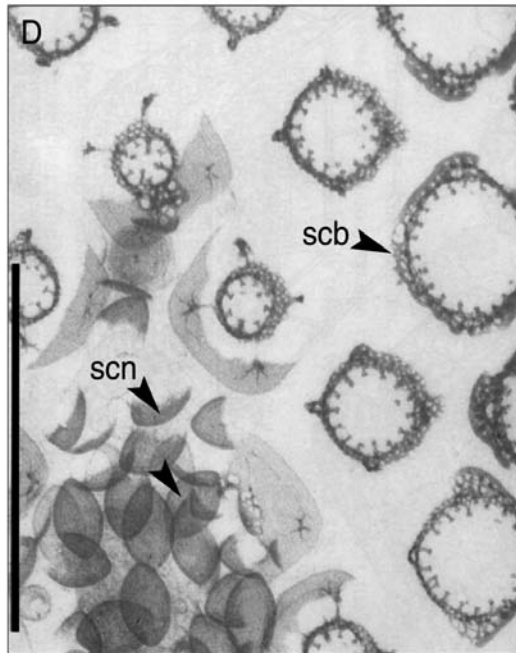
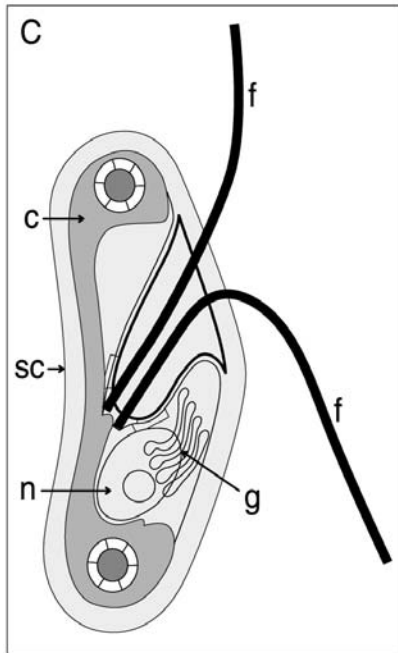
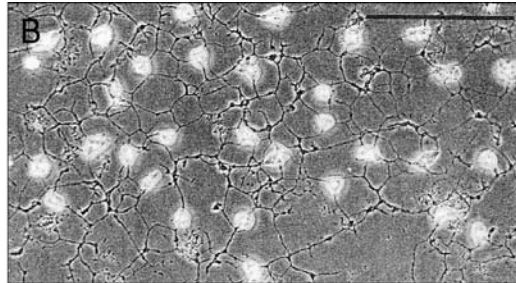
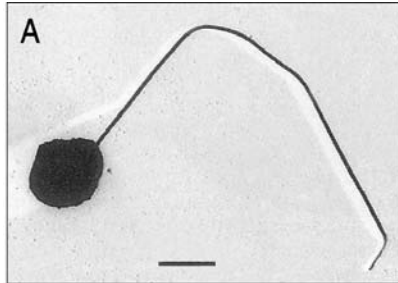
Examples of the nanoplanktonic Haptophyta: (A – C); SEMs of coccolithophorids, showing coccolith structures; (D) organic body scales; (E) two cells of *Pavlova* sp. showing a short haptonema (arrow); and (F) five cells of the cryptomonad *Chroomonas* sp.

# SEMs of dinoflagellates



SEMs of dinoflagellates (A) *Cochlodinium* sp. – note transverse flagellum (arrowhead); (B) *Oxytoxum* sp.; (C) *Amphidinium* sp. – note two flagella (arrowheads); (D) *Ceratocorys* sp.; (E) the chain-forming *Gymnodinium catenatum*; (F) Divided pair of *Dinophysis tripos* (scale bars, all 10  $\mu\text{m}$ ).

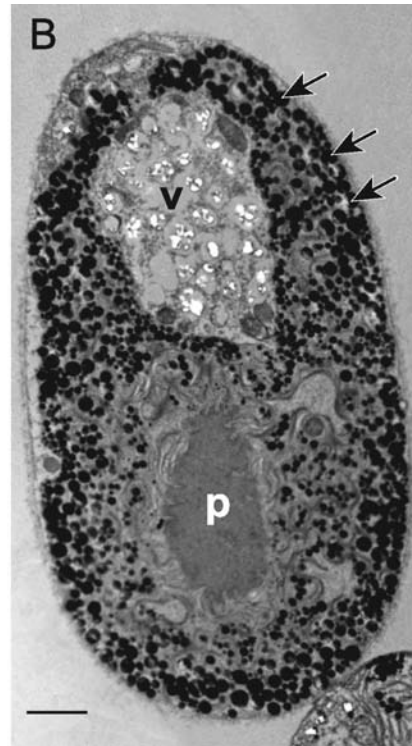
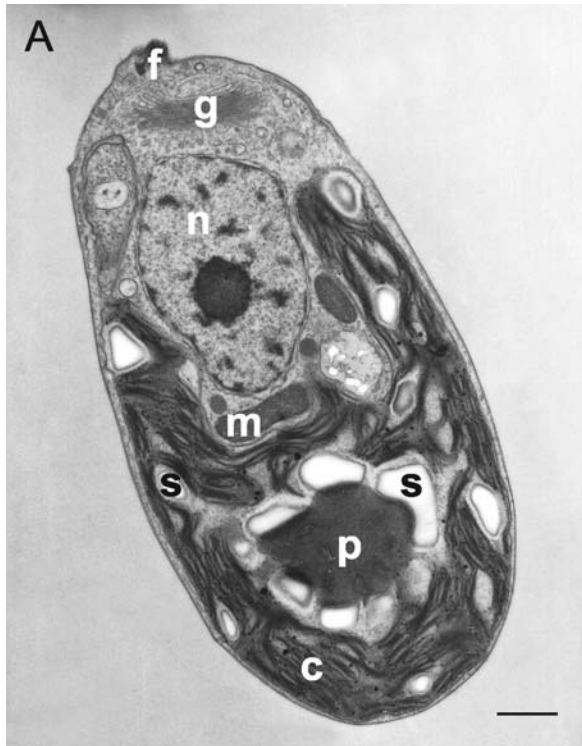
# Examples of Chlorophyta (green microalgae)



Examples of Chlorophyta (green microalgae):  
(A) flagellate cell of the chlorarachniophyte (green spider) *Bigeloviella* (scale bar 2 $\mu$ m);  
(B) amoeboid stage of *Chlorarachnion* (green spider; scale bar 20 $\mu$ m);  
(C) Diagram of the microflagellate *Mesostigma* sp.;  
(D) SEMs of the two body scale types (scale bar, 1 $\mu$ m).



# Green and red forms of *Dunaliella*



(A) TEM of a green cell of the chlorophyte *Dunaliella tertiolecta*; and  
(B) TEM of a red cell of *D. tertiolecta* – note many b,b-carotene globules throughout the cell (arrows).

# Biological characteristics of microalgal classes



## Euglenophyta

<b>Distribution</b>	occur in most freshwater habitats (particularly those with decaying organic matter); also in brackish and marine environments (open sea, tidal zone or on beaches)
<b>Anatomy and morphology</b>	unicellular, ovoid or fusiform; most species have a flexible pellicle, which allows movement by deformation (metaboly); other species have a rigid lorica; common marine forms are 40-60 $\mu\text{m}$ long (sometimes up to 500 $\mu\text{m}$ ) and about 10 $\mu\text{m}$ wide.
<b>Cellular organization</b>	mucilage-producing bodies lie beneath the proteinaceous pellicle; large mesokaryotic nucleus present with many condensed chromosomes; chloroplasts of green algal origin (one to many) vary in size, shape and pyrenoid structure; chloroplast bound by three membranes; thylakoids in extended and interconnected stacks of two or three; some species have an eyespot, located outside the chloroplast; storage product: a crystalline $\beta$ -1,3 glucose polymer, paramylon; some species phagotrophic.
<b>Pigments</b>	<b>Chlorophylls:</b> Chls <i>a</i> and <i>b</i> , MgDVP; <b>Carotenoids:</b> eutreptiellanone, diadinoxanthin, diatoxanthin, 9-cis-neoxanthin, $\beta$ , $\beta$ -carotene (Bjornland 1982; Fiksdahl <i>et al.</i> 1984 <i>b</i> ; Bjornland <i>et al.</i> , 1986; Jeffrey and Wright, 1997)
<b>Colour</b>	grass green
<b>Flagella</b>	one or two, equal or unequal in length, with a single row of fine hairs.
<b>Phylogeny</b>	nearly 20 years of molecular systematics have resulted in many taxonomic revisions. Similarities noted between euglenophytes and kinetoplastids, suggesting that the ancestral host was a kinetoplastid protozoan (see Table 1.01); four major clades of photosynthetic euglenoids are now recognized (Triemer and Farmer, 2007)
<b>References</b>	Bjornland (1982); Fiksdahl <i>et al.</i> , (1984); Bjornland <i>et al.</i> , (1986); Jeffrey and Wright, (1997); Marin <i>et al.</i> (2003); Triemer <i>et al.</i> (2006); Triemer and Farmer (2007)

# Pigments of the Cyanobacterial Lineage



Pigment	Cyanobacterial Radiation						Present in Other Lineages	
	Cyano-bacteria		Prochloro-phytes			GLAUCO-1	RED	GREEN
	CYANO-1	CYANO-2	CYANO-3	CYANO-4	CYANO-5			
<b>Chlorophylls</b>								
Chl <i>a</i>	●	●	●		t	●	+	+
DV Chl <i>a</i> (Chl <i>a</i> <sub>2</sub> )				●			-	-
Chl <i>b</i>			●	●			-	+
DV Chl <i>b</i> (Chl <i>b</i> <sub>2</sub> )				●			-	-
Chl <i>d</i>					●		-	-
MgDVP	t	t	t	t	●		+	+
<b>Phycobiliproteins</b>								
Allophycocyanin	●	●			t	●	+	-
Phycocyanin	●	●			t	●	+	-
Phycocerythrin	●	●		●			+	-
<b>Carotenes</b>								
β,β-carotene (β)	●	●	●			●	+	+
β,ε-carotene (α)				●	●		+	+
<b>Xanthophylls</b>								
β,β-carotene-epoxide			t				-	-
β,β-cryptoxanthin	●		●			●	-	-
Iso-cryptoxanthin	●		●				-	-
Canthaxanthin	●						+	-
Echinenone	●		●				-	-
OH-Echinenone	●						-	-
Mutachrome	●		●				-	-
Myxoxanthophyll	●						-	-
Myxoxanth. deriv. <sup>a</sup>	○						-	-
Oscillaxanthin	○						-	-
Zeaxanthin	●	●	●	●	●	●	+	+
Source data	1	2	3	4	5	6		





# Pigments of the Green Algal Lineage



Pigment	Chlorophyll <i>b</i> -containing classes of the Green Algal lineage											Present in other lineages	
	EUGLENO-1	CHLORARACH-1	CHLORO-1	CHLORO-2	PRASINO-1	PRASINO-2	PRASINO-3	PRASINO-4	TREBOUXIO-1	MESOSTIG-1	DINO-5	CYANO	RED
<b>Chlorophylls</b>													
Chl <i>a</i>	●	●	●	●	●	●	●	●	●	●	●	+	+
Chl <i>b</i>	●	●	●	●	●	●	●	●	●	●	●	+	-
<b>Chl <i>c</i> series</b>													
MgDVP		t	t		t	•	●	t	t		t	+	+
Chl <i>c</i> <sub>es-170</sub> <sup>a</sup>												-	-
<b>Carotenes</b>													
β,β-carotene (β) <sup>b</sup>	•	•	●	●	●	●	●	●	•	●	●	+	+
β,ε-carotene (α)	t		•	•	•	•	•	•				+	+
β,ψ-carotene (γ)			○		○					•		+	+
<b>Xanthophylls</b>													
Alloxanthin <sup>c</sup>			†						•	•		-	+
Antheraxanthin		•	•	•	•	•	•		•			-	+
Astaxanthin <sup>b</sup>			○						t			-	-
Dihydroxylutein								•				-	-
Diadinoxanthin	●											-	+
Diatoxanthin	•											-	+
Eutreptiellanone <sup>d</sup>	○											-	-
Loroxanthin			○									-	-
Loroxanthin ester		●						○				-	-
Lutein		●	●	●	●	●	•	•	●	•		-	-
Lycopene										•		-	-
Micromonal												-	-
Micromonol												-	-
Monadoxanthin <sup>c</sup>			†									-	+
<i>cis</i> -Neoxanthin	•	•	●	●	●	●	●	•		●		-	-
<i>trans</i> -Neoxanthin									●			-	-
Prasincoxanthin							●			○		-	-
Siphonaxanthin (Siph)				•		●			●			-	-
Siph ester(s) <sup>e</sup>	○		•			○			●			-	-
Unk. carotenoid- <i>M.pusilla</i> <sup>f</sup>												-	-
Uriolide								•				-	-
Violaxanthin		•	●	●	●	●	●	•	●	●		-	+
Zeaxanthin		•	•	•	•	•	•	•	•	•		+	+
Unk-carotenoid <sup>g</sup>											●	-	-
Source data	1	2	3	4	5	6	7	8	9	10	11		

# Specific pigment markers for taxonomic groups



## Specific pigment markers for taxonomic groups

Chlorophyll <i>a</i>	all microalgae
Chlorophylls <i>a + b</i>	green algal lineage
Chlorophylls <i>a + c</i>	red algal lineage (not red algae per se)
DV - Chl <i>a</i> ; DV - Chl <i>b</i>	prochlorophytes
Chl <i>c</i> family	haptophytes
biliproteins	red algae, cyanobacteria, cryptomonads
peridinin	dinoflagellates (DINO-1)
fucoxanthin	diatoms; and all “chromophyte algae”
19' - hex- fucoxanthin	haptophytes / dinoflagellates
19' - but - fucoxanthin}	haptophytes / dinoflagellates
alloxanthin	cryptomonads/ dinoflagellates
vaucheriaxanthin esters	eustigmatophytes / some chrysophytes
siphonaxanthin esters	some prasinophytes
prasinoxanthin	some prasinophytes / dinoflagellates
ureolide	some prasinophytes
micromonal (ol)	some prasinophytes
zeaxanthin	cyanobacteria / some chlorophytes

Note 1: Beware of endosymbionts within heterotrophic hosts and other environmental complexities!

Note 2: For quantitative analyses please refer to the CHEMTAX paper (Higgins *et al.*) to follow.

Note 3: Always look at your samples under the light microscope, otherwise you may get confused!

# Acknowledgements



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