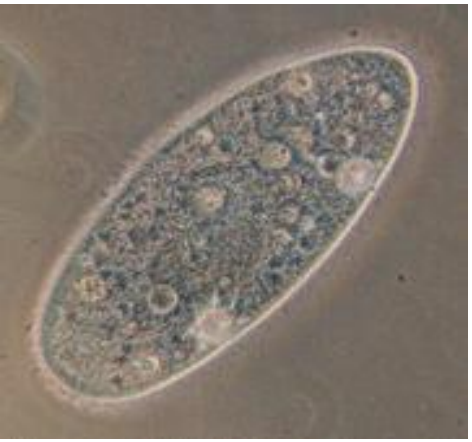
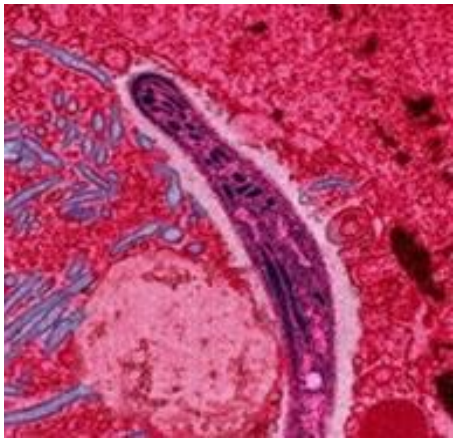
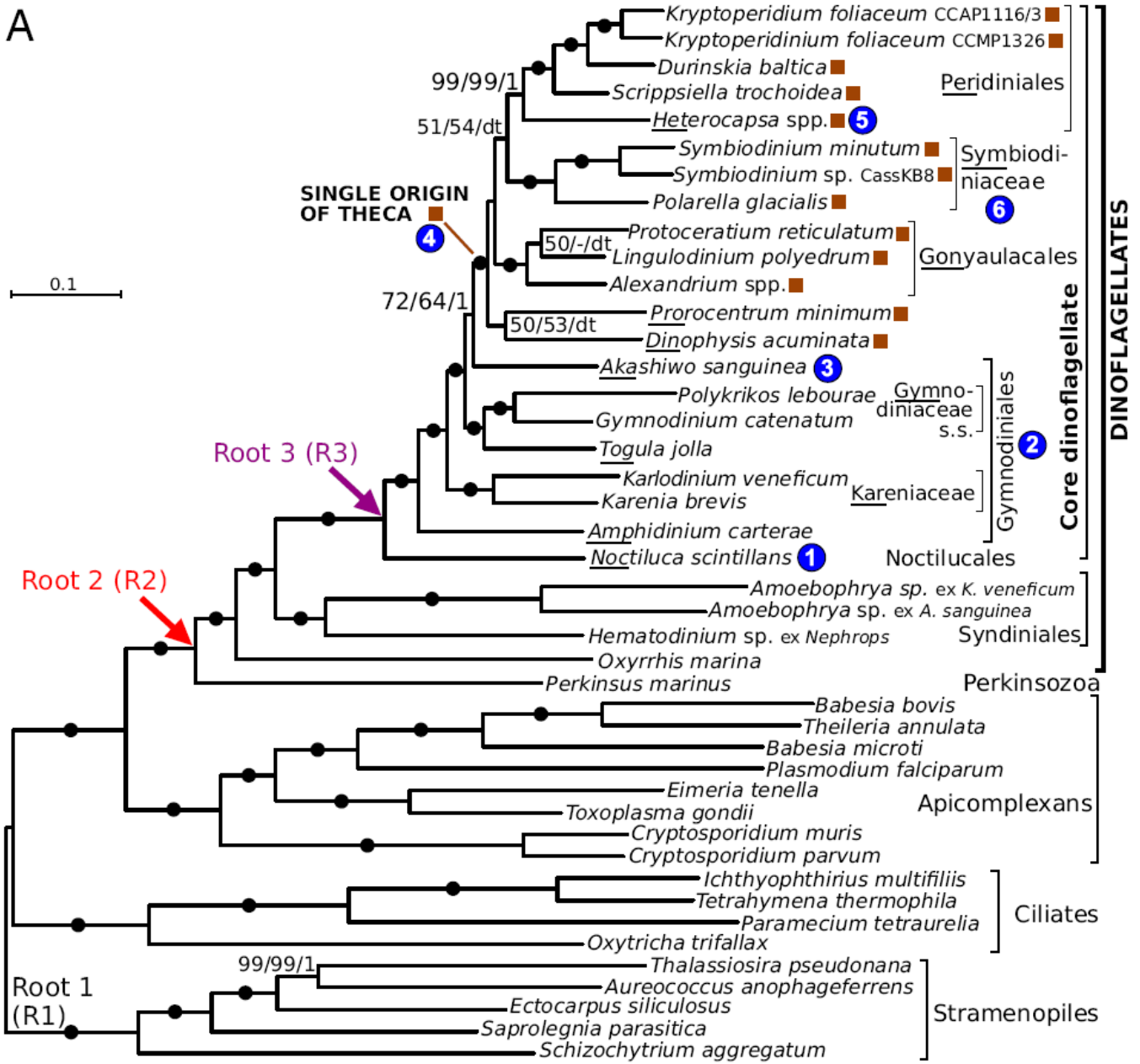
Dinophyta II. – Diversity, Evolution

- Alveolata (Cilliates, Dinophyta, Apicomplexa)
- traditional systematics (Dodge 1982) - 12 orders





Dinoflagellate evolution history



Principal findings:

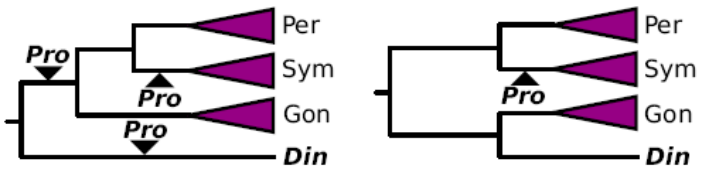
1. *Noctiluca* (and *Amphidinium*) early-branching
2. Gymnodiales paraphyletic to thecates, and *Togula* sister group of Gymnodiniaceae s.s.
3. *Akashiwo* sister group to thecates
4. Thecates monophyletic (unambiguous support)
5. *Heterocapsa* with other Peridiniales (not early-branching)
6. Symbiodiniaceae nested within thecates (not intermediate)

■ Cellulosic thecal plates

B

	Clade	Matrix	Species presence: All	All - *Din*	All - *Pro*	All - *Din* & *Pro*
1	*Noc* + other core dino.	R1	●	●	●	●
		R2	**100/100**/dt	**100/100**/dt	**100/100**/dt	**100/100**/dt
	Noc+Amp	R1	dt/dt/dt	dt/dt/dt	dt/dt/dt	dt/dt/dt
		R2	dt/dt/.99	dt/dt/.99	dt/dt/.99	dt/dt/.99
2	Kar +Gym,*Tog* *Aka*+thecates	R1	●	●	●	●
		R2	**100/100**/.95	**100/100**/.94	**100/100**/.82	**100/100**/.94
		R3	**100/100**/.98	**100/100**/.98	**100/100**/.92	**100/100**/.92
	Gym,*Tog*+*Aka* + thecates	R1	●	●	●	●
		R2	●	●	●	●
		R3	●	●	●	●
3	*Aka* + thecates	R1	72/64/**1**	68/62/**1**	62/54/**1**	56/48/**1**
		R2	88/85/**1**	86/86/**1**	86/84/**1**	84/87/**1**
		R3	90/87/**1**	90/87/**1**	85/88/**1**	84/84/**1**
4	Thecates	R1	●	●	**97/95/1**	●
		R2	●	●	**99/100/1**	●
		R3	●	●	●	●
5	*Het* + other Per	R1	**99/99/1**	**98/98/1**	●	●
		R2	**100/99/1**	**97/99/1**	●	●
		R3	●	**99/97/1**	●	●
6	Sym + Per	R1	51/54/dt	dt/dt/dt	**100/100/1**	**99/98/1**
		R2	dt/dt/dt	dt/dt/dt	**99/99/1**	**96/96/1**
		R3	dt/dt/**1**	dt/dt/**1**	**98/99/1**	93/93/**1**
	Sym + *Pro*	R1	dt/dt/**1**	84/87/**1**	not applicable	not applicable
		R2	57/48/**1**	80/67/**1**		
		R3	57/65/dt	84/79/dt		

C



Janouškovec et al. 2017

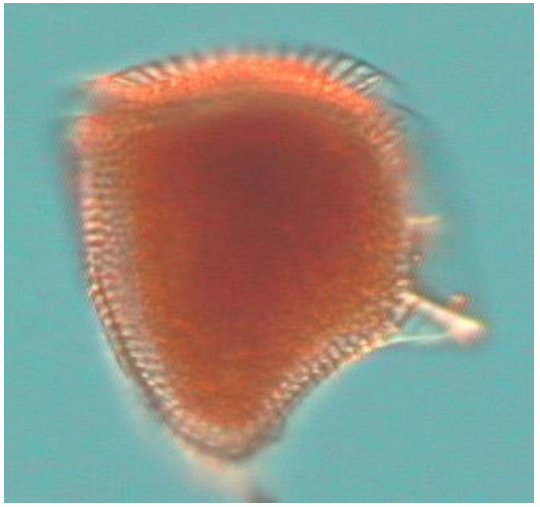
Dinophysiales I

CRYPTO

D. norvegica

Dinophysiales II

HAPTO



D. mitra

Kryptoperidinium

BACILLARIO

Durinskia, P. quinquecorne

Karenia

HAPTO

Karenia **sp.**

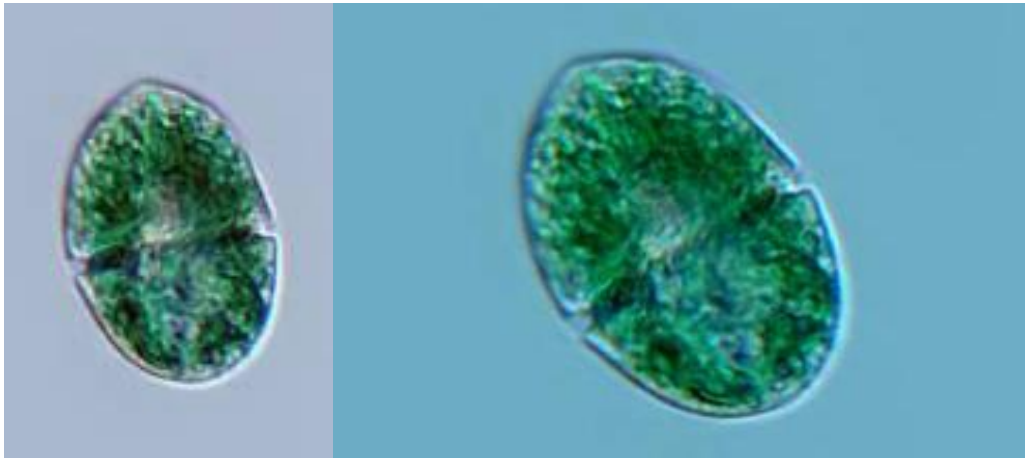
Lepidodinium

CHLORO

L. viride

Nusuttodinium aeruginosum

CRYPTO



Podolampas

DICTYOCHO

P. bipes

traditional features to recognize particular genera

- naked vs. thecate
- cingulum position (displacement)
- differences in plate ornamentation

features correlated with molecular data

- type of apical groove
- ultrastructural features (stigma types)

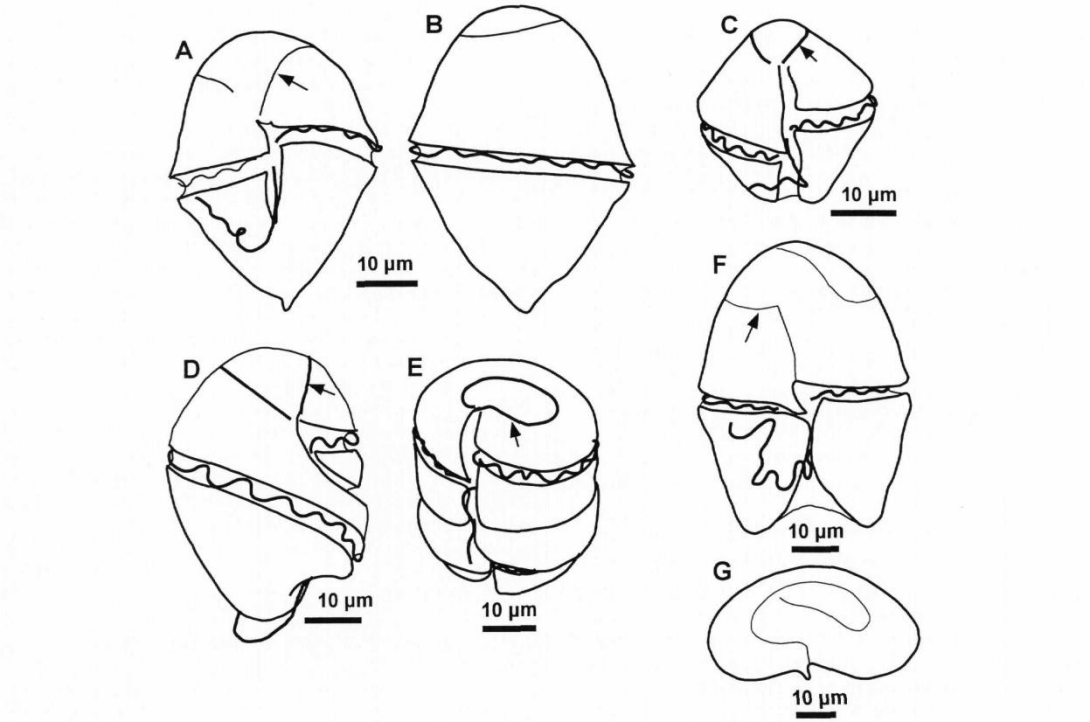
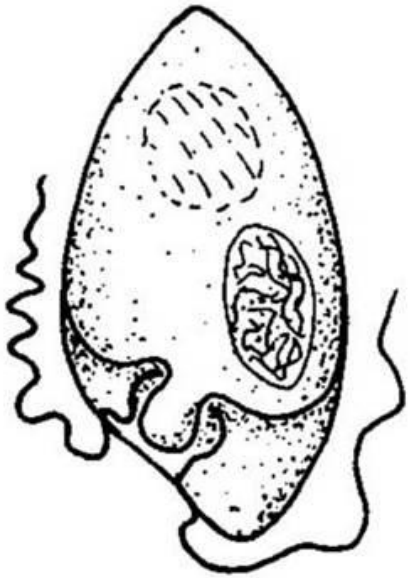
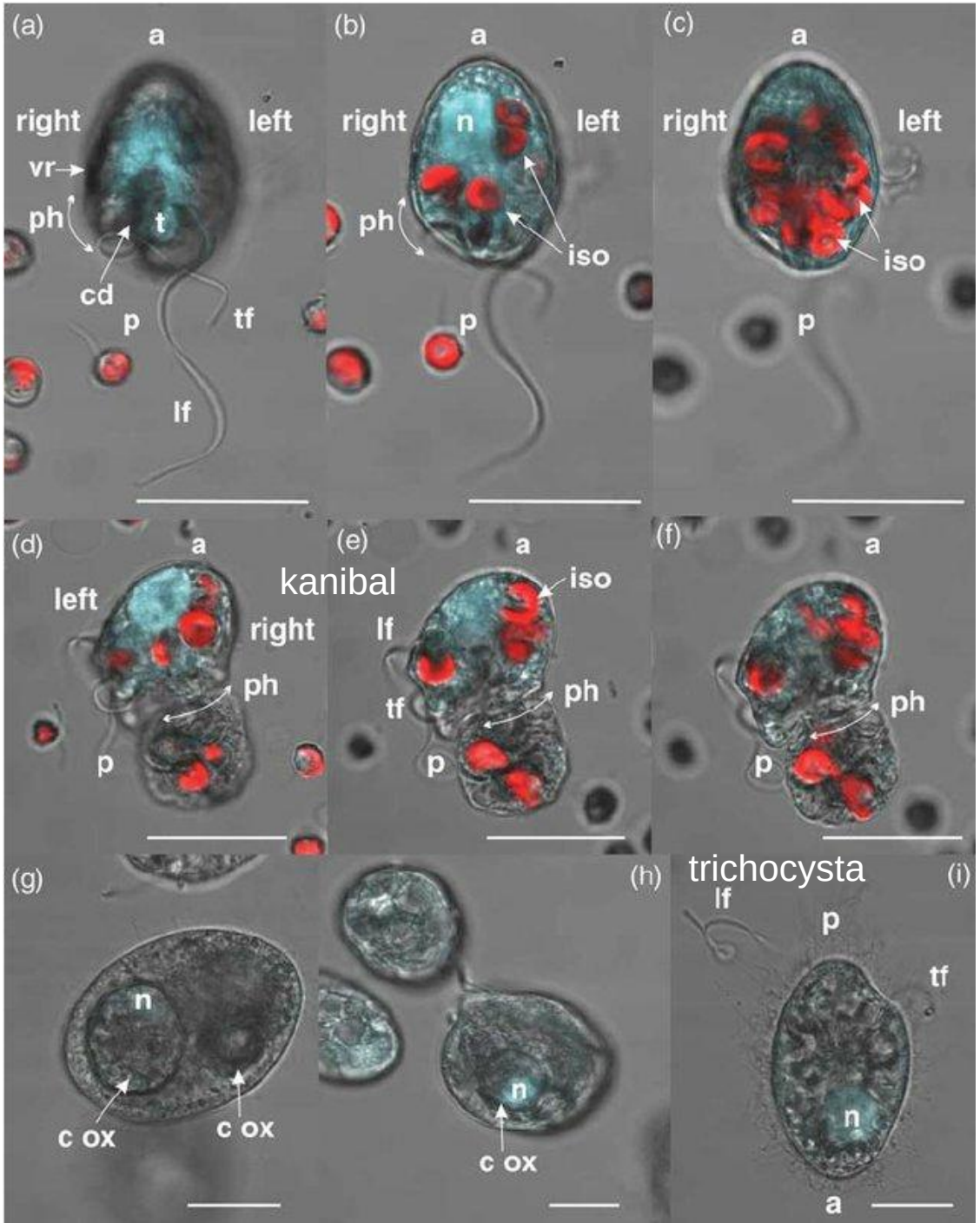


Fig. 2. Apical grooves (arrows) of unarmoured dinoflagellates (drawings based on Hansen *et al.* 2000b; Takayama 1985, 1998; Roberts *et al.* 1992; Hansen, unpublished observations). (A, B) *Gymnodinium fuscum,* ventral and dorsal view, respectively. (C) *Gymnodinium aureolum.* (D) *Nematodinium armatum.* (E) *Polykrikos kofoidii.* (F, G) *Akashiwo sanguinea,* ventral and apical views, respectively.

Oxyrrhinales (M)

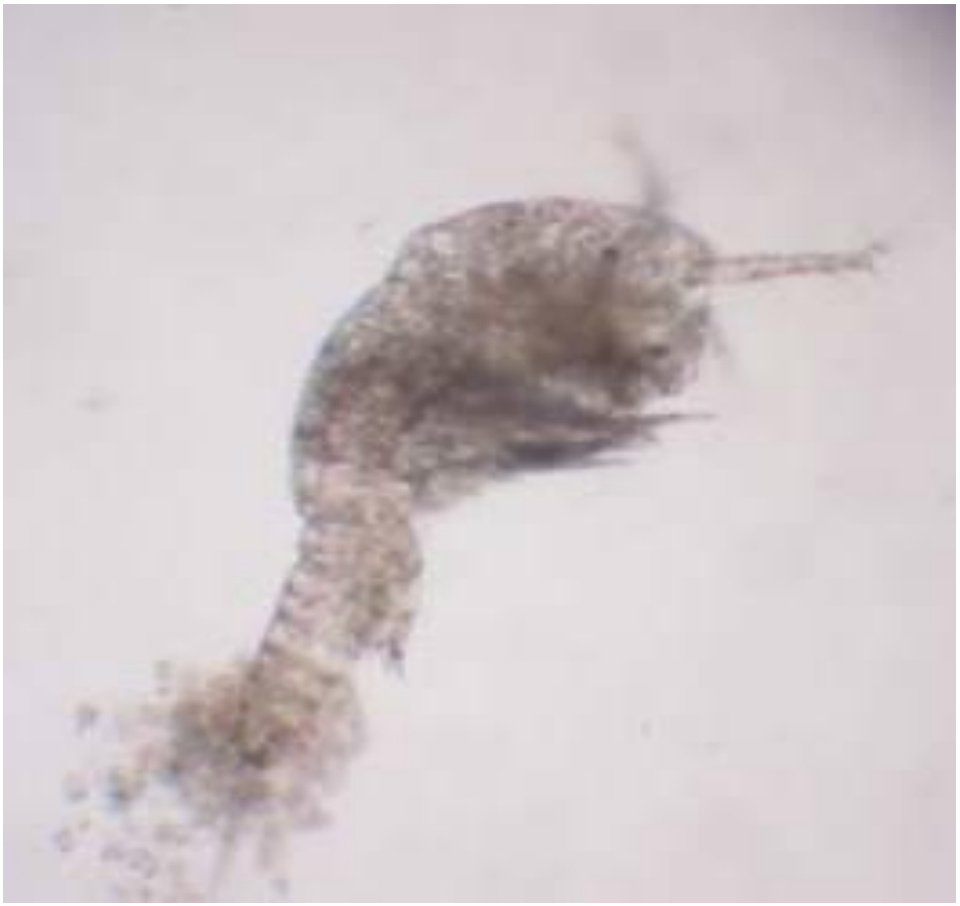
Oxyrrhis marina
– the oldest lineage of dinflagellates
– brackish species, toxic red tides
– primitive features: open mitosis, histons





Syndiniales (M)

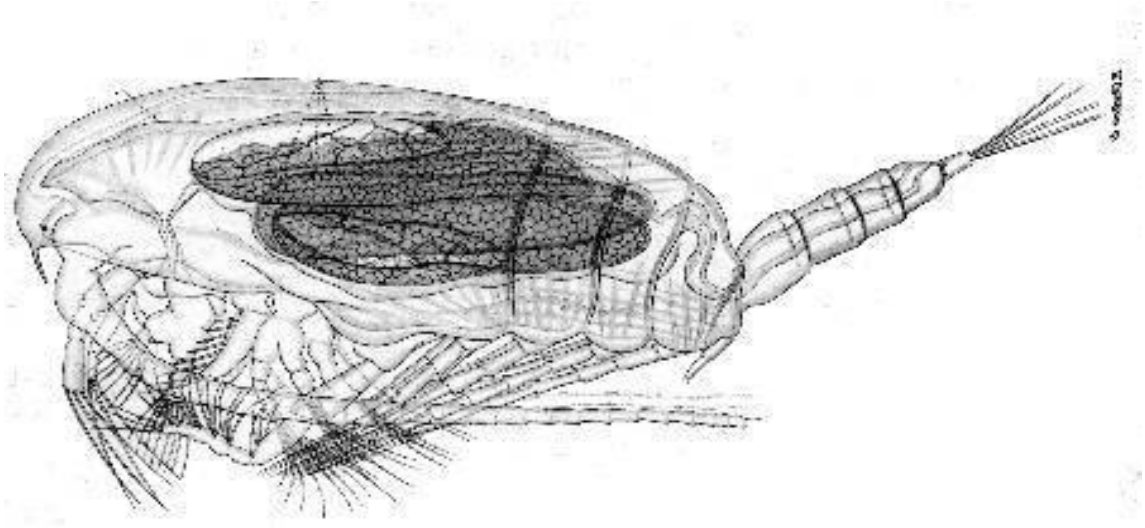
- ecto- and endoparasites of marine invertebrates and fish



***Syndinium* – release of zoospores**

Syndiniales (M)

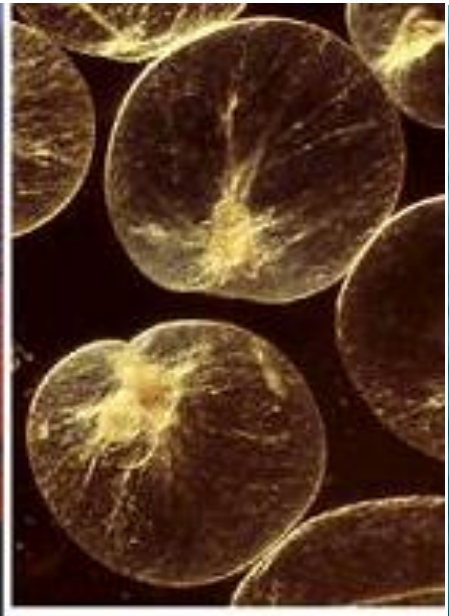
endoparasite in Copepods



Blastodinium

Noctilucales (M)

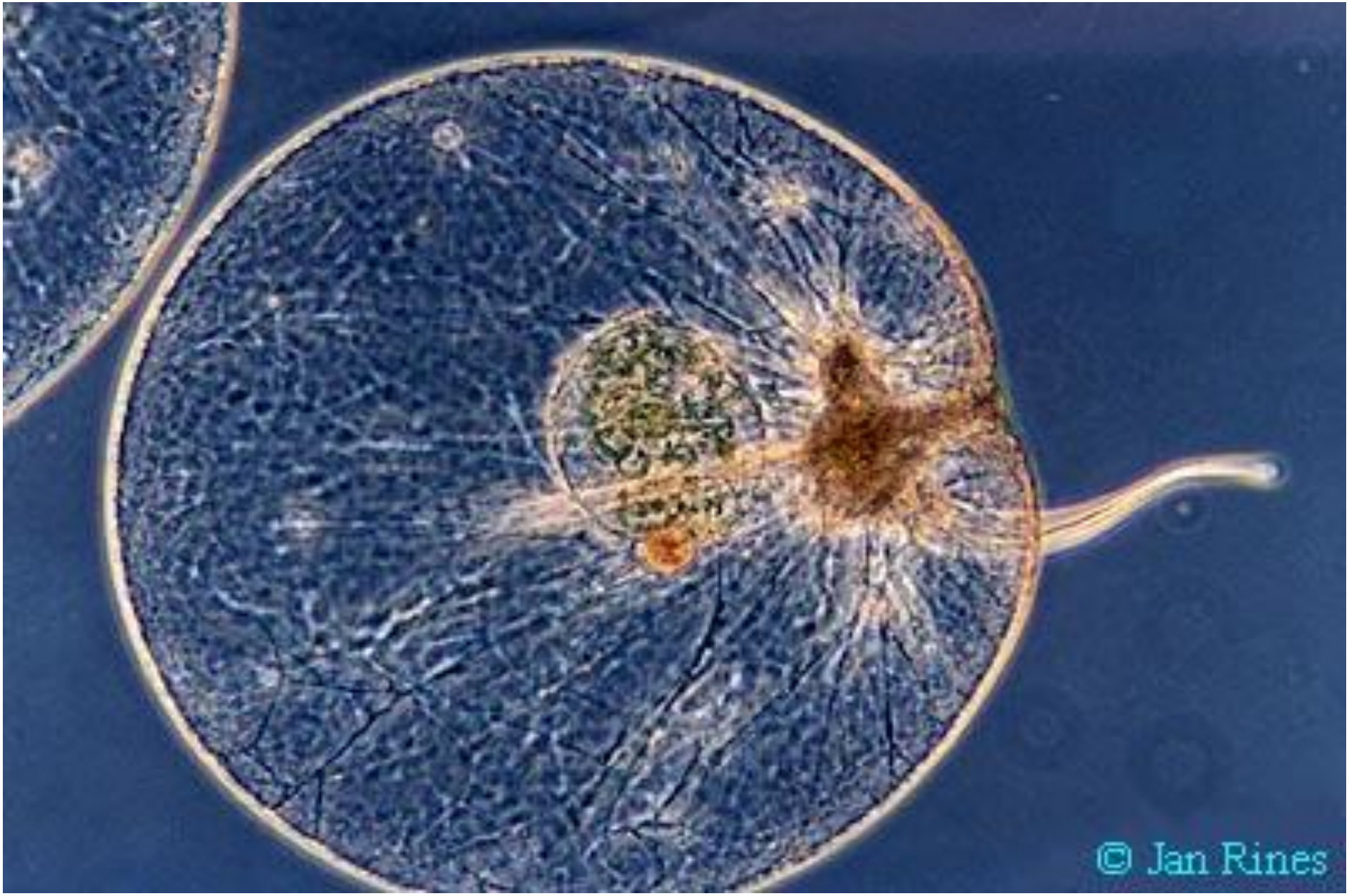
- marine *Noctiluca scintillans*
- free-living flagellates without plates, large vacuolised cells (up to 1.2 mm in diameter) – Na^+, K^+ replaced by H^+
- heterotrophic
- epitheca and hypotheca are not differentiated in adult cells, cingululm transformef in groove with tentacle



Red Tide caused by *Noctiluca scintillans*
occurred in Seto Inland Sea, Japan (May 6, 1976)

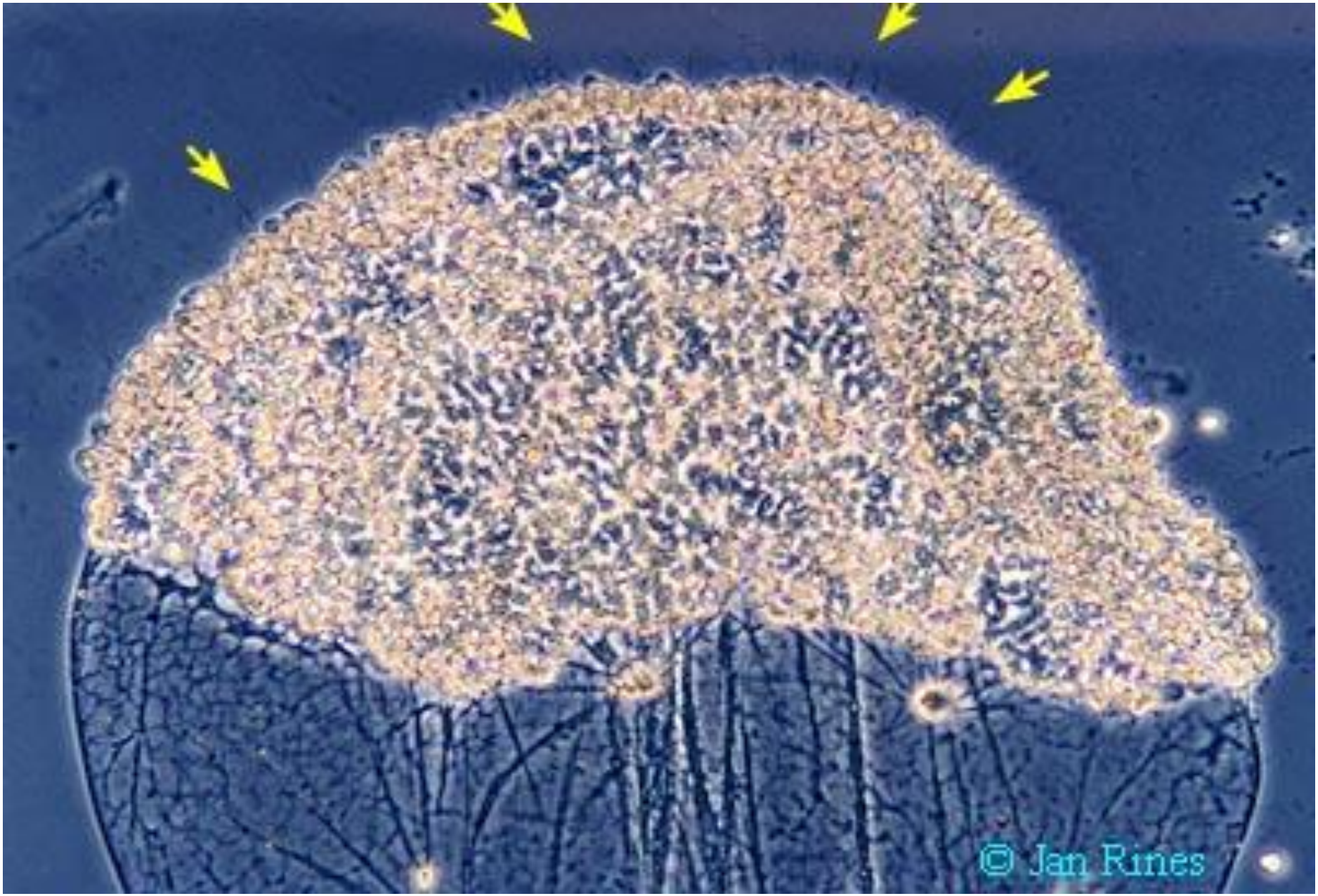
Noctilucales (M)

bioluminescence

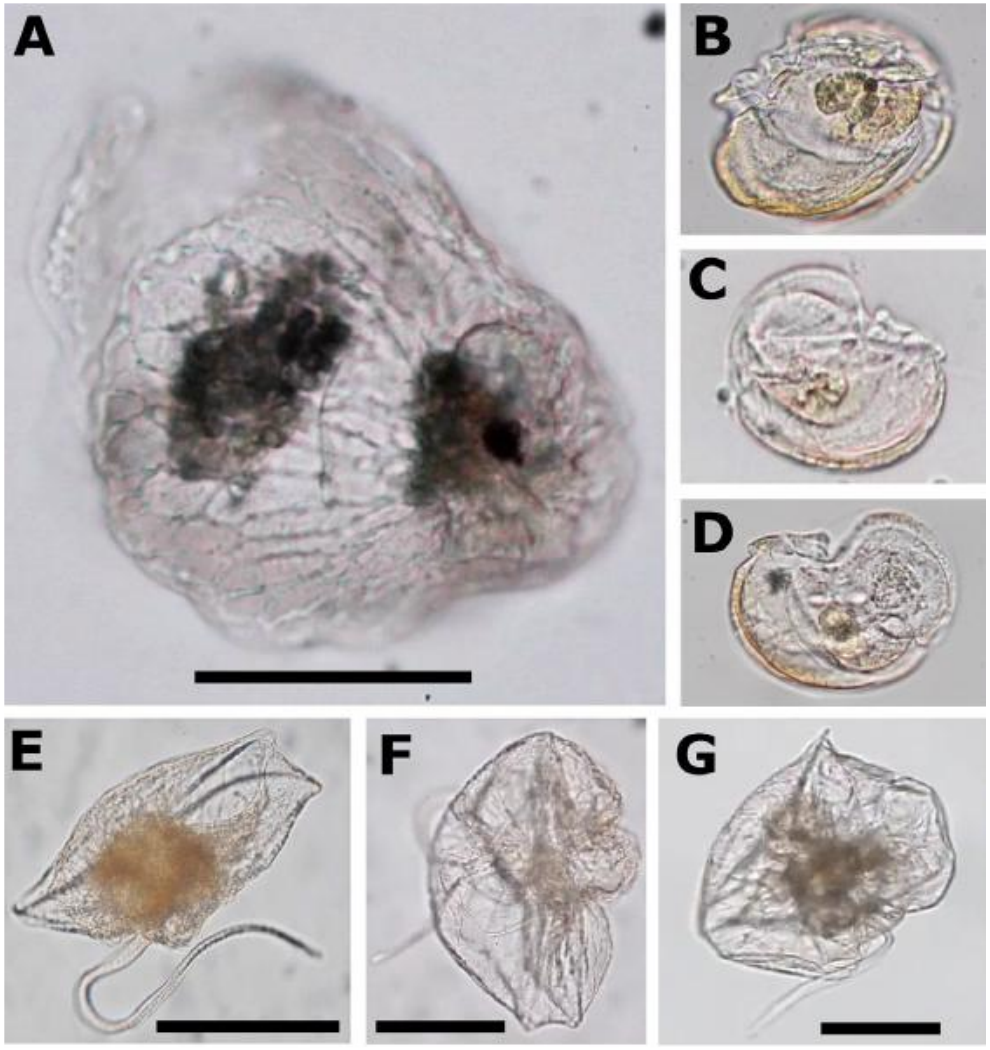


Noctilucales (M)

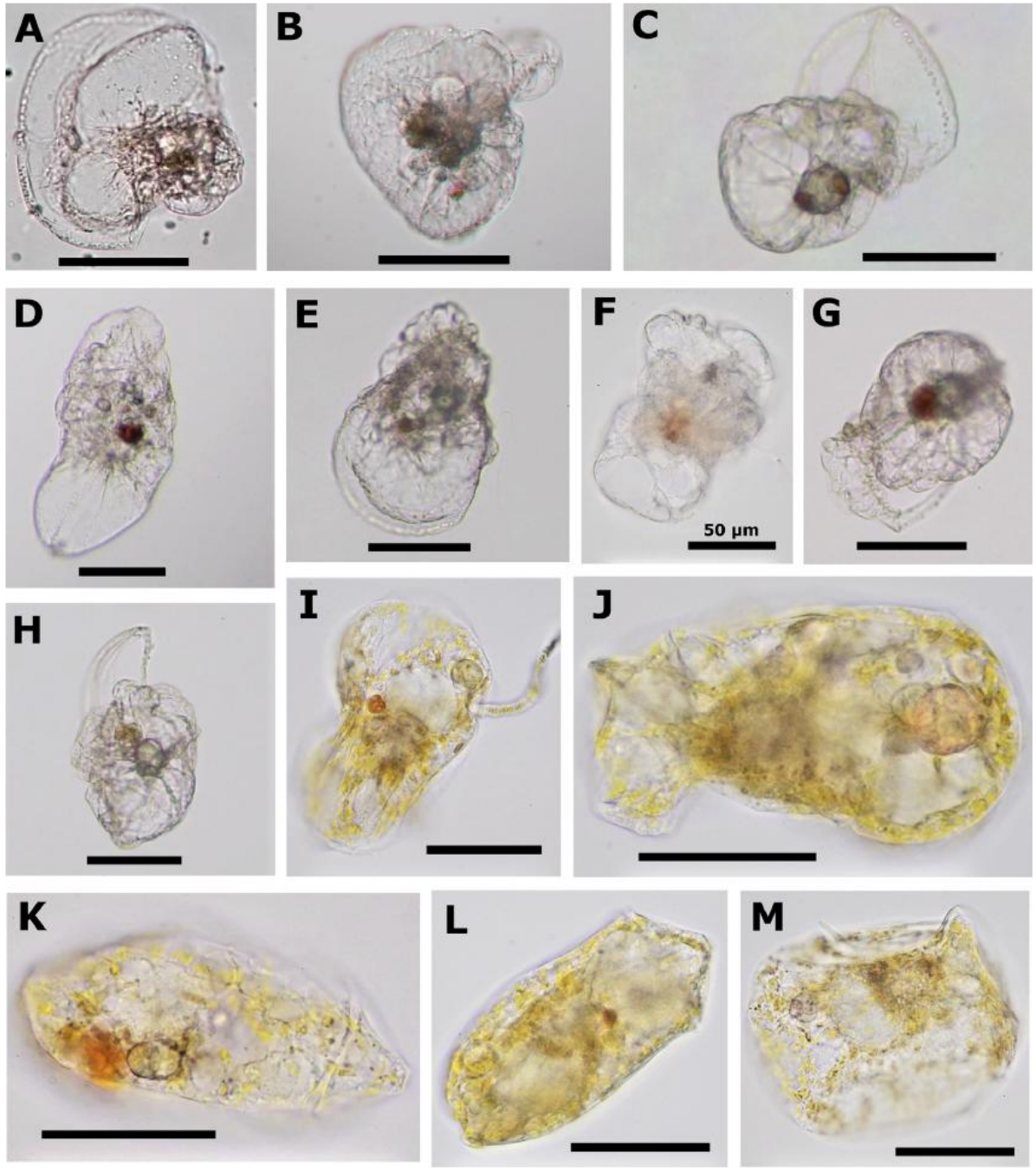
zoosporogenesis



Noctilucales (M)



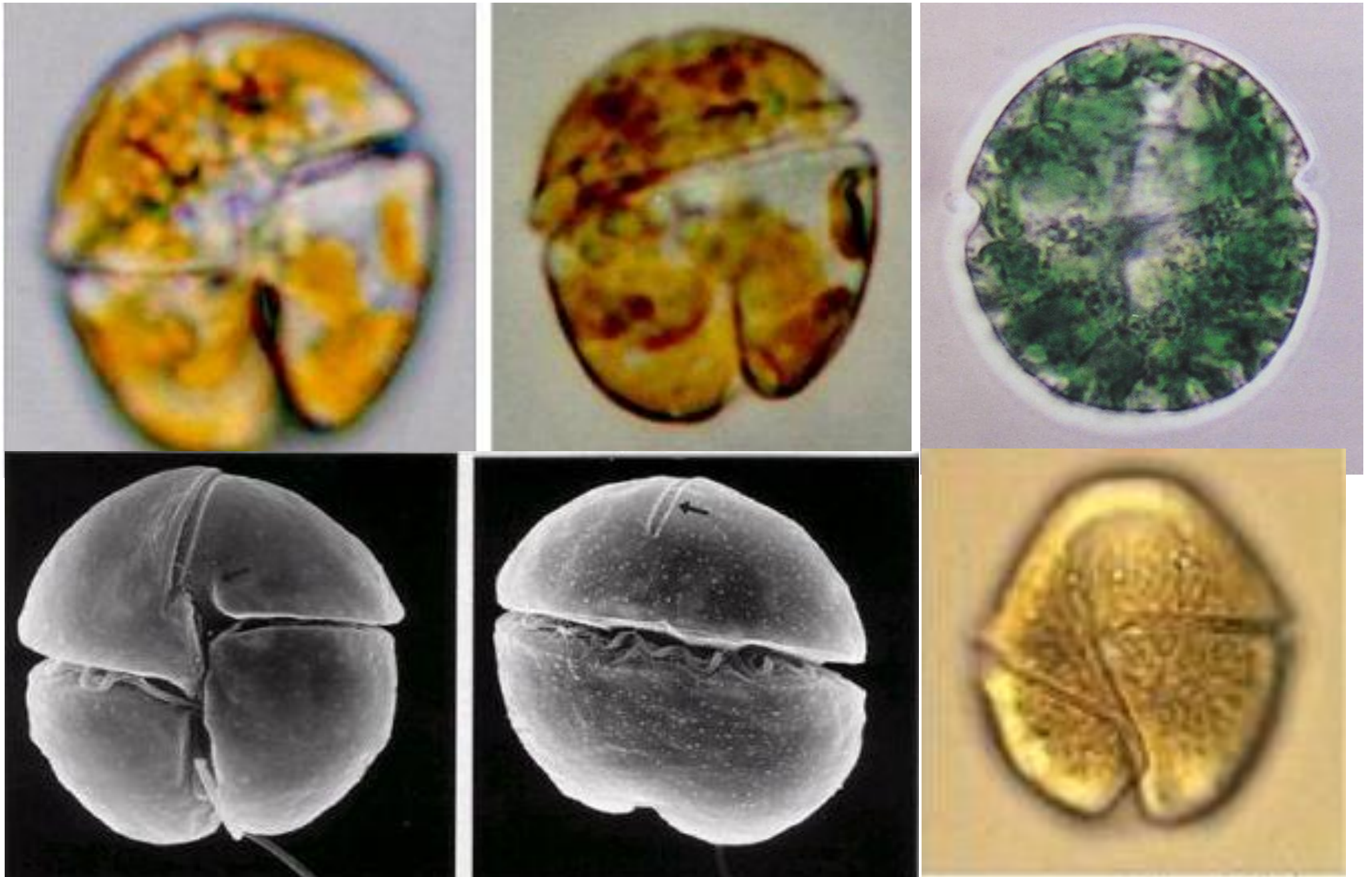
Fabadinium



Kofoidinium, Spatulodinium

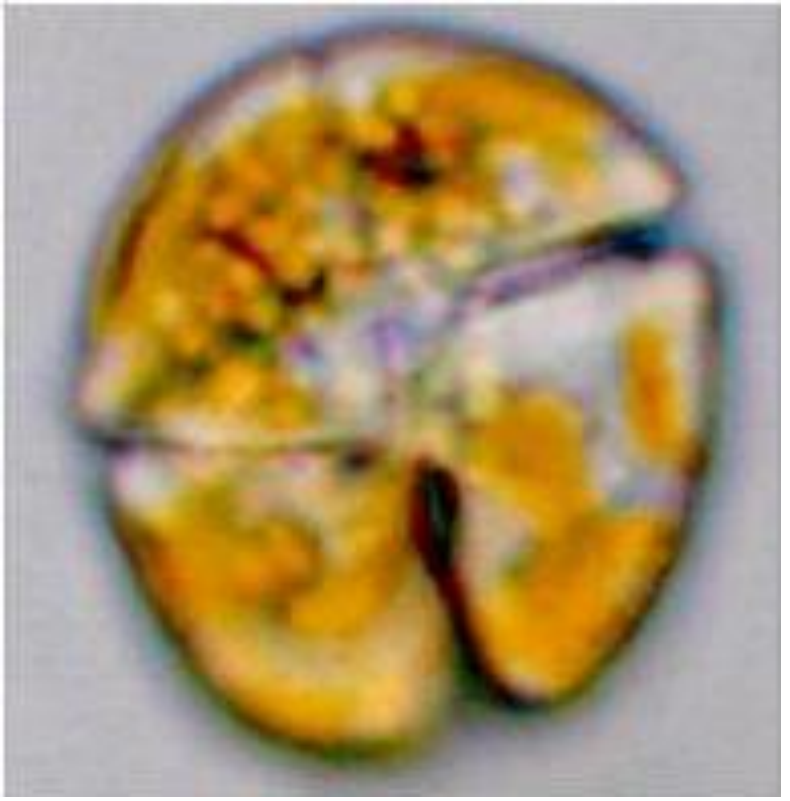
Gymnodiniales

- unarmored dinoflagellates

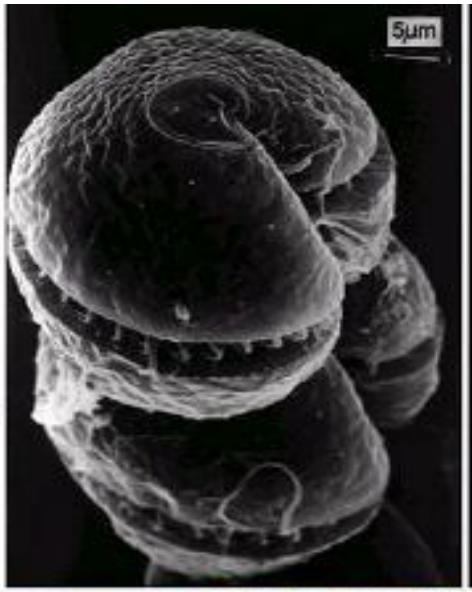


Gymnodinium

- free-living flagellates, sulcus + cingulum
- dorsiventrally flattened cells without visible plates
- autotrophic and heterotrophic species
- freshwater and marine



Gymnodinium (M)



***Gymnodinium catenatum* Graham**

saxitoxin - PSP !

Microphoto by Yasuwo Fukuyo and Haruyoshi Takayama

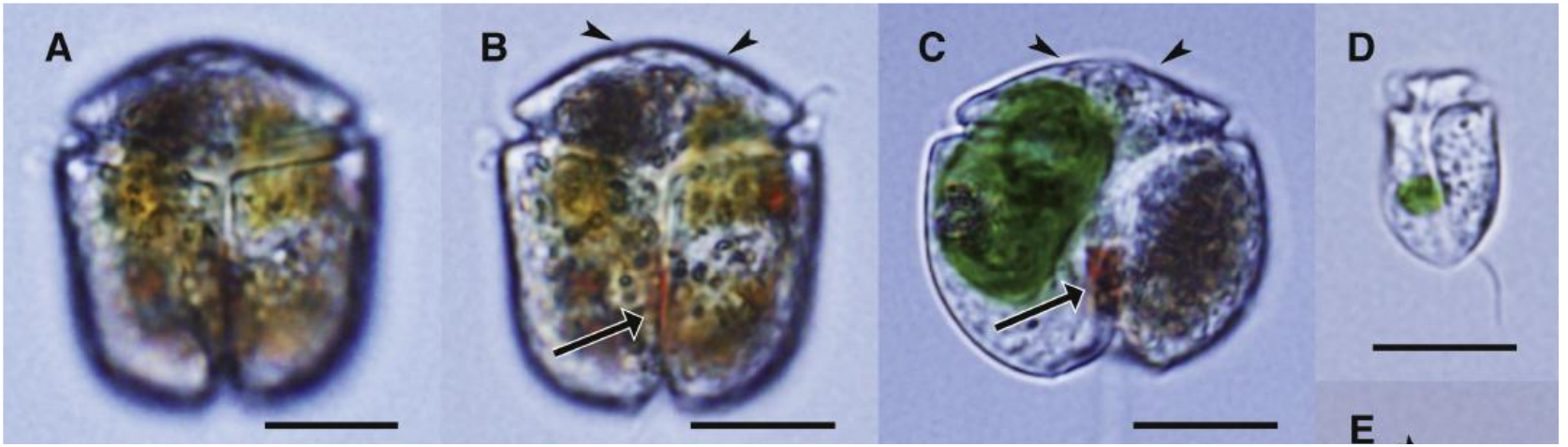
WESTPAC-HAB T0006

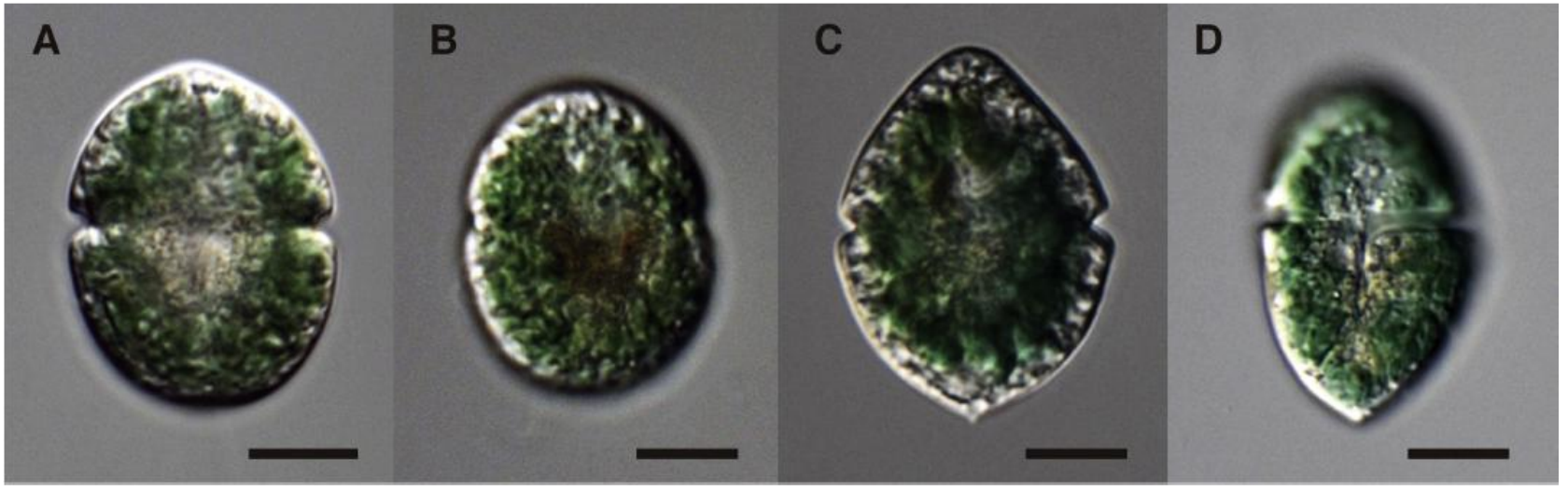
Gymnodinium (F)

G. fuscum

Nusuttodinium (F, M)

- kleptoplastidic = chloroplasts derived from endosymbiotic, periodically acquired and temporarily retained cryptomonads



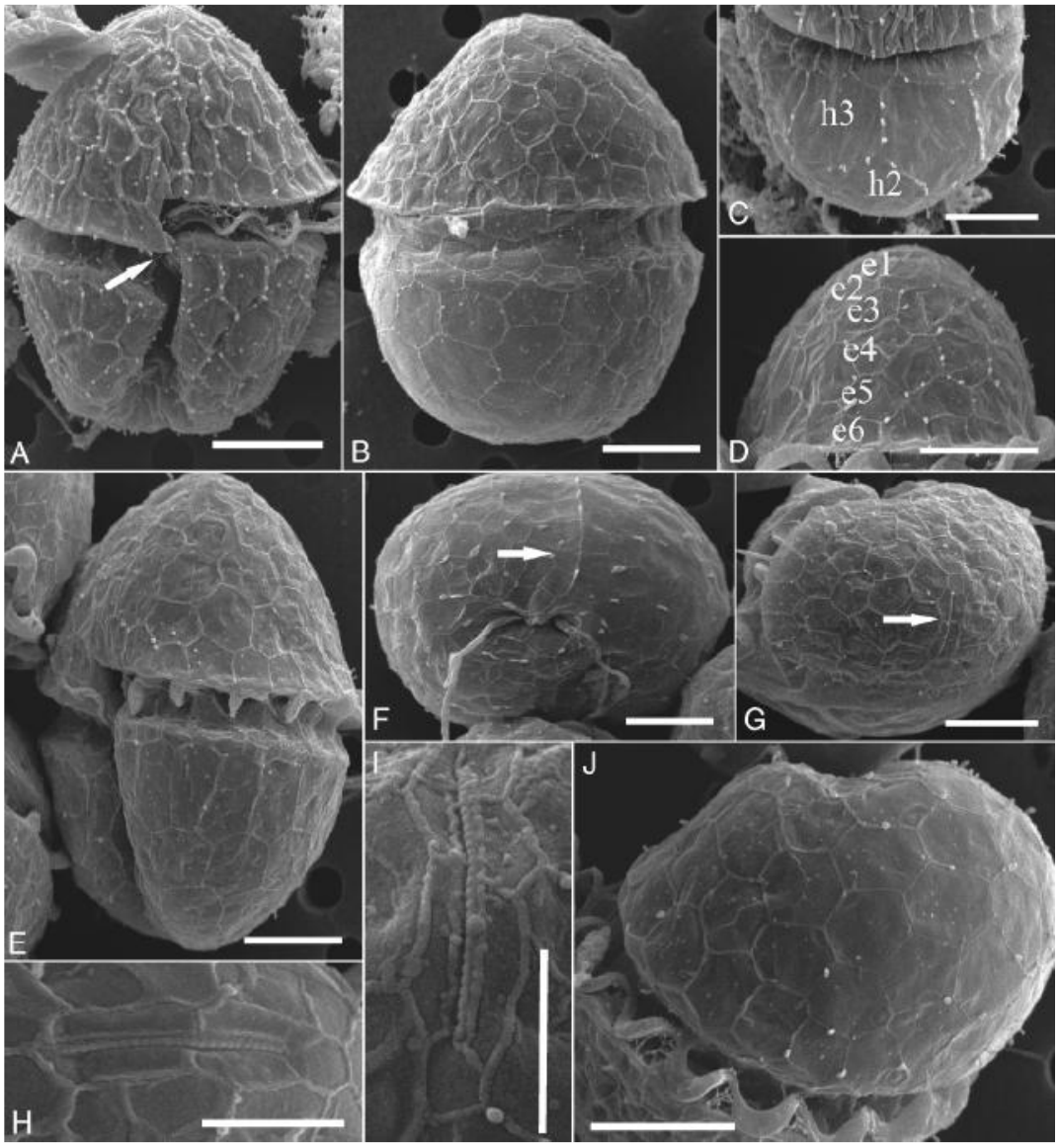


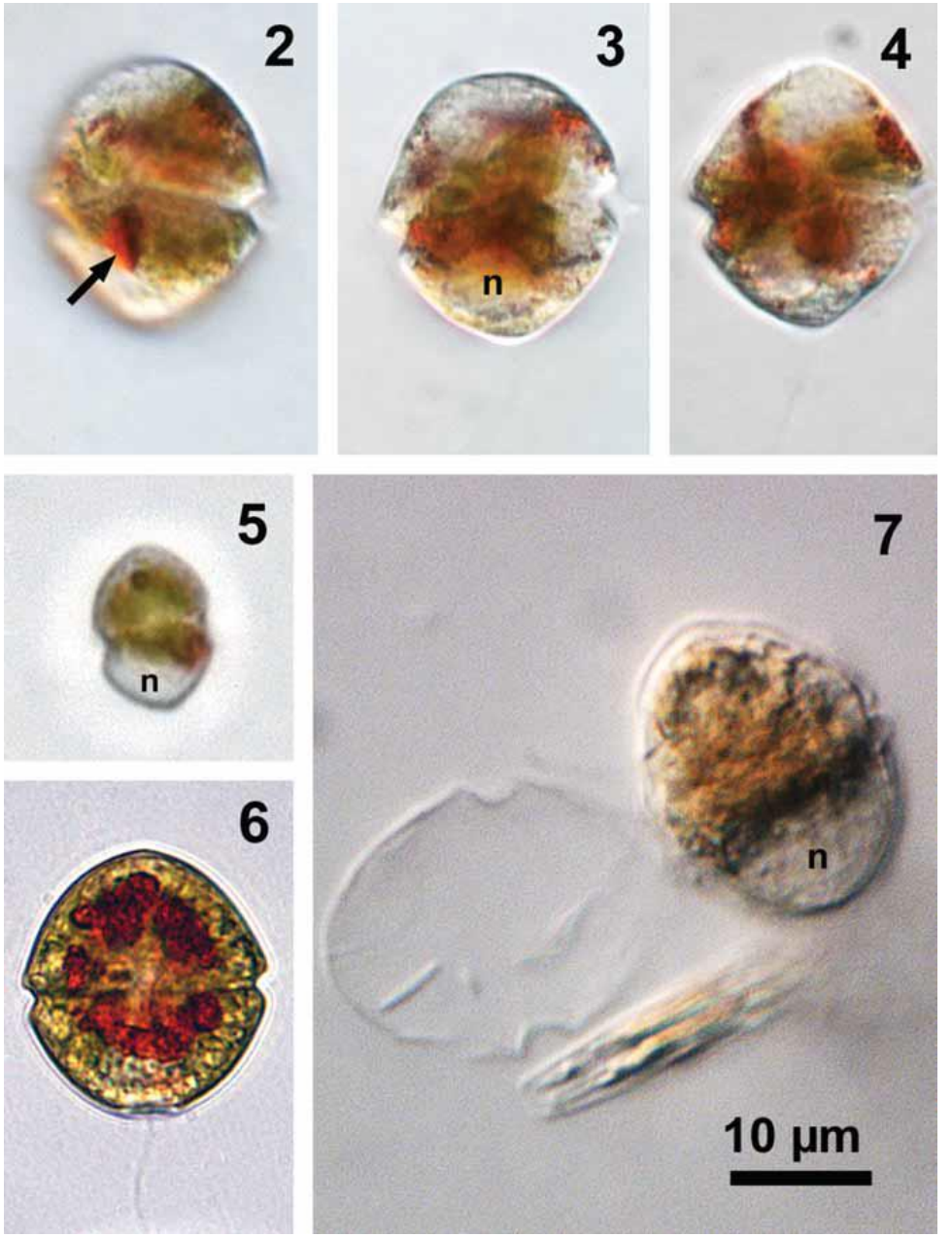
Nusuttodinium aeruginosum

Woloszynskia, Tovelia (F)

- a number of thin, hexagonal plates visible only on empty cells

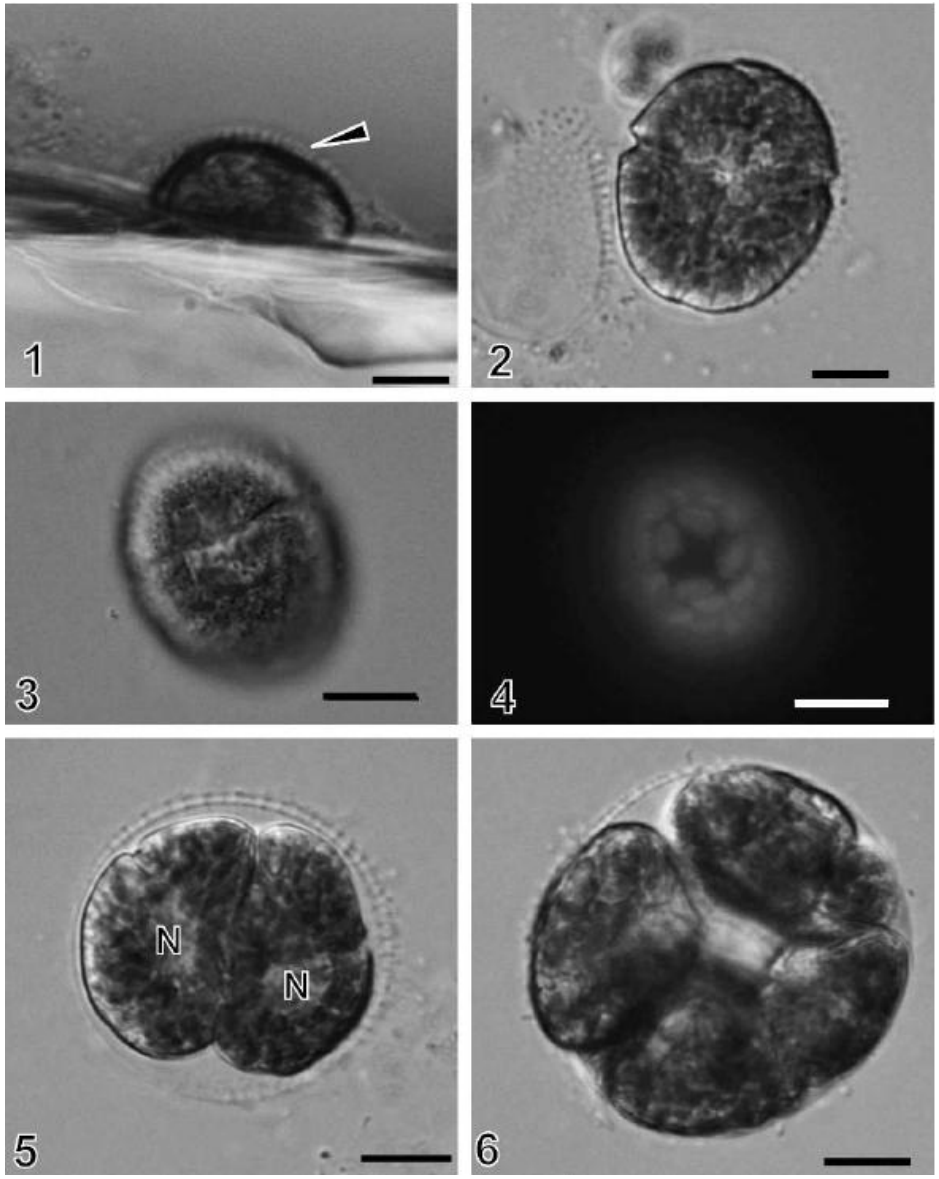
Tovelia sanguinea

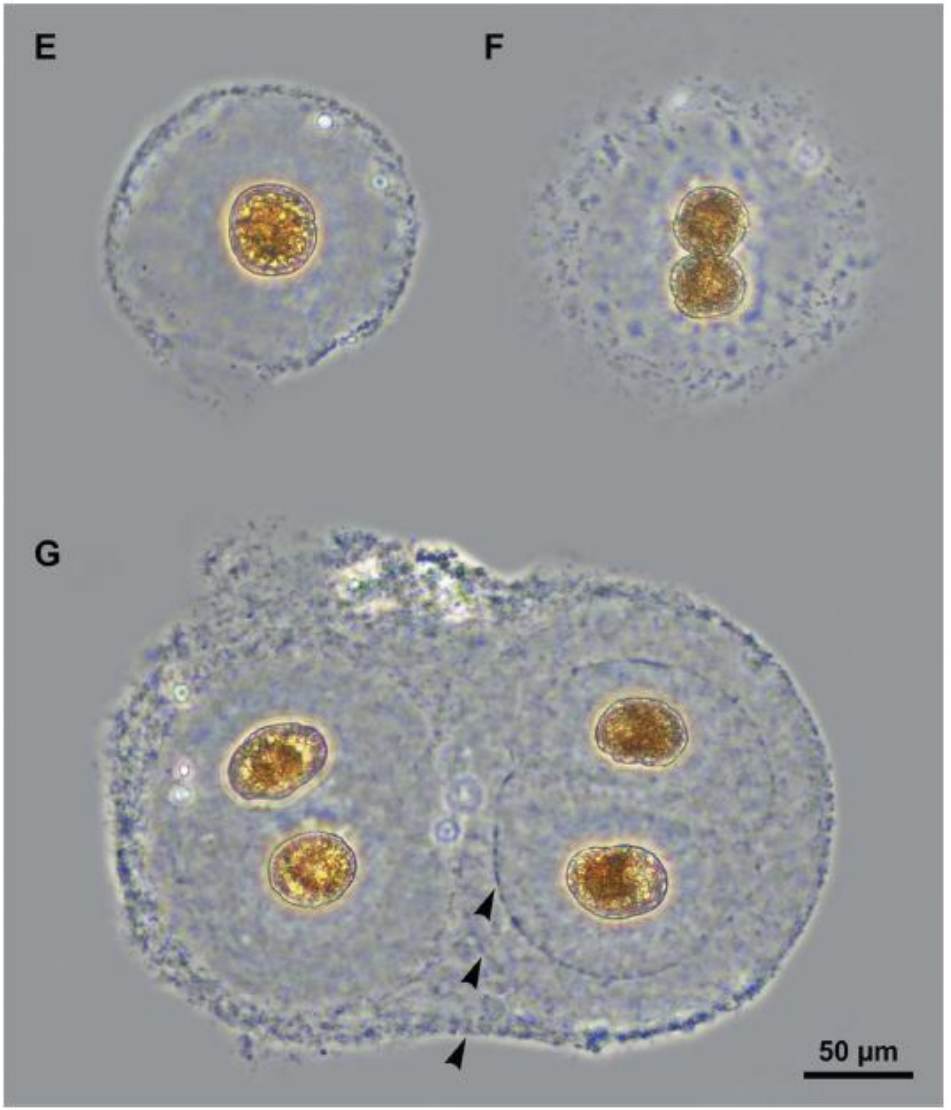




Spiniferodinium (F, M)

- a unique transparent, spiny, helmet-shaped cell covering, termed the ‘helmet shell’

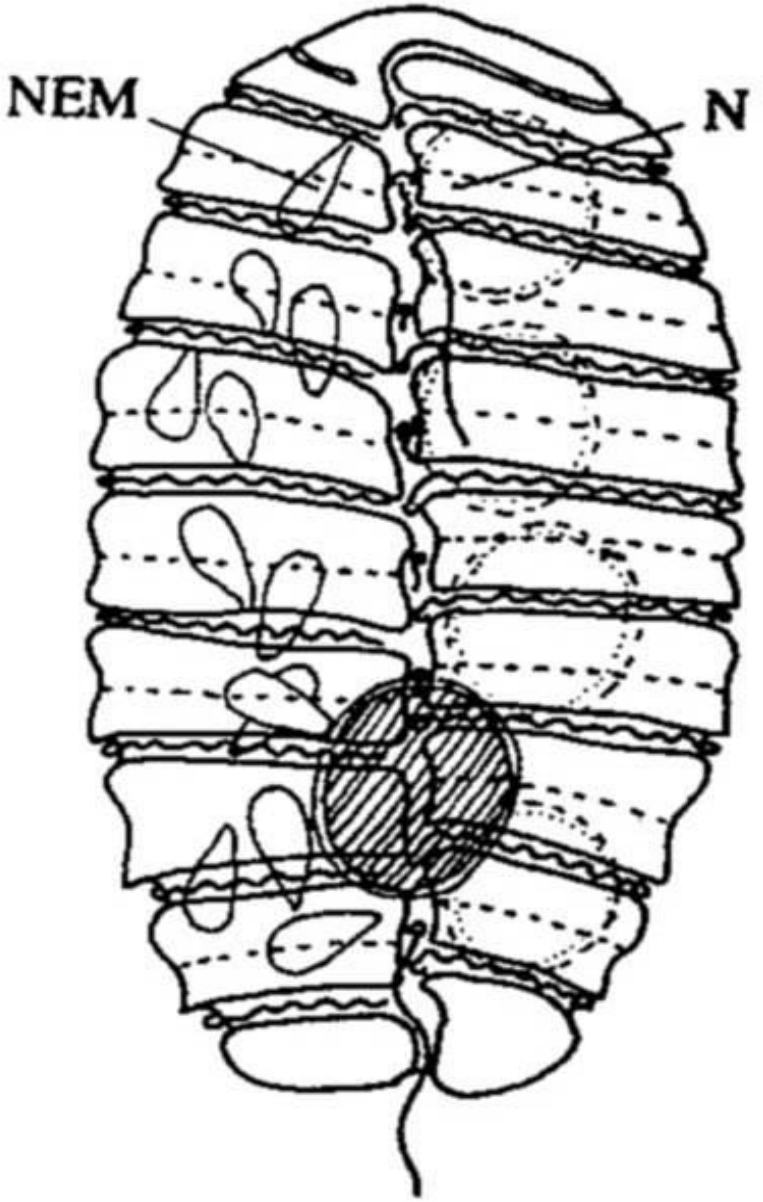


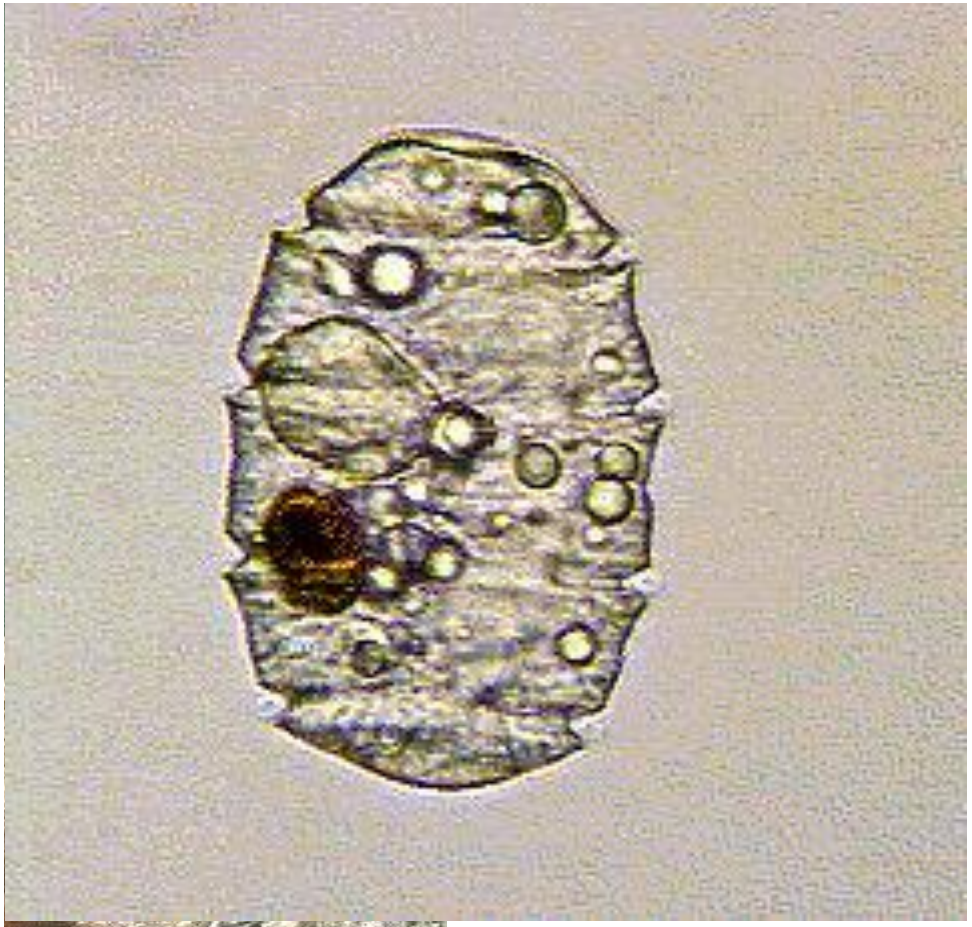


Spiniferodinium limneticum

Polykrikos, Phaeopolykrikos (M)

coenocytic organisation

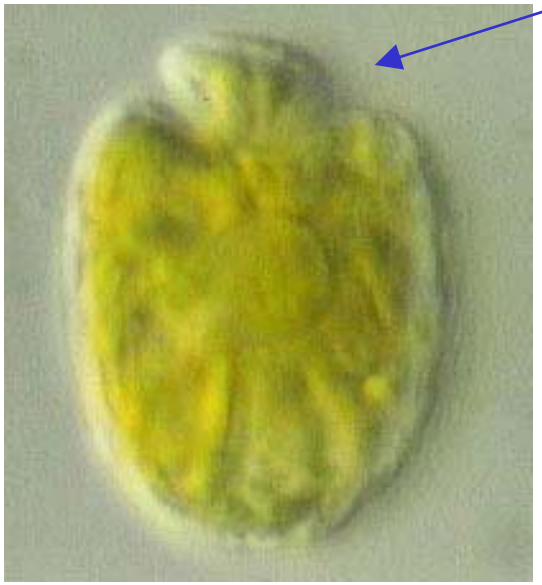




Polykrikos schwartzii

Amphidinium (F, M)

conspicuously small epitheca



Amphidinium carterae

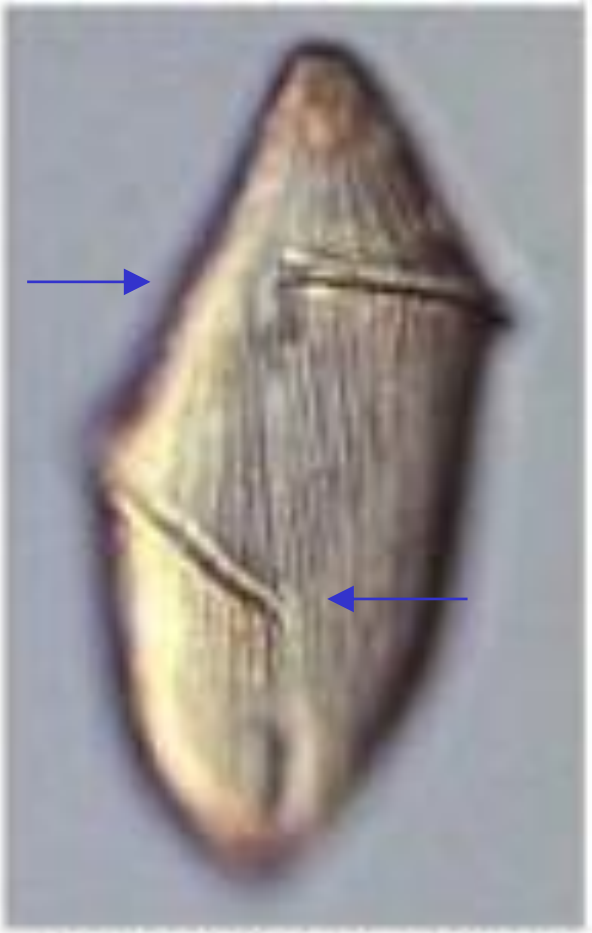
Amphidinium operculatum

ciguatoxin - CFP !

Gyrodinium (F, M)

strongly displaced cingulum

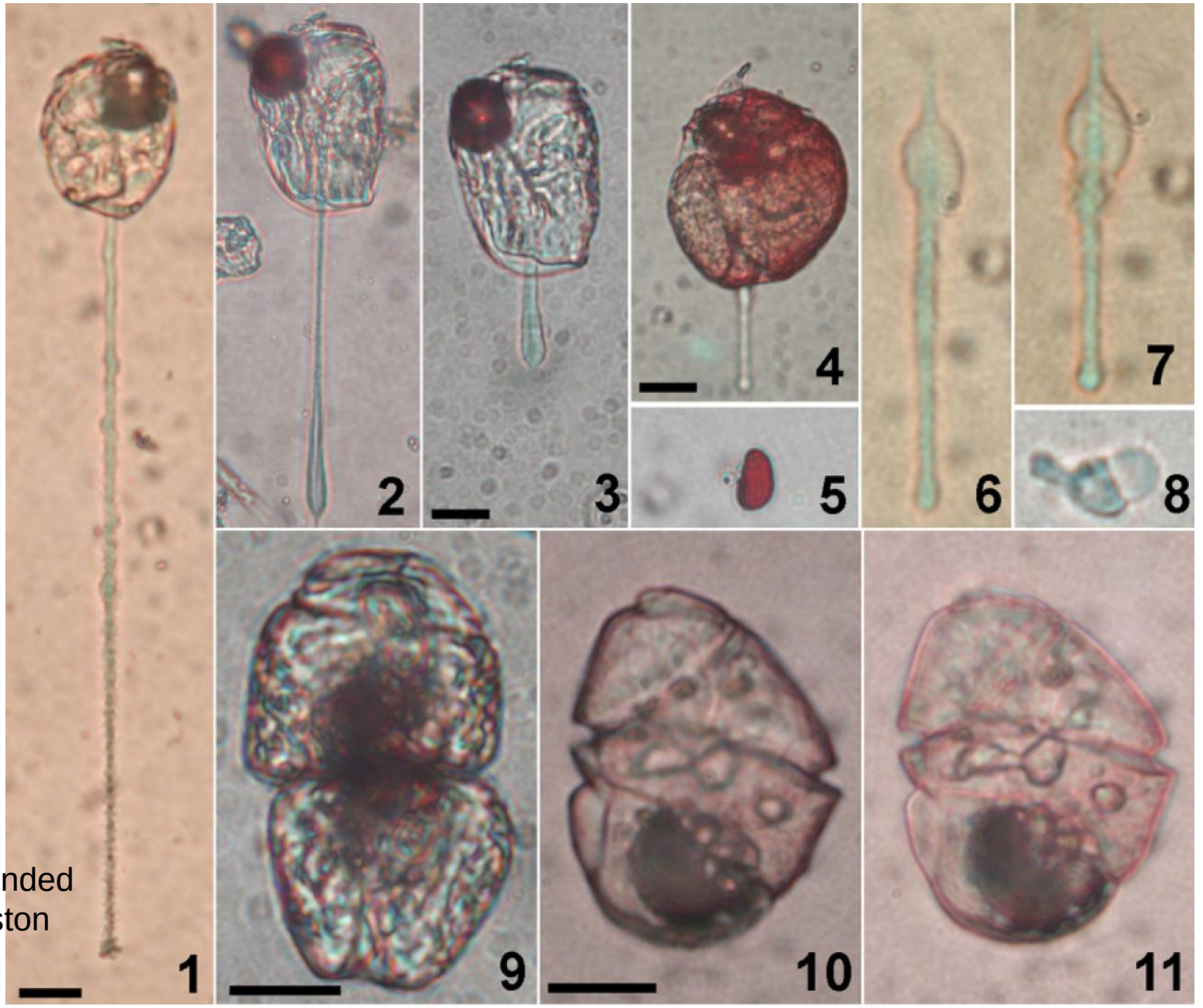
Gyrodinium instriatum



Gyrodinium spirale

Erythropsidinium, Warnowia (M)

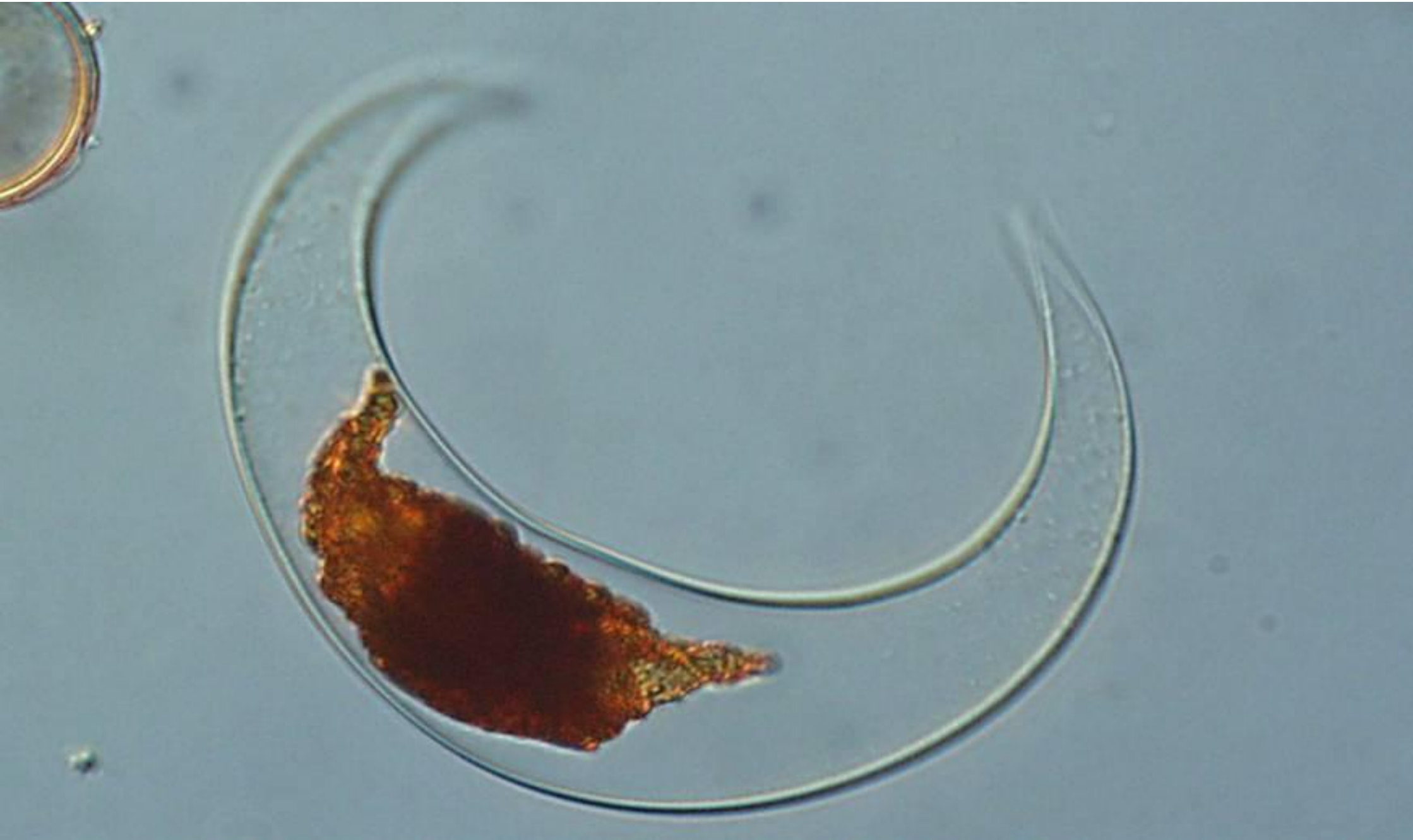
complex organells:
- **ocelloid**: a photo-receptor system with cornea, lens, and pigment cup-like structures
- **piston**: an exten-sible appendage for locomotion and prey location



extended piston

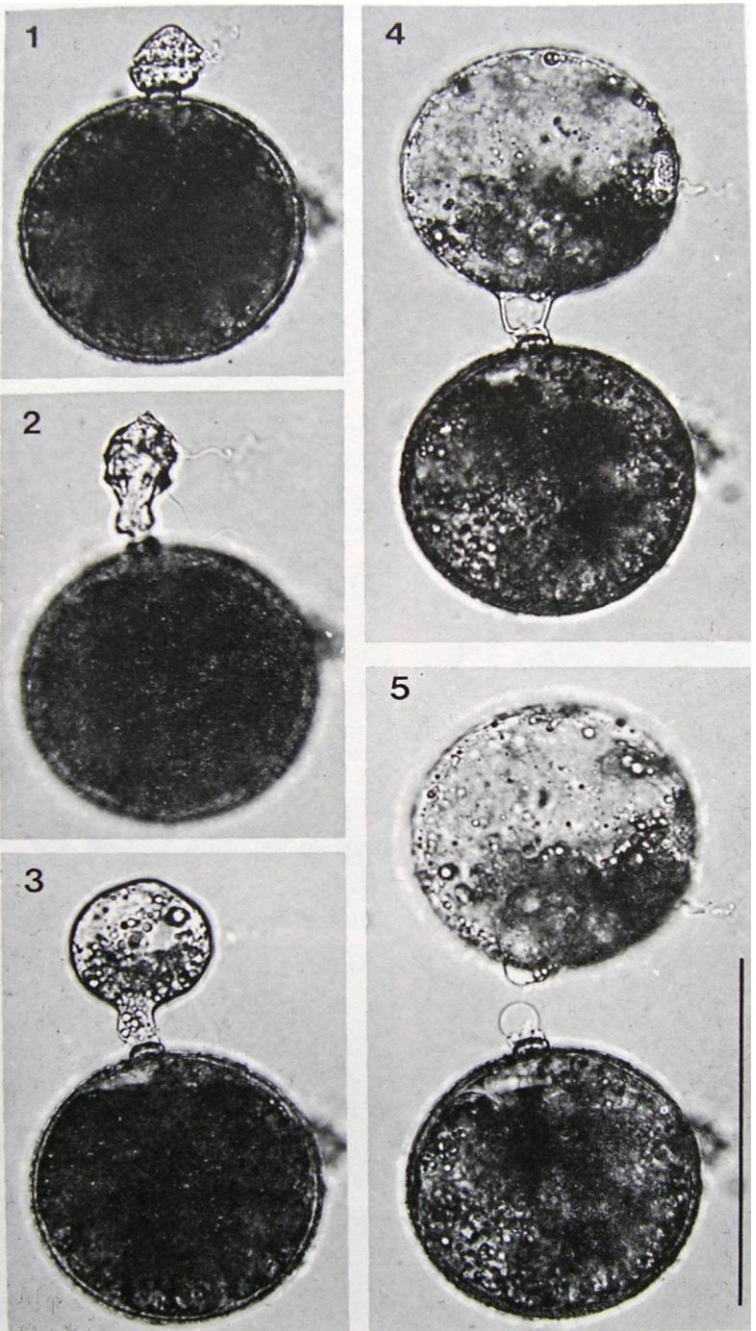
Dissodinium pseudolunula (M)

parasite on crustacean eggs



Dissodinium pseudolunula (M)

parasite on crustacean eggs

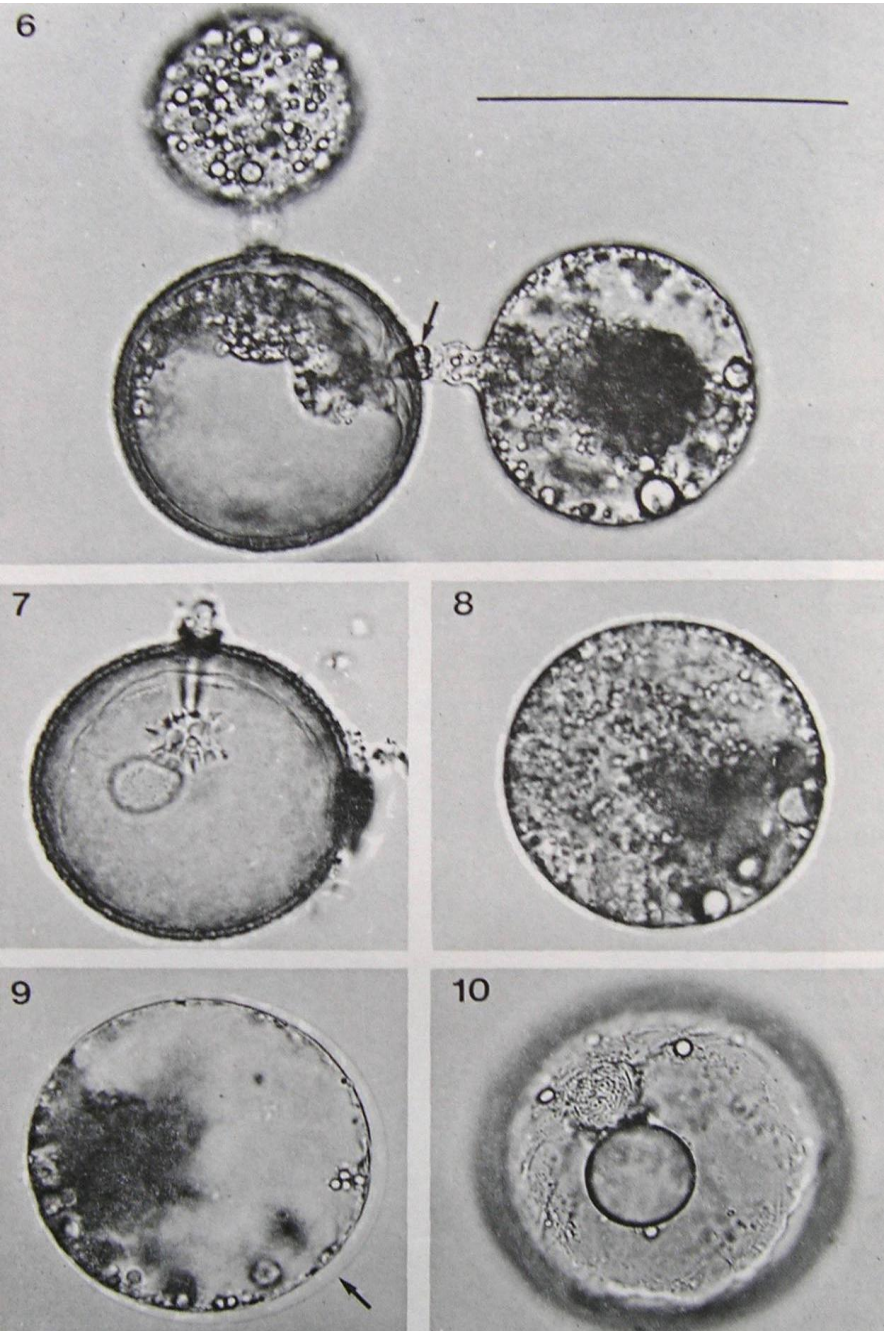


1 – dinospore is attaching the cell

5 – trophont separation (after 90 min)

Dissodinium pseudolunula (M)

parasite on crustacean eggs



1 – dinospore is attaching the cell

5 – trophont separation (after 90 min)

6 – several trophonts on one cell

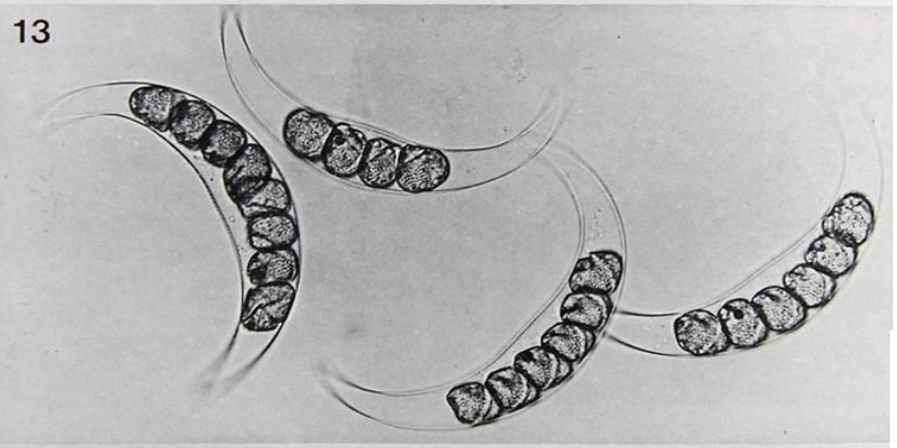
10 – primary cyst

12 – secondaty cyst

13 – secondary cysts with mature dinospores

Dissodinium pseudolunula (M)

parasite on crustacean eggs



1 – dinospore is attaching the cell

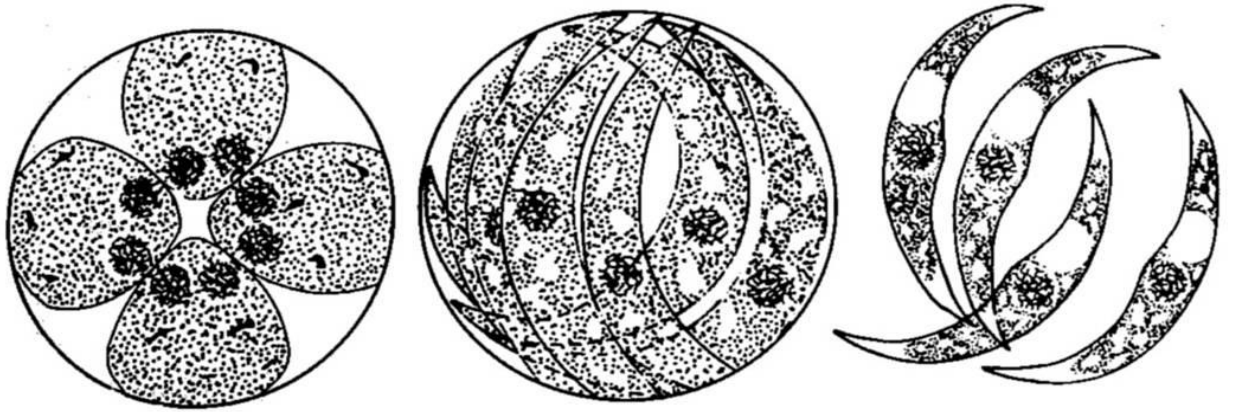
5 – trophont separation (after 90 min)

6 – several trophonts on one cell

10 – primary cyst

12 – secondaty cyst

13 – secondary cysts with mature dinospores

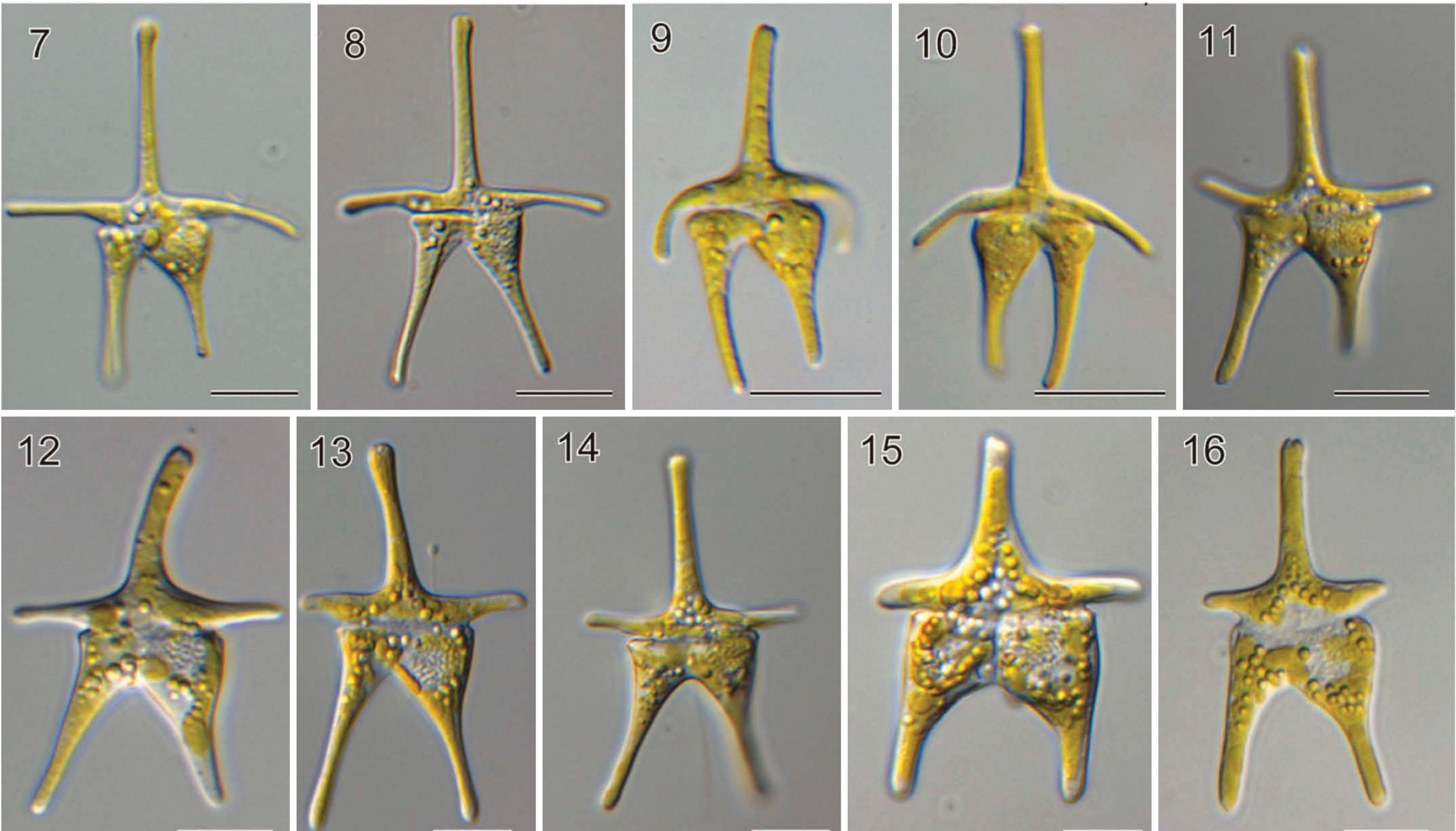


Karlodinium (M)

- massive blooms in coastal waters, toxin production
- paralysis and mortality of finfish, copepods, nematods, and even polychaete-larvae

Asterodinium (M)

- star-shaped, unarmored dinoflagellate from Japan



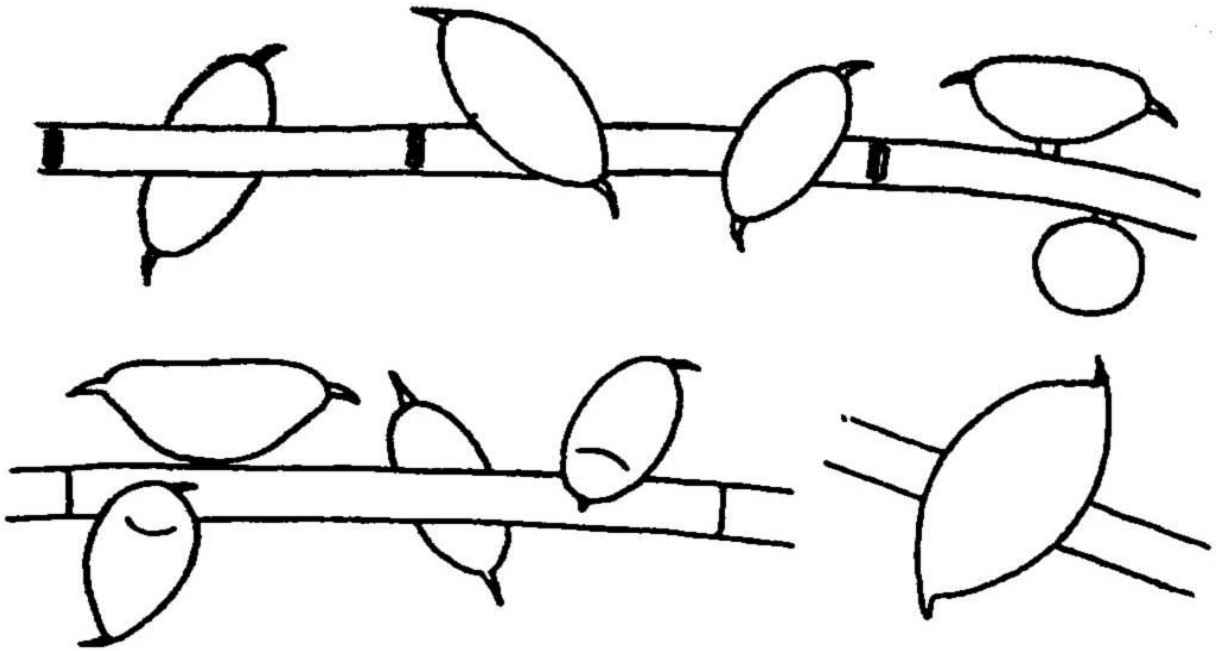
Akashiwo sanguinea (M)

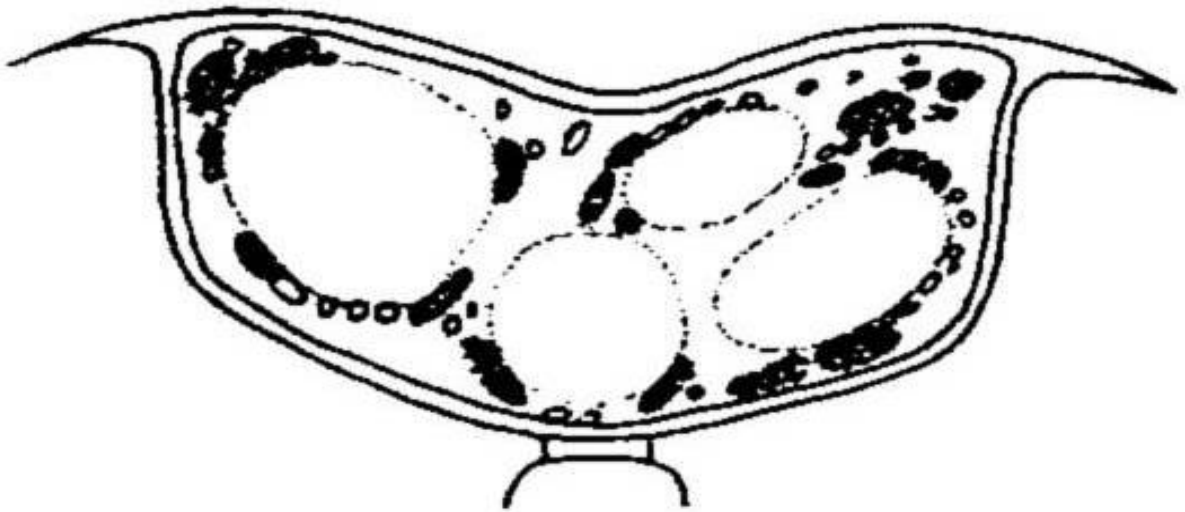
- a distinct lineage unrelated to any order
- forming blooms that result in red tides not harmful to humans

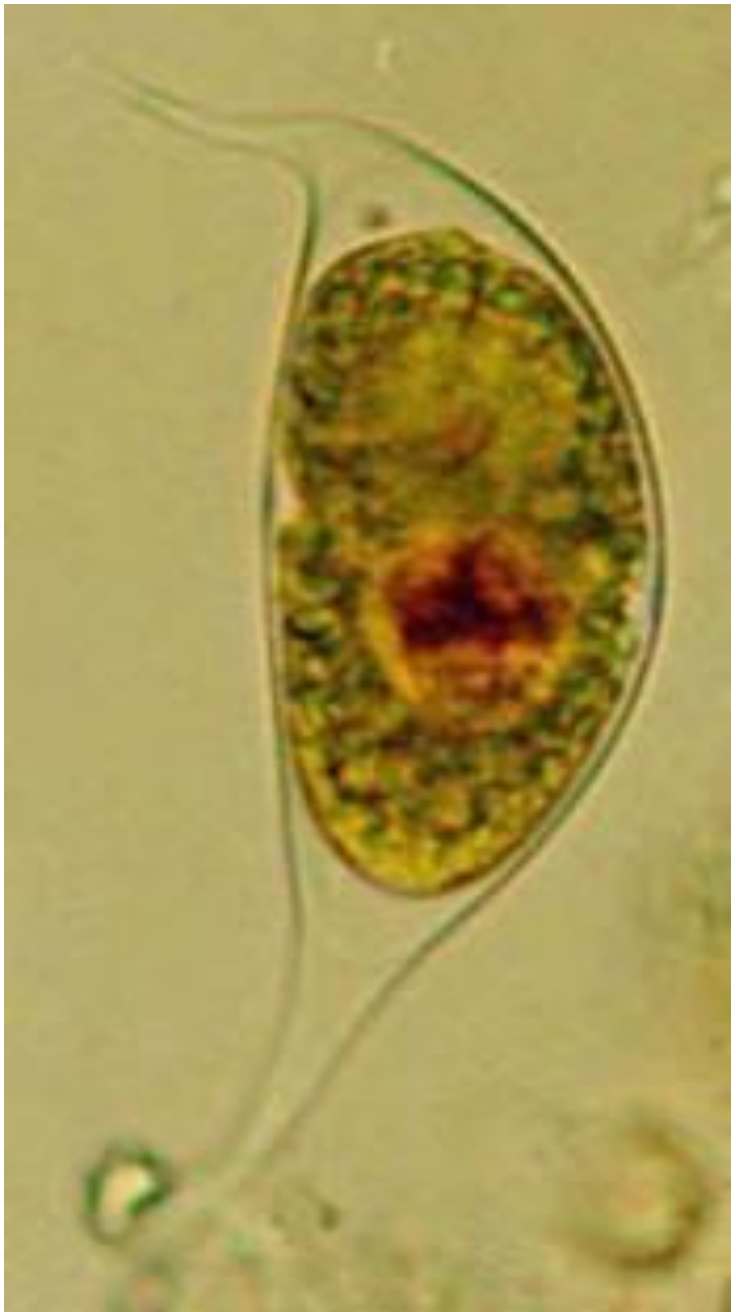
Phytodiniales

- coccoid dinoflagellates
- epifytes on filamentous algae

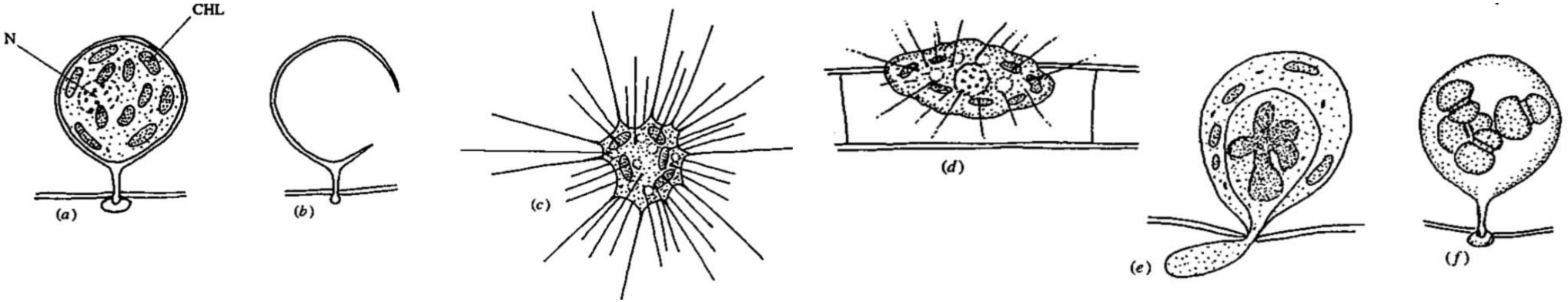
Dinococcus (F)

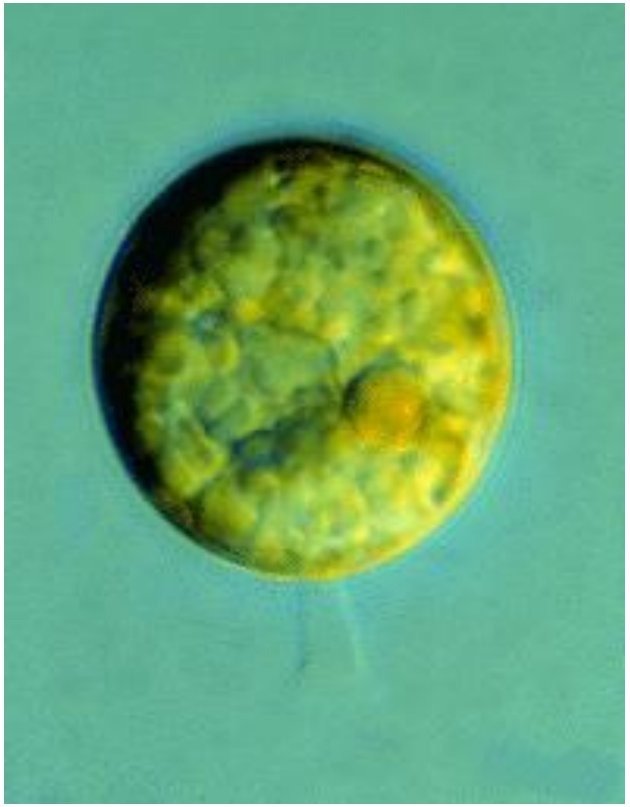


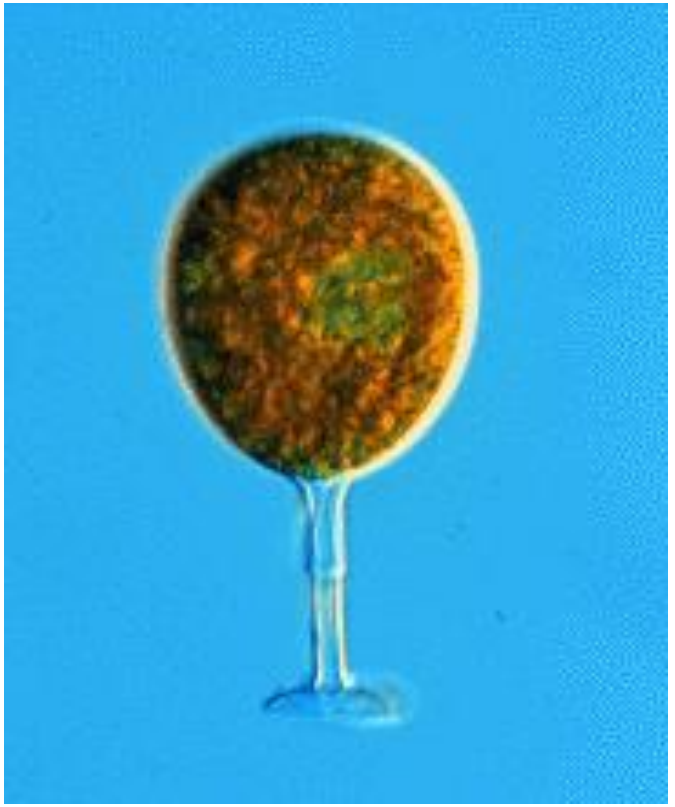




Stylodinium (F)

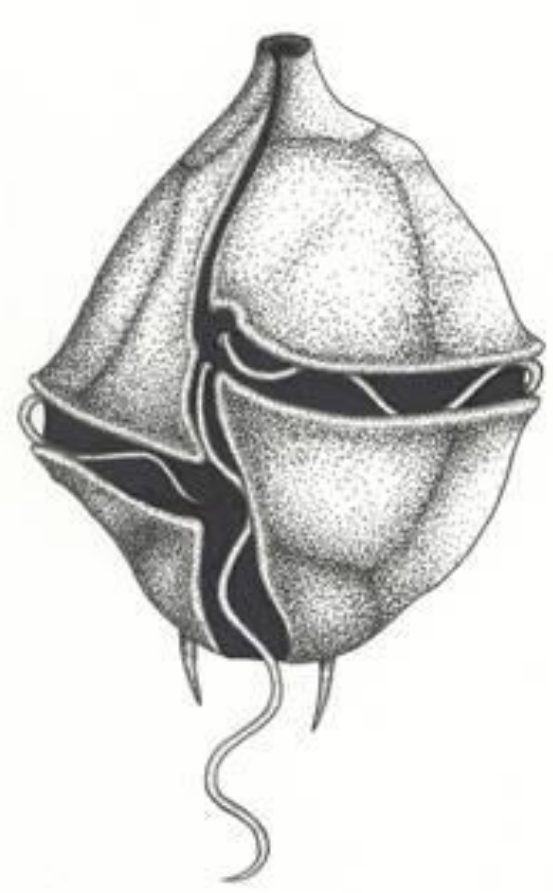


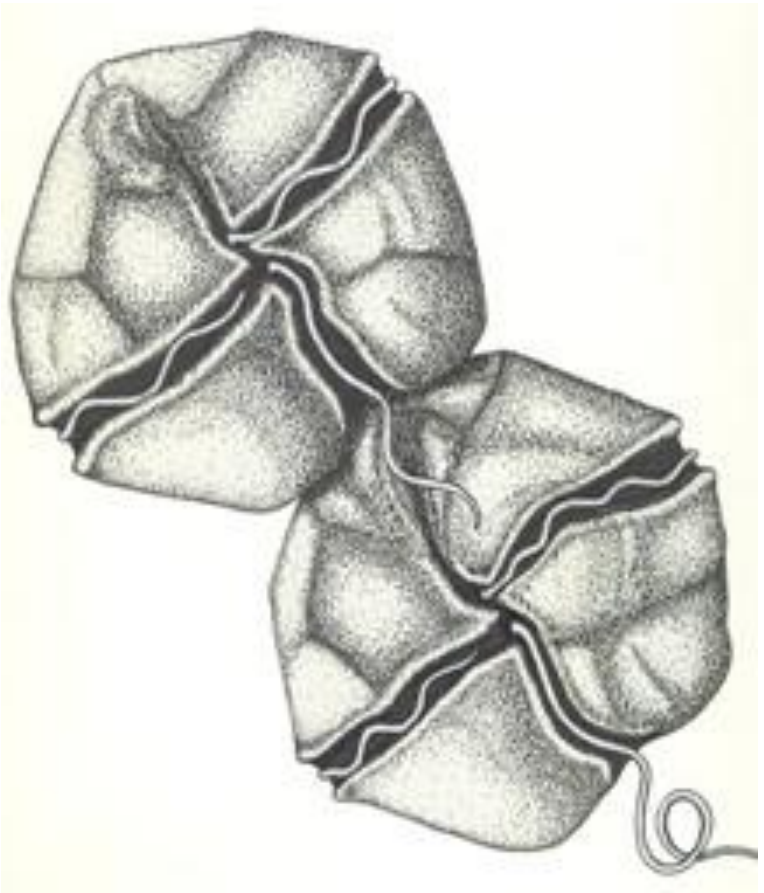


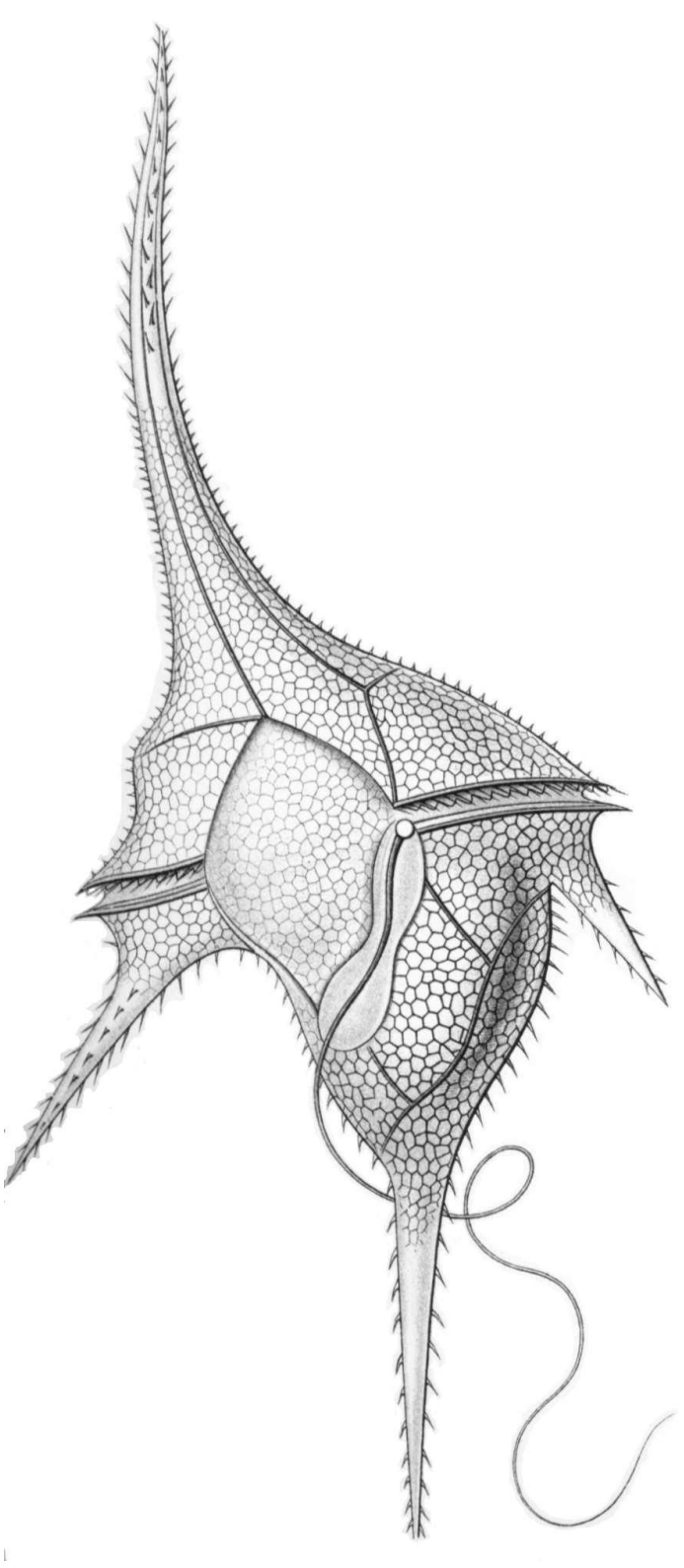


Gonyaulacales

- armored flagellates
- distinguished from the Peridiniales mostly by the arrangement and number of the thecal plates
- the first apical plate assymetrical

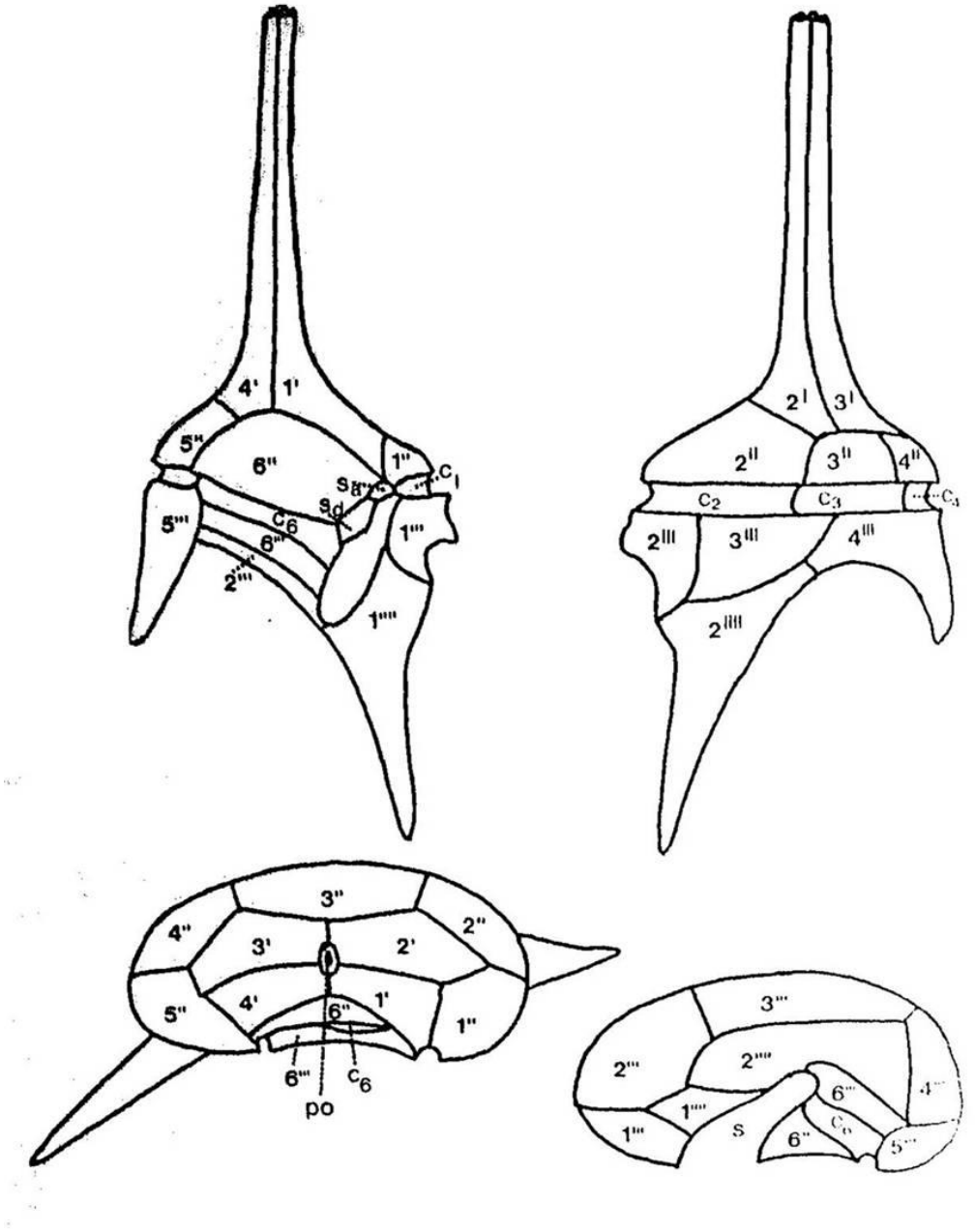






Ceratium (F)

formula 4´, 5´´, 5´´´, 2´´´´



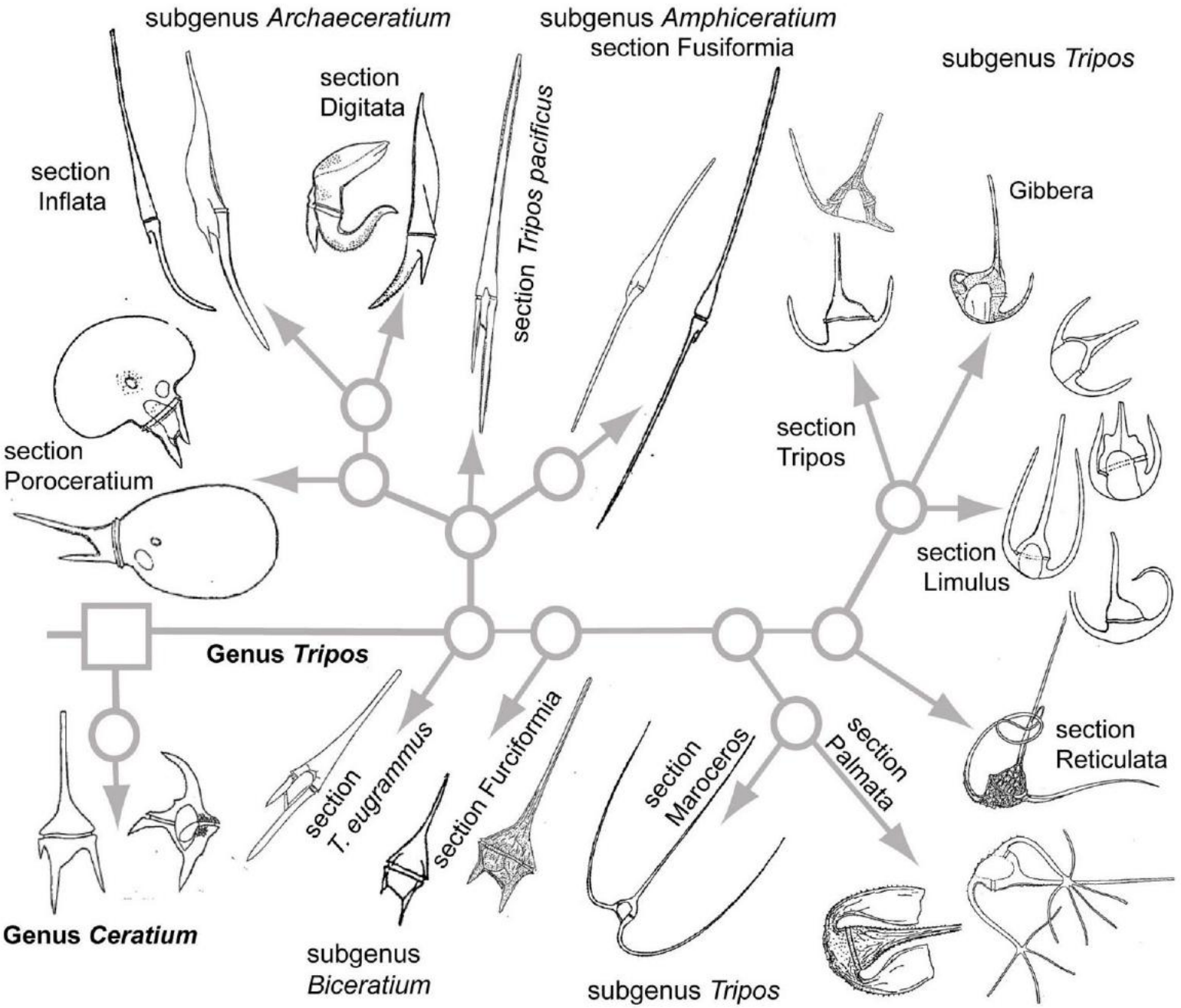
Ceratium (F)

Ceratium hirundinella

Ceratium cornutum

Tripos (M)

formula 4′, 5′′, 5′′′, 2′′′′



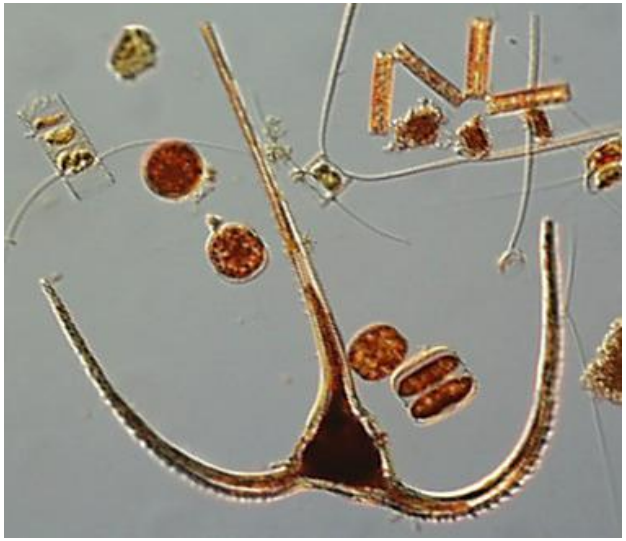
Tripos (M)

T. furca

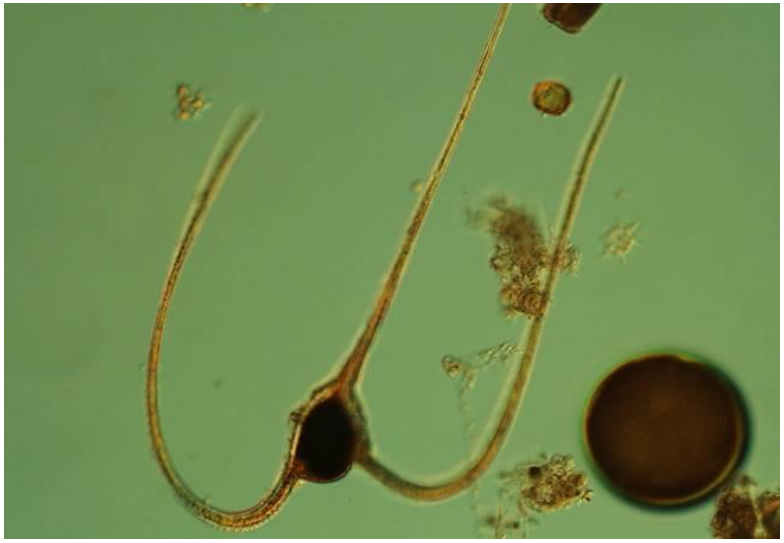
T. lineatus

T. fusus

T. muelleri



T. longipes



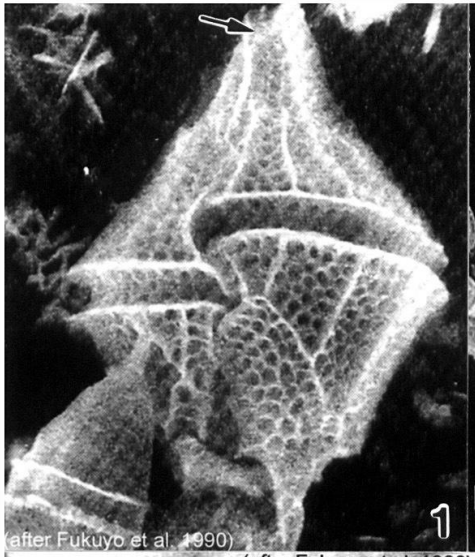
T. macroceros

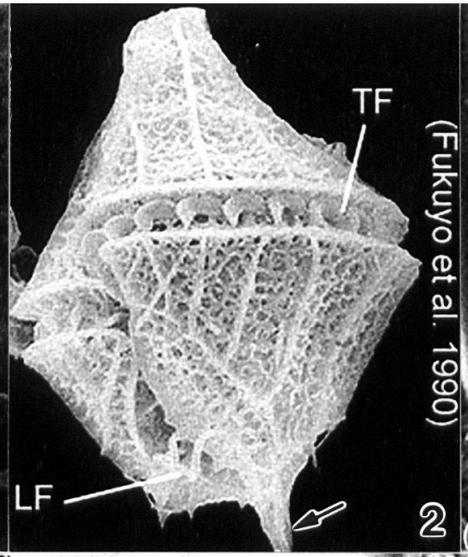
Tripos (M)

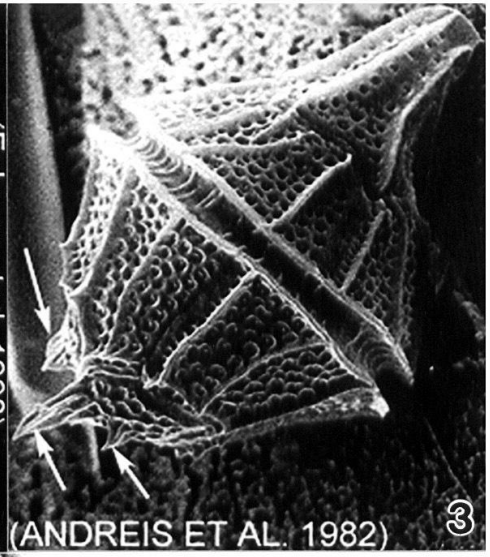

MONACO
2,20
CERATIUM RANIPES
PHYTOPLANCTON
1992
MUSÉE OCÉANOGRAPHIQUE

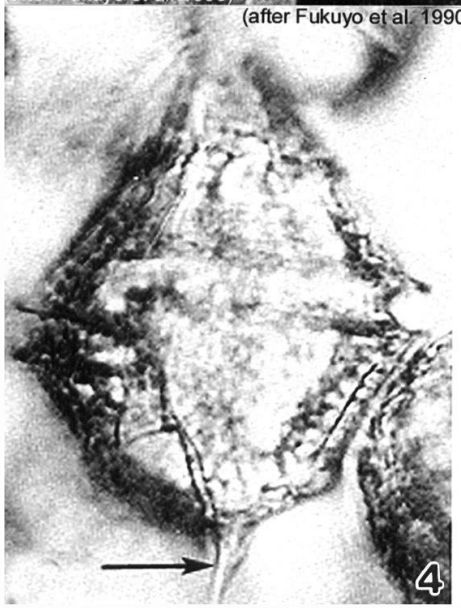
Gonyaulax (F, M)

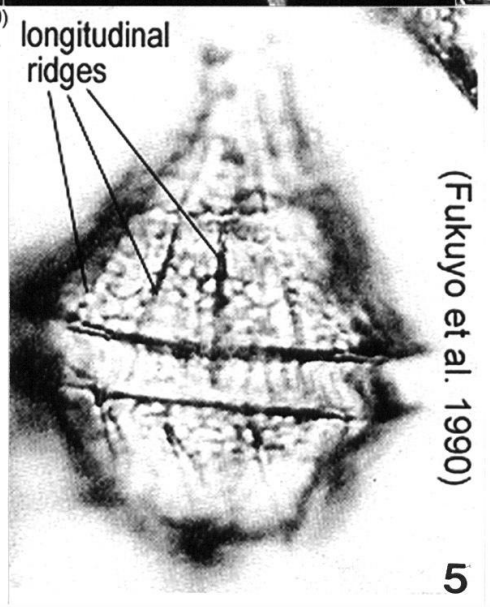
thick, ornamented plates, species determined according to the hypotheca morphology, hard to determine particular species

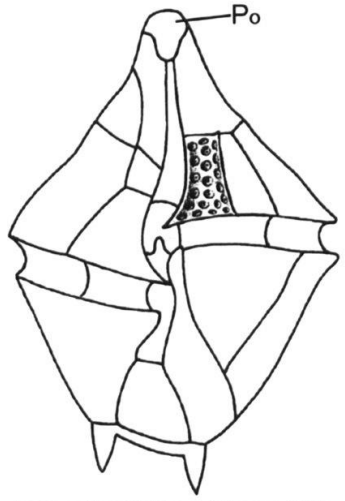


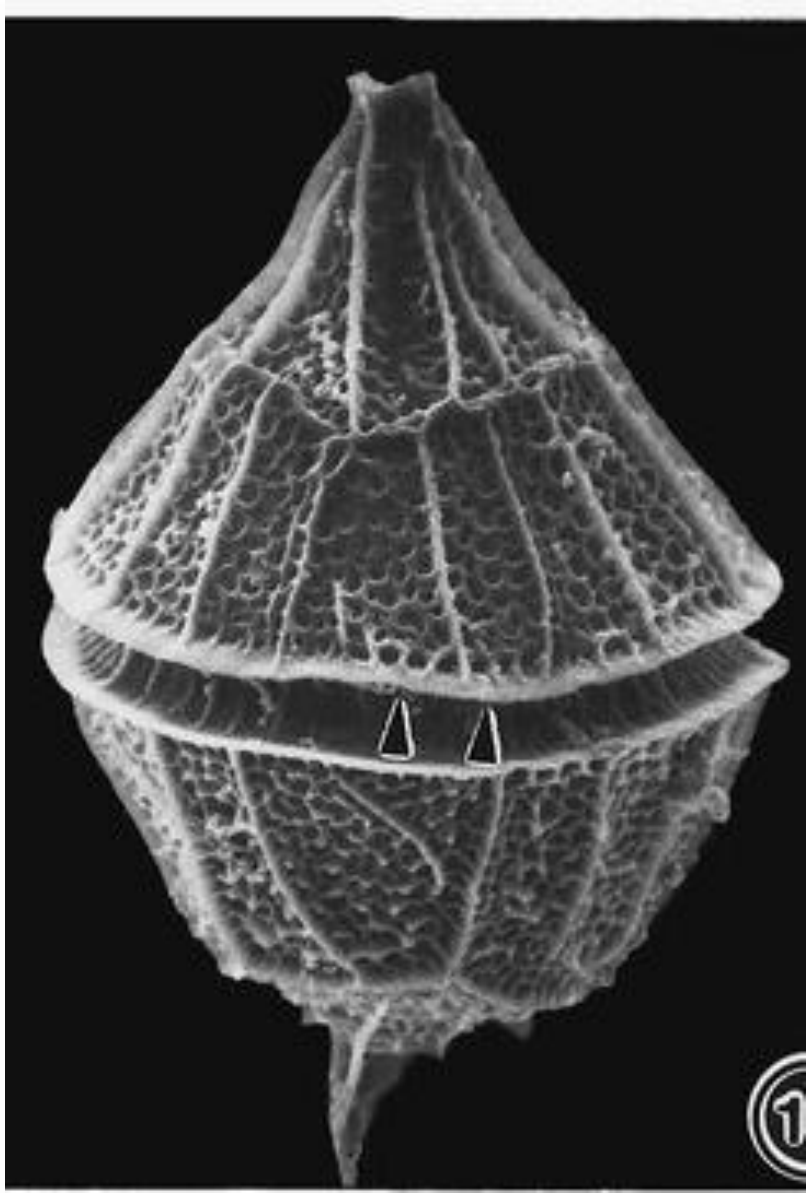






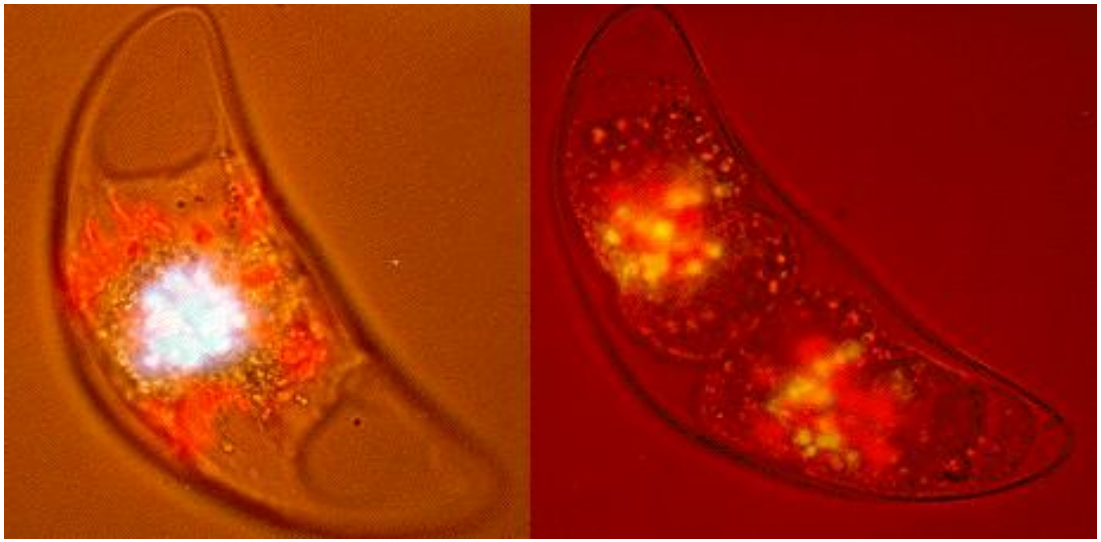


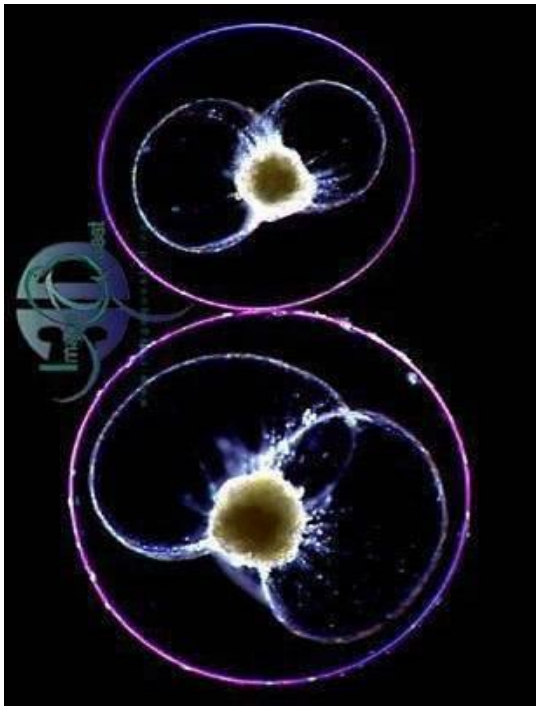


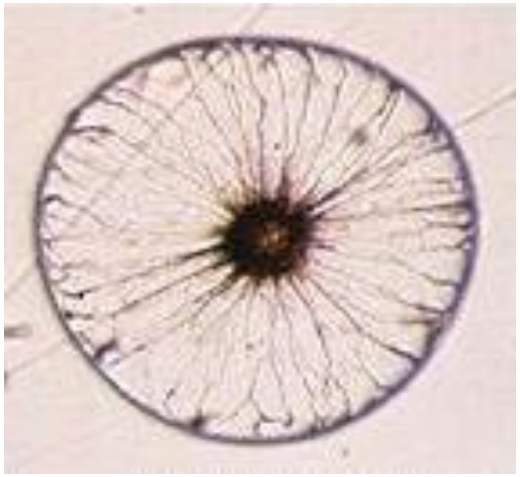


Pyrocystis (M)

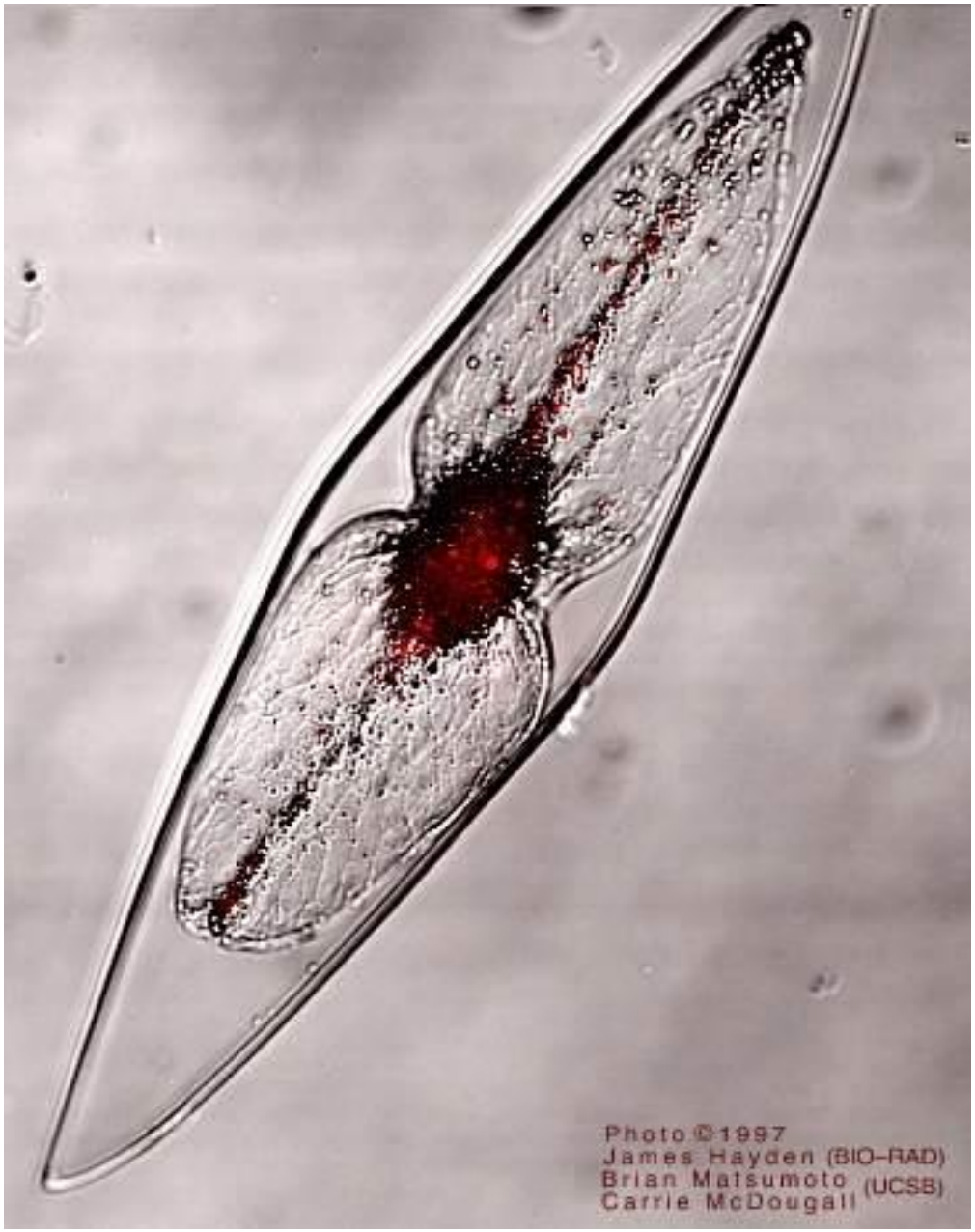
bioluminescence







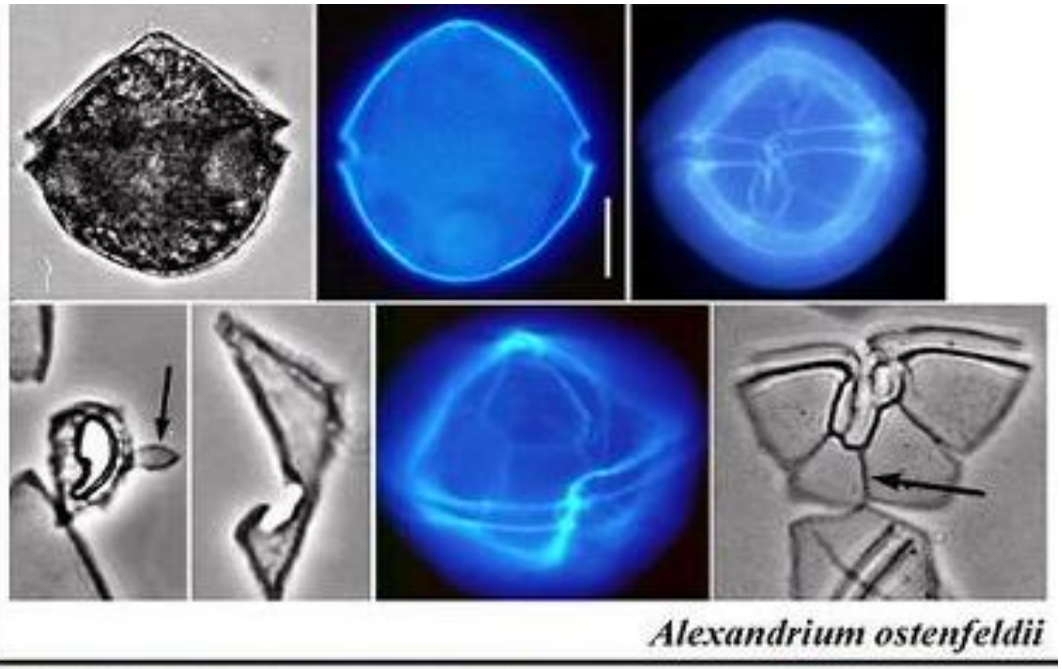
Pyrocystis noctiluca

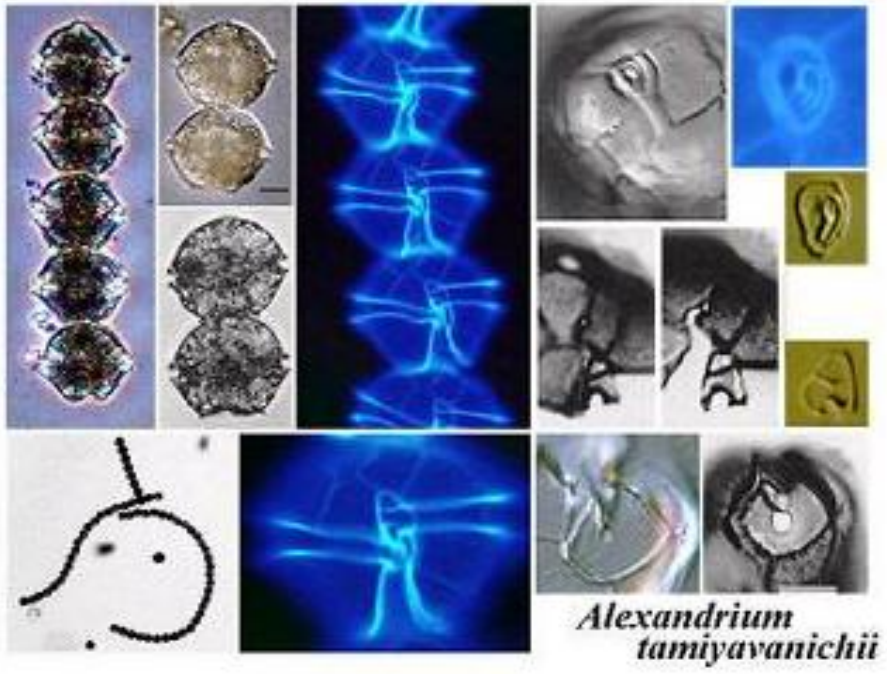


Pyrocystis fusiformis

Alexandrium (M)

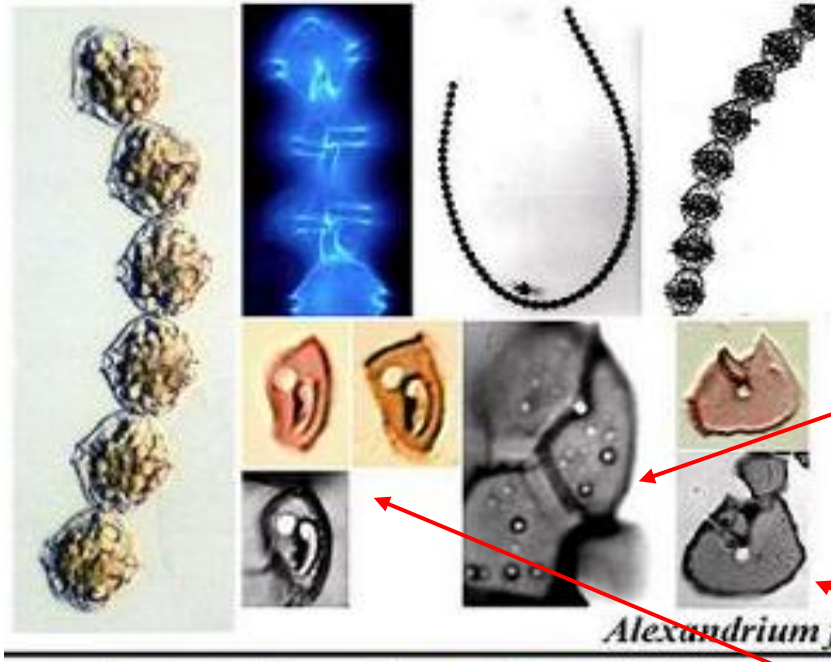
thin plates, pore at 1´ plate, often filamentous

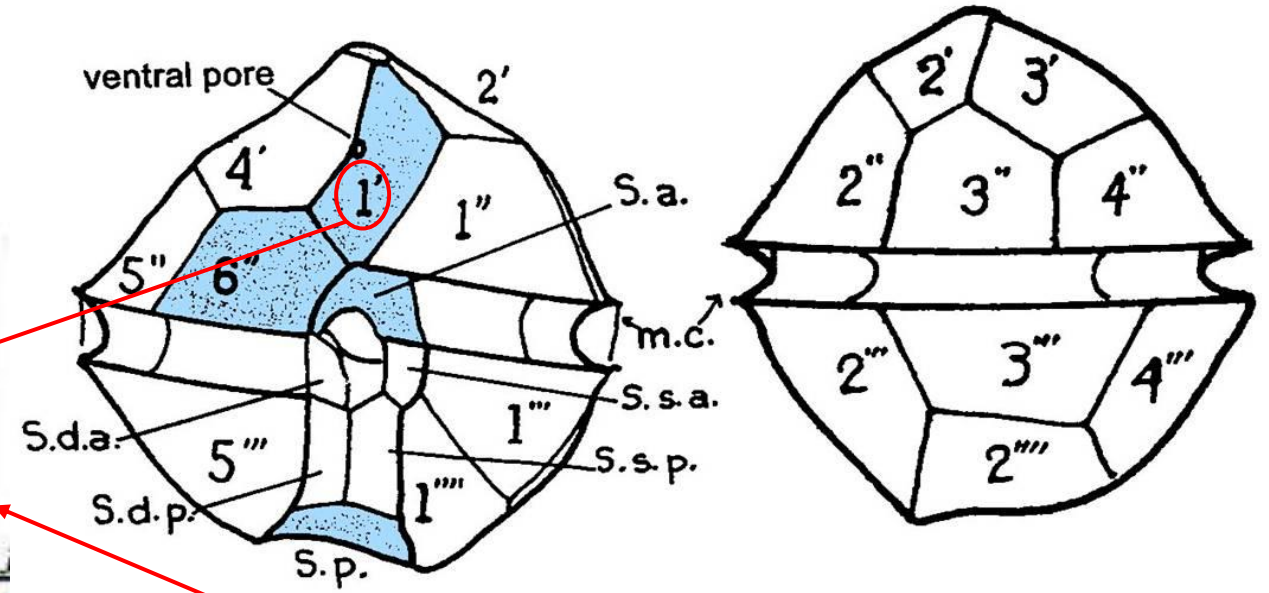


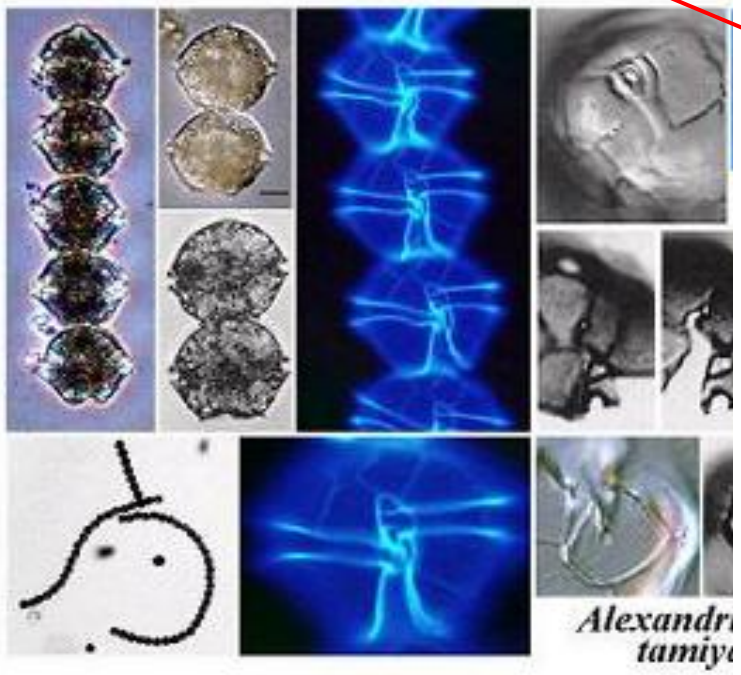


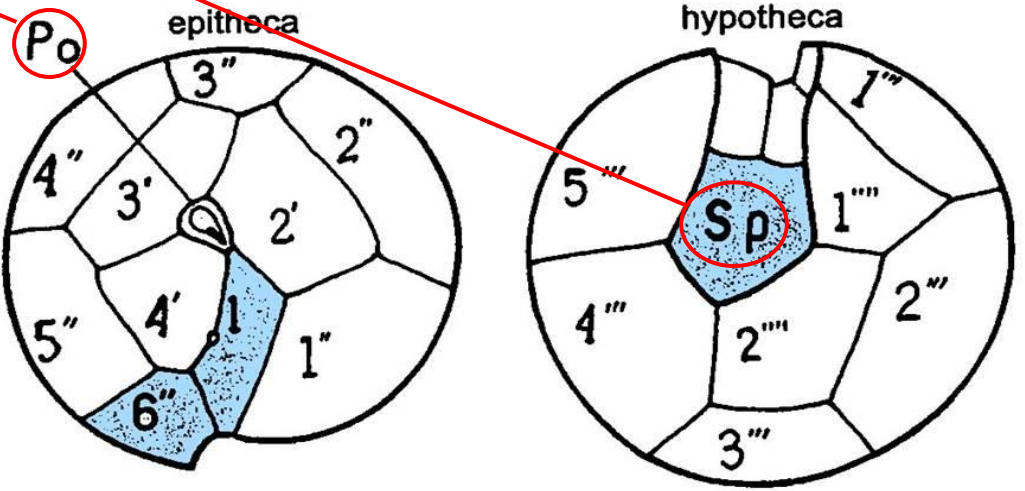
Alexandrium (M)

thin plates, pore at 1´ plate, often filamentous



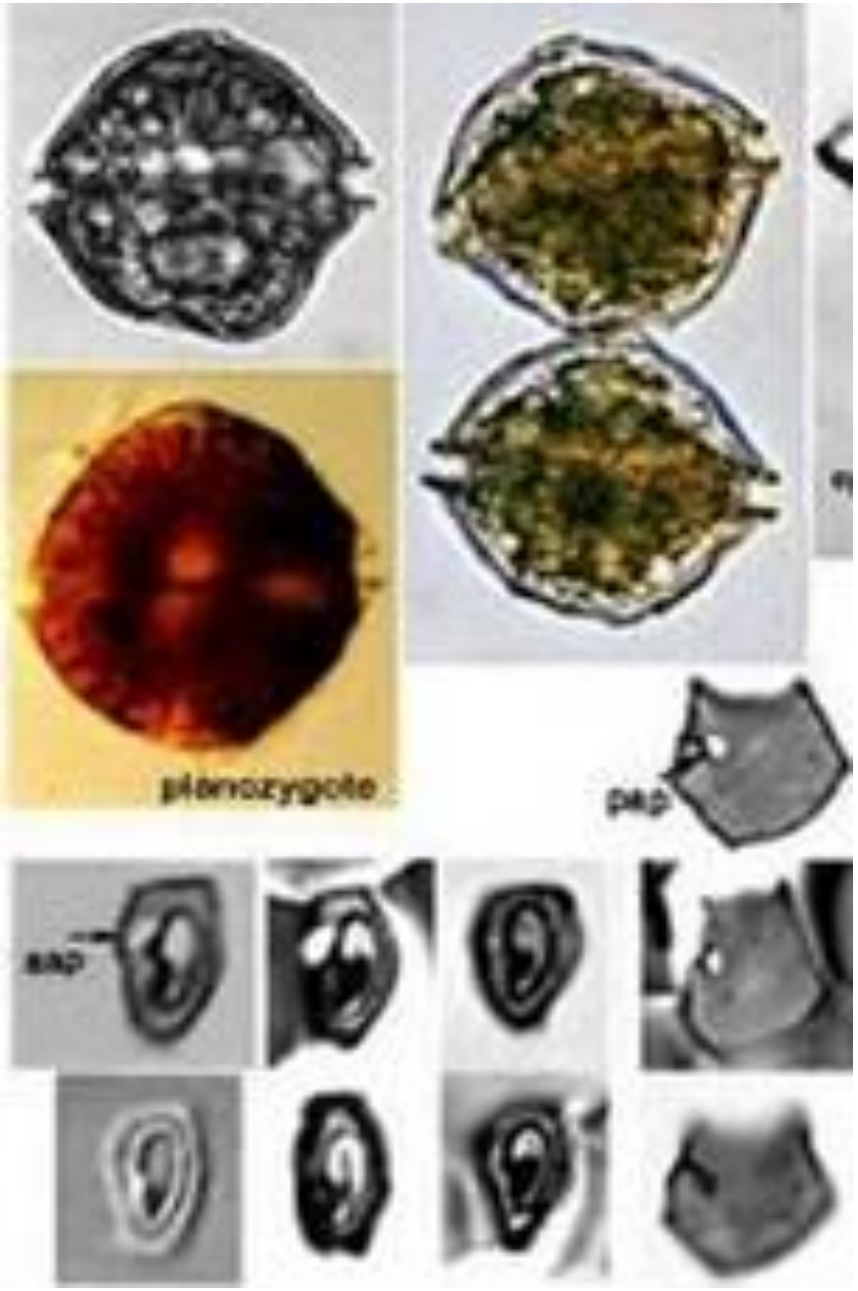


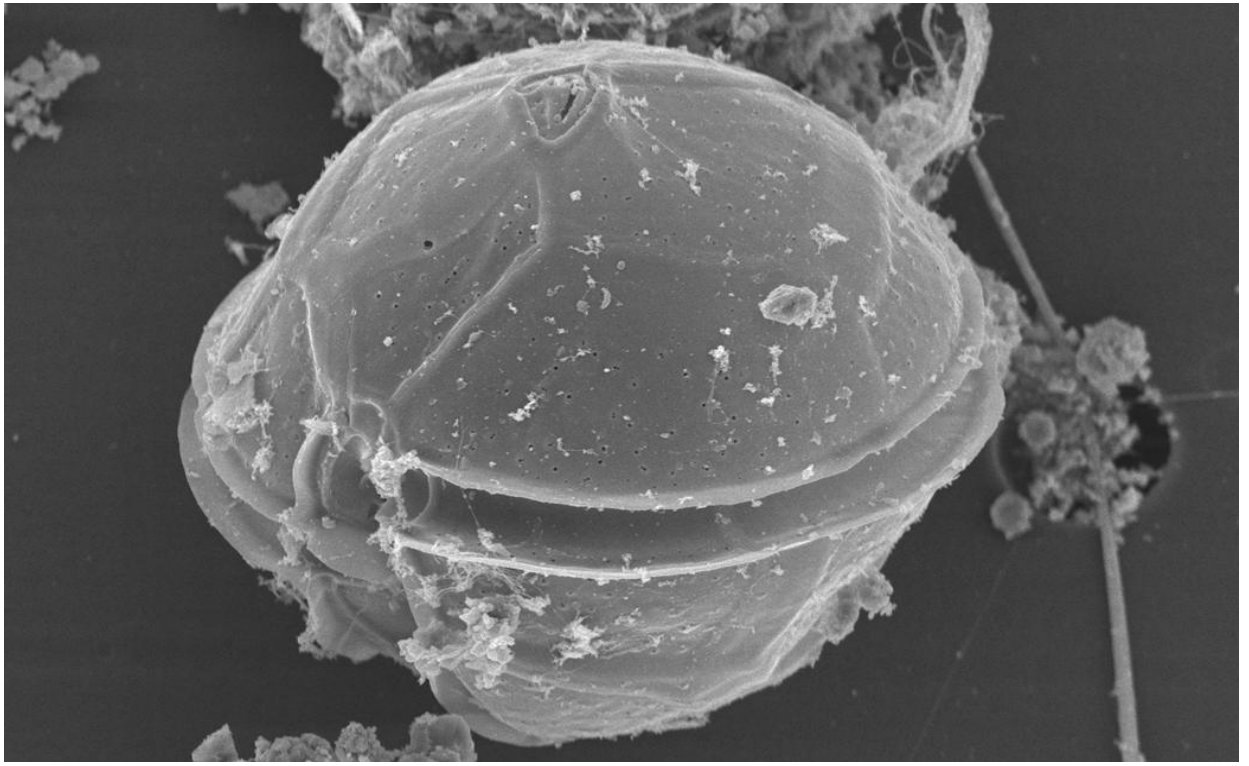


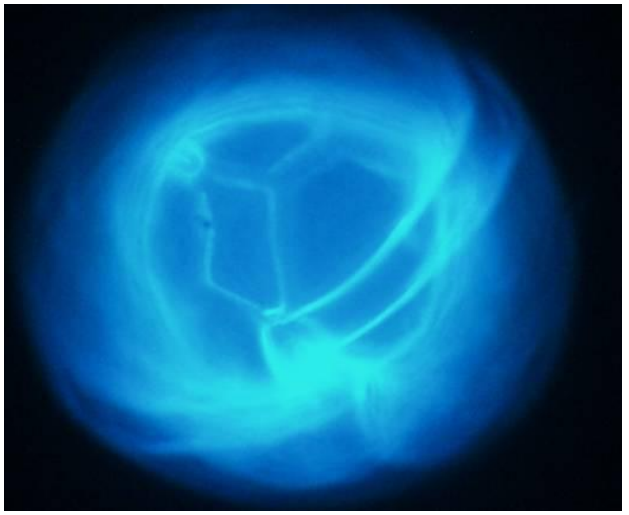


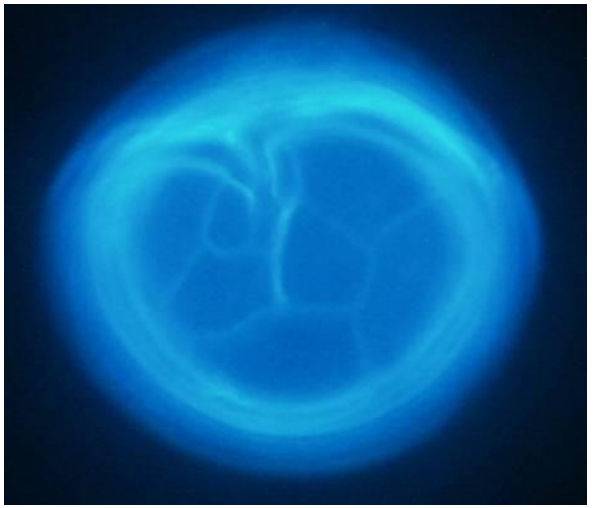
Alexandrium tamarense (M)

toxic species (PSP)



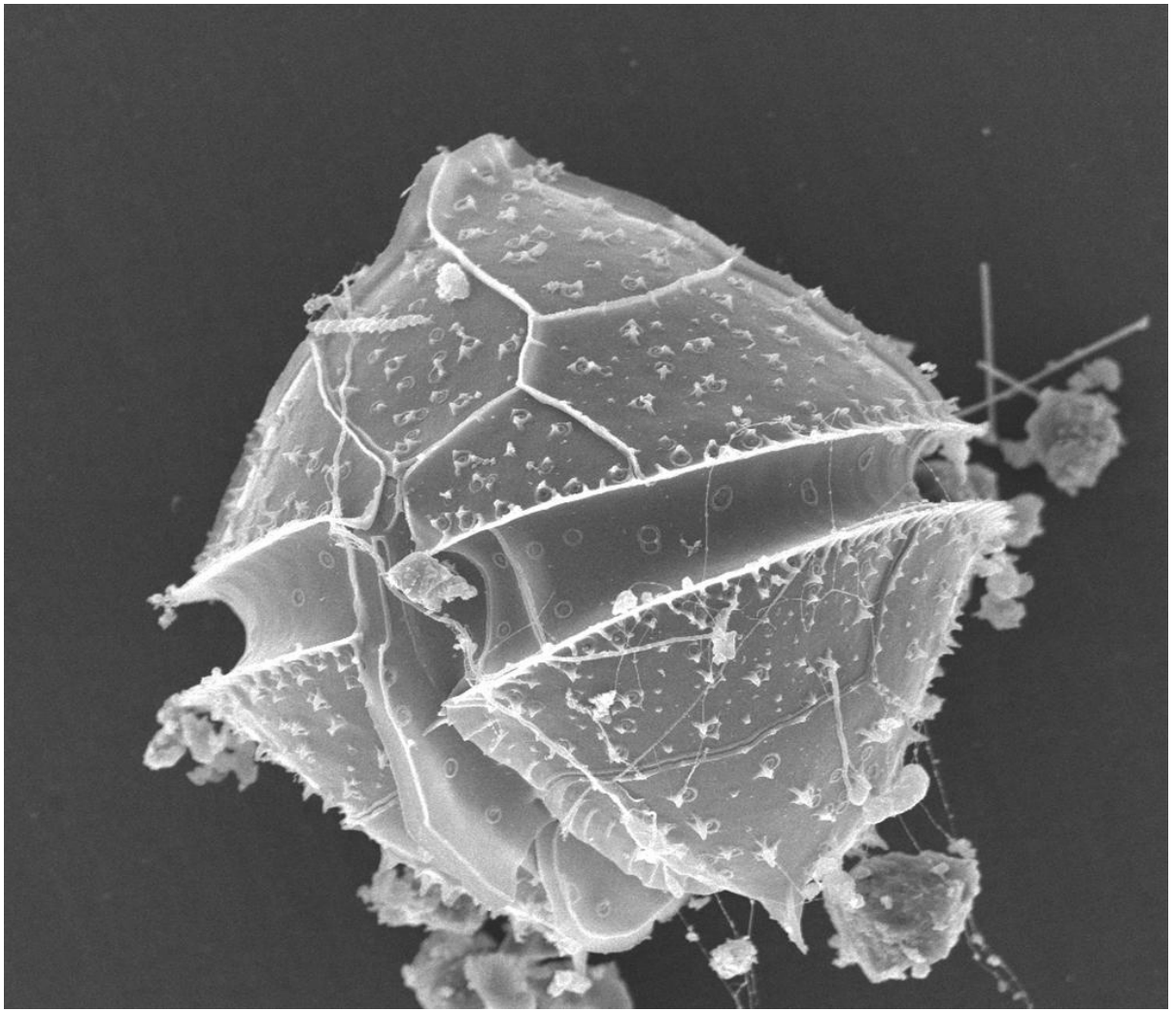






Peridiniales

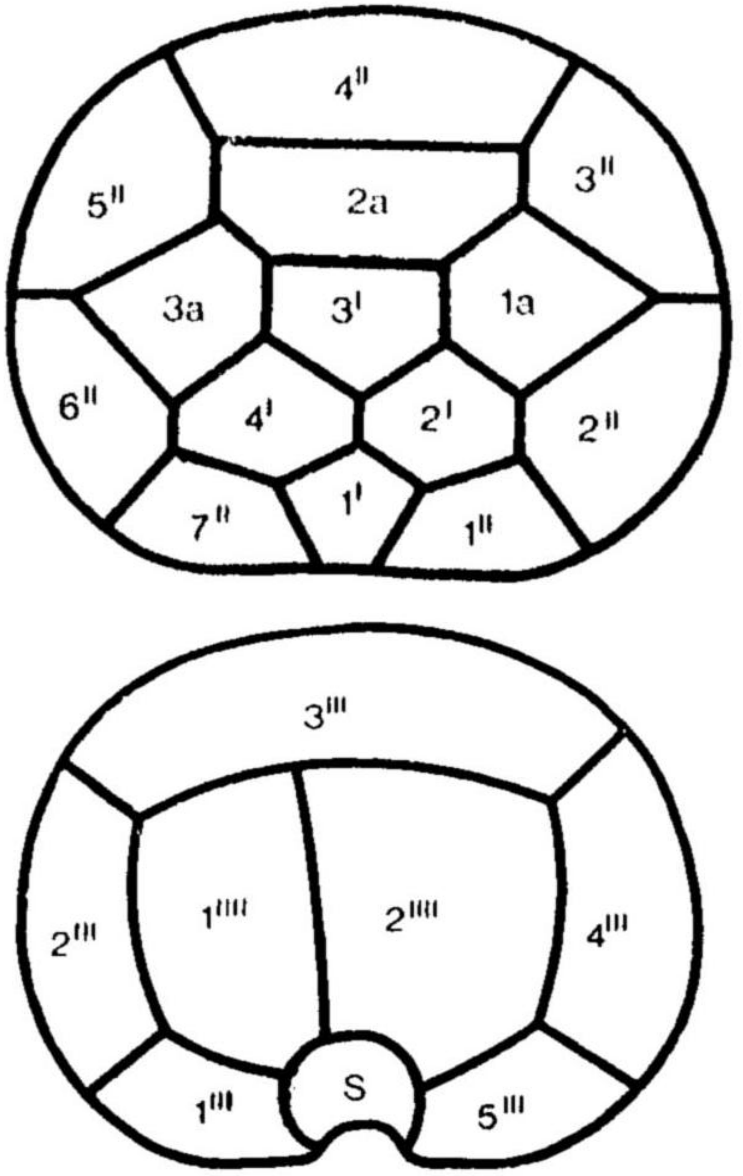
- flagellates, mostly dorsiventrally flattened cells
- polygonal plates, sulcus + cingulum
- marine and freshwater species



Peridinium (F)

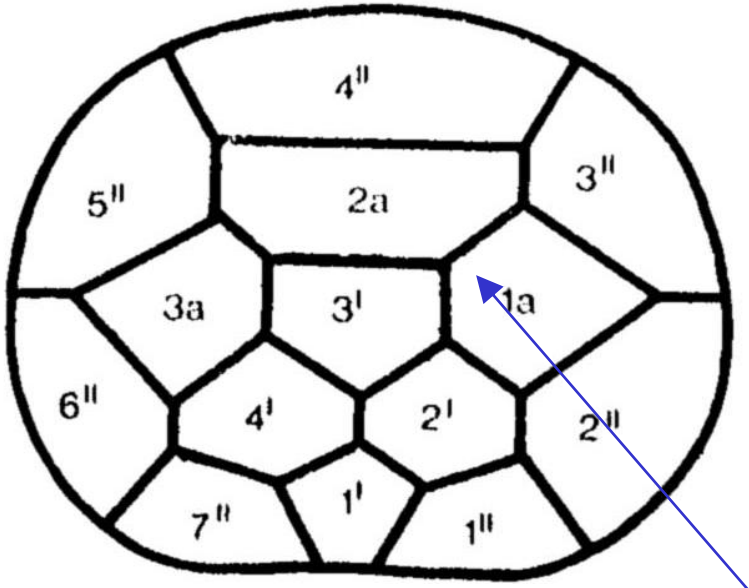
formula 4´, 2a-3a, 7´´, 5´´´, 2´´´´

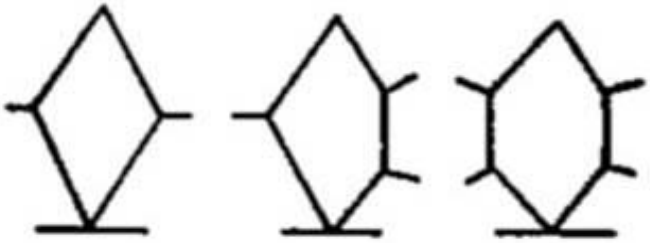
- autotrophic, freshwater, 5-6 cingular plates



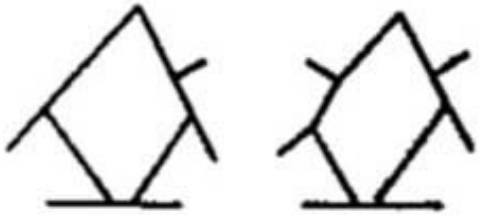
Peridinium (F)

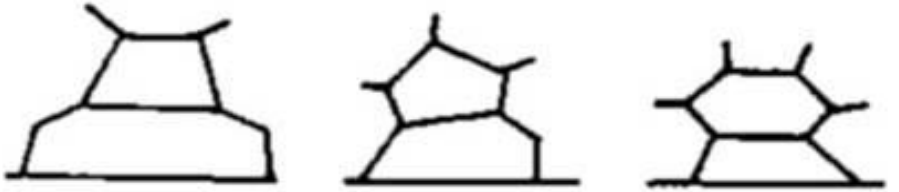
shapes of relevant plates



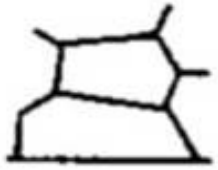


ortho **meta** **para**



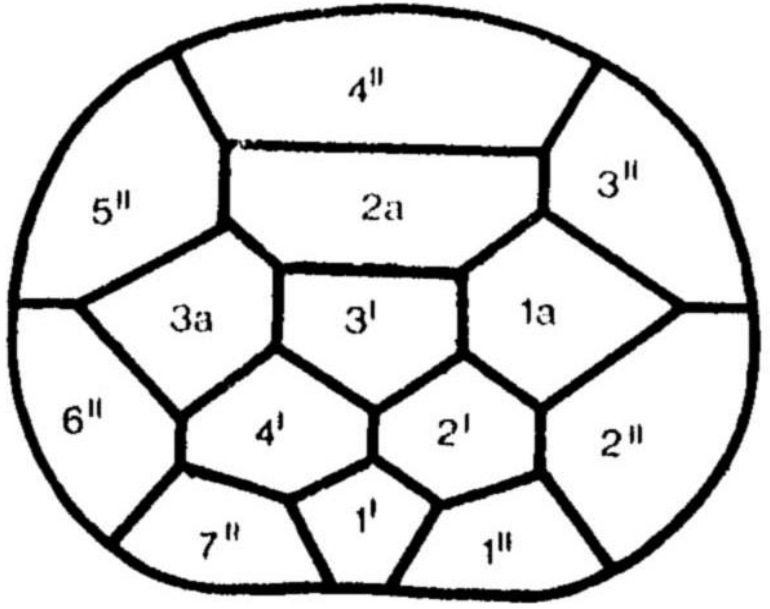


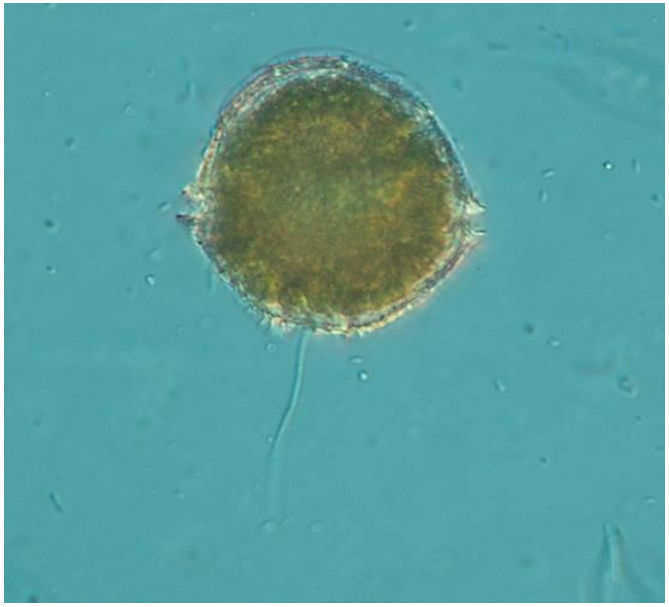
quadra **penta** **hexa**

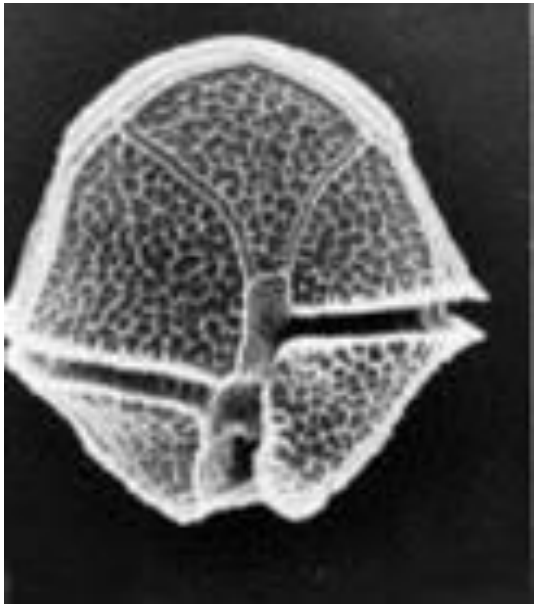


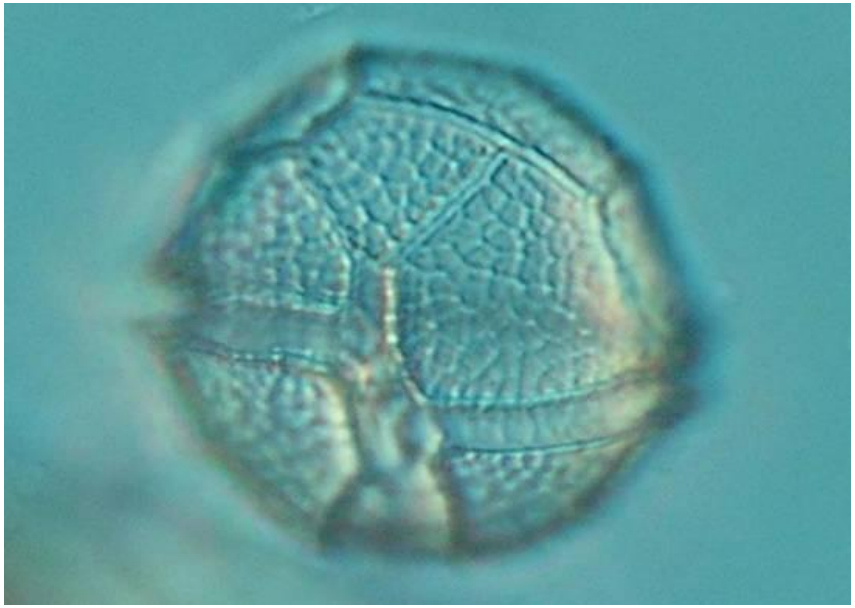
Peridinium (F)

Peridinium willei – no pore, symmetrical plates



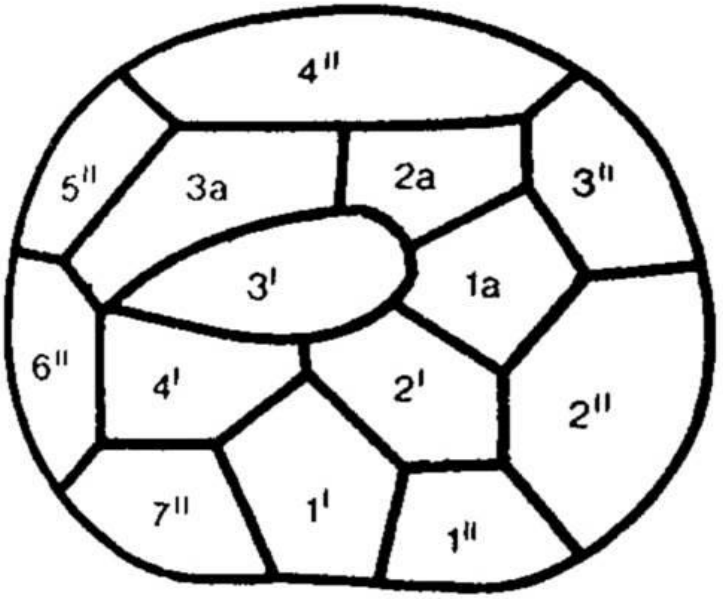


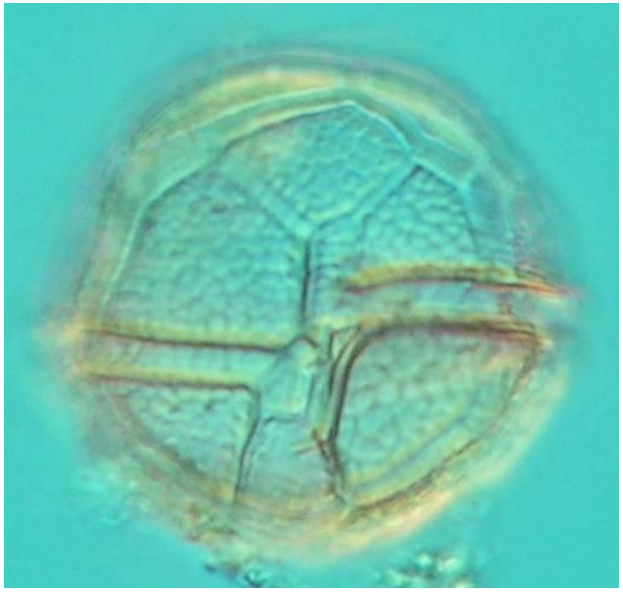


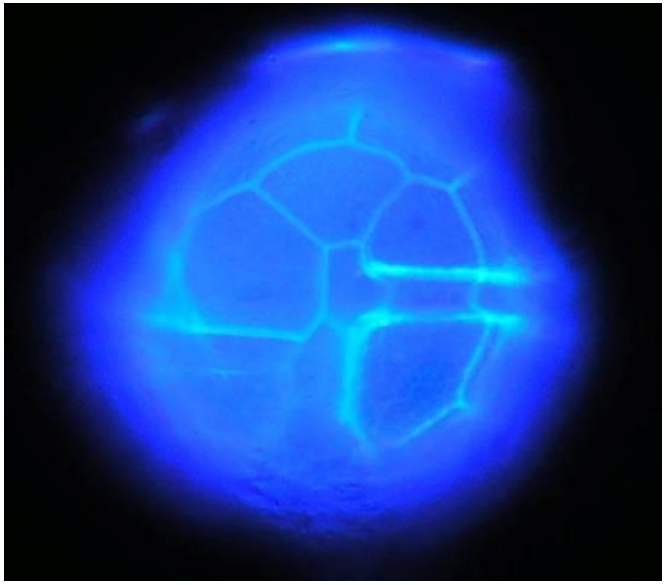


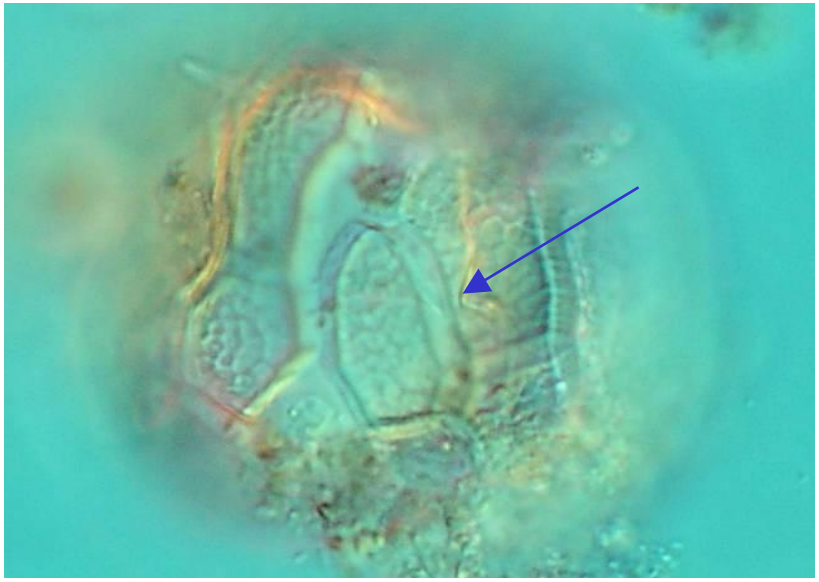
Peridinium (F)

Peridinium cinctum – typical shape of 3´ plate



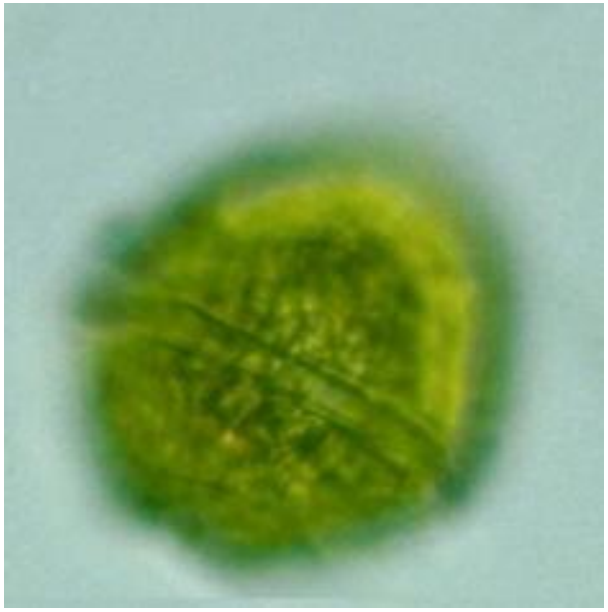


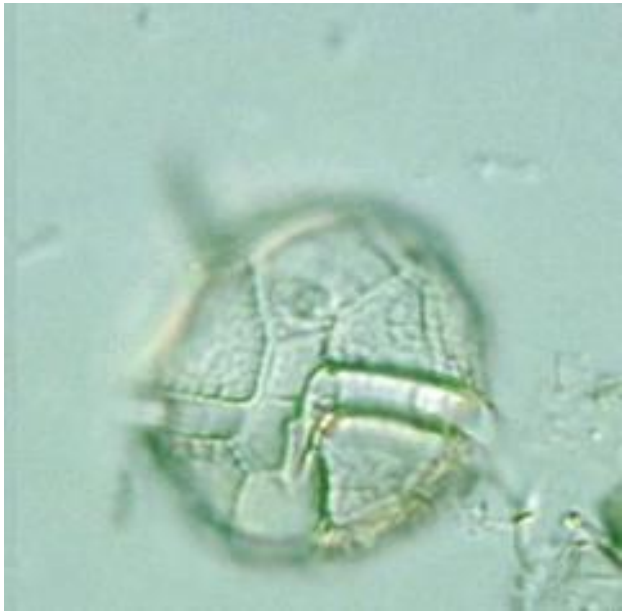


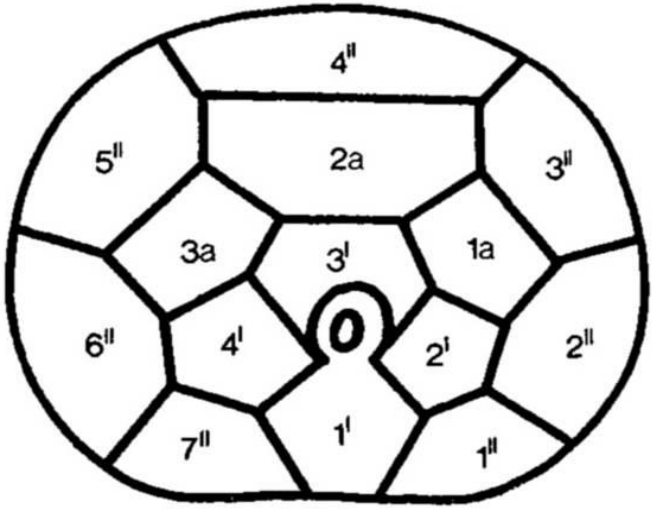


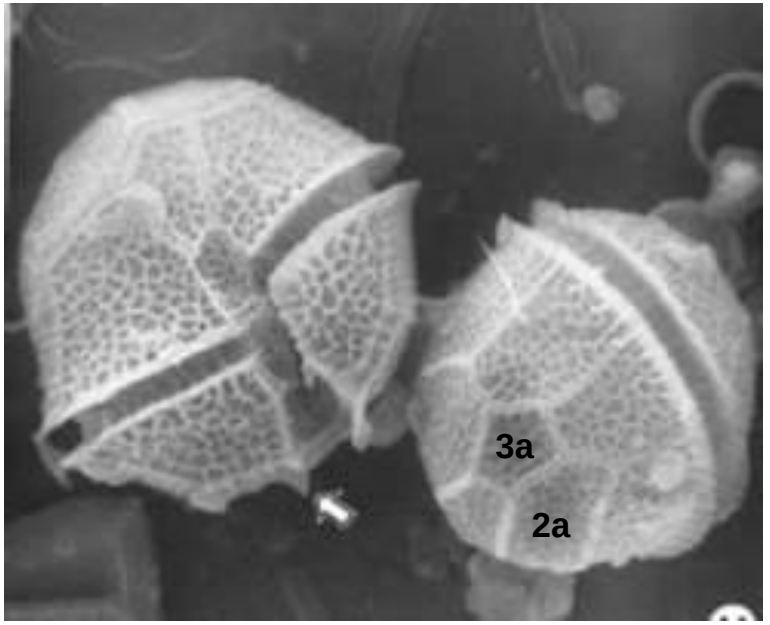
Peridinium (F)

Peridinium bipes – pore, symmetrical plates





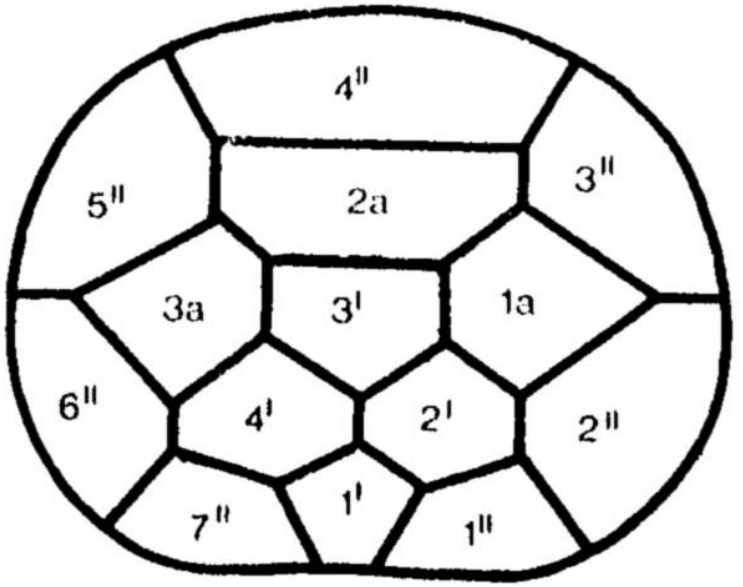


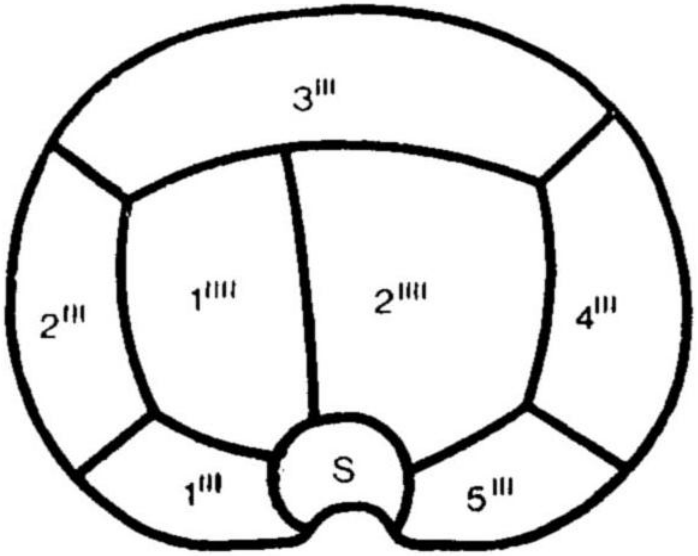


Protoperidinium (M)

formula 4´, 3a, 7´´, 5´´´, 2´´´´

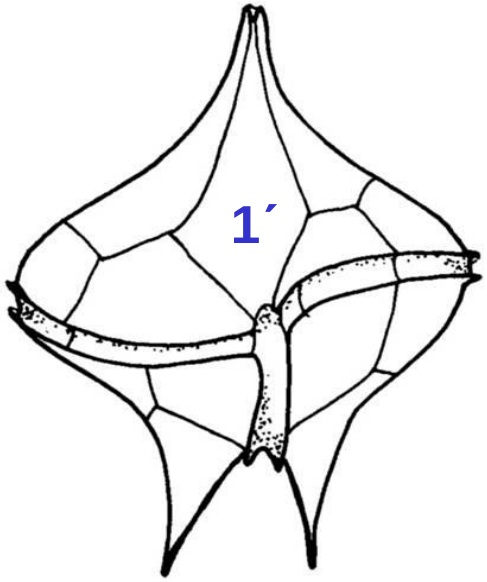
- heterotrophic, marine, only 3 cingular plates

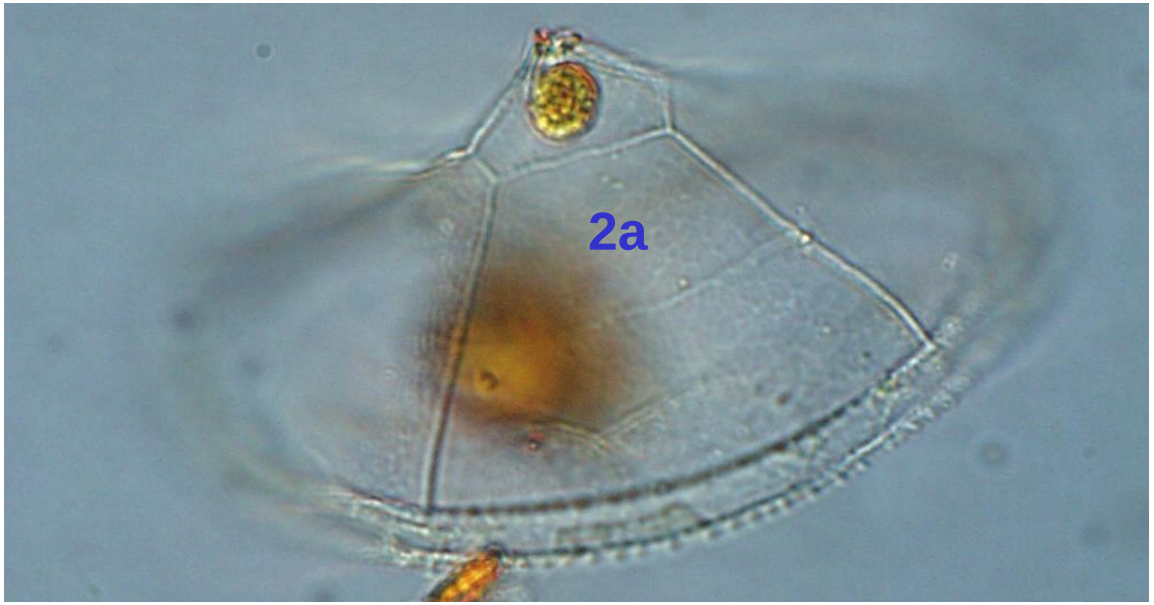




Protoperidinium (M)

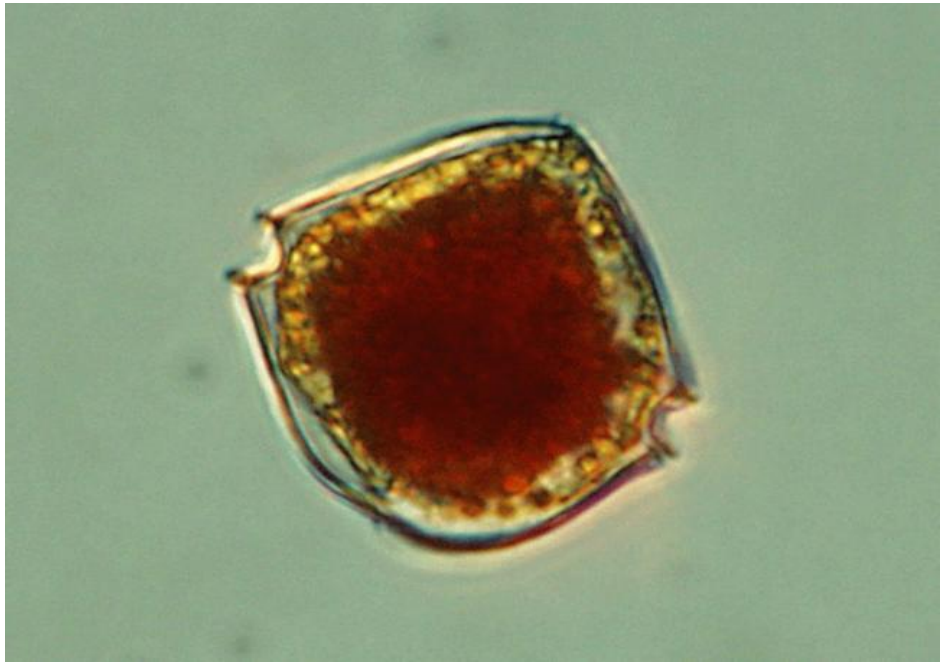
Protoperidinium depressum – 1´ ortho, 2a quadra

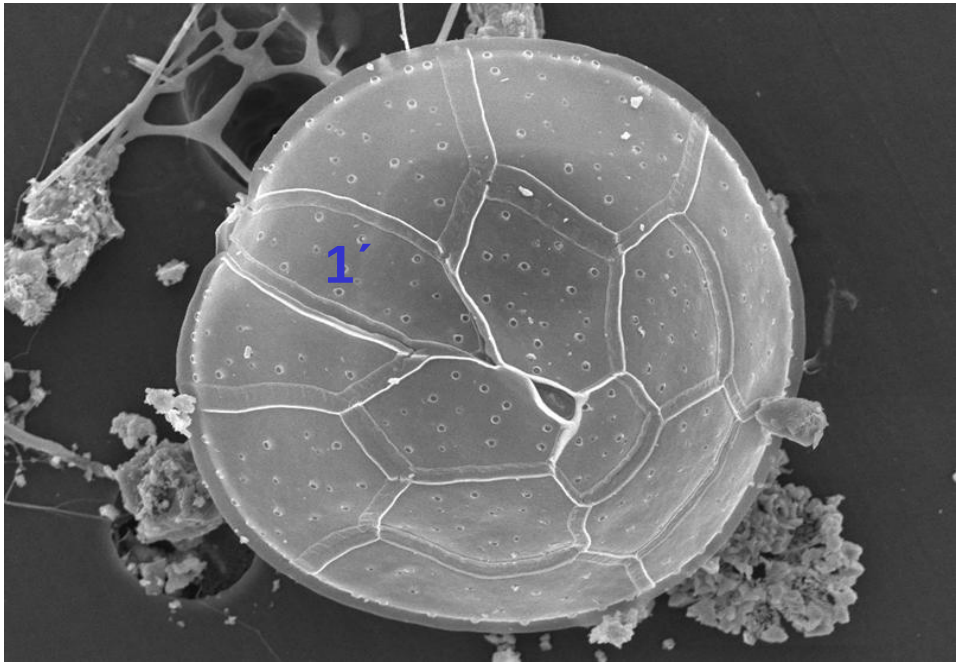


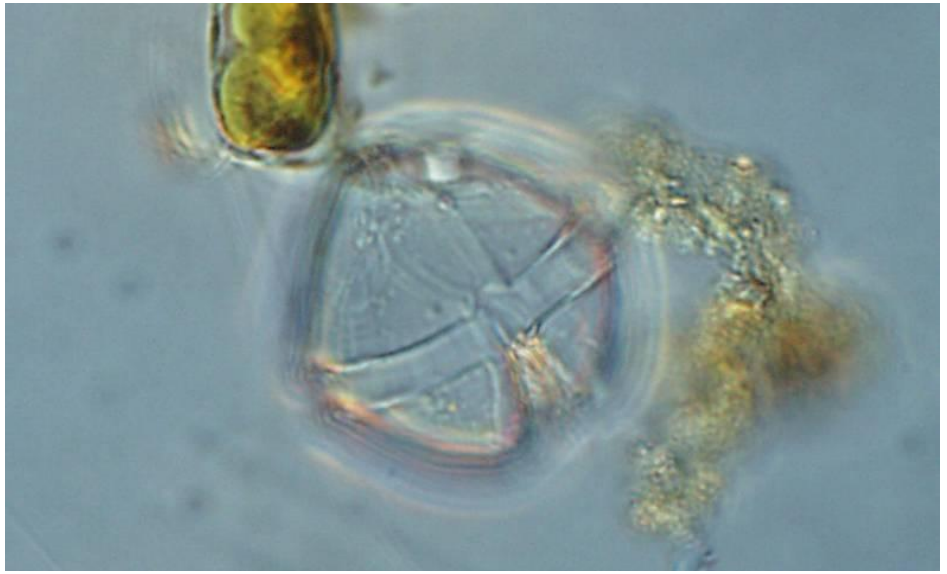


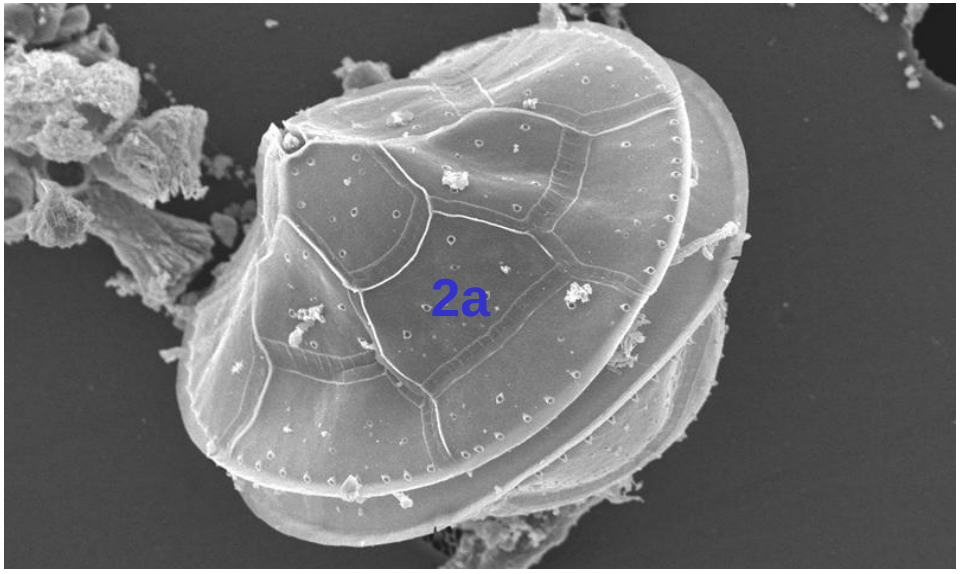
Protoperidinium (M)

Protoperidinium achromaticum – 1´ ortho, 2a hexa



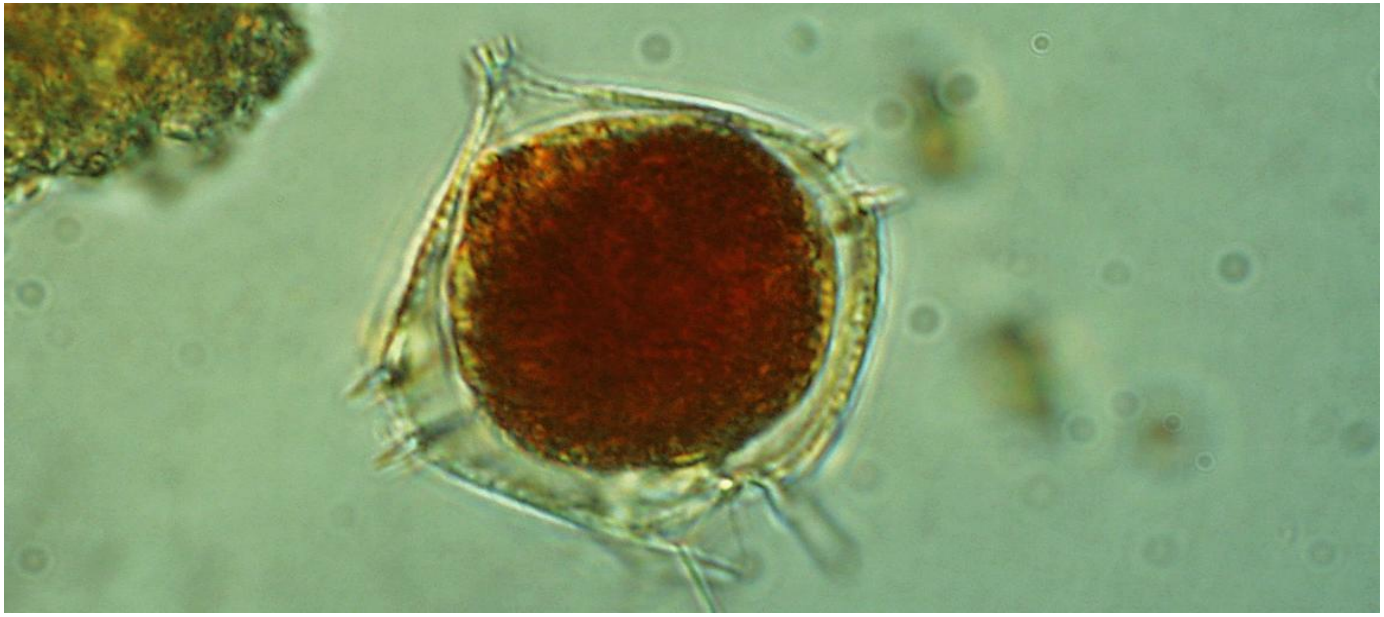


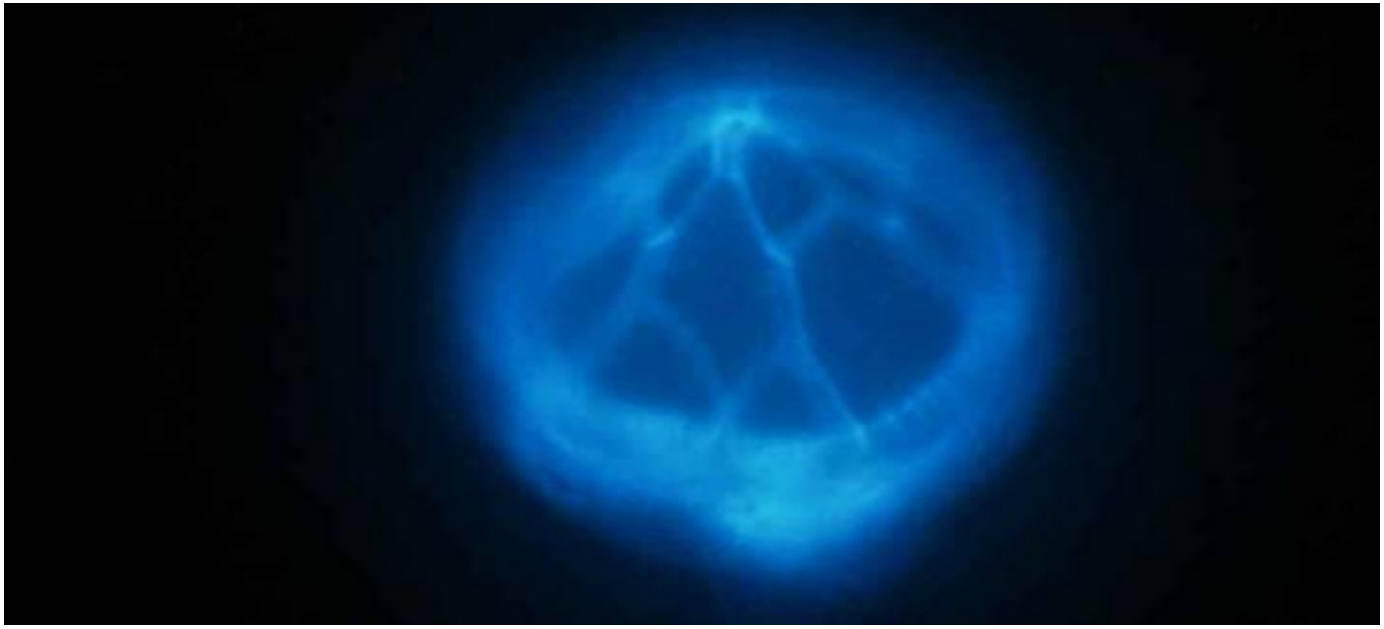


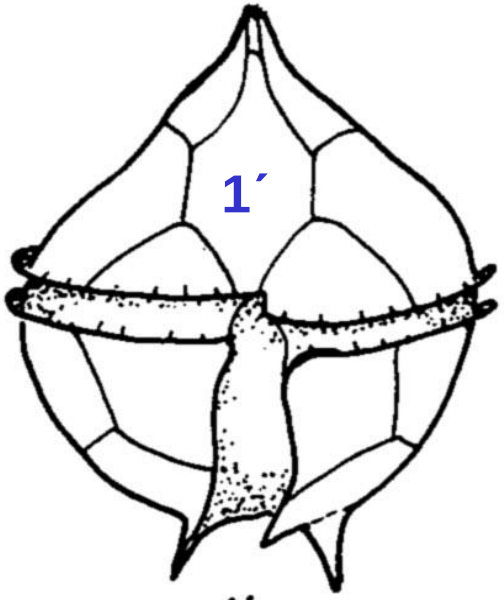


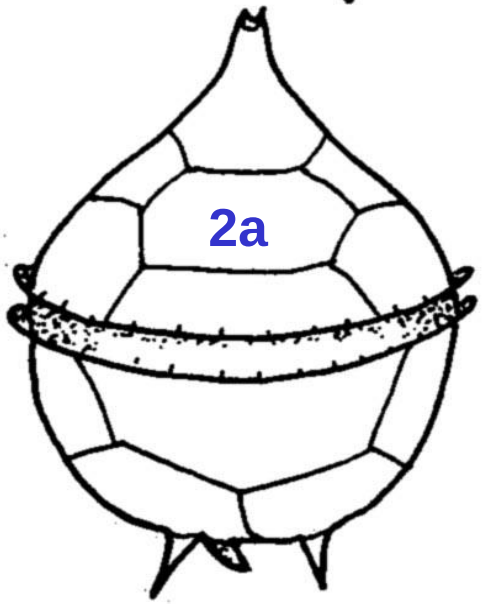
Protoperidinium (M)

Protoperidinium pellucidum – 1´ para, 2a hexa



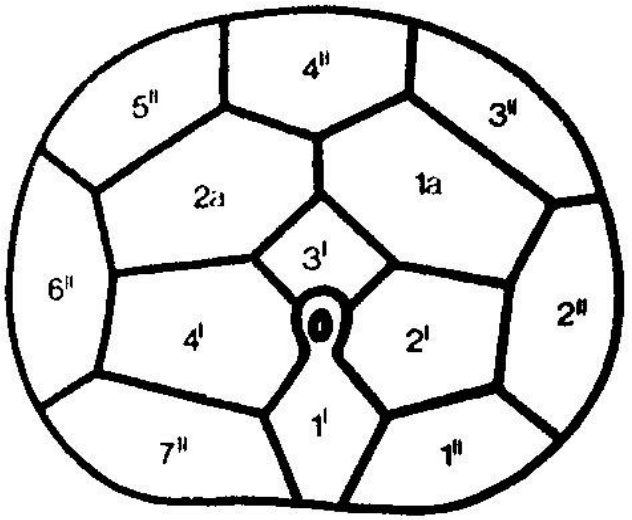




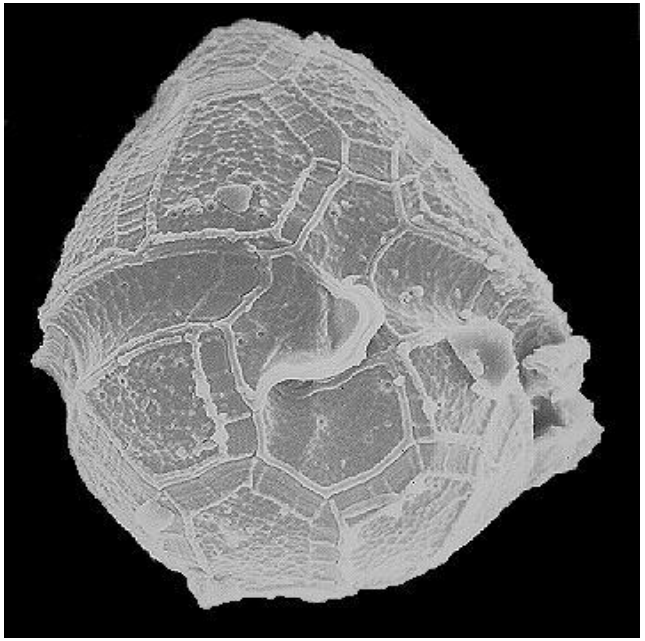


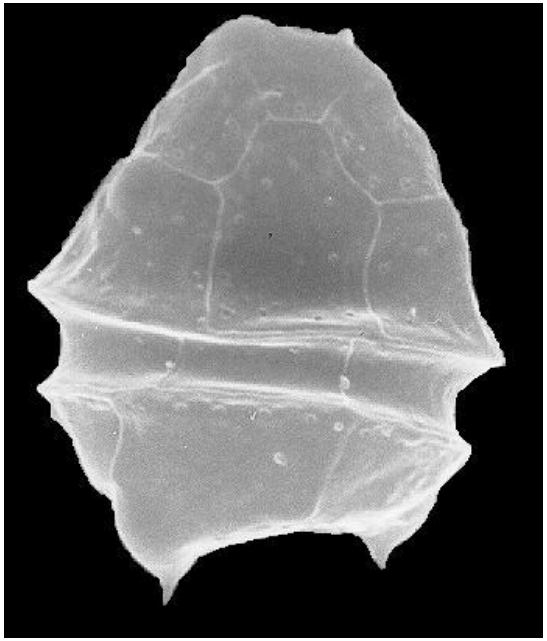
Parvodinium (F)

formula 4‘, 2a, 7‘‘, 5‘‘‘,2‘‘‘‘, apical pore



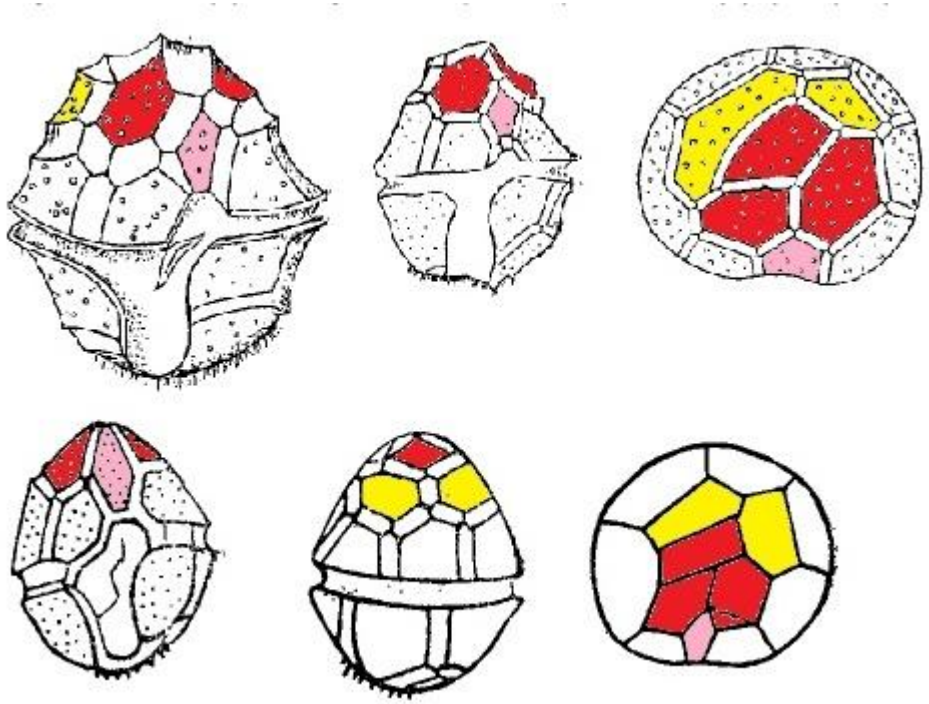

Parvodinium umbonatum

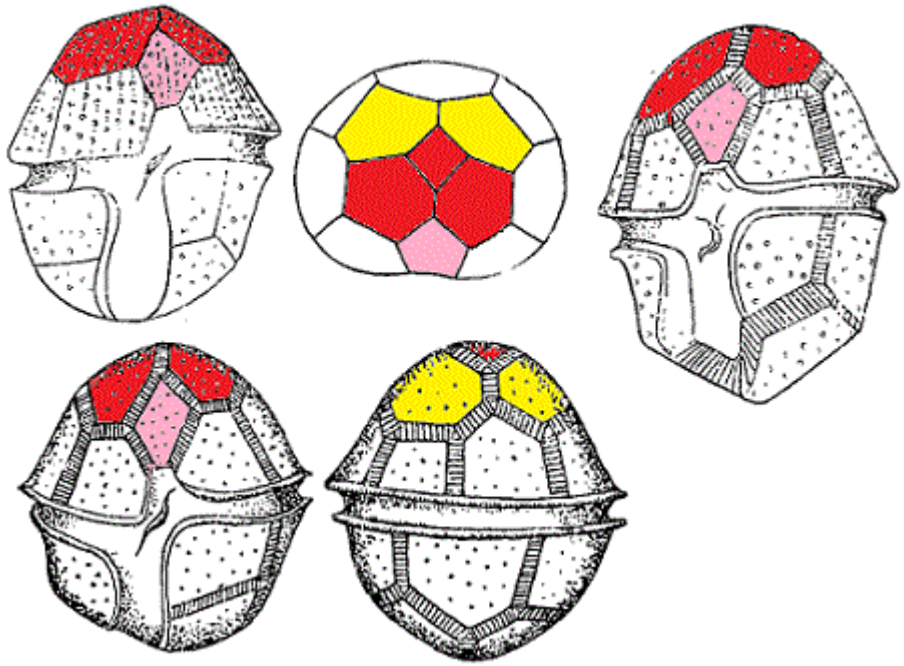




Palatinus (F)

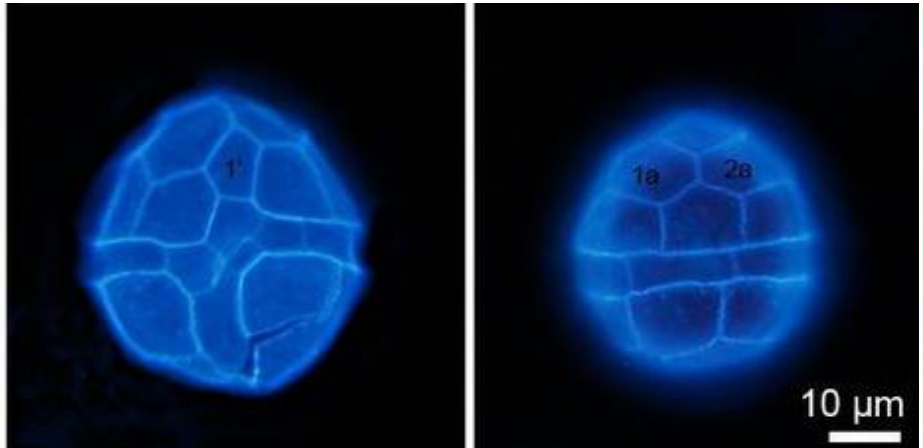
formula 4‘, 2a, 7‘‘, 5‘‘‘,2‘‘‘‘, no apical pore

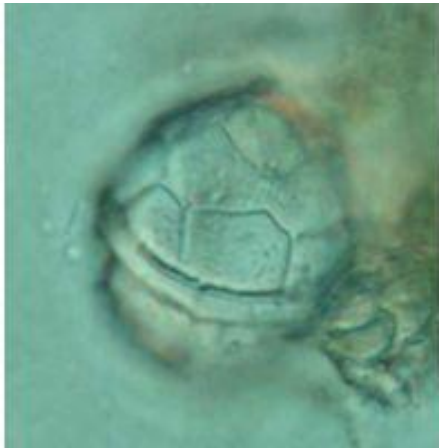




Palatinus apiculatus

Palatinus pseudolaevis

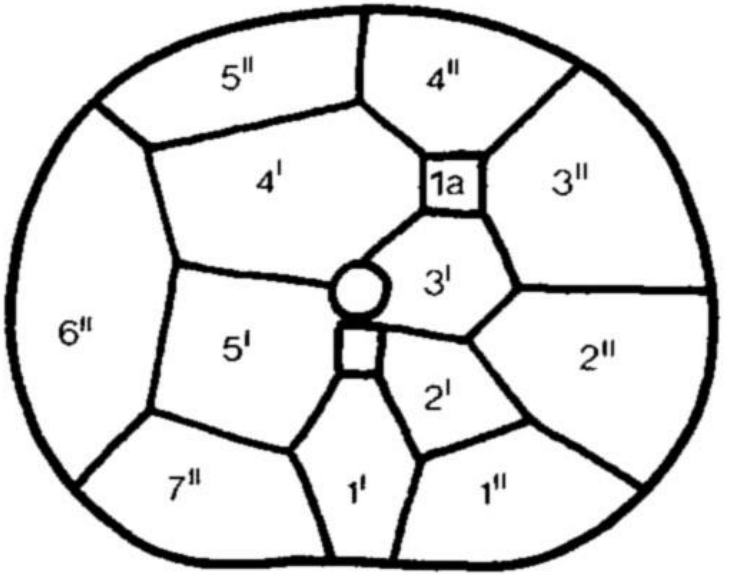


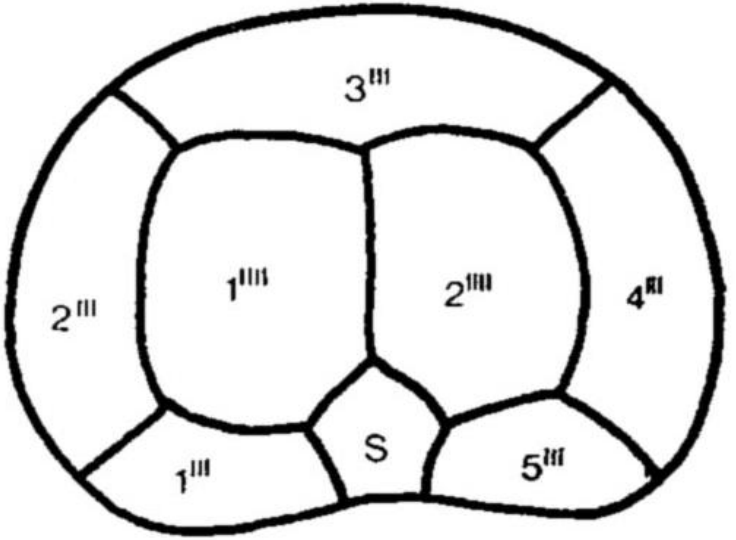


Peridiniopsis (F)

formula 3-5´, 0a-1a, 6-8´´, 5´´´, 2´´´´

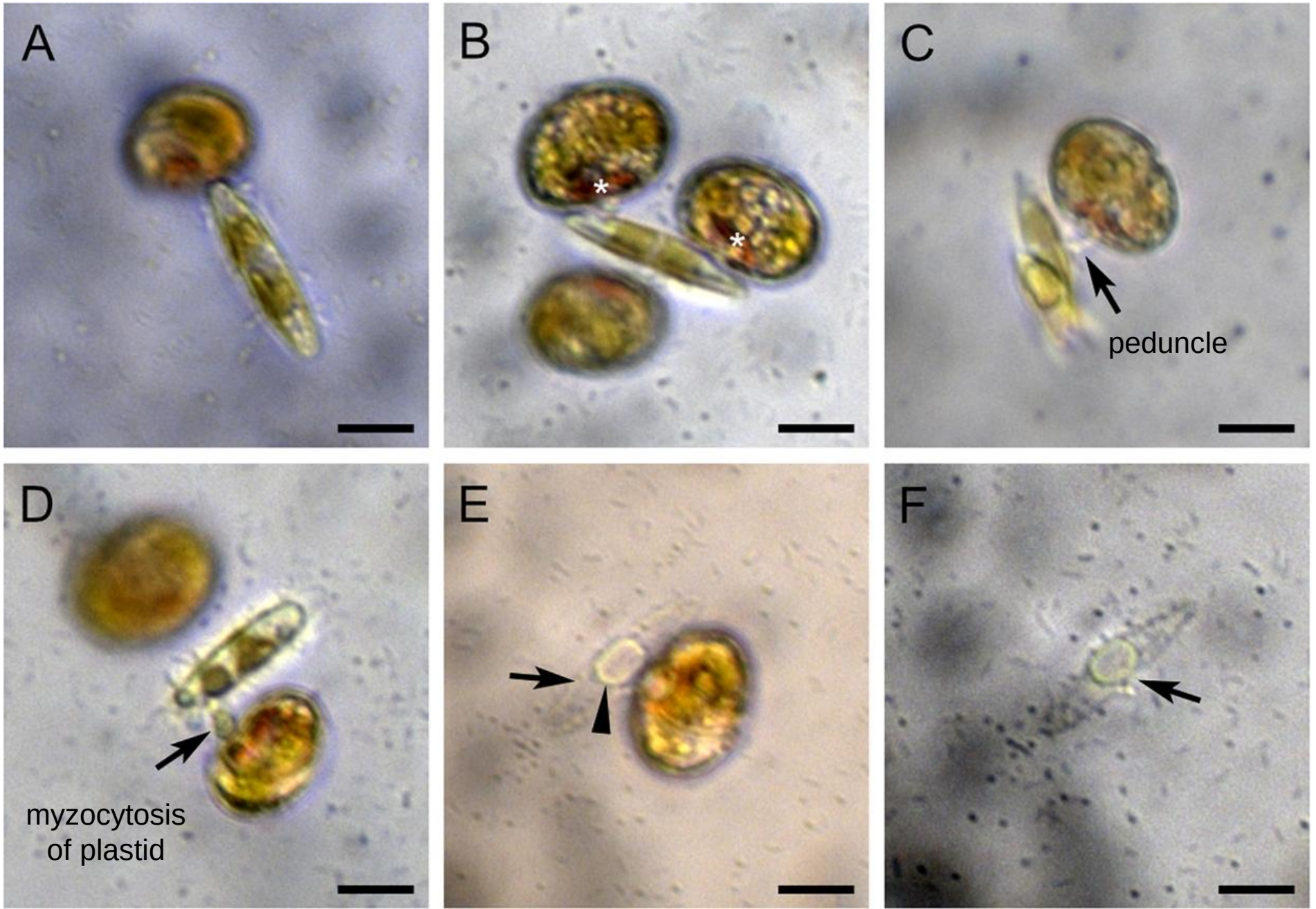
- autotrophic, freshwater and brackish species





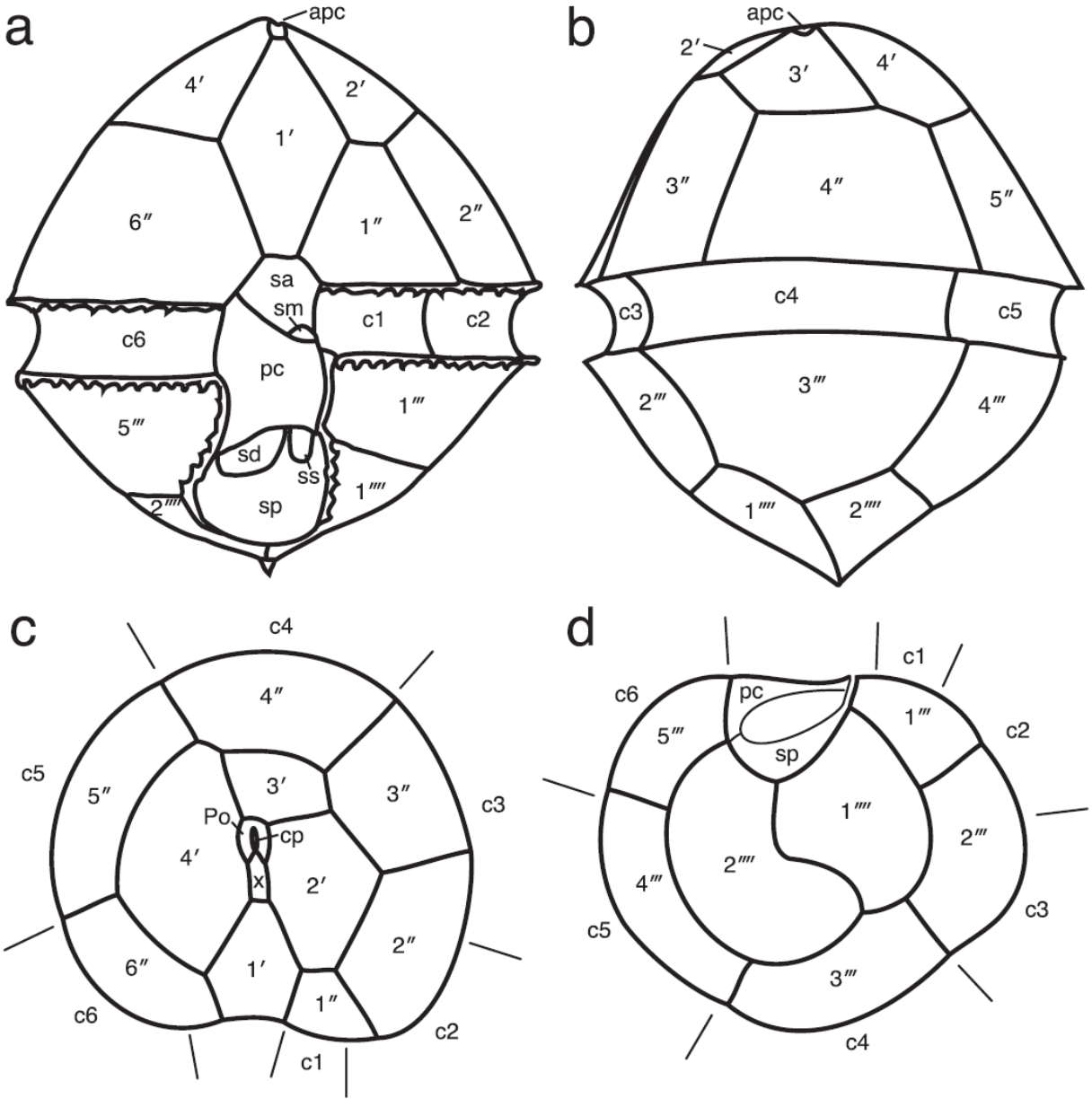
Unruhdinium, Durinskia (F,M)

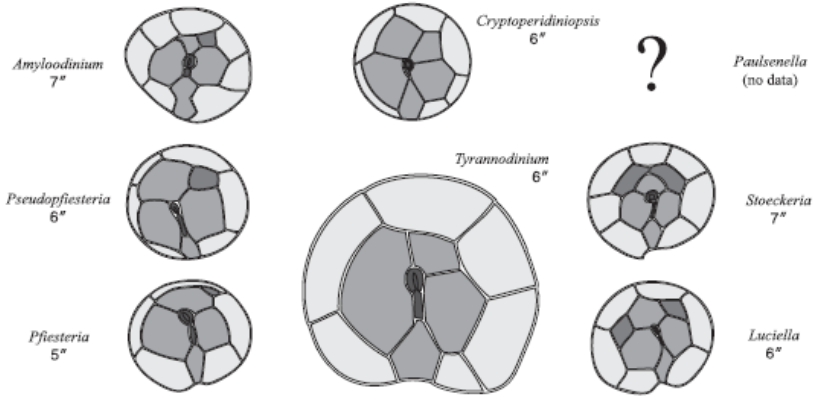
chloroplast of diatom origin



Tyrannodinium (F)

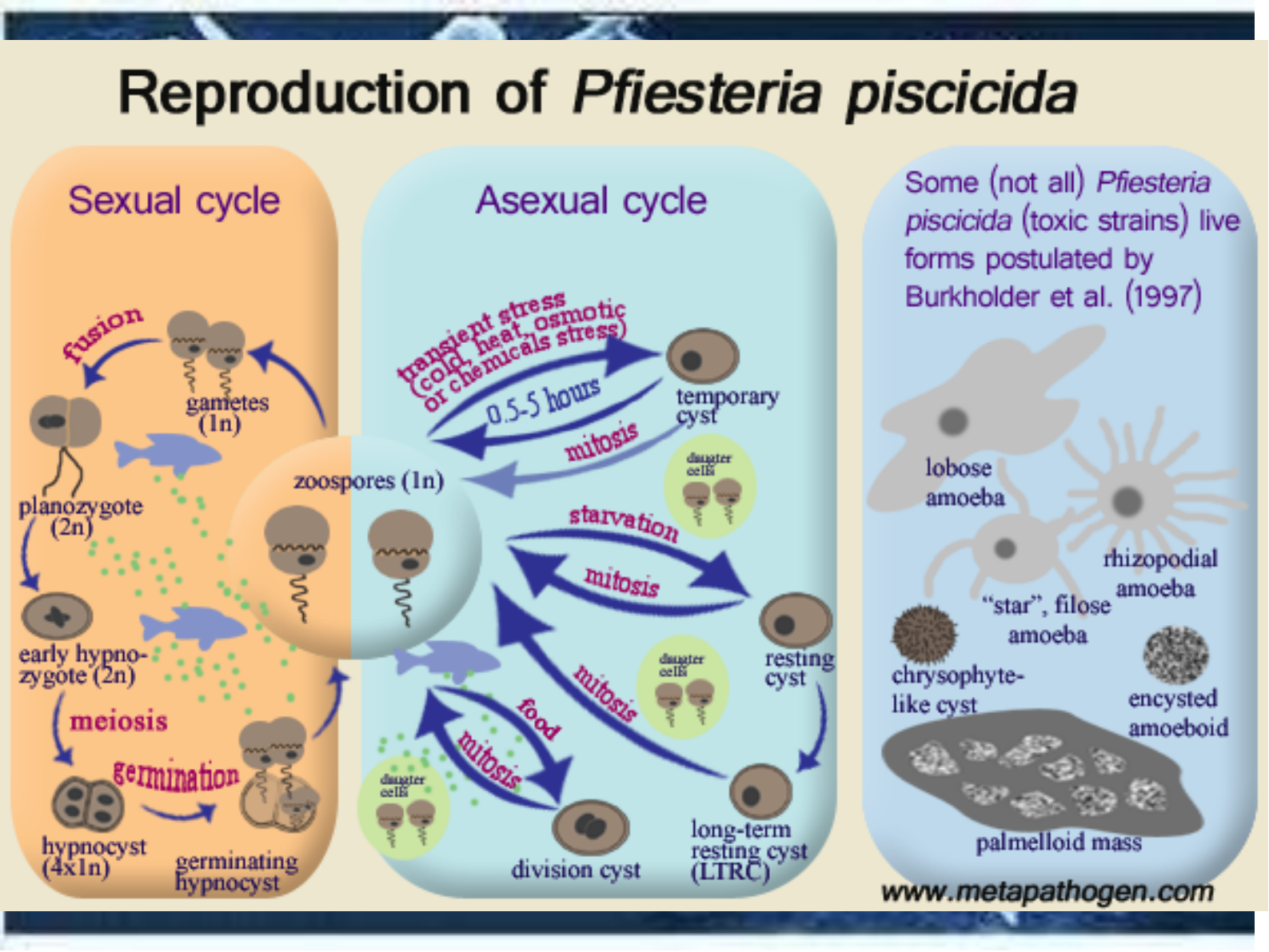
freshwater, heterotrophic, with relatively thin theca

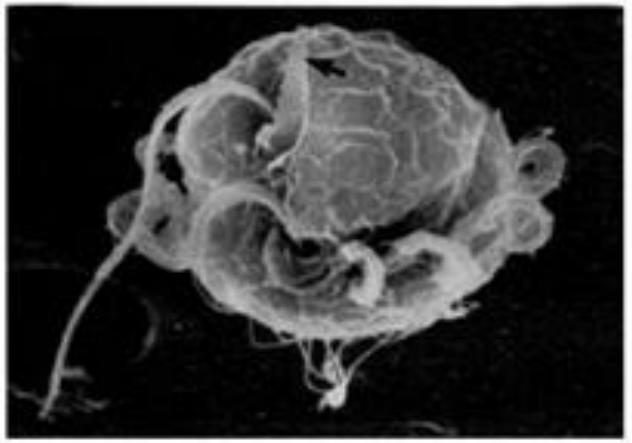


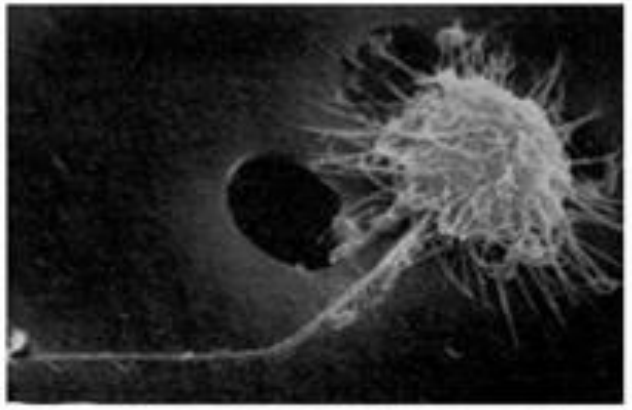


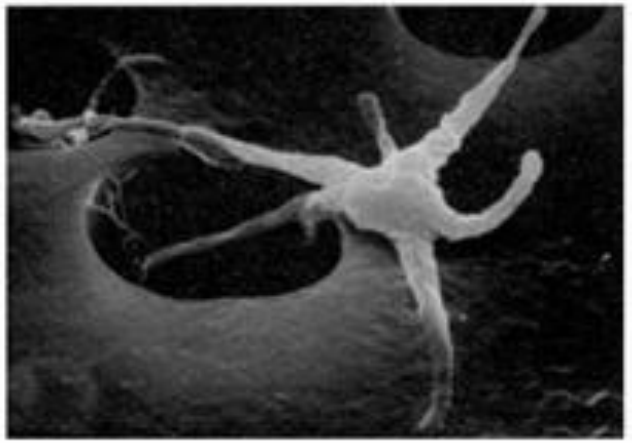
Pfiesteria piscicida (M)

dangerous parasite of fish,toxin production

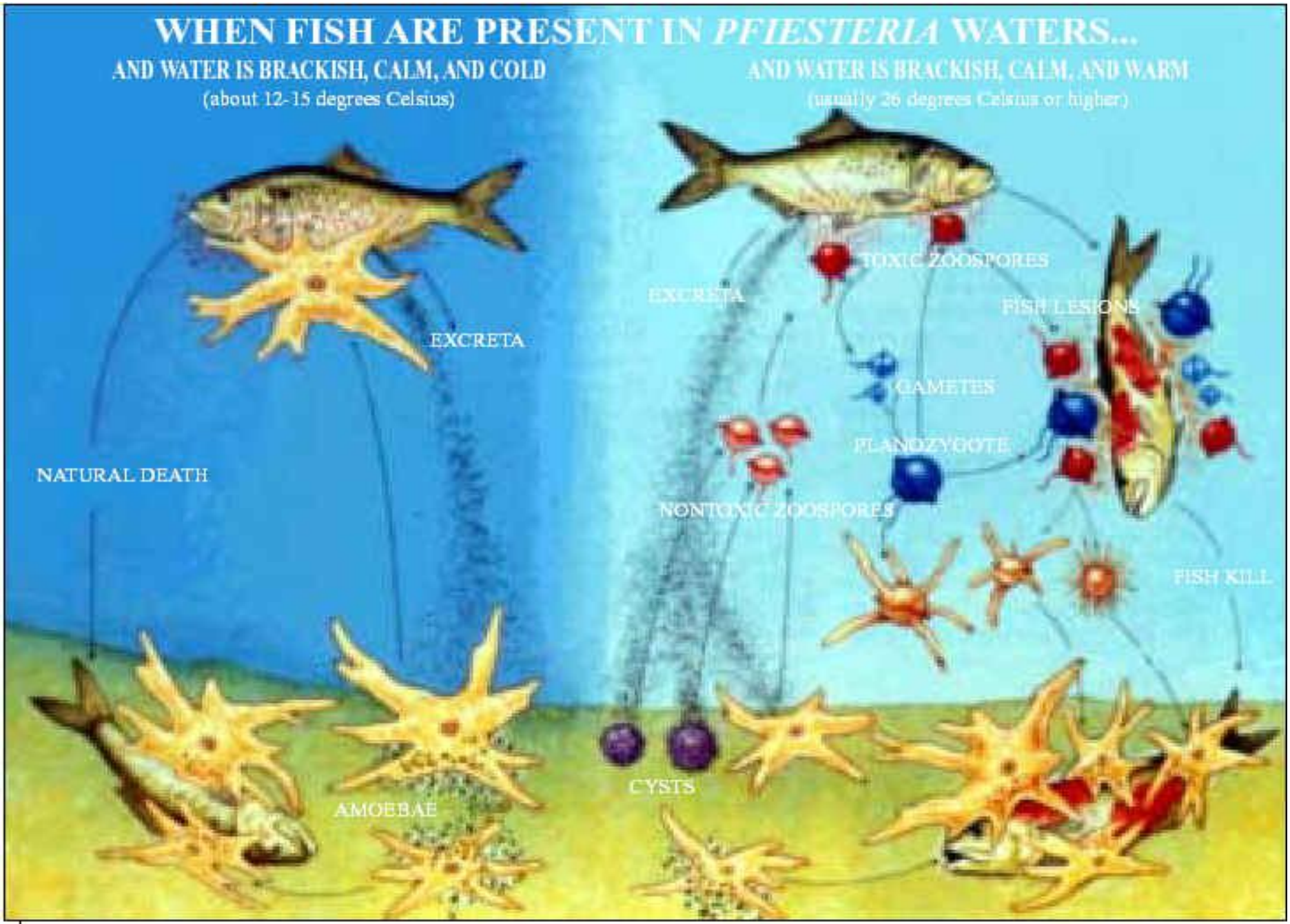








Pfisteria piscicida (M)

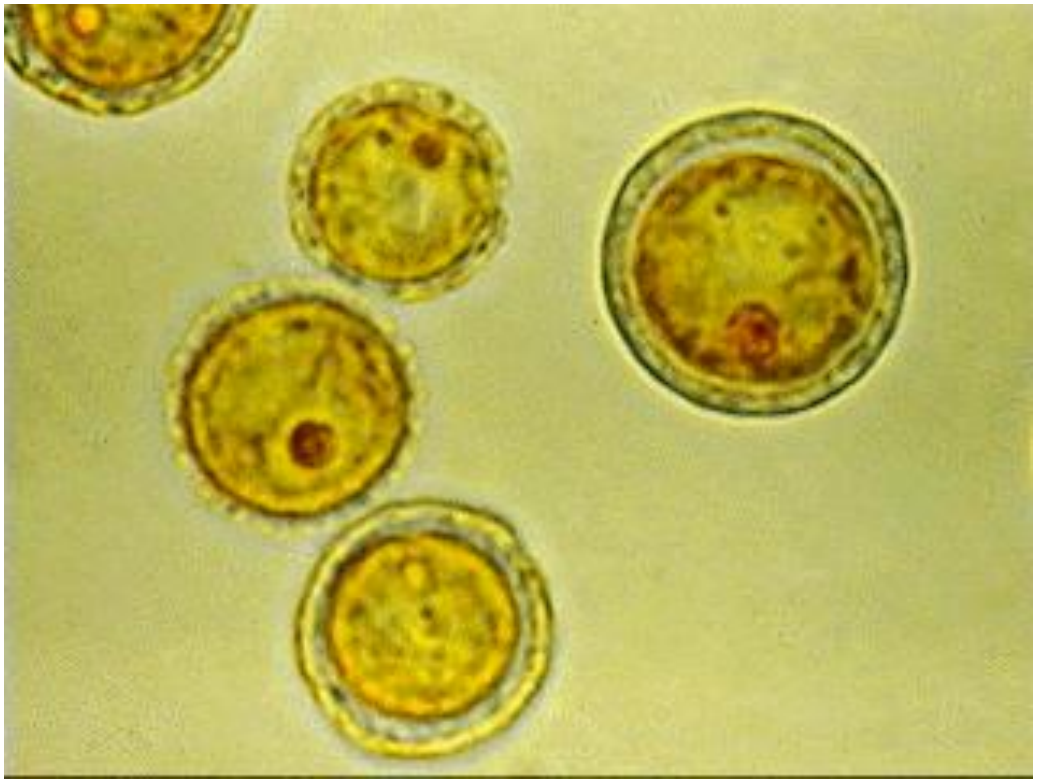


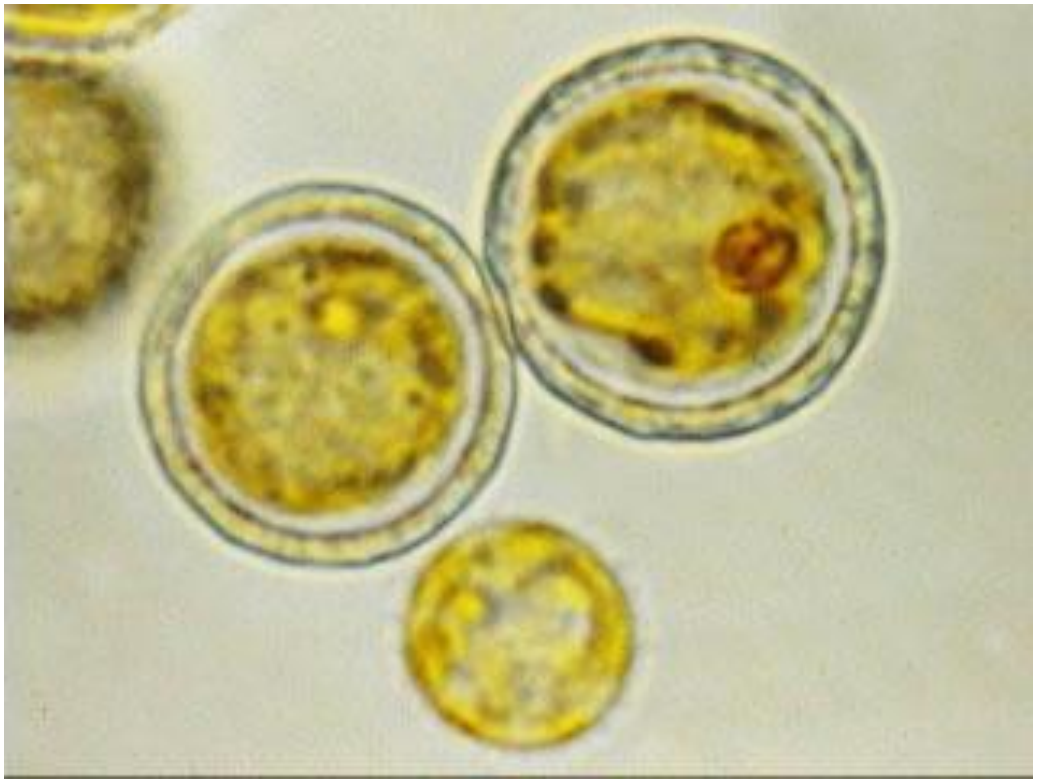
Pfisteria piscicida (M)

- blood lesions

Thoracosphaera (M)

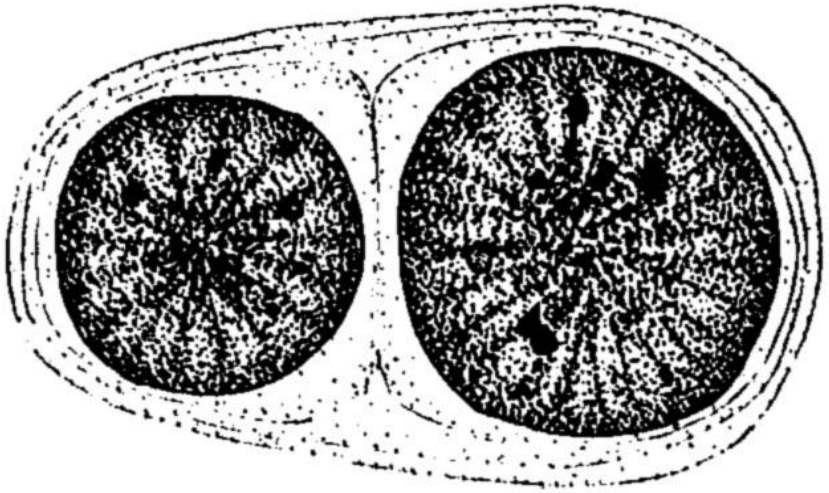
- coccoid dinoflagellate surrounded by a calcareous cell wall
- a number of fossil species

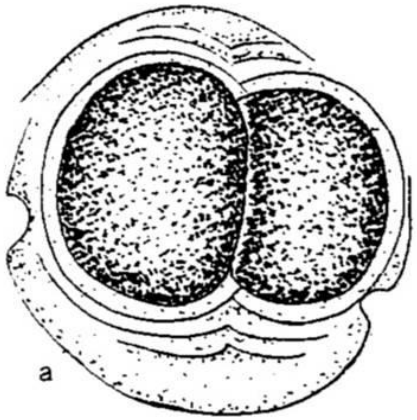


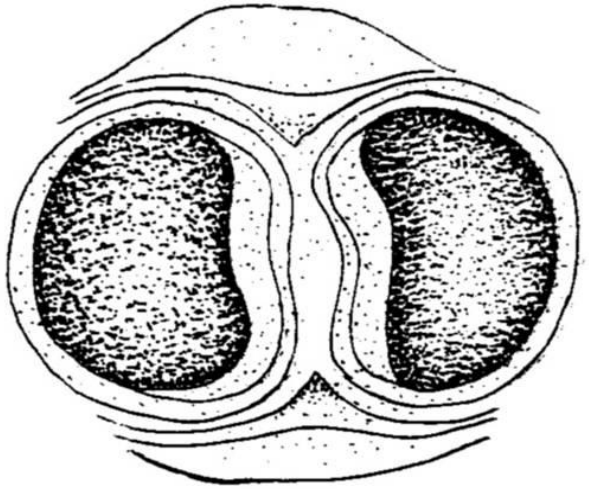


Gloeodiniales - *Gloeodinium montanum*

- capsal thallus
- peat bogs (N Europe, N America, New Zaeland)

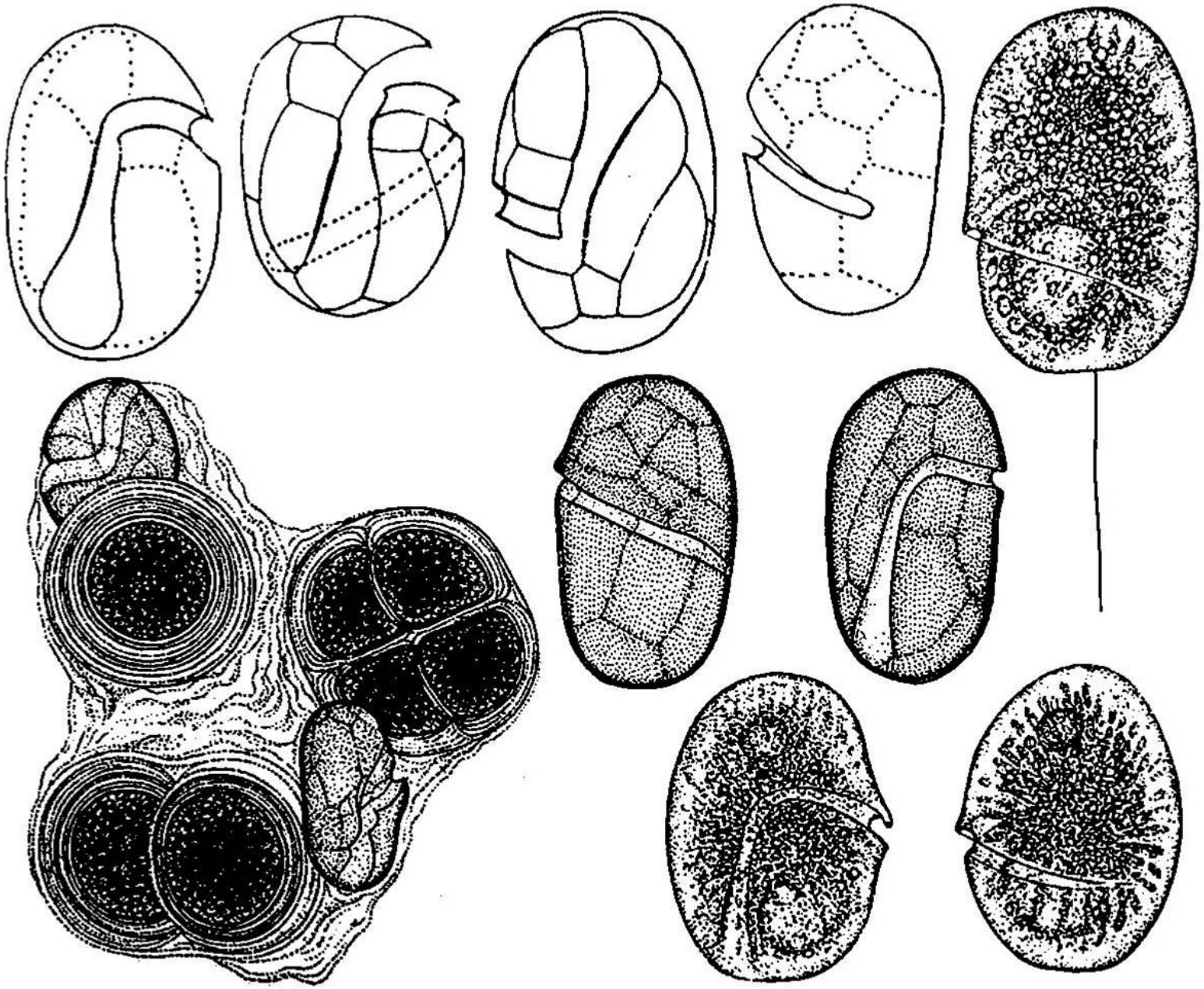




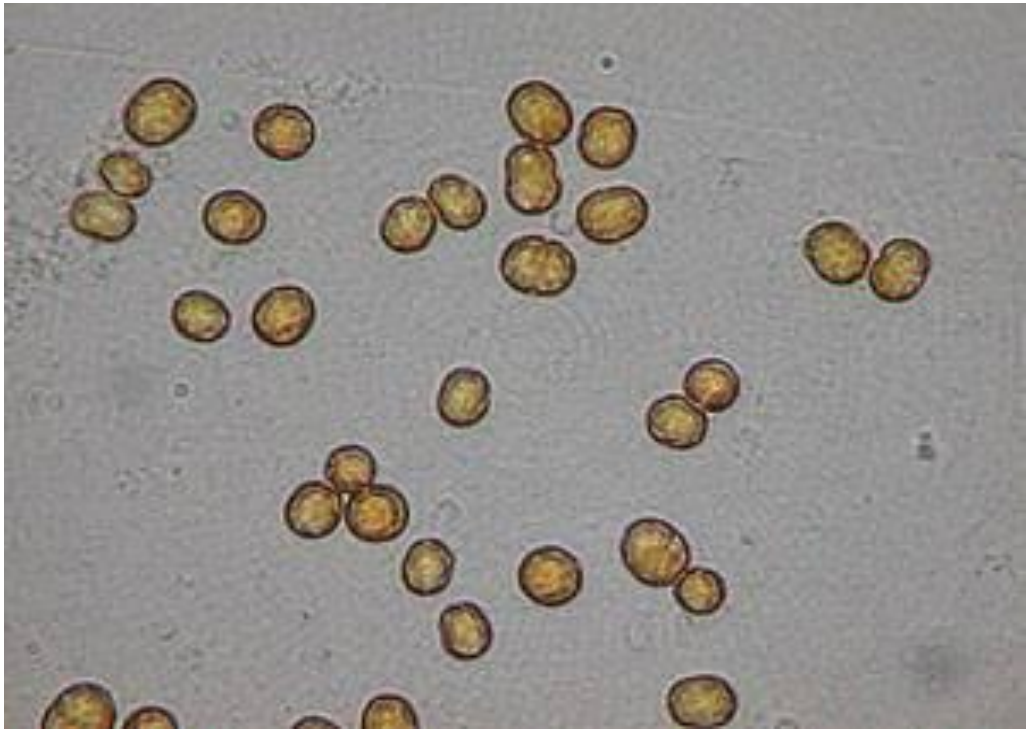


Suessiales - *Hemidinium* (F)

assymetric cells, incomplete cingulum

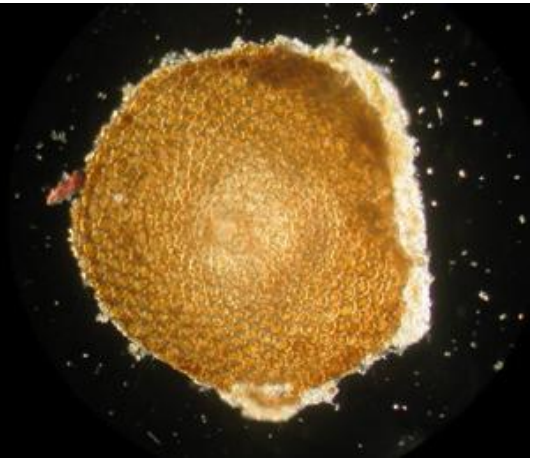


Suessiales - *Symbiodinium* (M)



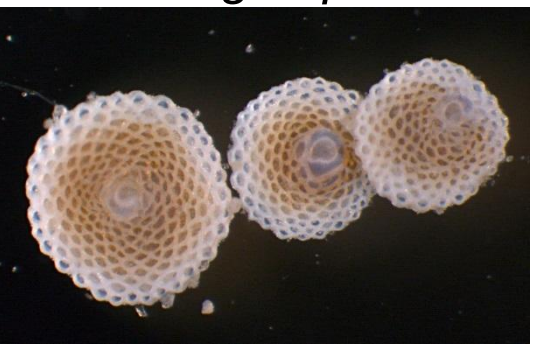
http://www.youtube.com/watch?feature=player_detailpage&v=9Lm9hUj2h_0

Symbiodinium



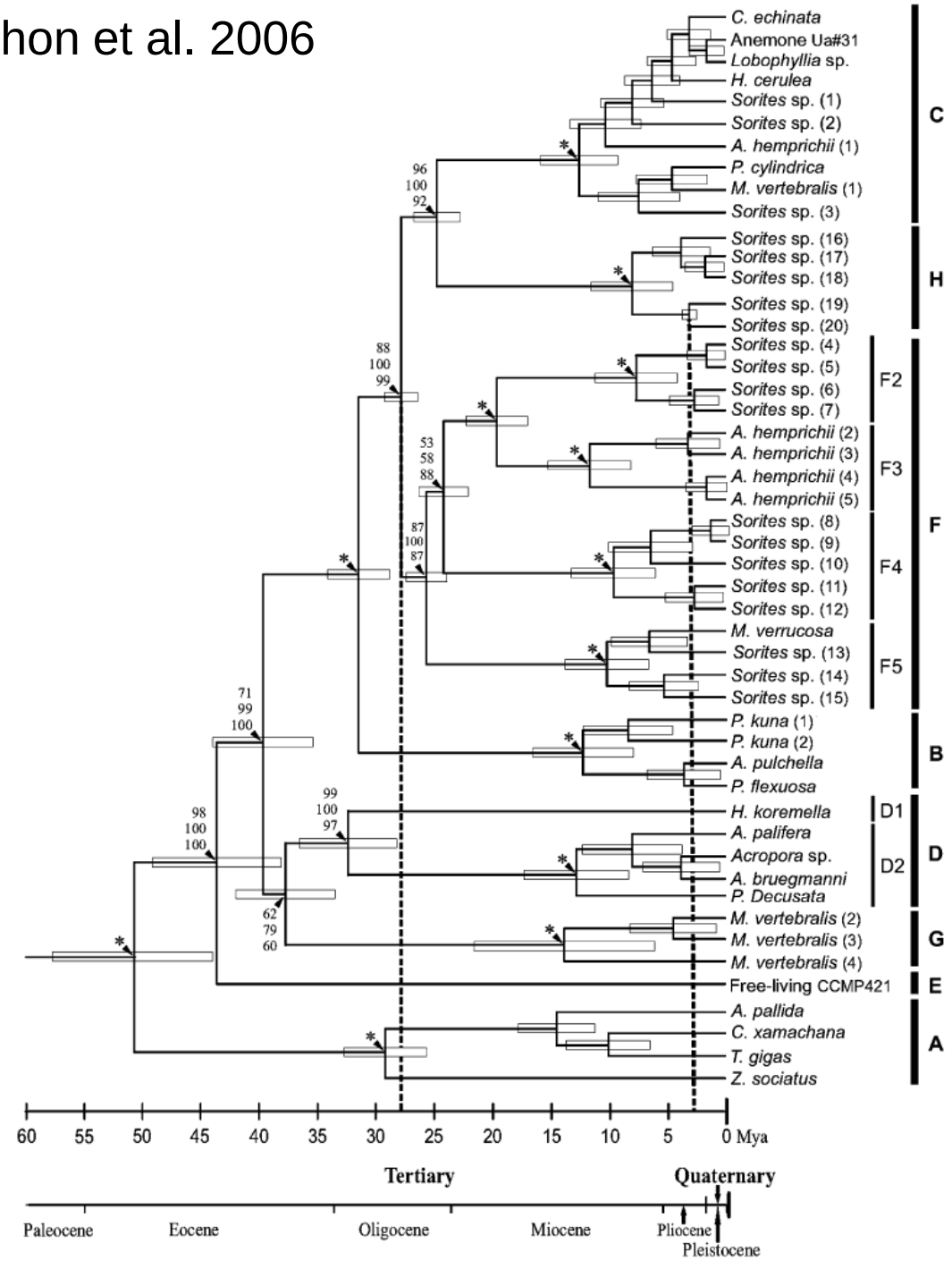
Sorites

Marginopora



Amphisorus

Pochon et al. 2006



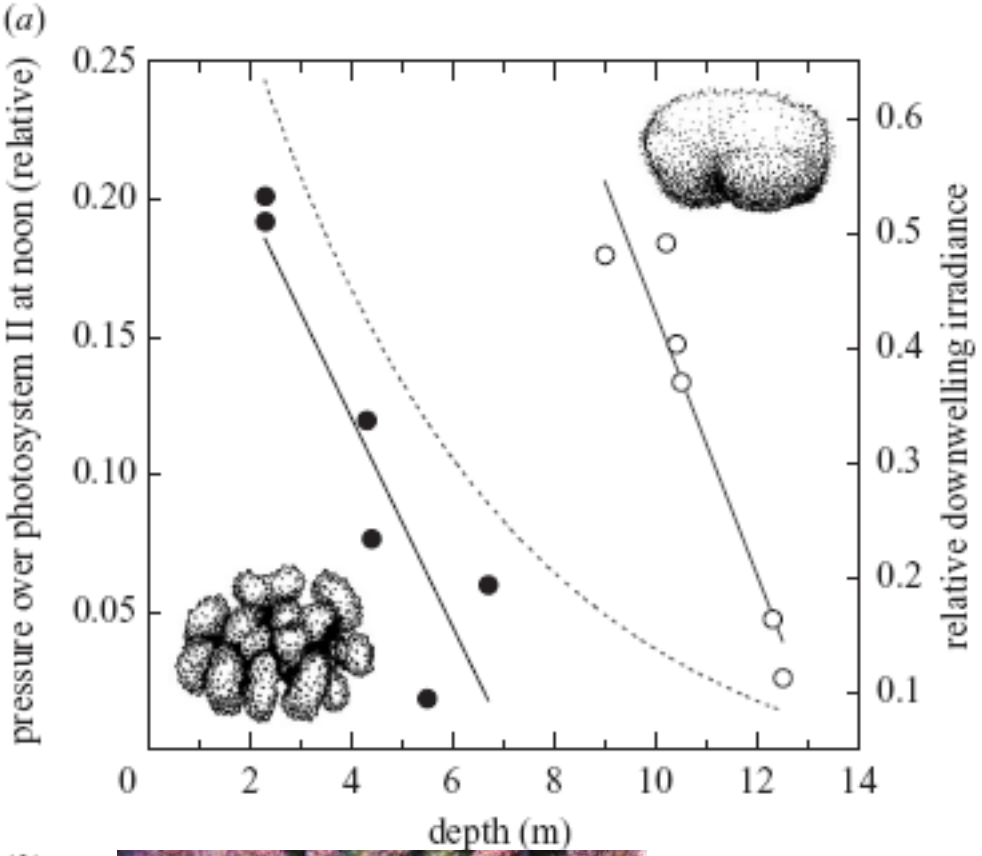
Acropora

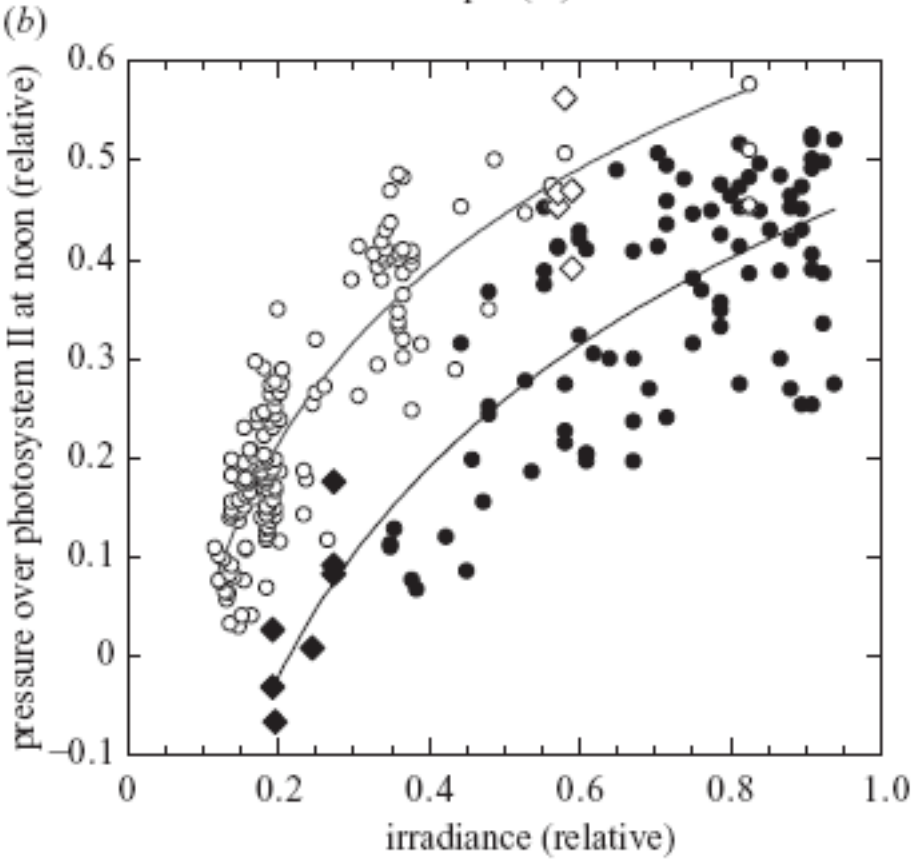
Plexaura

Zoanthus

Symbiodinium

- *Symbiodinium* lineages exhibit different physiologies in response to variations in light and temperature





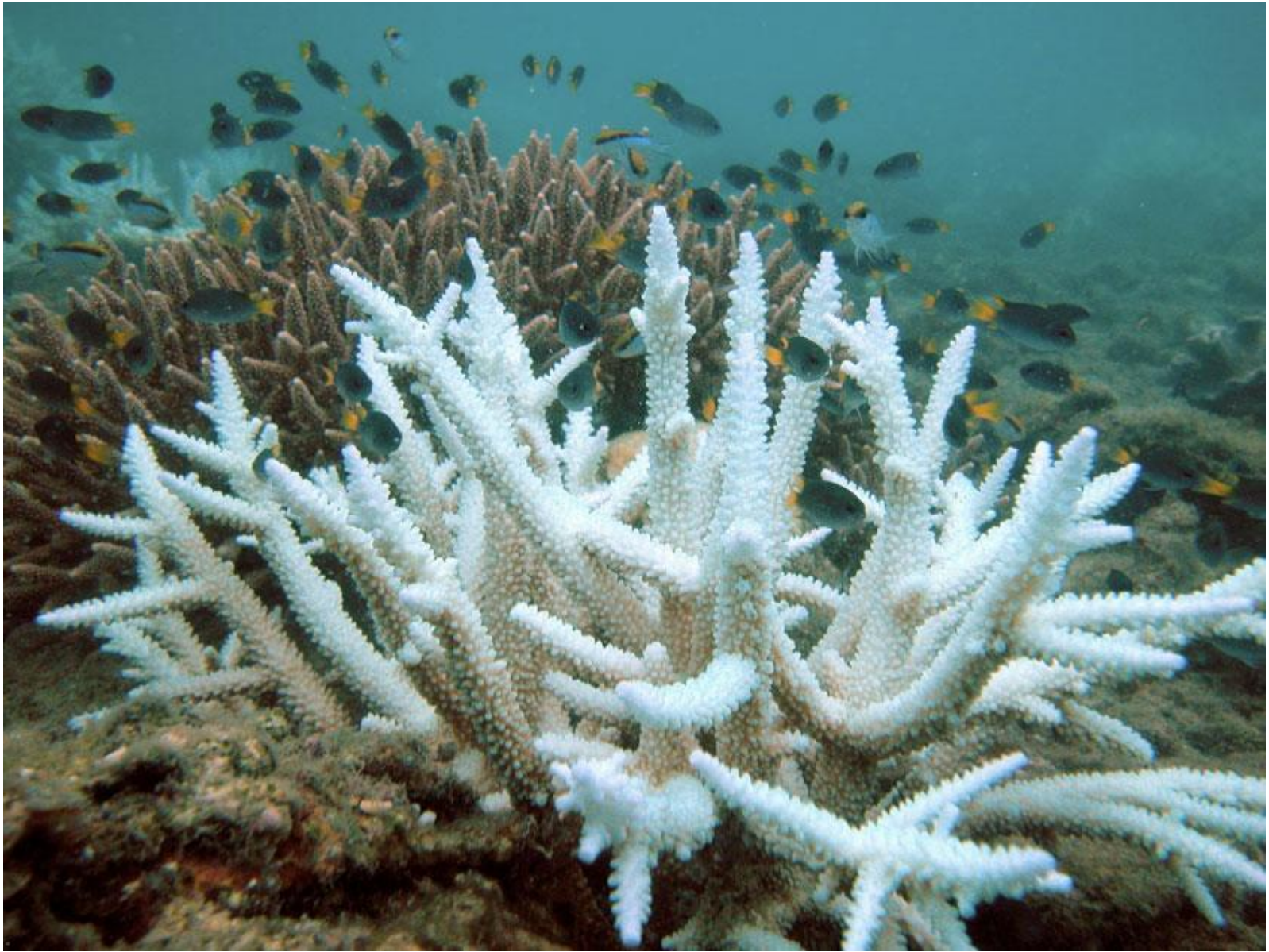
Pocillopora

Pavona

Iglesias-Prieto et al. 2004

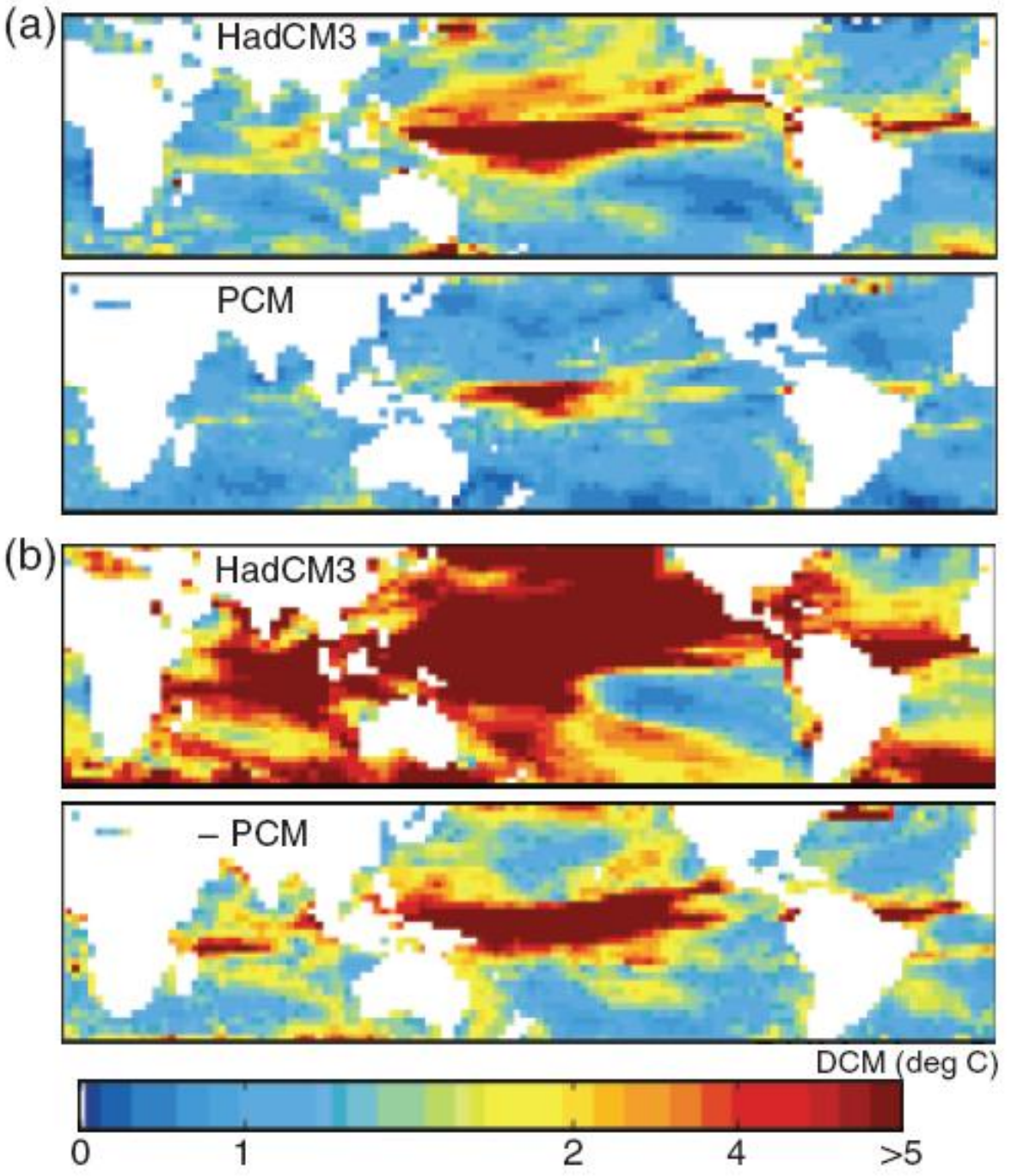
Symbiodinium

- Coral bleeching - the loss of intracellular endosymbionts
  - increase of temperature, solar radiation, acidification, ...



Symbiodinium

- Sea heating



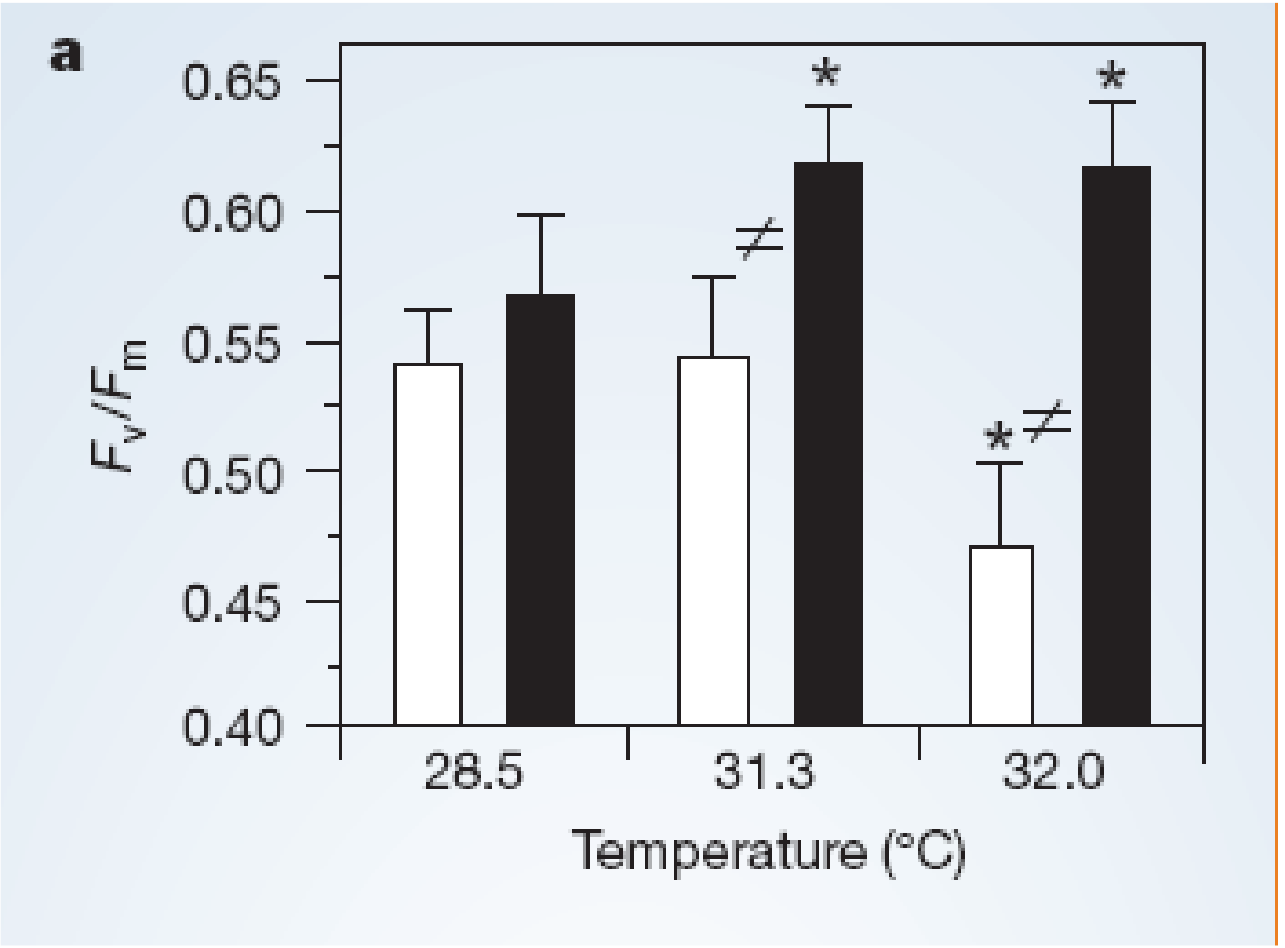
2030-2039

2050-2059

Donner et al. 2005

Symbiodinium

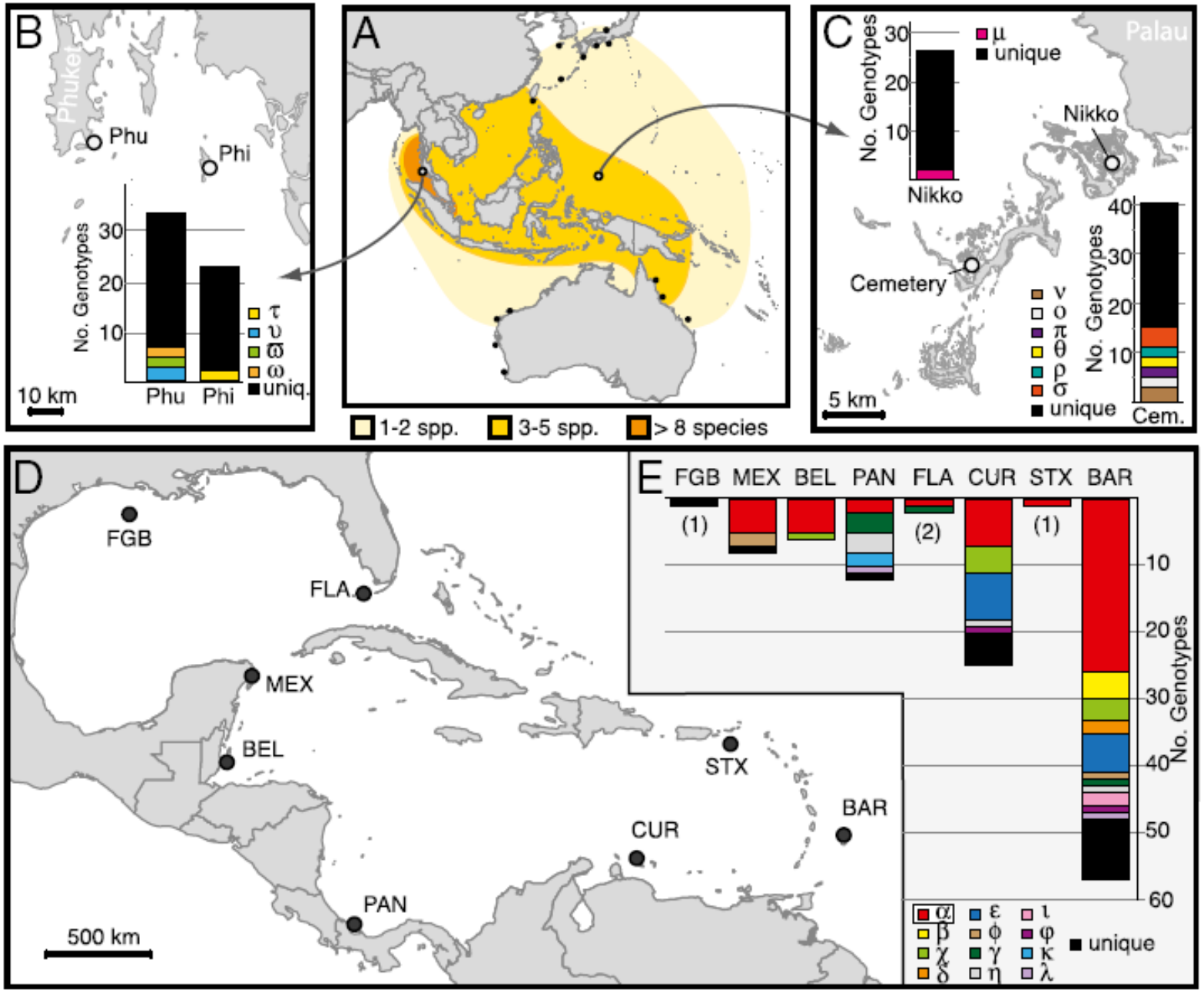
- To prevent bleeching, corals host specifically adapted *Symbiodinium*
  - clade C – sensitive to higher temperatures, PSII damage
  - clade D – tolerant to higher temp., photoprotection



Rowan 2004

Symbiodinium

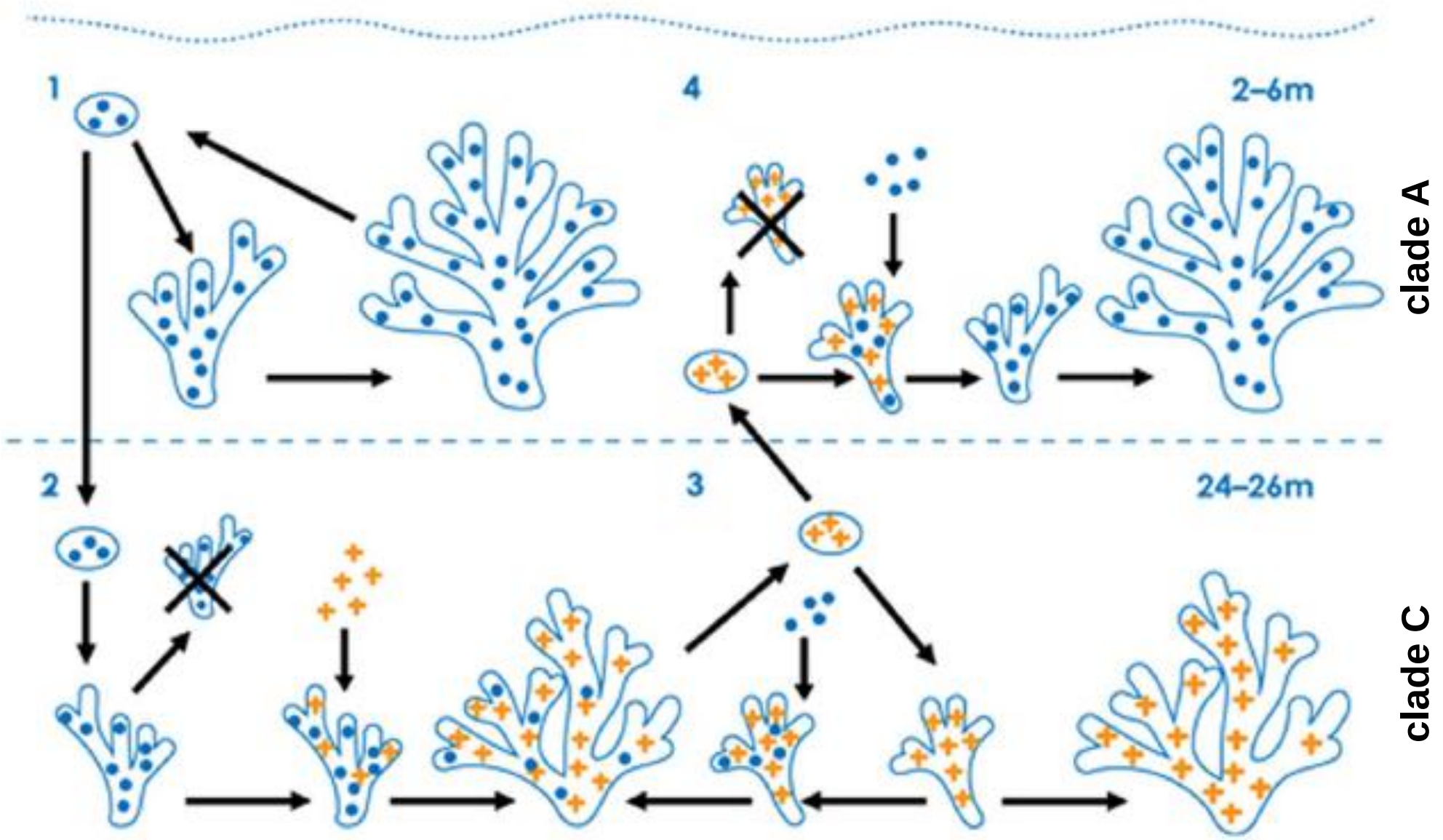
- *S. trenchii*



Pettay et al. 2015

Symbiodinium

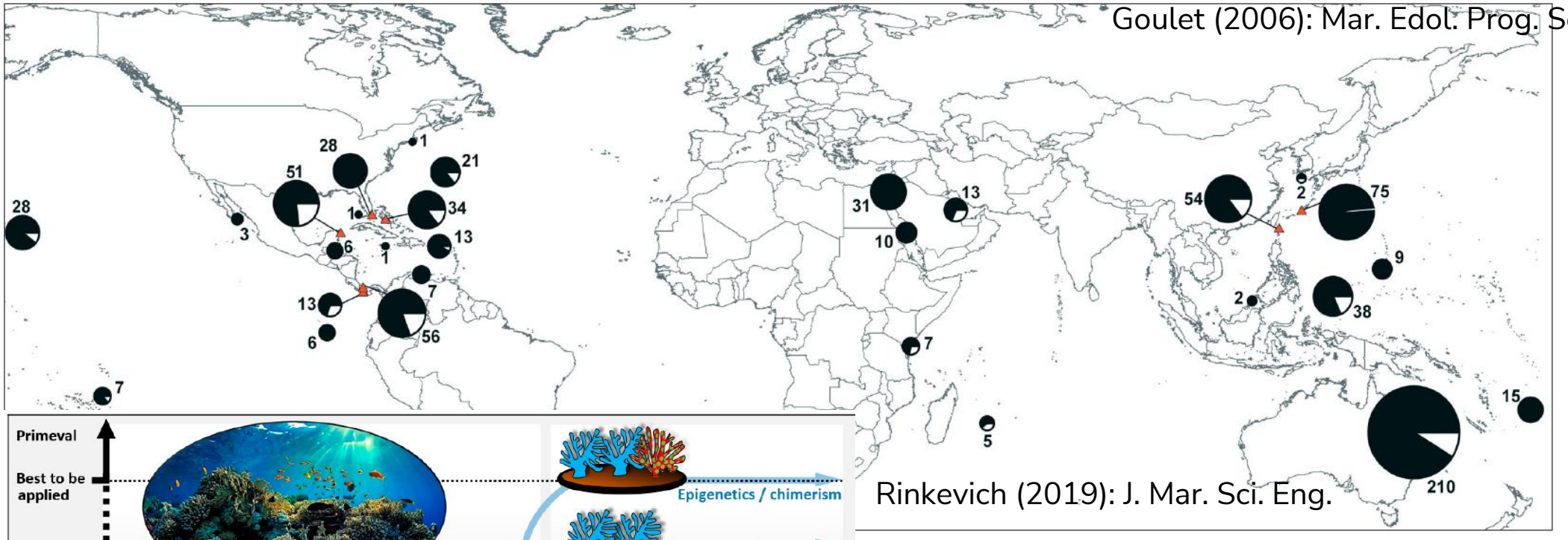
- Habitat adapted symbiosis



Byler et al. 2013

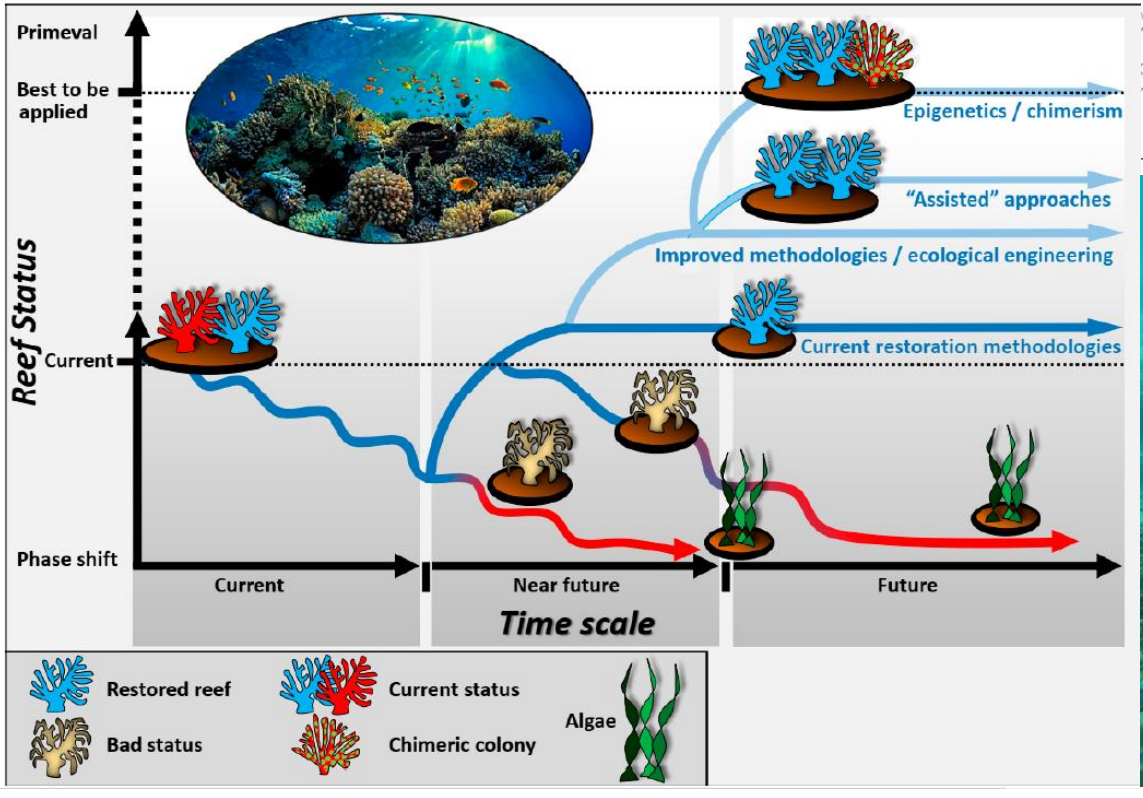
Habitat adapted symbiosis

- Only 23% of coral species host multiple symbions



Goulet (2006): Mar. Edol. Prog. Ser.

Rinkevich (2019): J. Mar. Sci. Eng.



coral nursery


The University of Hong Kon

Symbiodinium

LaJeunesse et al. 2011

- Enormous cryptic diversity
- Strong phylogeograhic structure
- Host-specific lineages

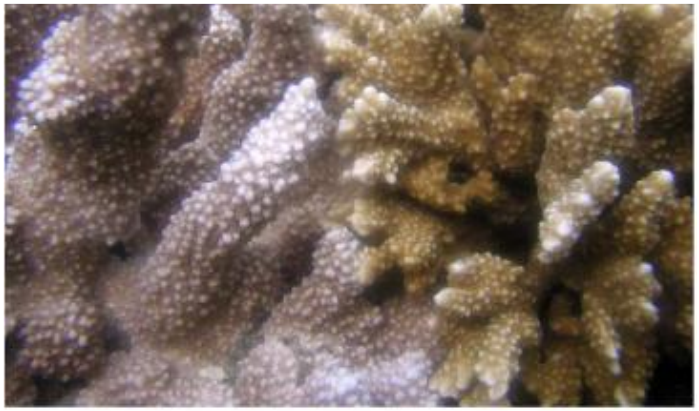
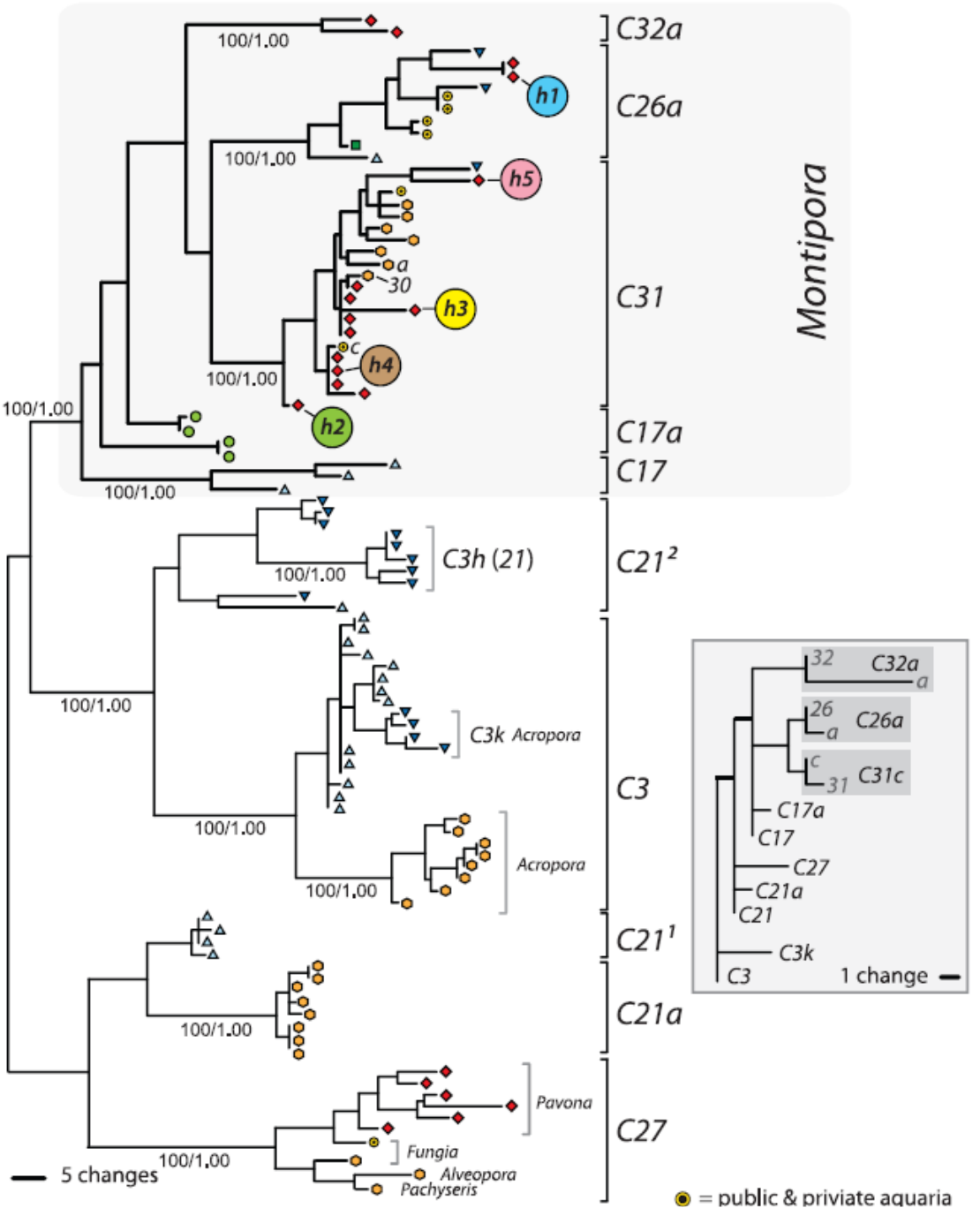


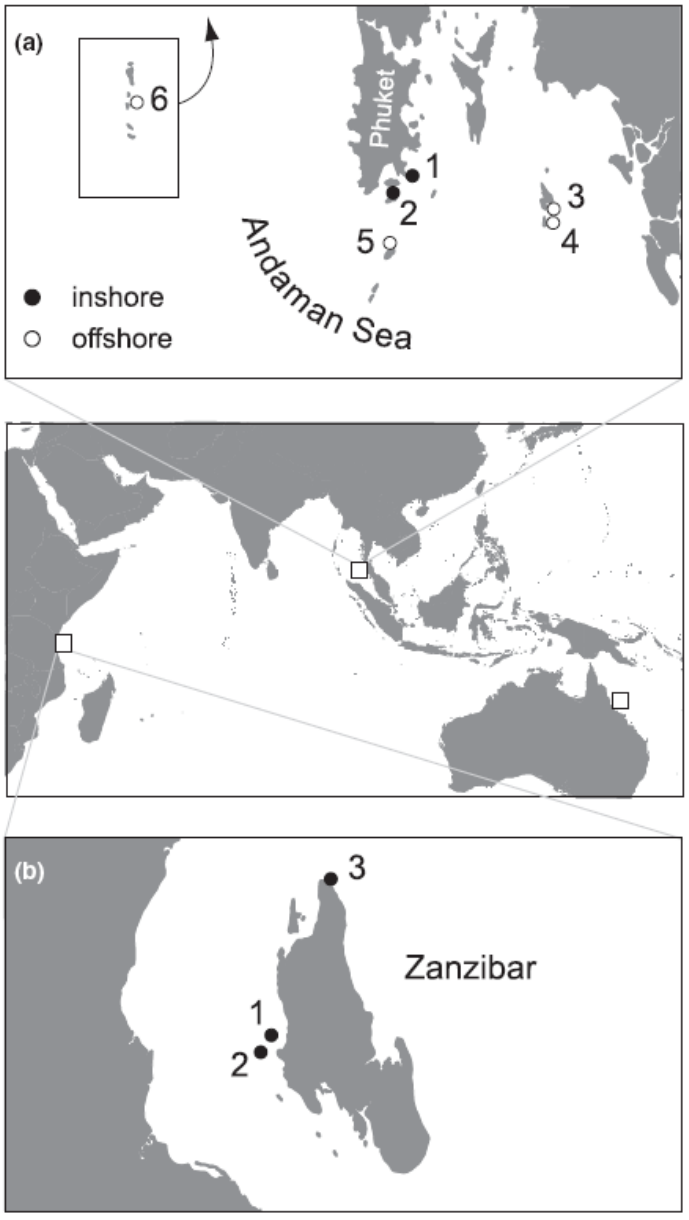
Figure 4. Color morphs of *Montipora capitata* are dominated by different species of *Symbiodinium*. The reddish brown colony on the left harbors the *Montipora*-specific symbiont *C31/C31c*, while the orangish-brown colony on the right harbors the Clade D symbiont, *D1-4-6*.

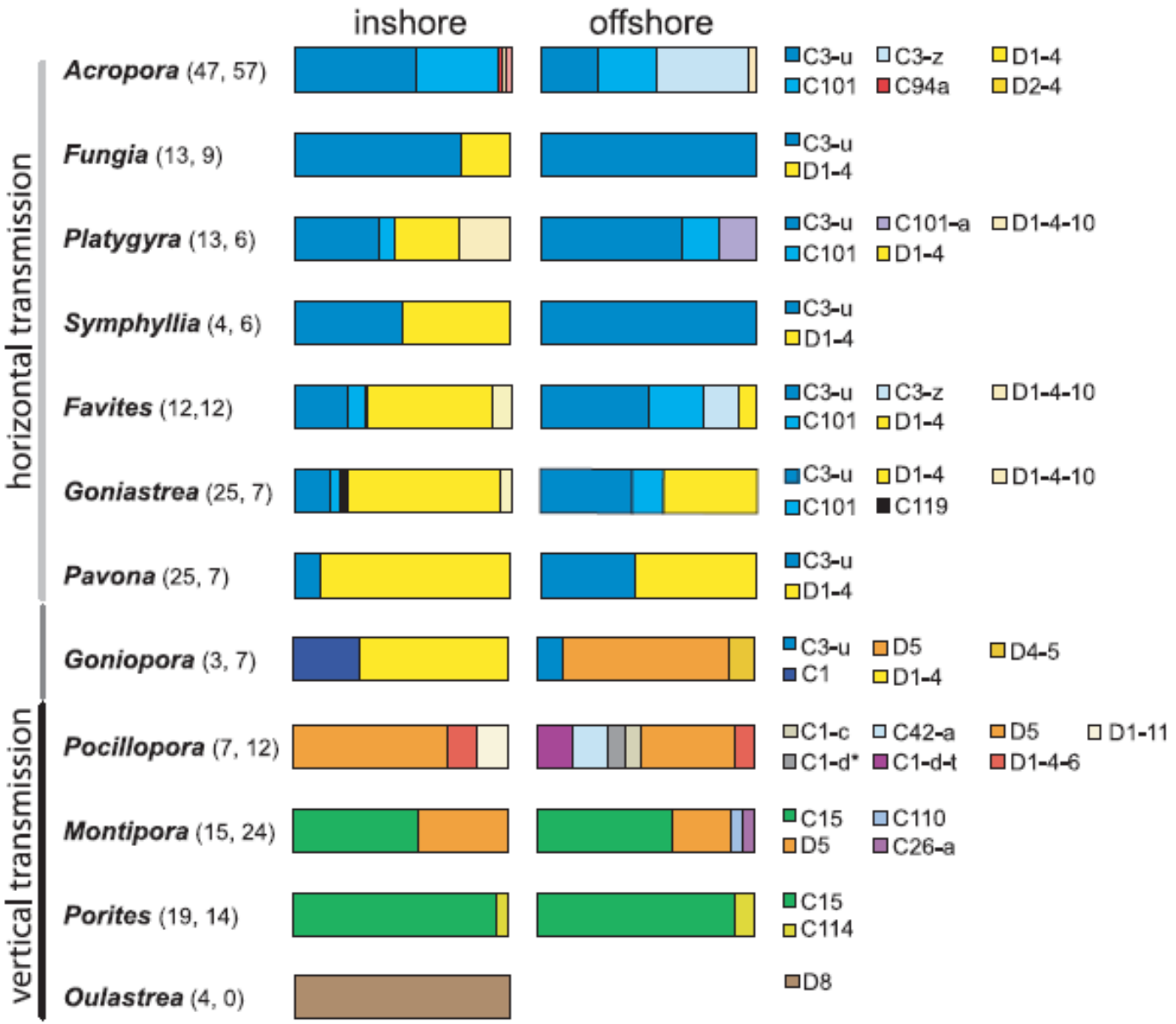


Symbiodinium

LaJeunesse et al. 2010

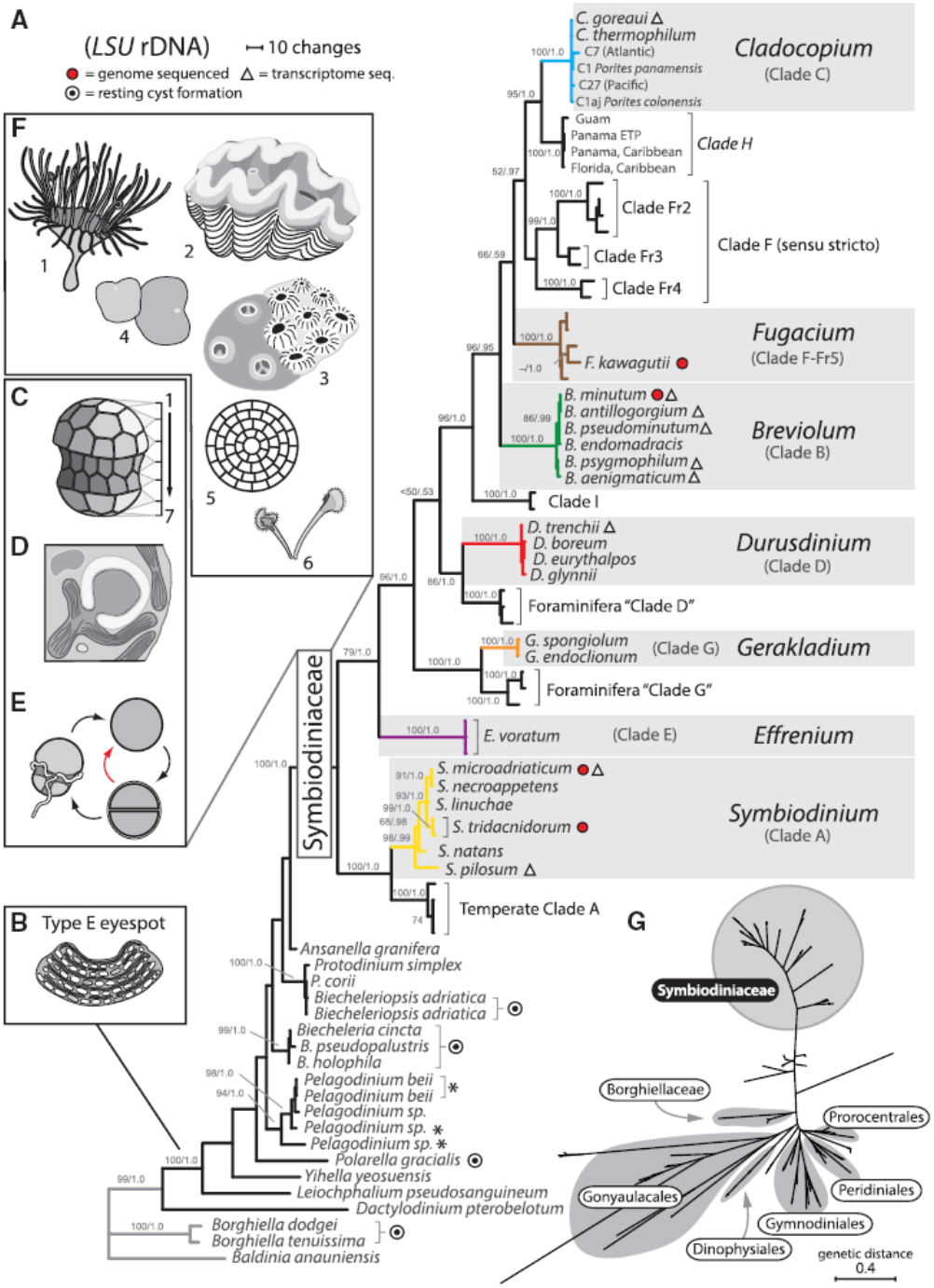
- Host-symbiont specificity, ecological differences
  - C3-z: offshore; C15: thermally tolerant

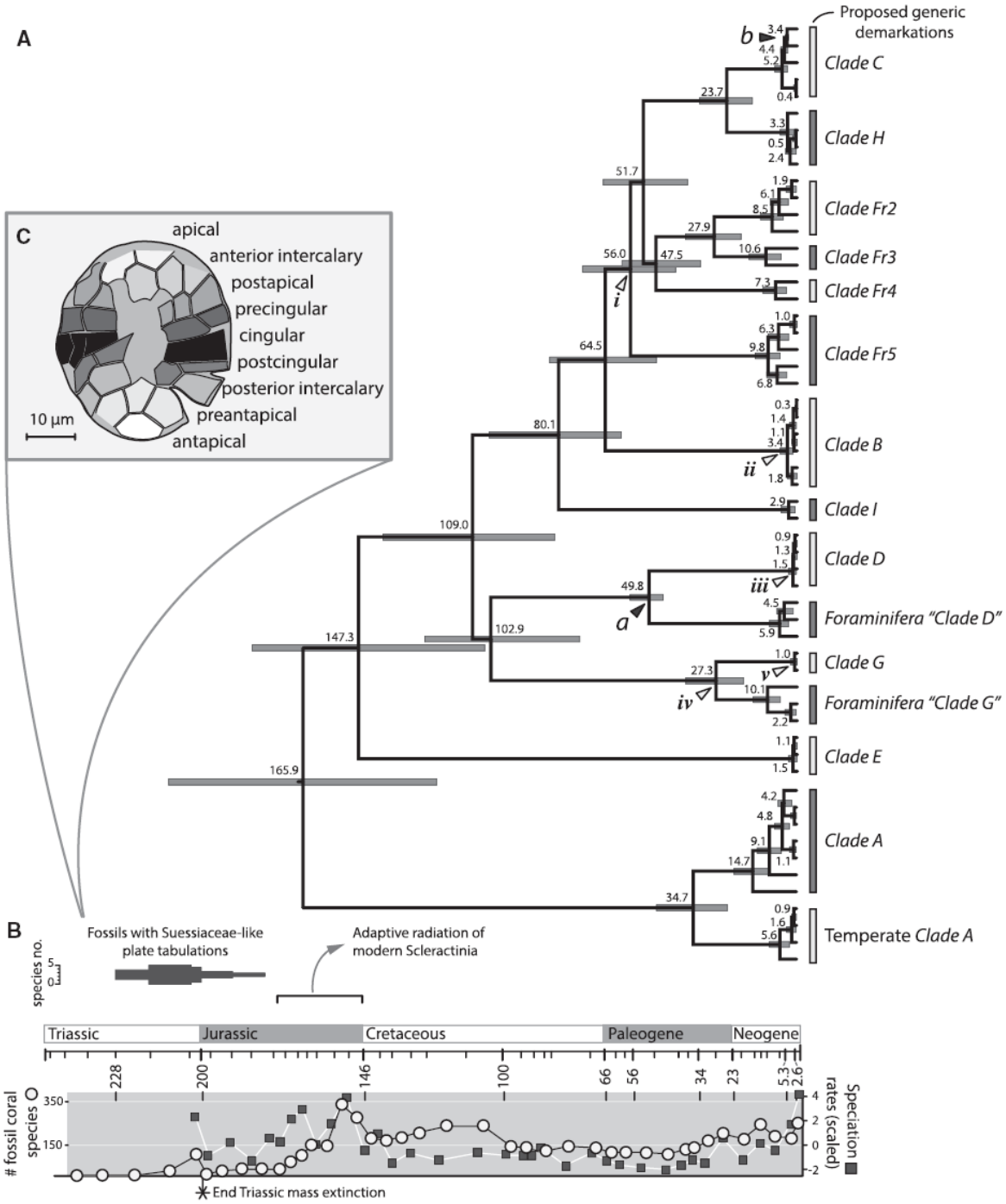




Symbiodinium

LaJeunesse et al. 2018

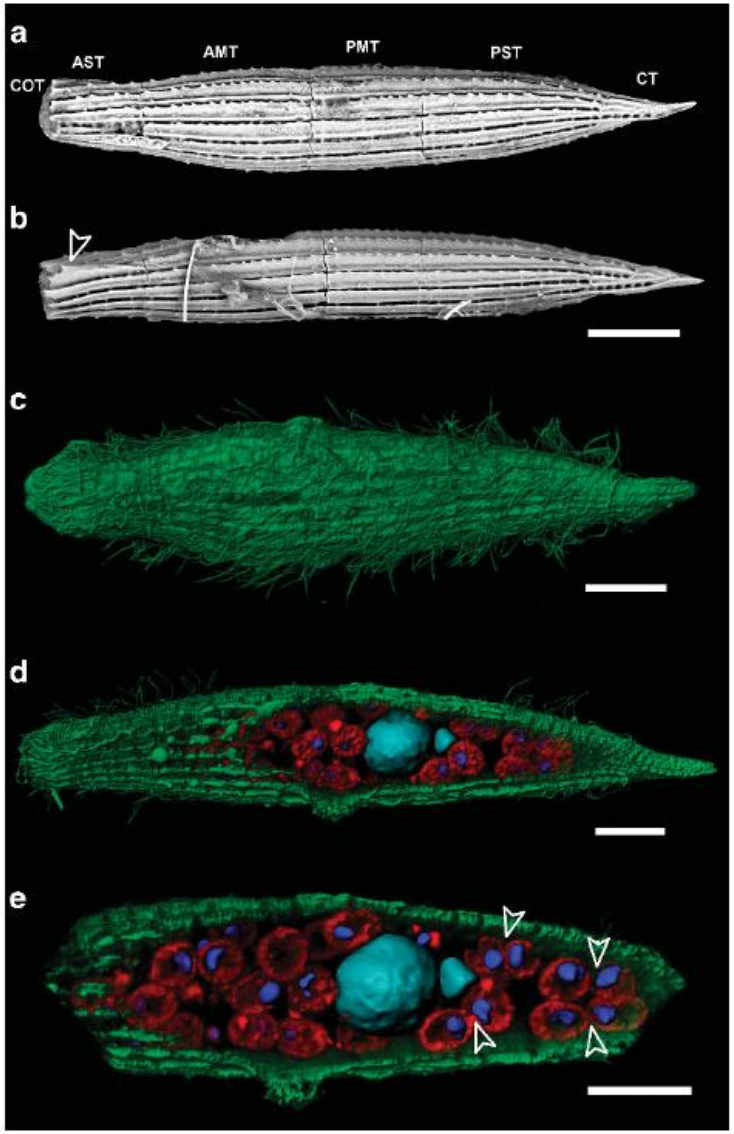




Symbiodinium

Mordret et al. 2016

- A symbiont of calcifying ciliate *Tiarina*



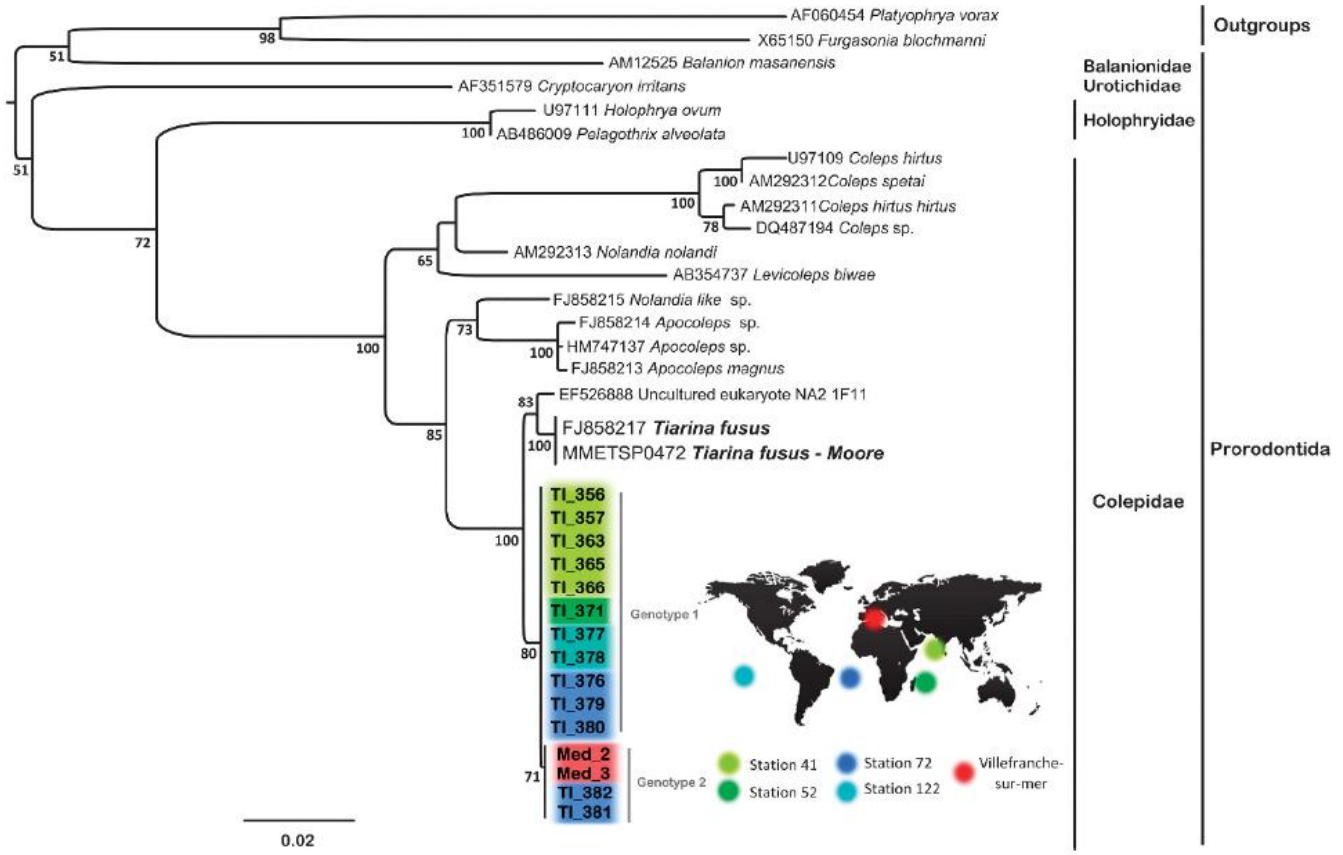
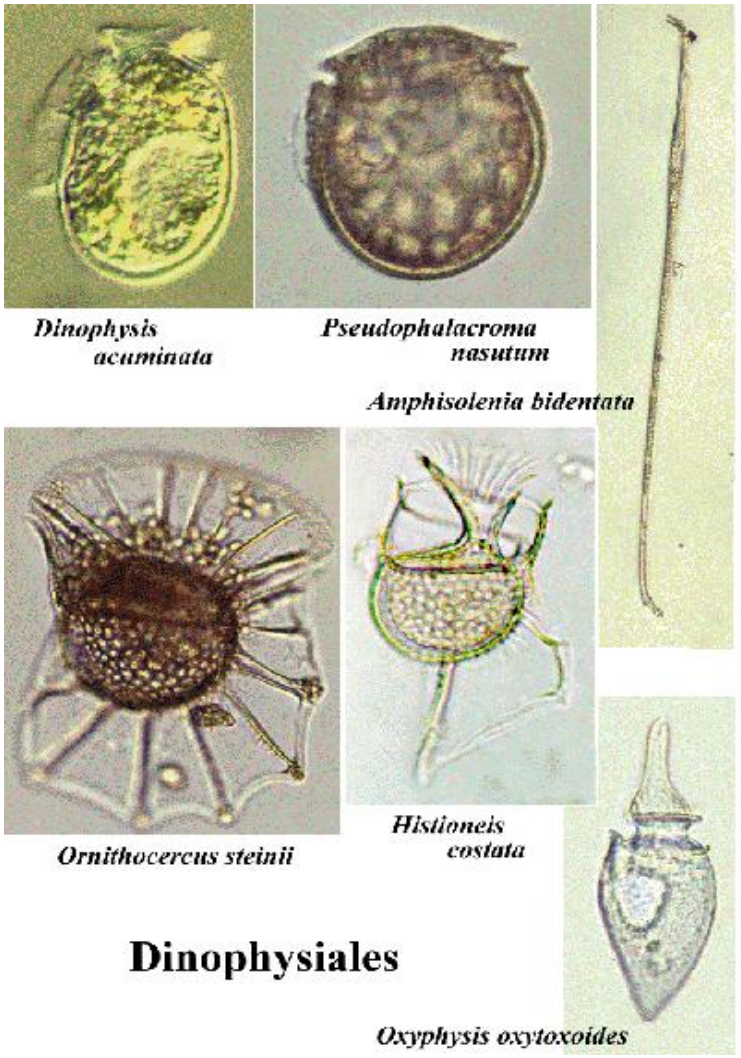


Figure 1 Microscopy images of the photosymbiosis between the ciliate *Tiarina* sp. (the host) and its intracellular symbiotic microalgae collected in surface oceanic waters. (**a**, **b**) Scanning electron microscopy images reveal the calcified skeleton of the ciliate composed of six different tiers: circumoral (COT), anterior

Dinophysiales

- flagellates, lateraly flattened cells
- thecate, epitheca + hypotheca, left and right half of the cell separated by longitudinal suture
- only marine species



Dinophysis (M)

toxic species (DSP)

D. acuminata

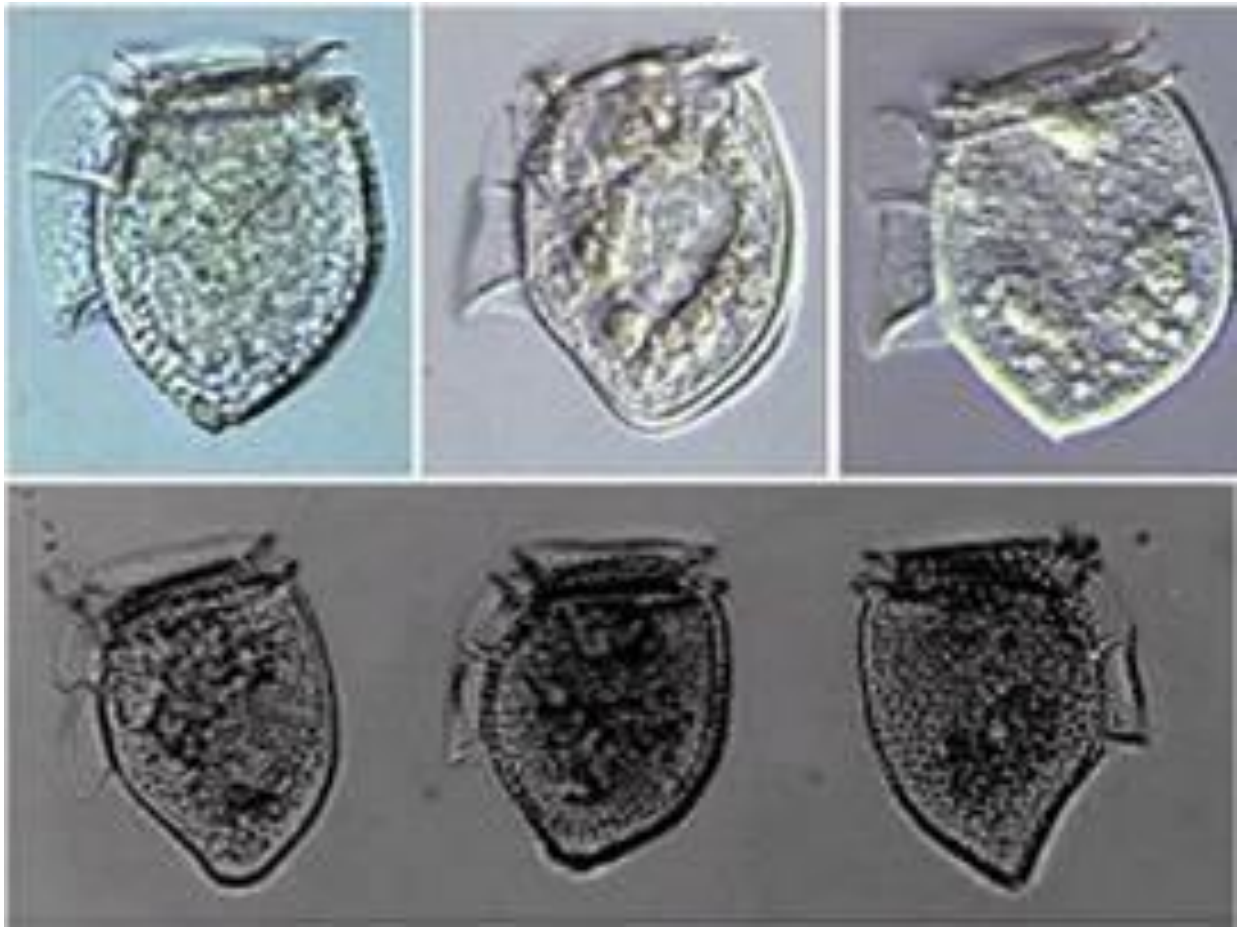
D. fortii

D. mitra

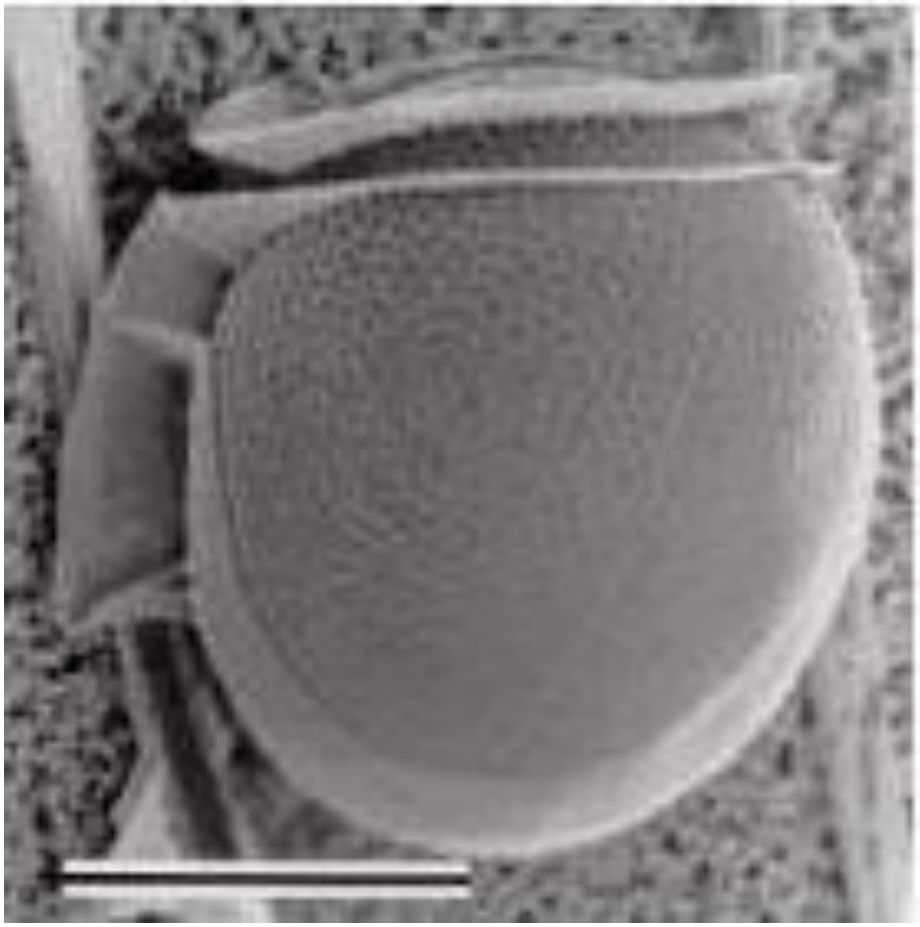
D. caudata

Dinophysis (M)

non-toxic species



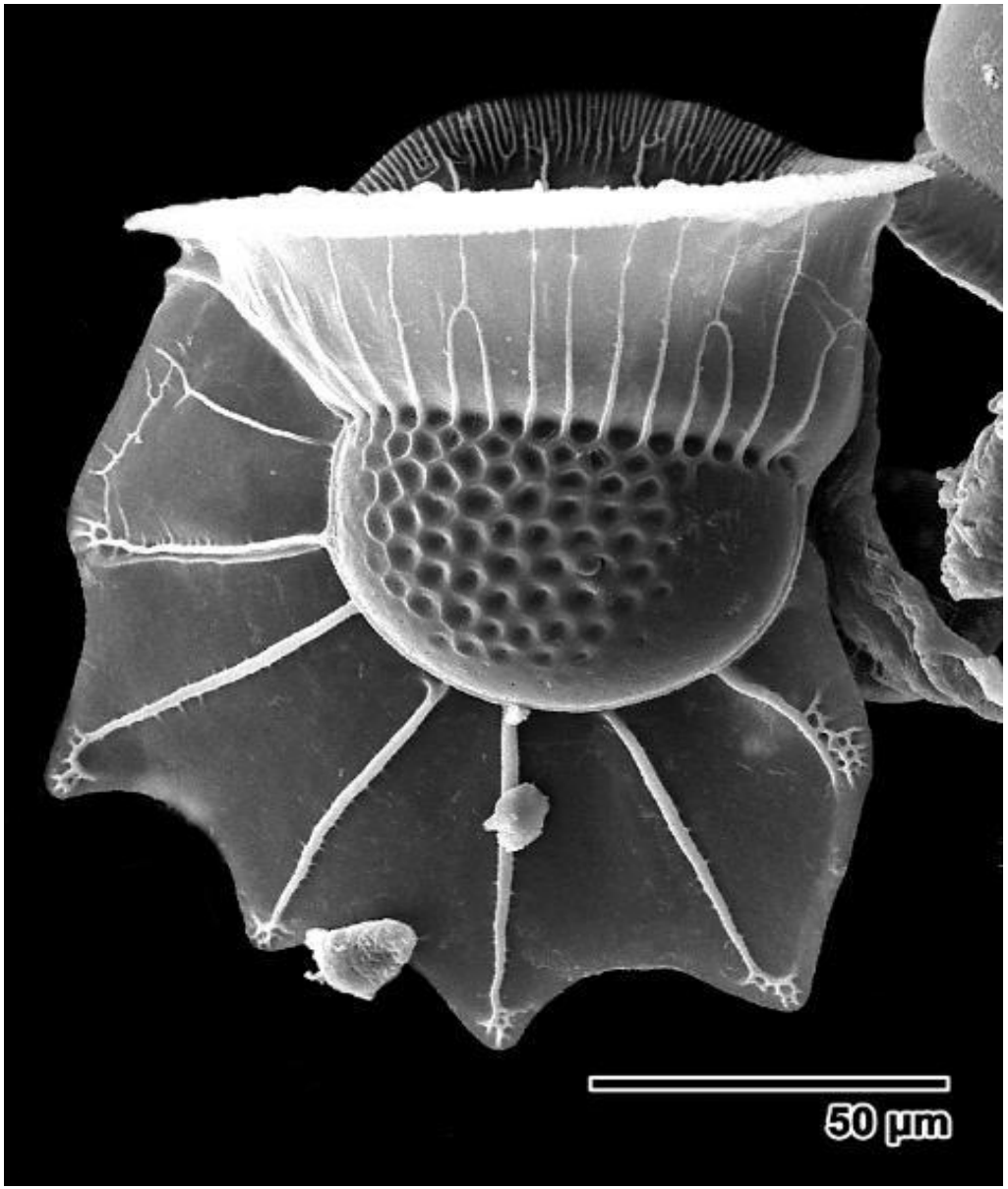
Dinophysis norvegica



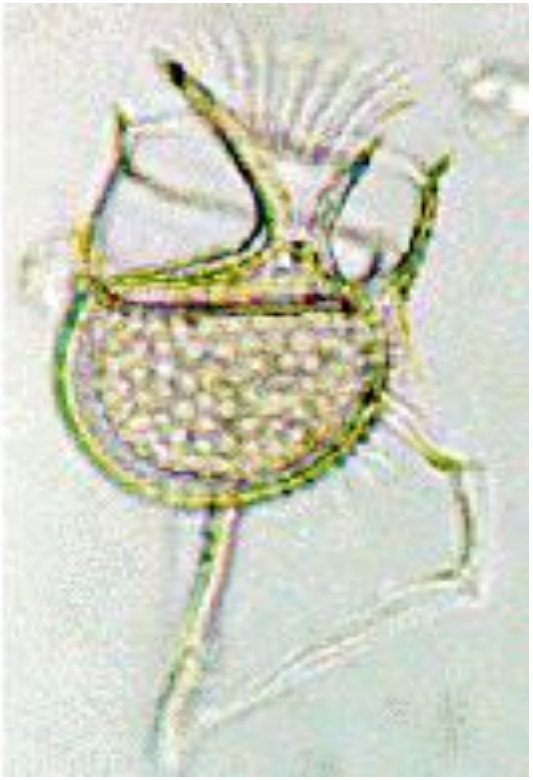
Dinophysis rotundata
(= Phalacroma)

Ornithocercus (M)

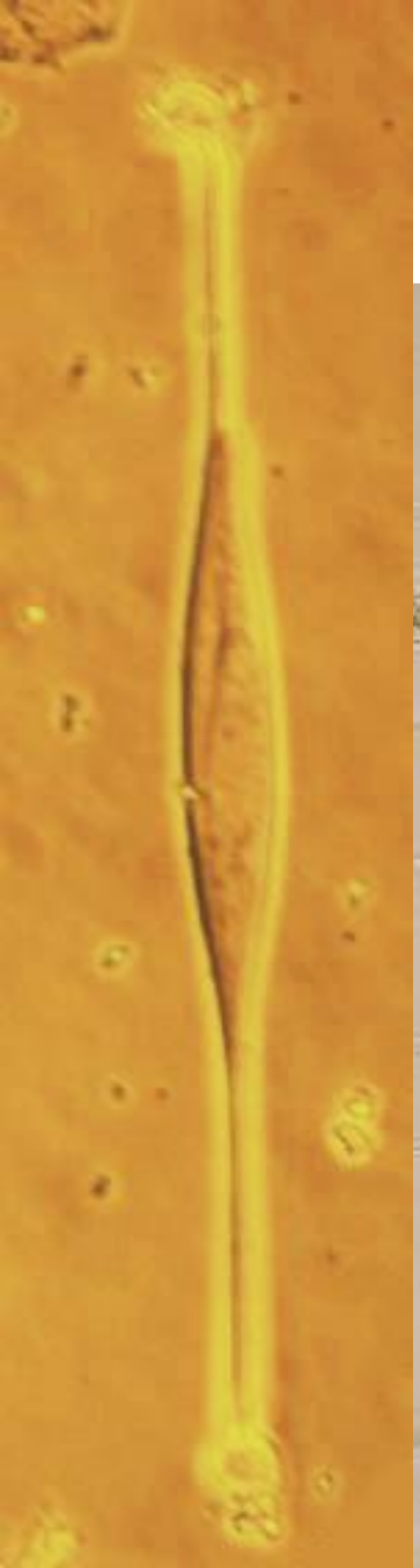
symbiotic heterocytous cyanobacteria instead of plastids (between two large wings)

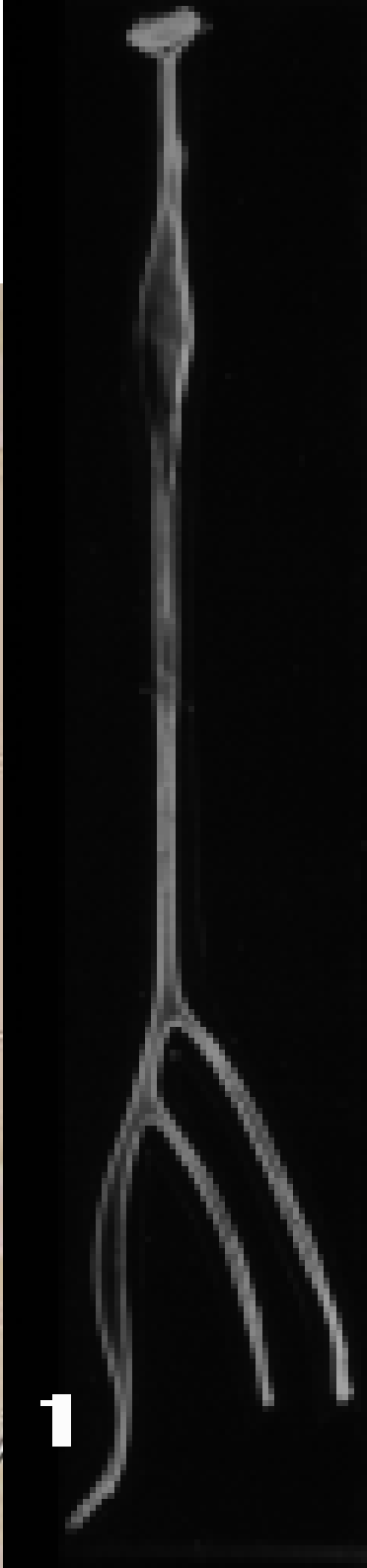


Histioneis (M)

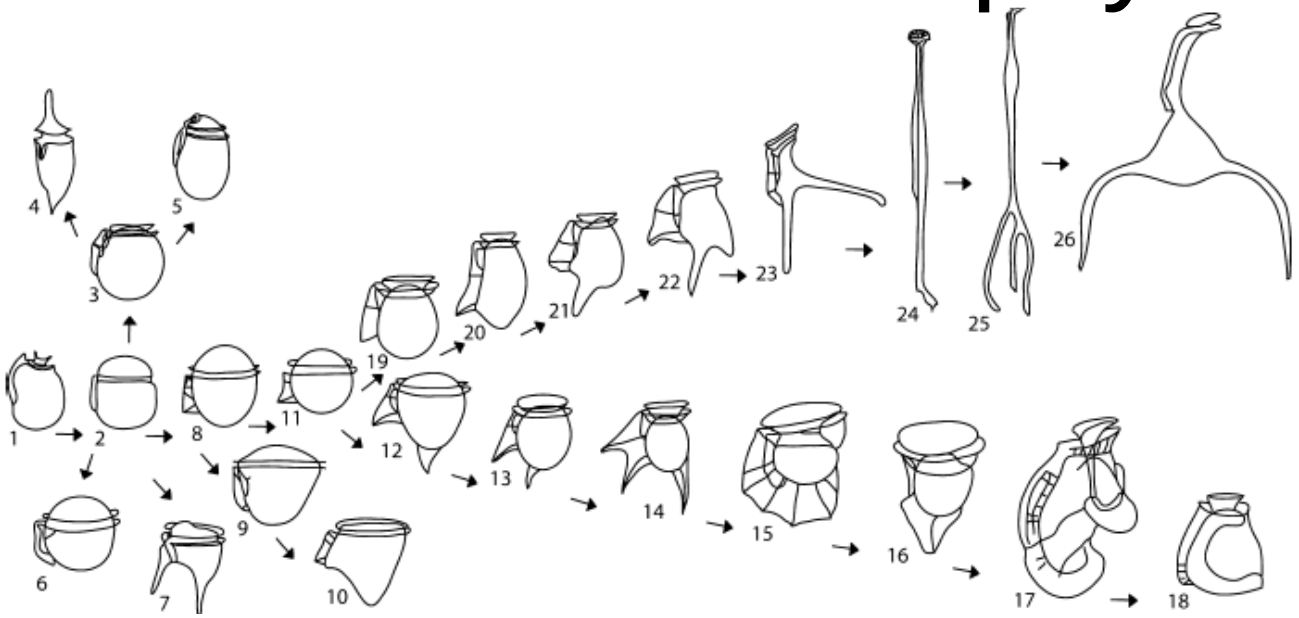


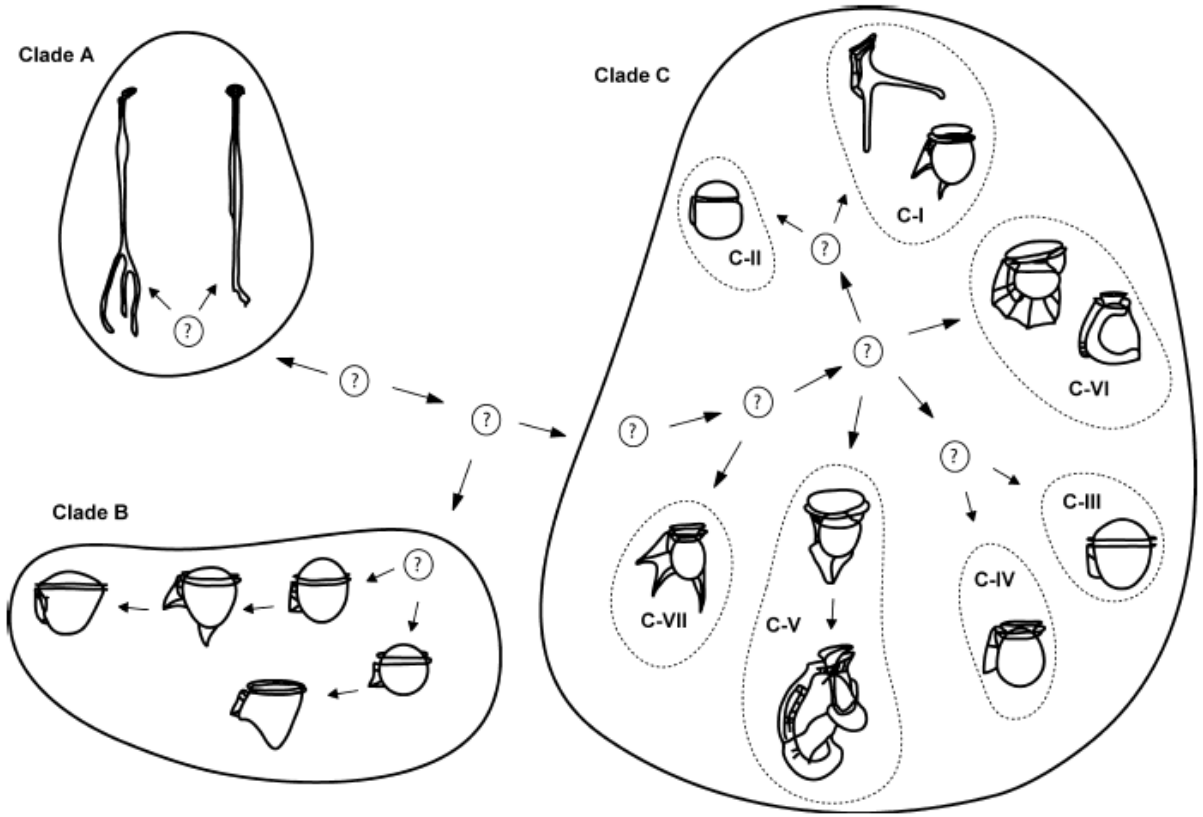
Amphisolenia (M)





Dinophysiales

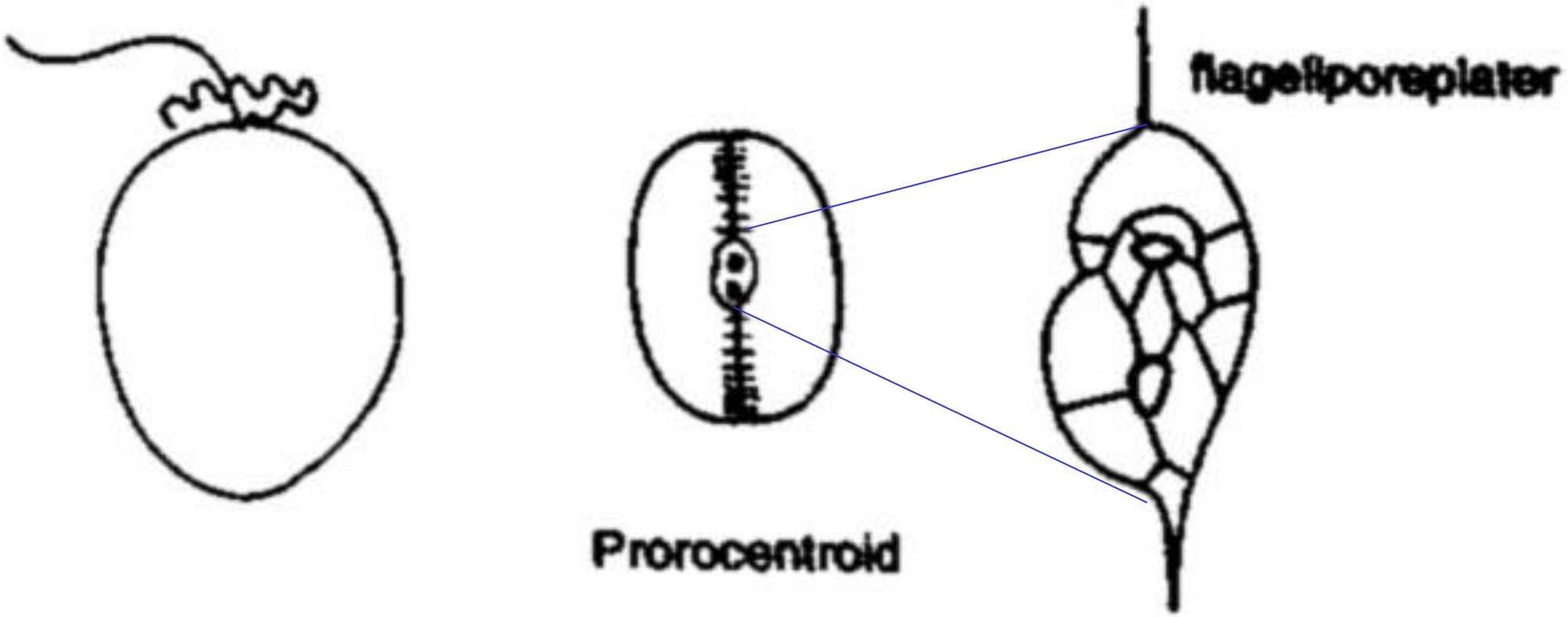




- comparison of traditional and modern evolutional hypotheses
- A – *Amphisolenia*
  B – *Phalacroma*
  C – other genera
- convergent evolution of morphological attributes

Prorocentrales

- flagellates, lateraly flattened cells
- thecate, 2 big plates separated by longitudinal suture + several minute plates near apical pores
- only marine species, autotrophic



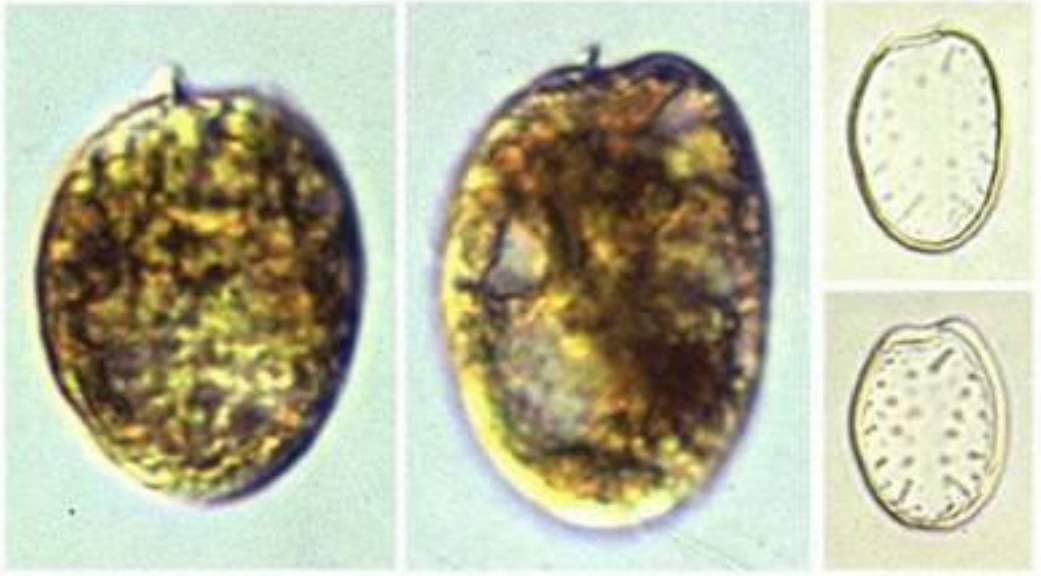
Prorocentrum (M)

Prorocentrum lima (Ehrenberg) Dodge

Photomicrograph
by Yasuwo Fukuyo

WESTPAC-HAB
IOC Harmful Algal Bloom Programme

T0009



Prorocentrum mexicanum Tafall

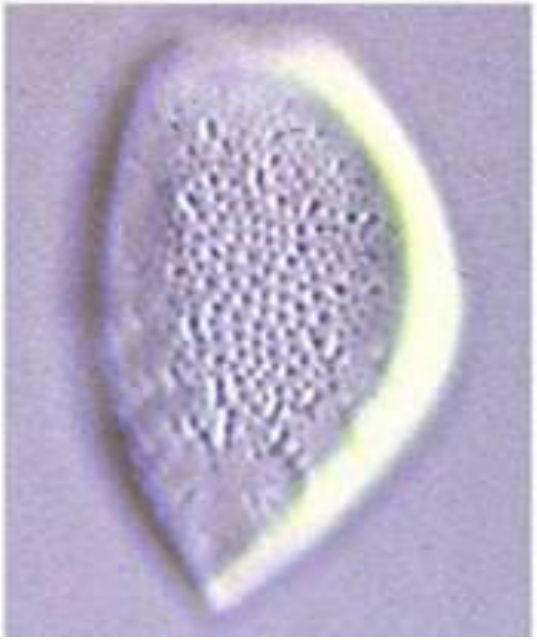
Photomicrographs
by Yasuwo Fukuyo

Prorocentrum sigmoides Böhm

WESTPAC-HAB

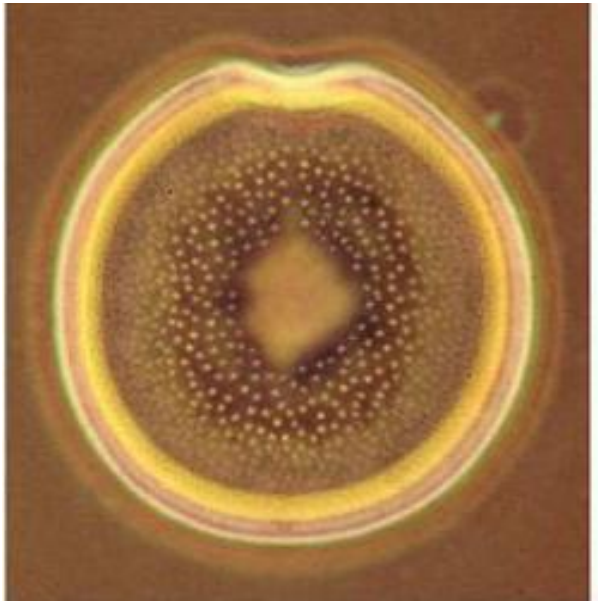
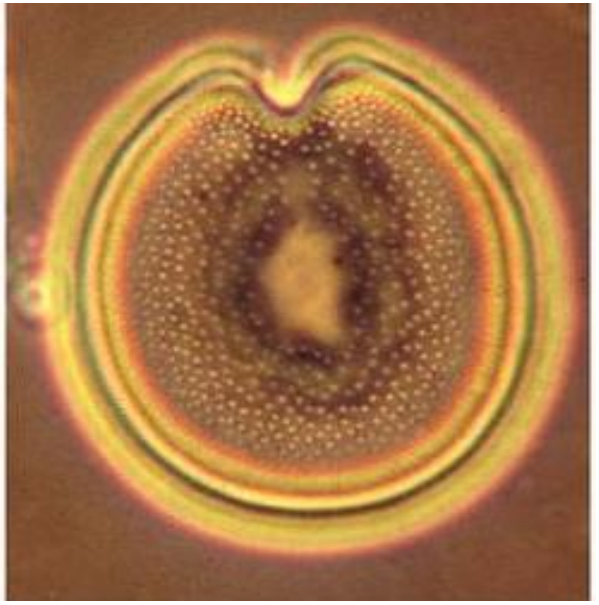
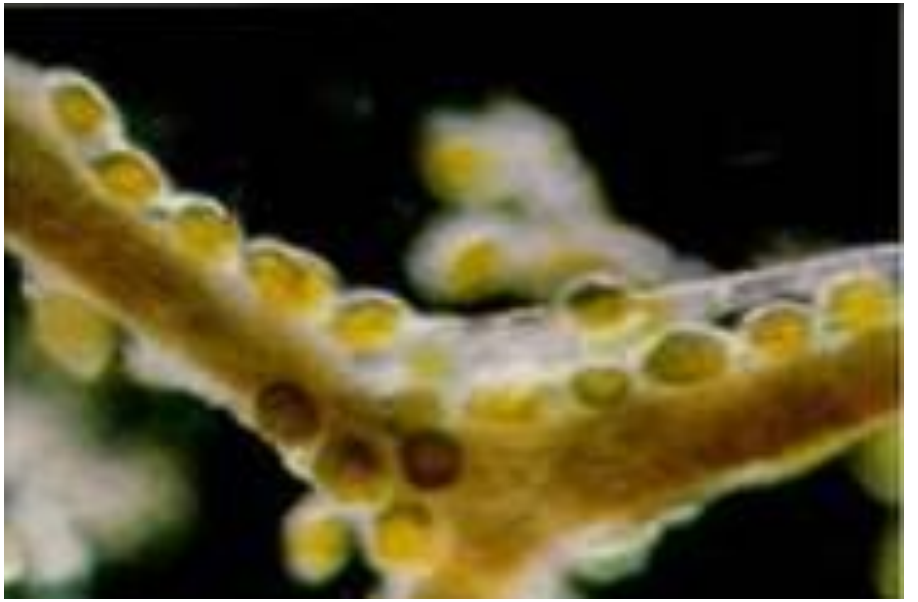
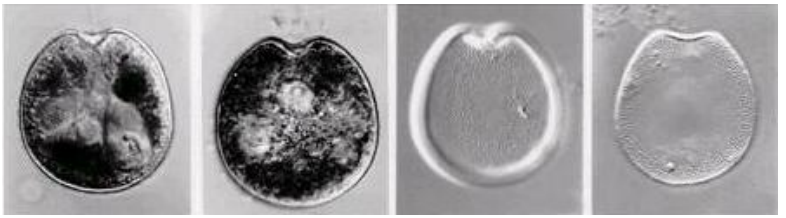
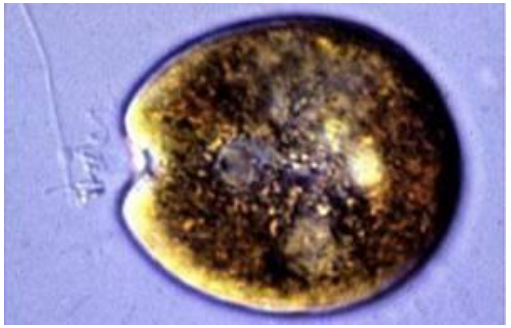
Prorocentrum micans (M)

planktonic species, red tides

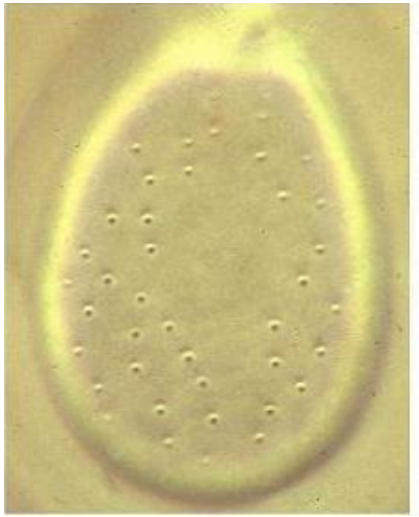


Prorocentrum (M)

benthic species, CFP !

Prorocentrum concavum



Prorocentrum lima