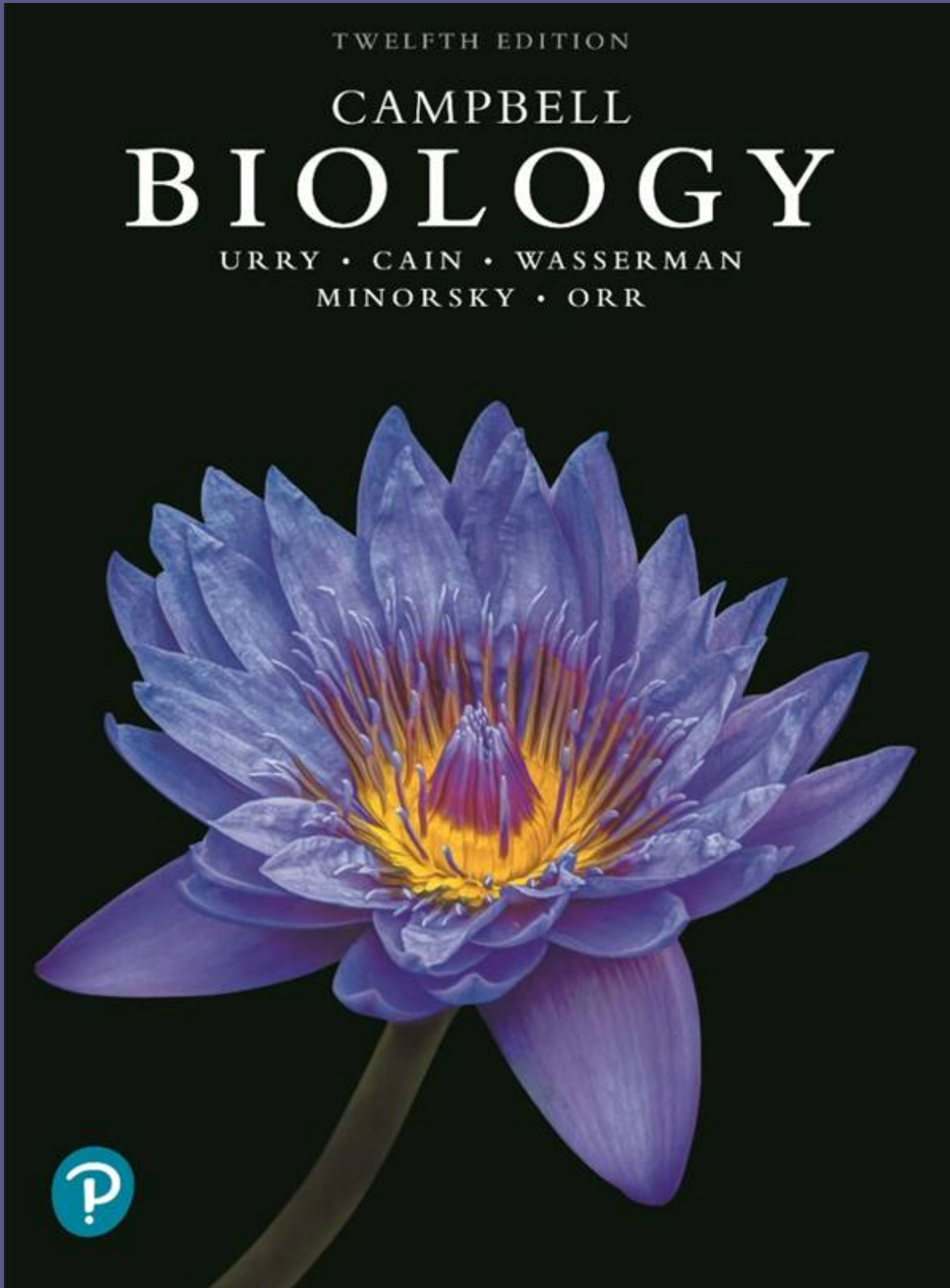


Chapter 28

Protists

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 28.1a

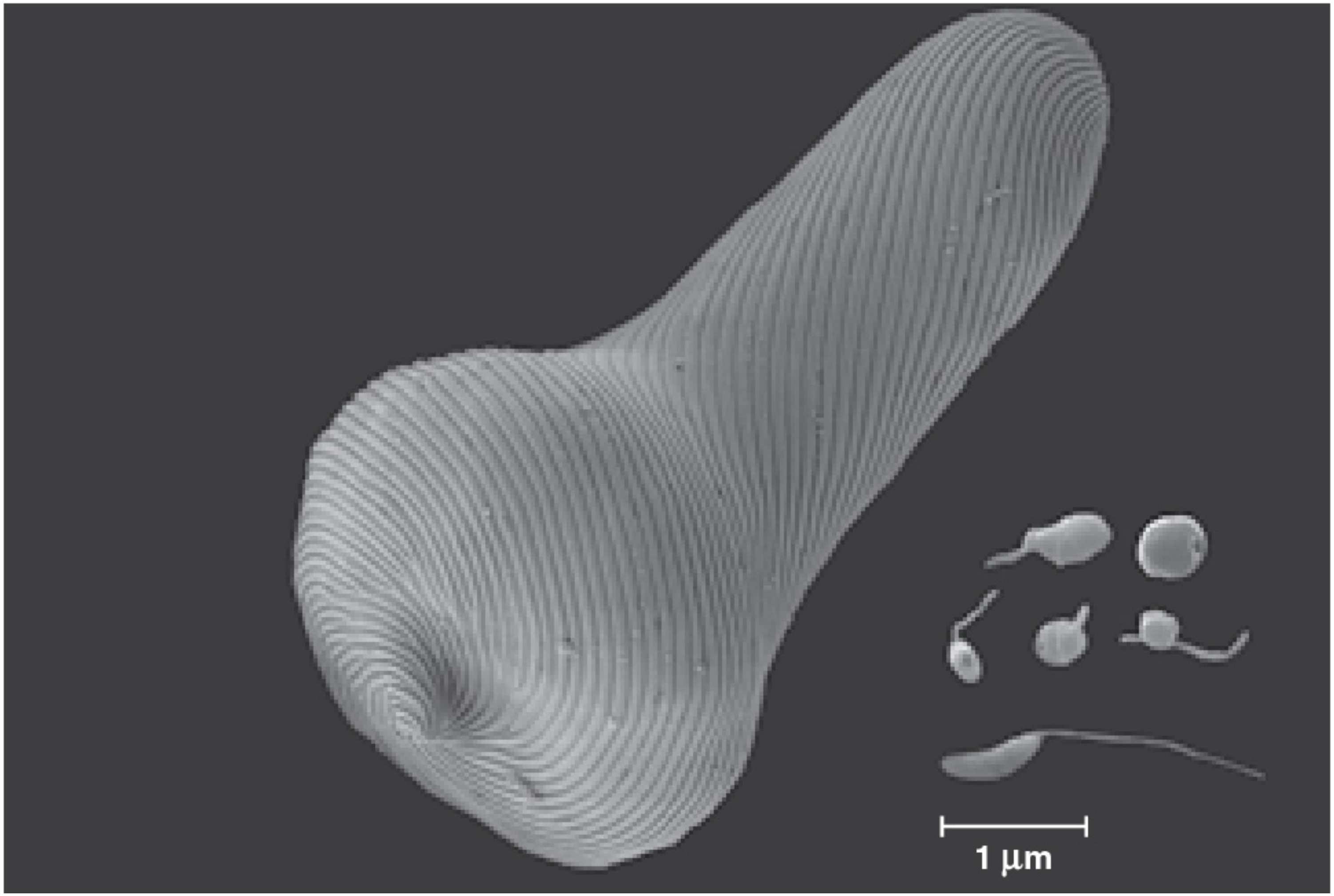
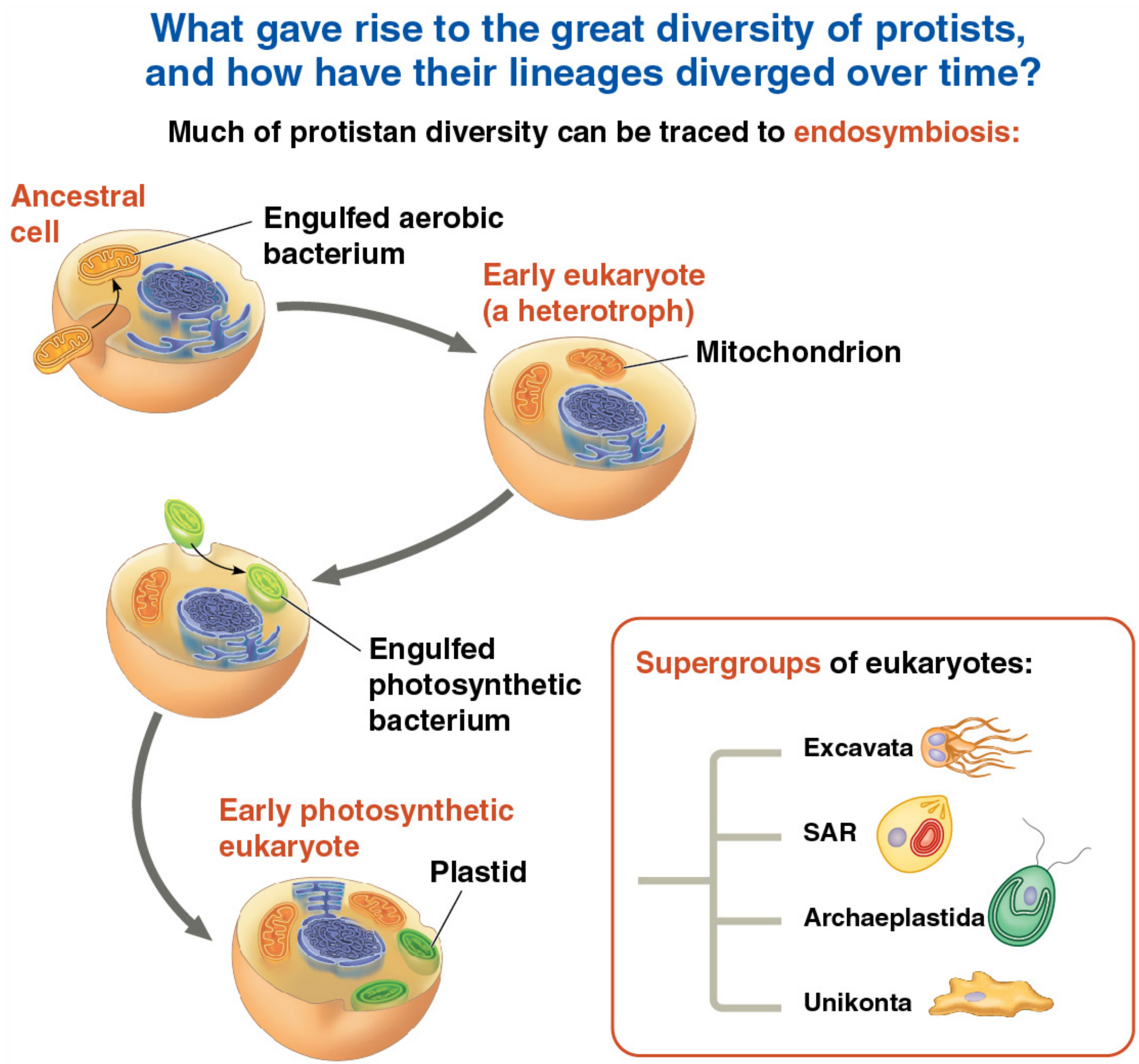


Figure 28.1b


What gave rise to the great diversity of protists,
and how have their lineages diverged over time?
Much of protistan diversity can be traced to endosymbiosis:
Ancestral cell
Engulfed aerobic bacterium
Early eukaryote (a heterotroph)
Mitochondrion
Engulfed photosynthetic bacterium
Early photosynthetic eukaryote
Plastid
Supergroups of eukaryotes:
Excavata
SAR
Archaeplastida
Unikonta

CONCEPT 28.1: Most eukaryotes are single-celled organisms

- **Protist** is an informal term used to refer to all eukaryotes that are not plants, animals, or fungi
- This group is no longer considered a kingdom because some protists are more closely related to plants, fungi, or animals than other protists

- The cells of protists and other eukaryotes have a nucleus and other membrane-enclosed organelles
- Organelles isolate functions within eukaryotic cells, making them more complex than prokaryotic cells
- The well-developed cytoskeleton of the eukaryotic cell allows it to have asymmetric shape and to change shape over time

- Protists make up much of the diversity of eukaryotes
  - The organisms in most eukaryotic lineages are protists
  - Most protists are unicellular organisms

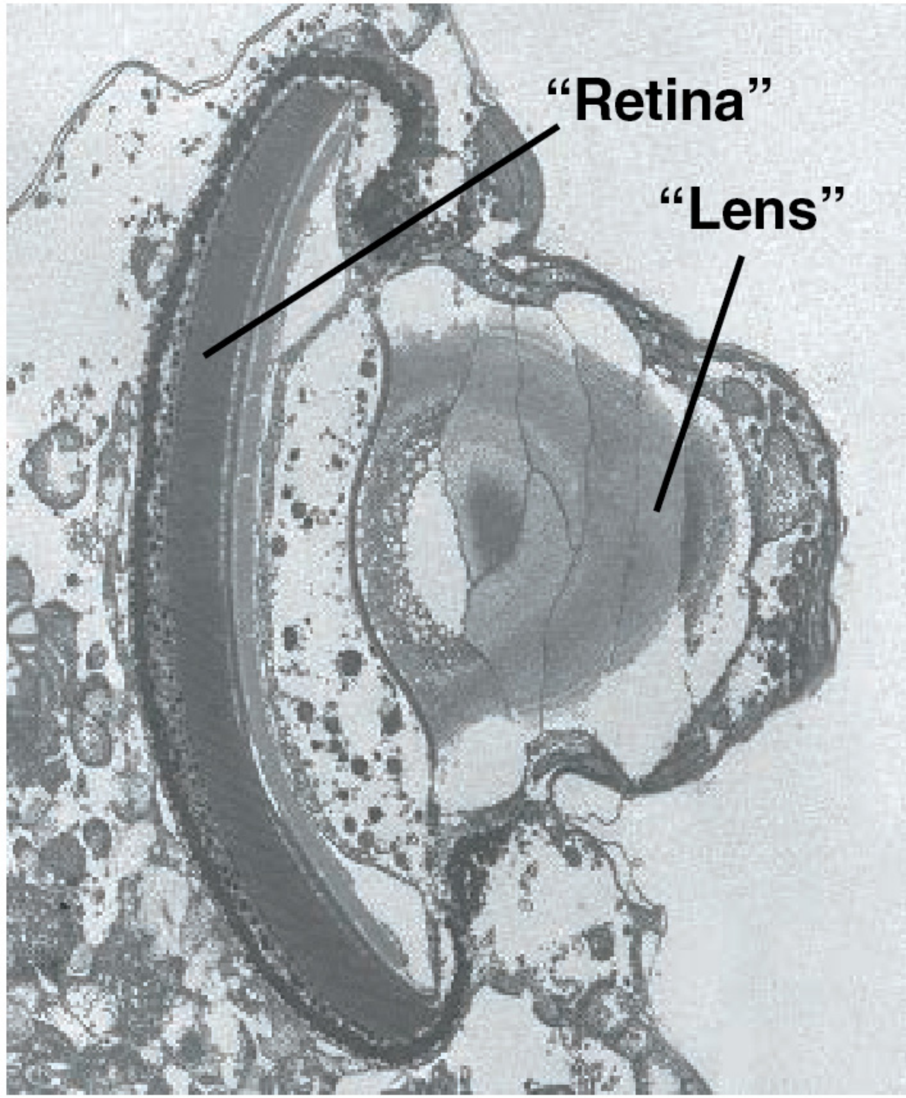
Video: Seeing the Invisible: Van Leeuwenhoek's First Glimpses of the Microbial World

Structural and Functional Diversity in Protists

- Protists exhibit more structural and functional diversity than any other group of eukaryotes
- Though most are unicellular, there are some colonial and multicellular protist species
- Unicellular protists are the most complex of all cells because each cell must carry out all functions of life

- Some unicellular protists have organelles not found in most other eukaryotic cells
  - For example, some dinoflagellate protists have an eye-like organelle called an ocelloid

Figure 28.2



- Protists are the most nutritionally diverse of all eukaryotes
  - Some are photoautotrophs containing chloroplasts
  - Some are heterotrophs that absorb organic molecules or ingest larger food particles
  - Some are **mixotrophs** that combine photosynthesis and heterotrophic nutrition

- Some protists only reproduce asexually; others have both asexual and sexual phases in their life cycle
- All three basic types of sexual life cycles (animal, plant, and fungal) are represented among protists

Endosymbiosis in Eukaryotic Evolution

- There is abundant evidence that much of protistan diversity has its origins in endosymbiosis
- **Endosymbiosis** is a relationship between two species in which one organism lives inside the cell or cells of the other organism (the host)

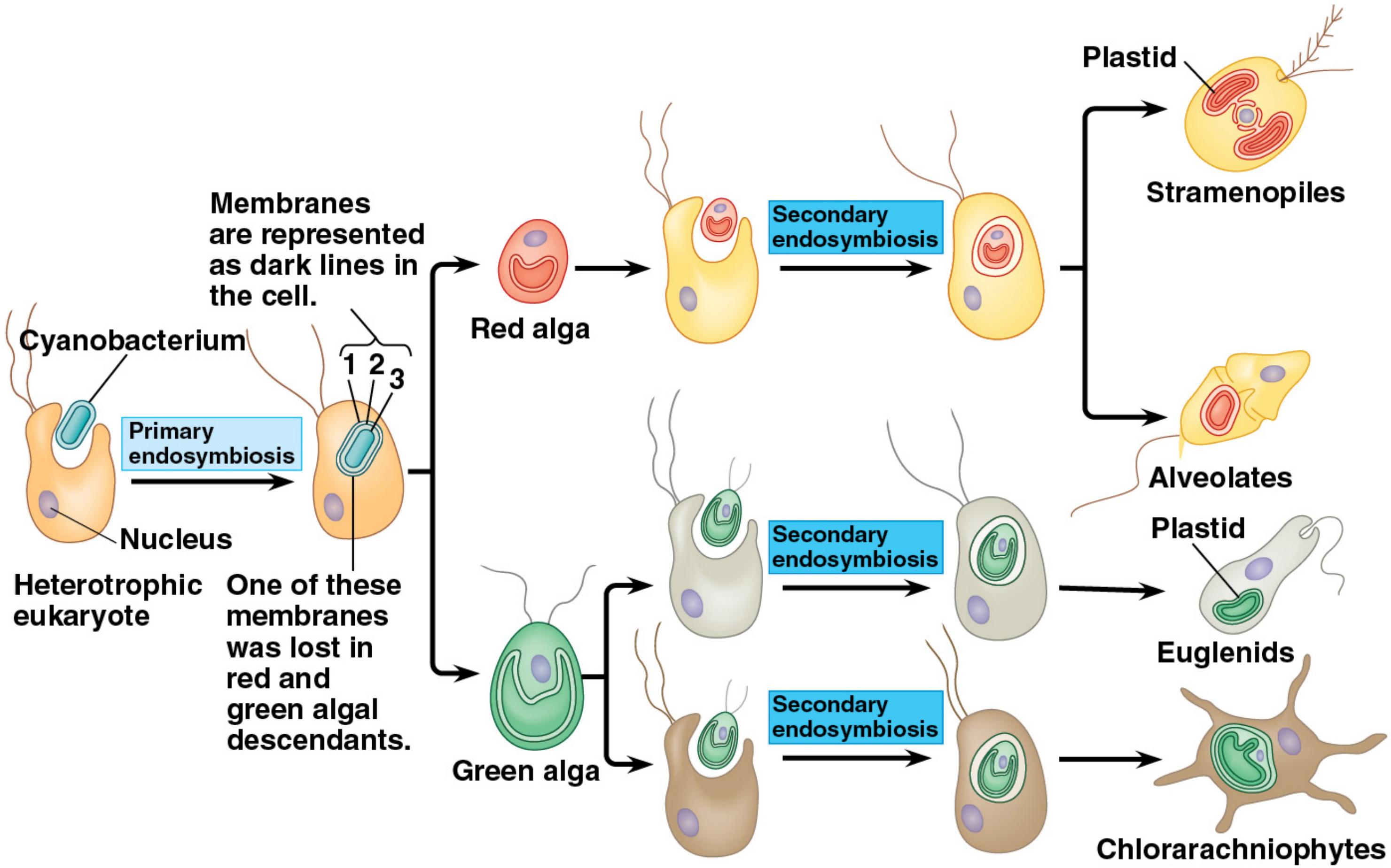
- Mitochondria and plastids are derived from bacteria that were engulfed by ancestors of early eukaryotes
- Evidence suggests that mitochondria evolved before plastids and arose from an alpha proteobacterium
- Molecular analysis indicates that mitochondria and plastids each evolved only once in the history of life

- The ancestral host was a relatively complex cell with eukaryotic features, such as a cytoskeleton
- The host cell lineage is uncertain, but lokiarchaeotes, the archaean sister group to the eukaryotes, is a candidate taxon

Plastid Evolution: A Closer Look

- The evolution of mitochondria gave rise to the eukaryotes
- Plastids arose later when a heterotrophic eukaryote engulfed a photosynthetic cyanobacterium
- Two lineages of photosynthetic protists, red and green **algae**, evolved from the plastid-bearing ancestor

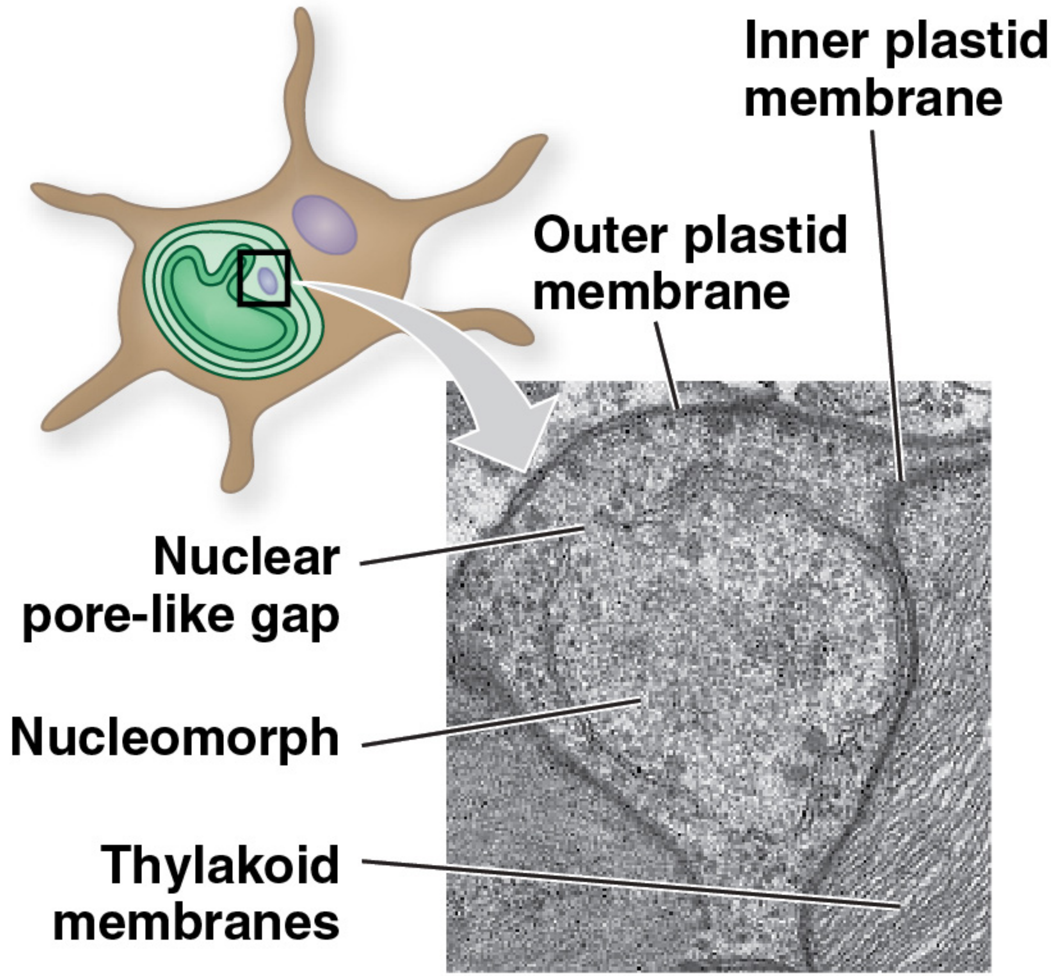
Figure 28.3


Membranes are represented as dark lines in the cell.
Cyanobacterium
1
2
3
Primary endosymbiosis
Nucleus
Heterotrophic eukaryote
One of these membranes was lost in red and green algal descendants.
Red alga
Green alga
Secondary endosymbiosis
Secondary endosymbiosis
Secondary endosymbiosis
Plastid
Stramenopiles
Alveolates
Plastid
Euglenids
Chlorarachniophytes

- Like cyanobacteria, plastids of red algae and green algae have two membranes
- Transport proteins in these membranes are homologous to those found in the inner and outer membranes of cyanobacteria

- Red and green algae themselves were ingested by heterotrophic eukaryotes, a process called **secondary endosymbiosis**, several times
  - For example, chlorarachniophytes likely evolved when a heterotrophic eukaryote engulfed a green alga
  - The engulfed cell contains a vestigial nucleus called a nucleomorph

Figure 28.4


Inner plastid membrane
Outer plastid membrane
Nuclear pore-like gap
Nucleomorph
Thylakoid membranes

Four Supergroups of Eukaryotes

- Our understanding of the evolutionary relationships among protist groups continues to change rapidly
- One current hypothesis divides all eukaryotes (including protists) into four supergroups

Figure 28.5

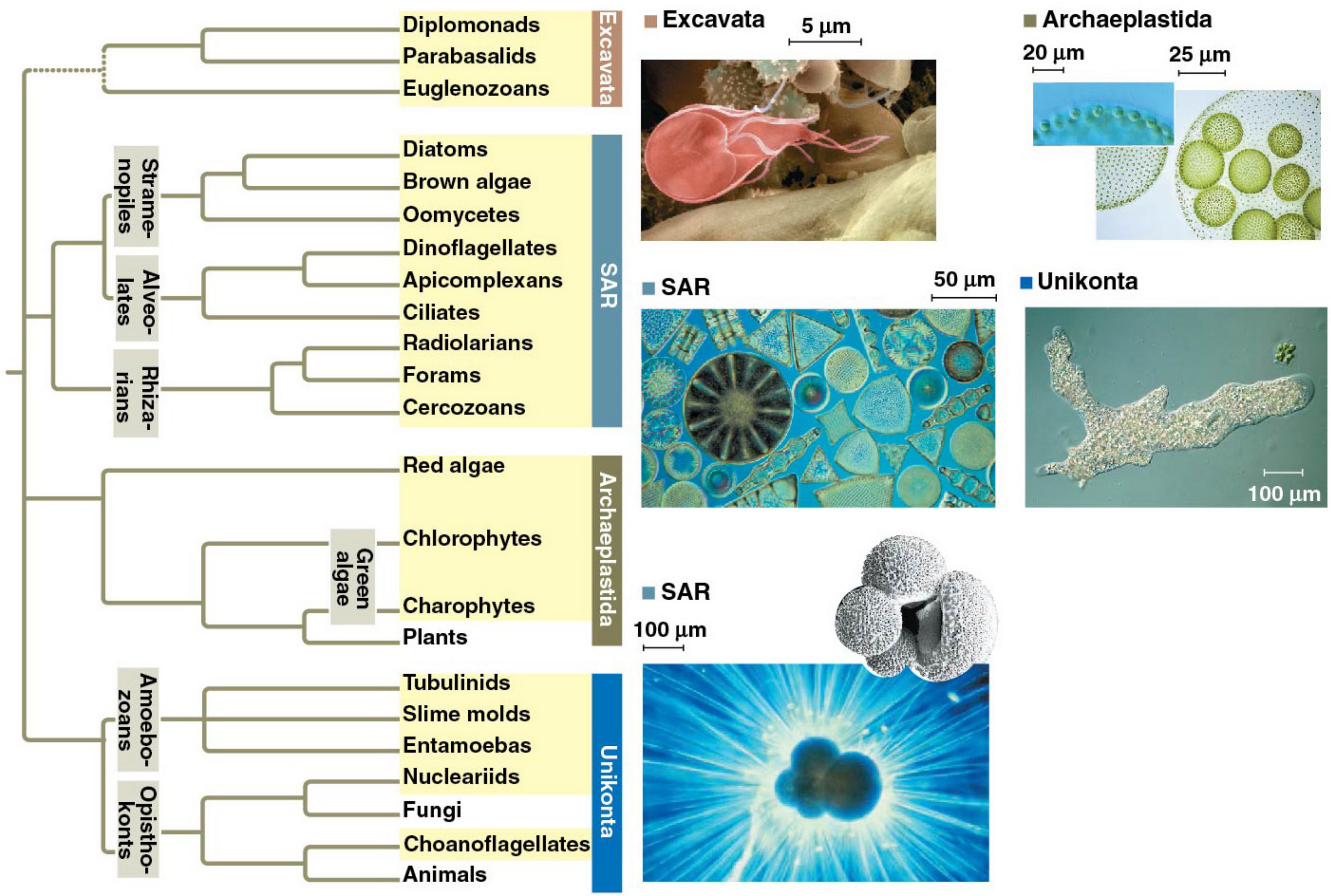
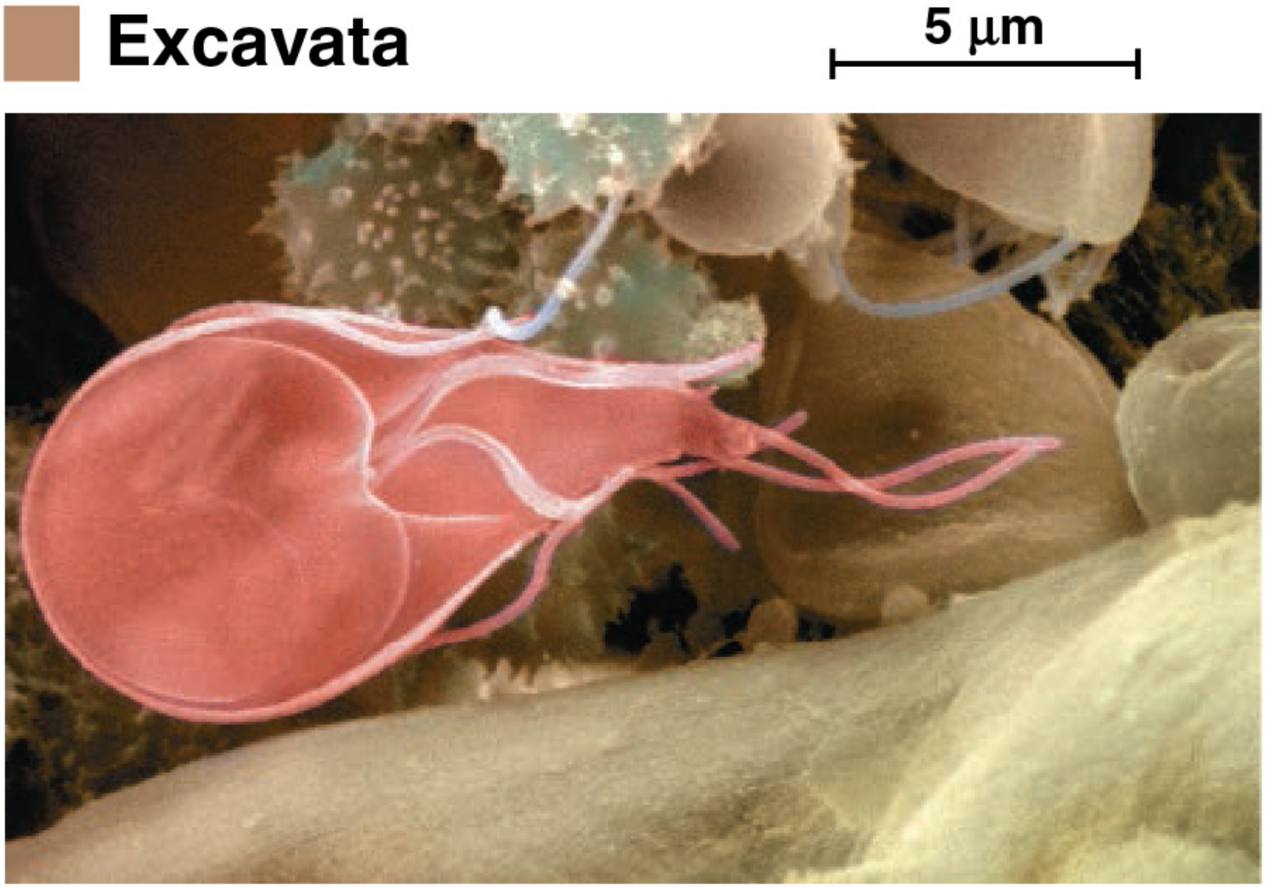

Diplomonads
Parabasalids
Euglenozoans
Excavata
Diatoms
Brown algae
Oomycetes
Dinoflagellates
Apicomplexans
Ciliates
Radiolarians
Forams
Cercozoans
Strame-nopiles
Alveo-lates
Rhiza-rians
SAR
Red algae
Chlorophytes
Charophytes
Plants
Green algae
Archaeplastida
Tubulinids
Slime molds
Entamoebas
Nucleariids
Fungi
Choanoflagellates
Animals
Amoebo-zoans
Opistho-konts
Unikonta
Excavata
5 µm
Archaeplastida
20 µm
25 µm
SAR
50 µm
Unikonta
100 µm
SAR
100 µm

Figure 28.5 Exploring protistan diversity

Excavata

- This supergroup includes three clades: parabasalids, diplomonads, and euglenozoans
  - For example, *Giardia intestinalis* is a diplomonad parasite that causes intestinal infections in mammals

Figure 28.5



***Giardia intestinalis*, a diplomonad parasite**

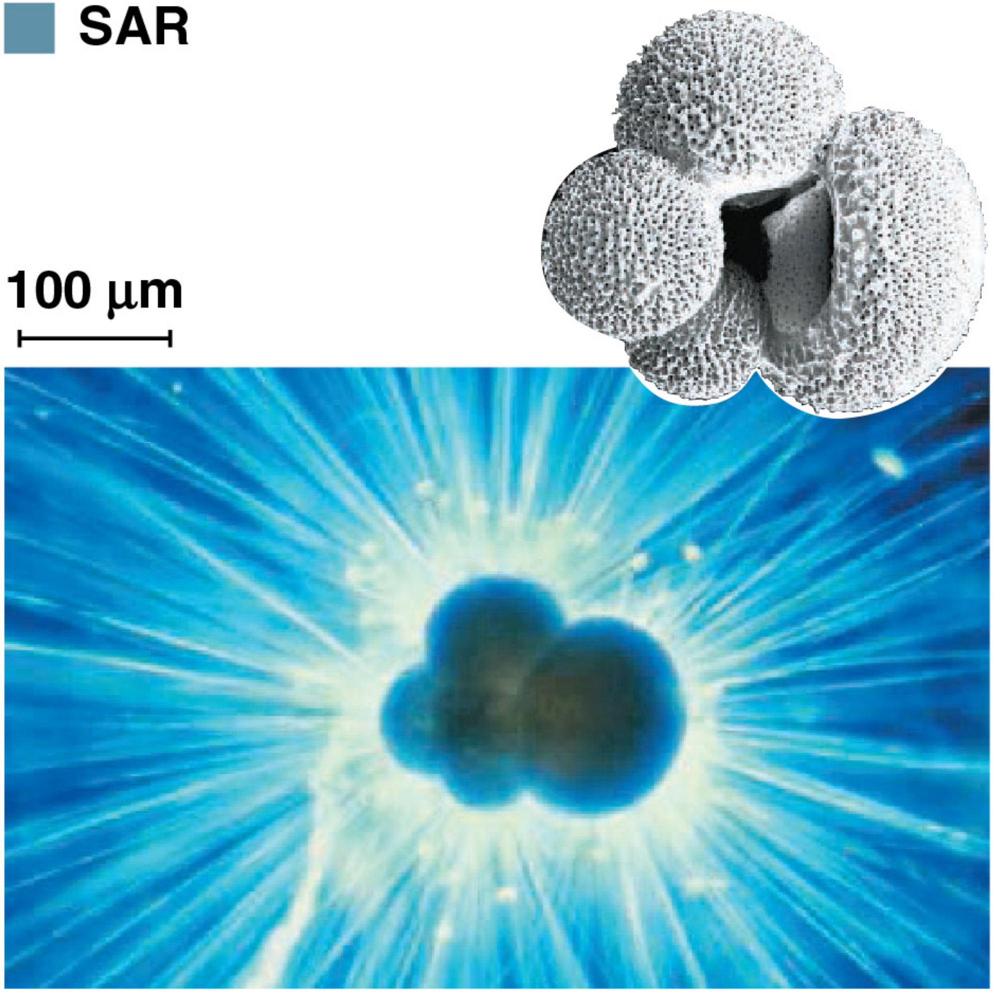
SAR

- This supergroup includes three large clades: Stramenopila, Alveolata, and Rhizaria
  - For example, diatoms are important photosynthetic stramenopiles
  - For example, many rhizarians are amoebas with threadlike pseudopodia, such as *Globigerina*

Figure 28.5

Figure 28.5

SAR



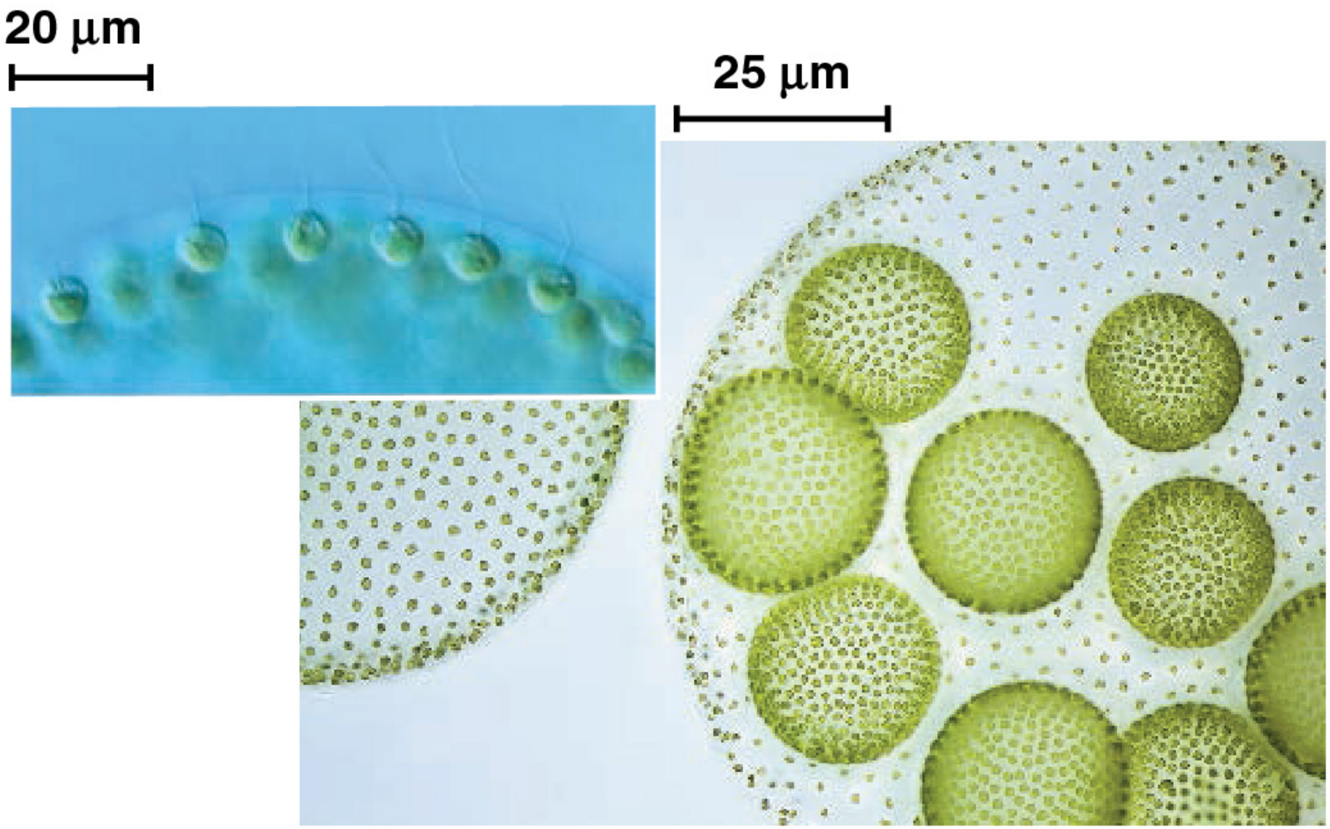
***Globigerina*, a rhizarian in SAR**

Archaeplastida

- This supergroup includes red and green algae, and plants
- Red and green algae include unicellular, colonial, and multicellular species
  - For example, *Volvox* is a multicellular green algae

Figure 28.5

Archaeplastida



***Volvox*, a multicellular freshwater green alga**

Video: *Volvox*

Unikonta

- This supergroup includes amoebas with lobe- or tube-shaped pseudopodia, animals, fungi, and non-amoeba protists closely related to animals or fungi
  - For example, *Amoeba proteus* is a tubulinid amoeba

Figure 28.5

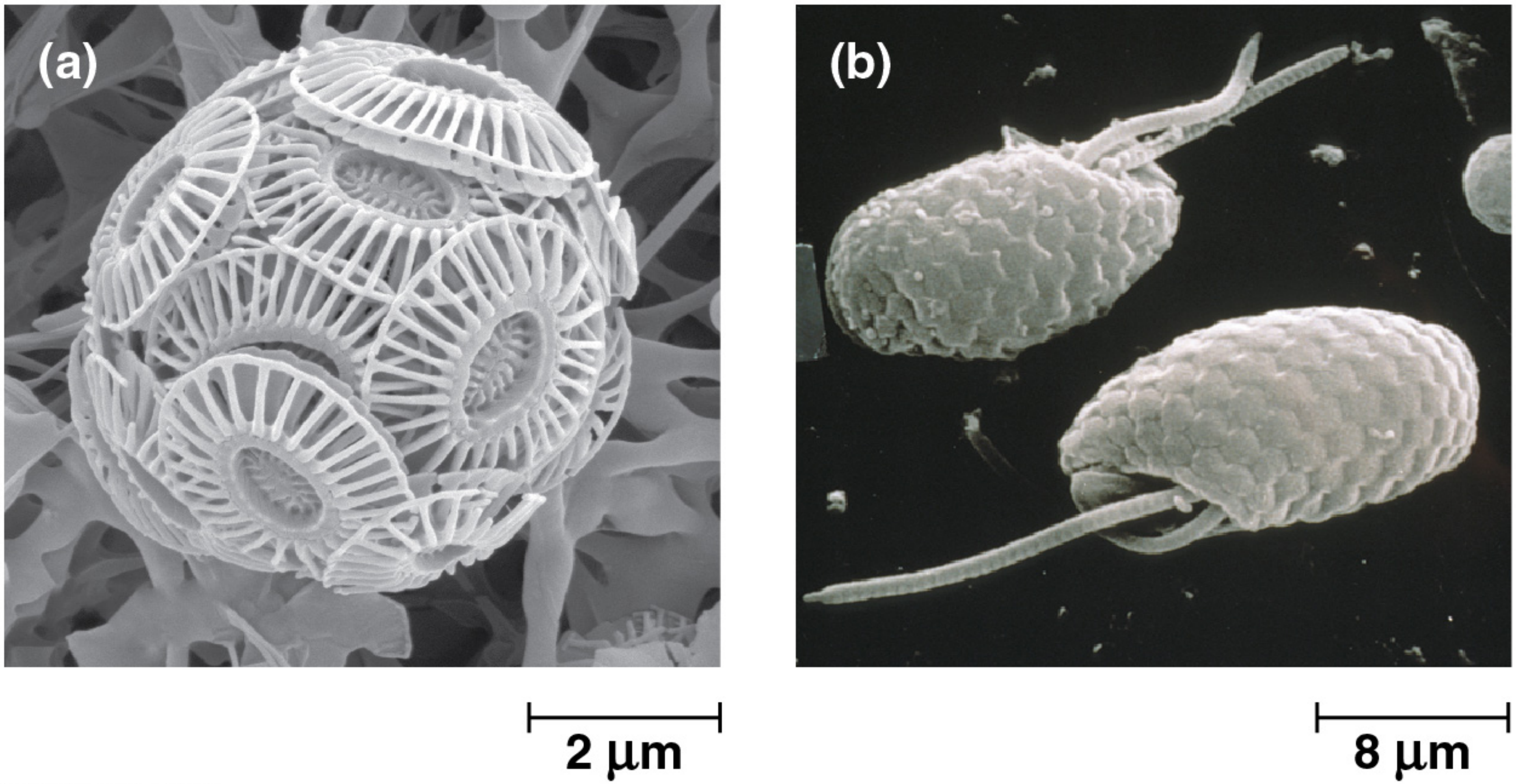
Unikonta

A unikont amoeba

Video: *Amoeba* Pseudopodium

- The root of the eukaryotic tree is not known
- Some major new groups of protists have been recently discovered, but their relationship to the supergroups is unresolved
  - For example, haptophytes, cryptophytes, and hemimastigophores are unresolved groups

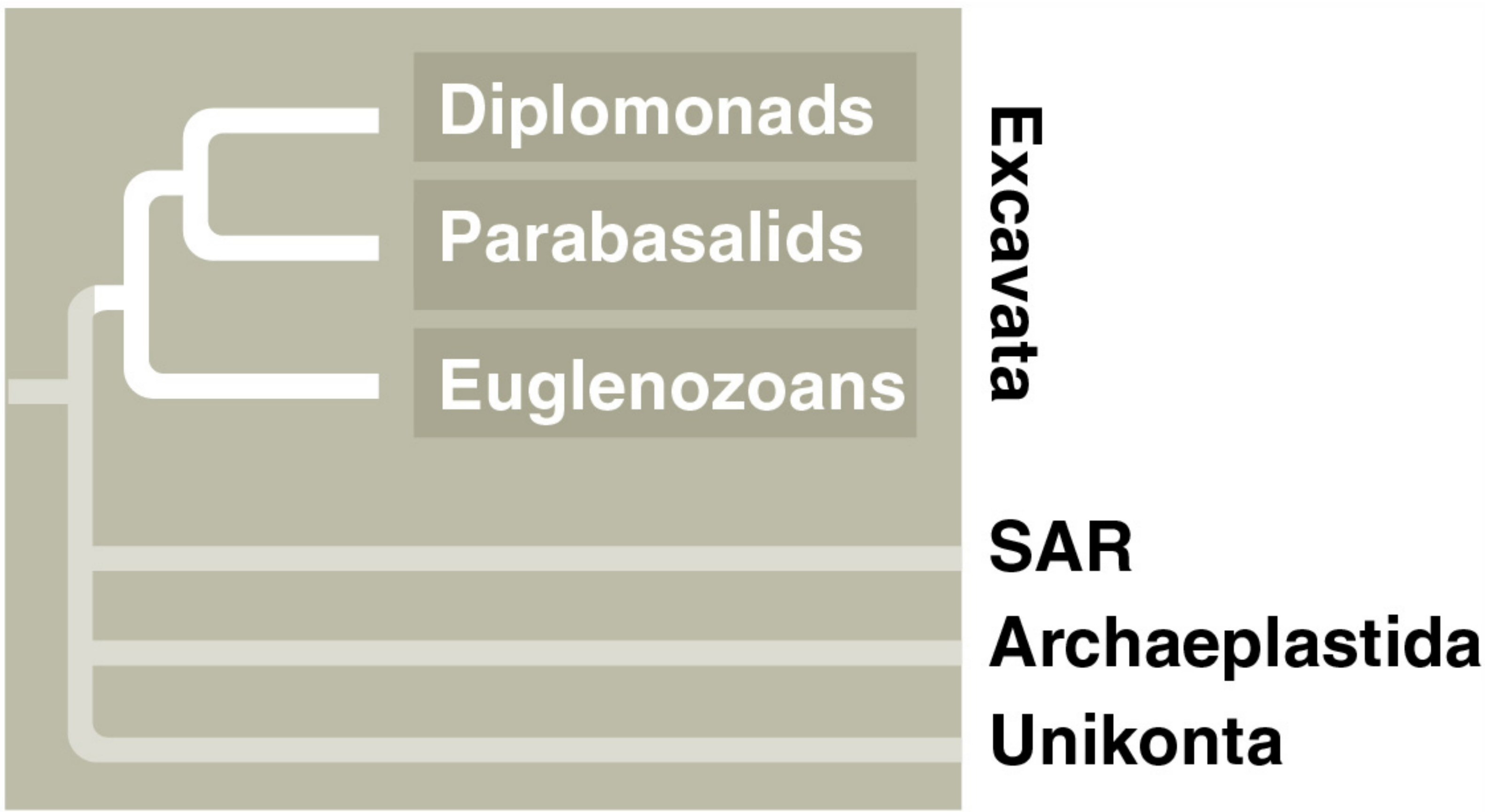
Figure 28.6



CONCEPT 28.2: Excavates include protists with modified mitochondria and protists with unique flagella

- **Excavata** is characterized by its cytoskeleton
- Some members have an "excavated" feeding groove on one side of the body
- The excavates include three monophyletic groups: the diplomonads, parabasalids, and euglenozoans

Figure 28.UN01



Diplomonads and Parabasalids

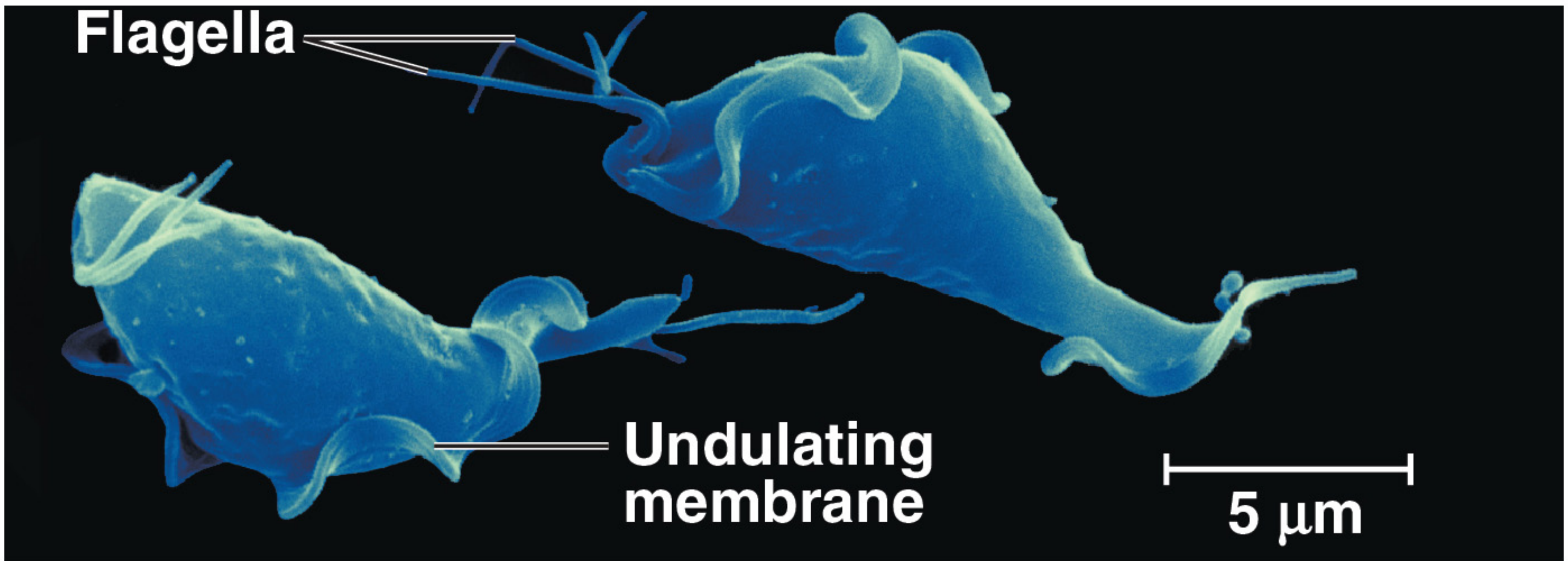
- Diplomonads and parabasalids lack plastids and have reduced mitochondria
- Most live in anaerobic environments

- **Diplomonads** have reduced mitochondria, called mitosomes, that lack electron transport chains
- Energy is derived from anaerobic pathways
- They have two equal-sized nuclei and multiple flagella
- Many are parasites, such as *Giardia intestinalis*

- **Parabasalids** have reduced mitochondria, called hydrogenosomes, that generate some energy anaerobically
- Hydrogen gas is released as a by-product of anaerobic metabolism

- The best known parabasalid is *Trichomonas vaginalis*, a sexually transmitted parasite
- It travels along the human reproductive and urinary tracts and feeds on the vaginal lining in females
- *T. vaginalis* infects about 140 million people per year worldwide

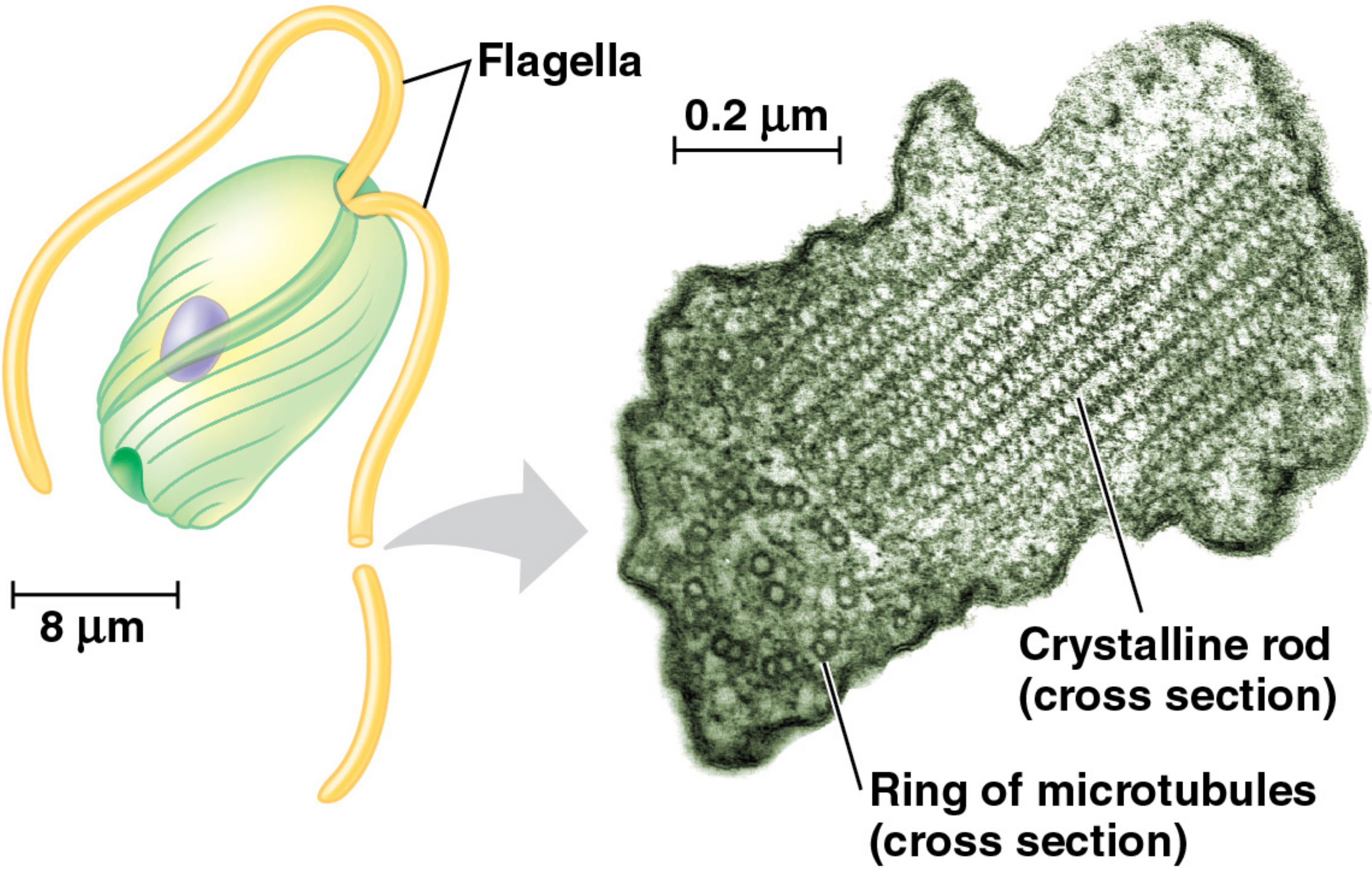
Figure 28.7



Euglenozoans

- **Euglenozoa** is a diverse clade including predatory heterotrophs, photosynthetic autotrophs, mixotrophs, and parasites
- The main feature distinguishing the clade is a spiral or crystalline rod inside each flagella
- This clade includes the kinetoplastids and euglenids

Figure 28.8



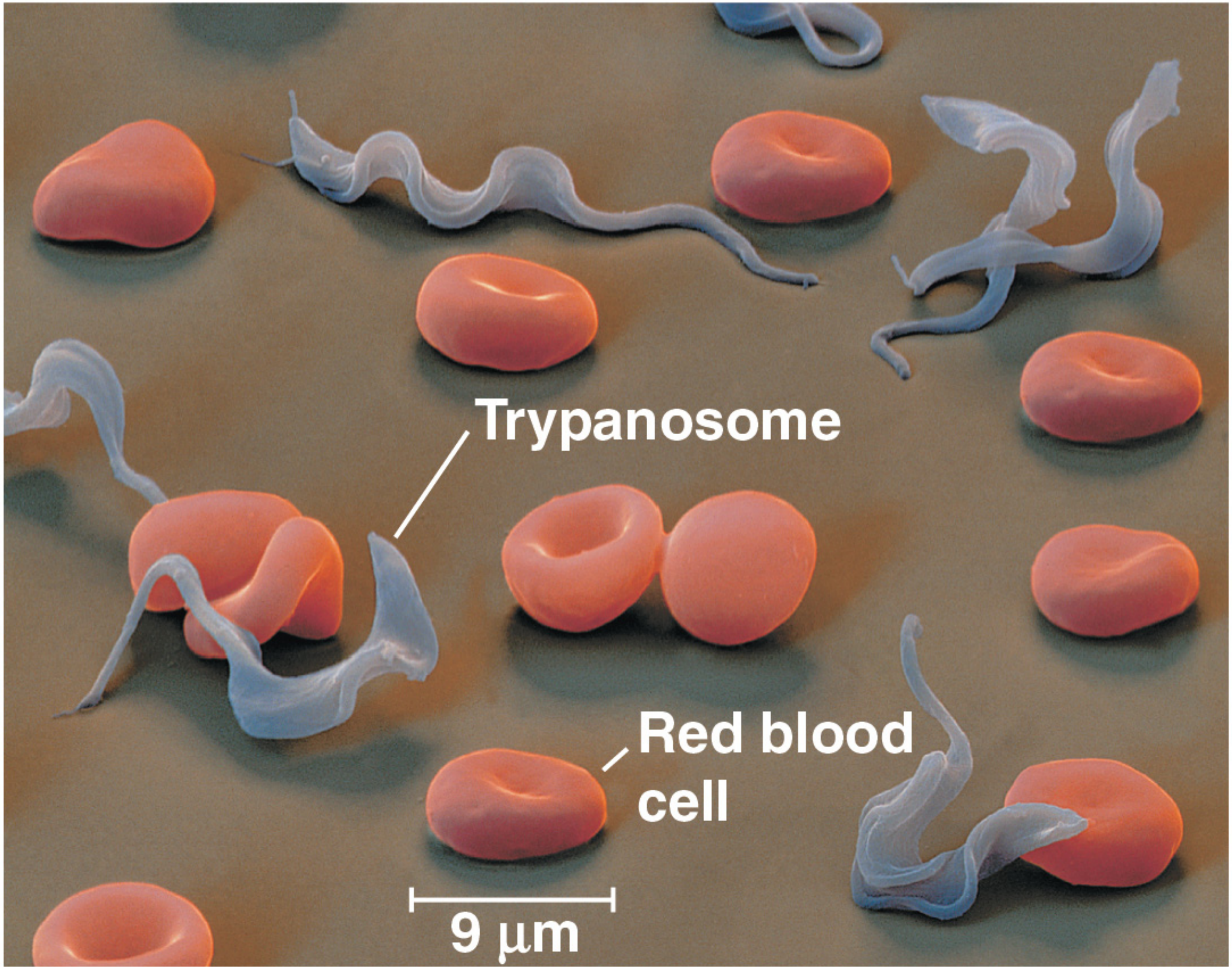
Flagella
8 µm
0.2 µm
Crystalline rod
(cross section)
Ring of microtubules
(cross section)

Kinetoplastids

- **Kinetoplastids** have a single mitochondrion containing an organized mass of DNA called a kinetoplast
- Free-living species are consumers of prokaryotes in freshwater, marine, and moist terrestrial ecosystems

- Some species parasitize animals, plants, and other protists
  - For example, members of the genus *Trypanosoma* infect humans, causing sleeping sickness in about 10,000 people per year
  - Trypanosomes also cause Chagas' disease which can lead to congestive heart failure

Figure 28.9

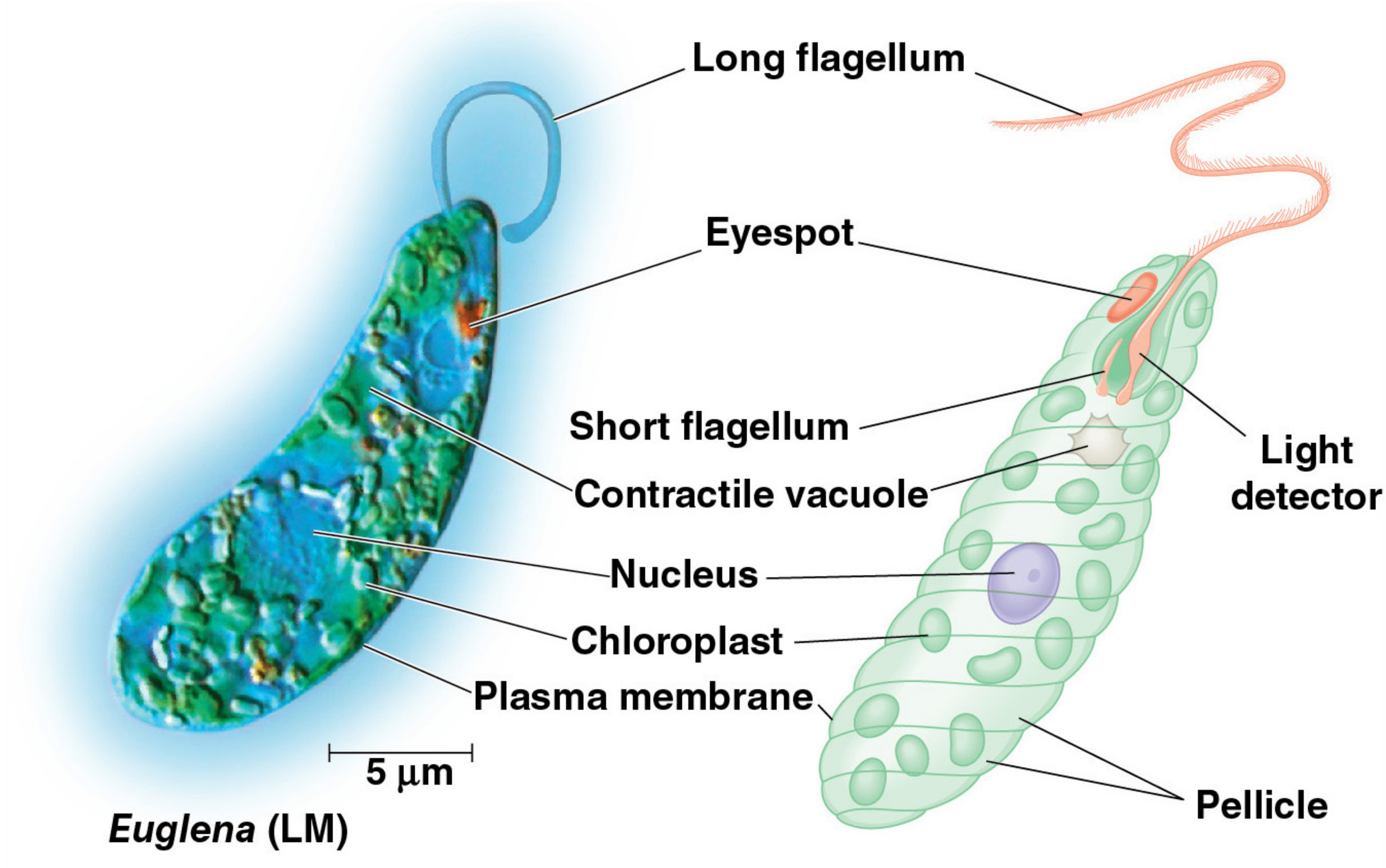


- Trypanosomes have a single cell-surface protein that changes from one generation to the next
- The host is prevented from developing immunity by this “bait-and-switch” defense

Euglenids

- **Euglenids** have one or two flagella that emerge from a pocket at one end of the cell
- Some species are mixotrophs that switch between autotrophic and heterotrophic modes, depending on the environmental conditions

Figure 28.10



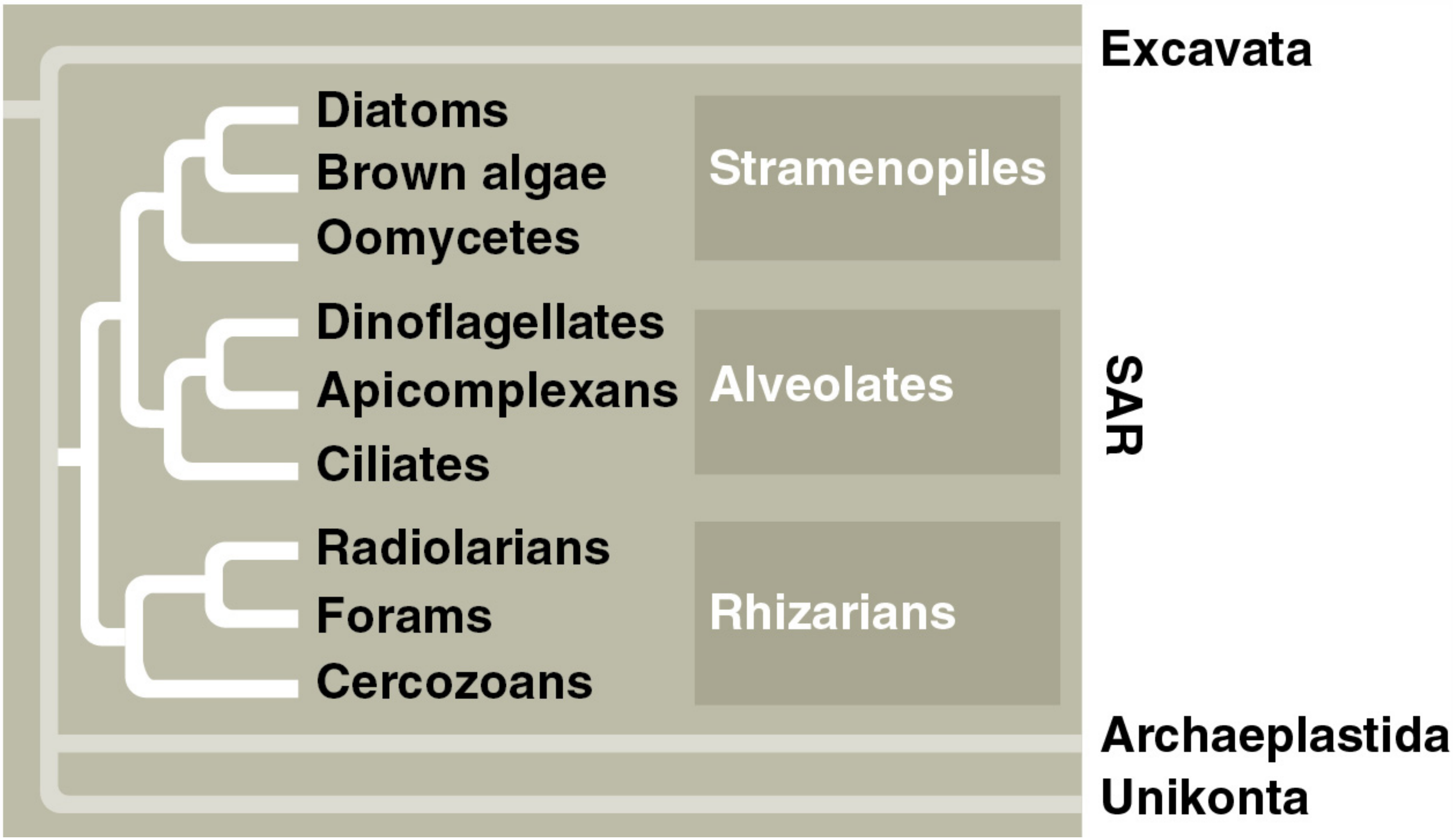
Long flagellum
Eyespot
Short flagellum
Contractile vacuole
Nucleus
Chloroplast
Plasma membrane
Light detector
Pellicle
5 µm
Euglena (LM)

Video: *Euglena*

CONCEPT 28.3: SAR is a highly diverse group of protists defined by DNA similarities

- **SAR** is a monophyletic supergroup named for the first letters of its three major clades: stramenopiles, alveolates, and rhizarians

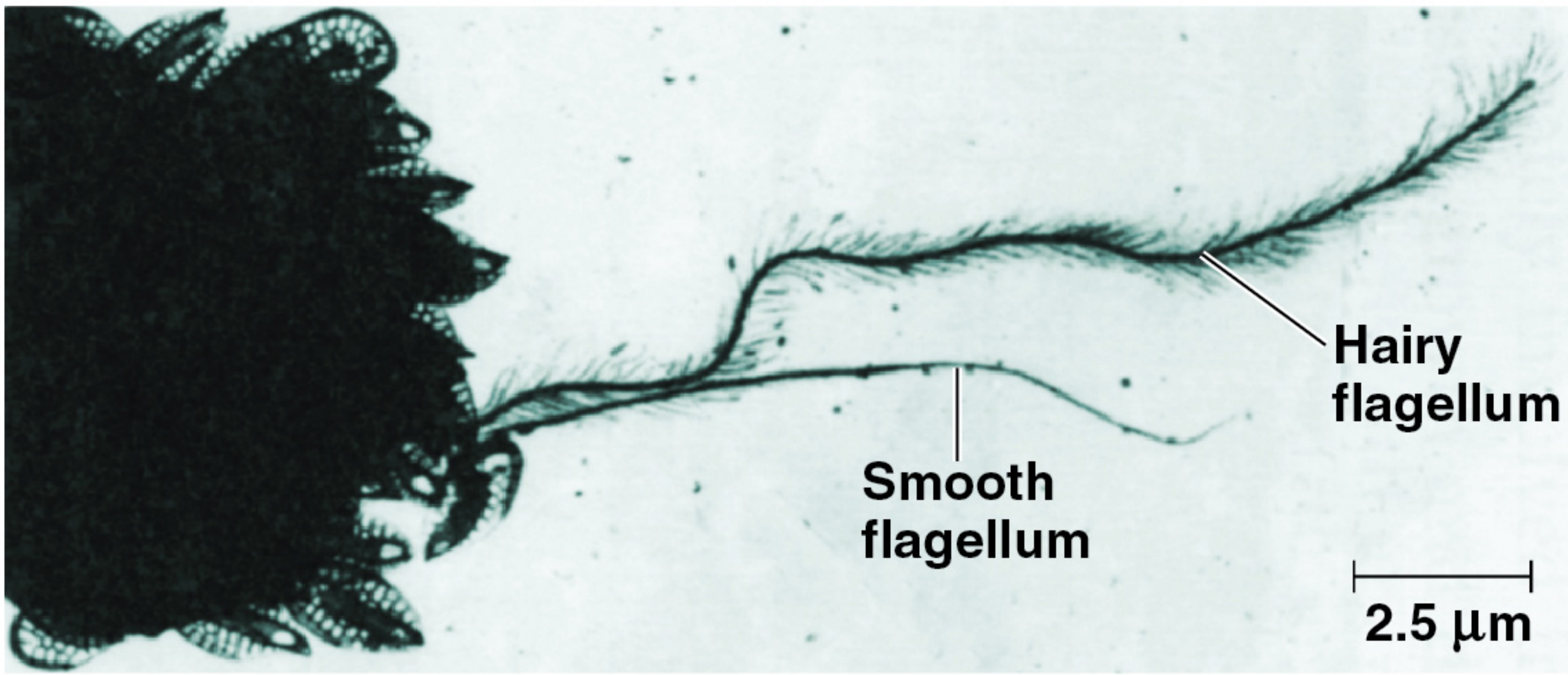
Figure 28.UN02



Stramenopiles

- **Stramenopiles** include some of the most important photosynthetic organisms on Earth
- Most have a “hairy” flagellum paired with a “smooth” flagellum
- Diatoms, oomycetes, and brown algae are three important groups of stramenopiles

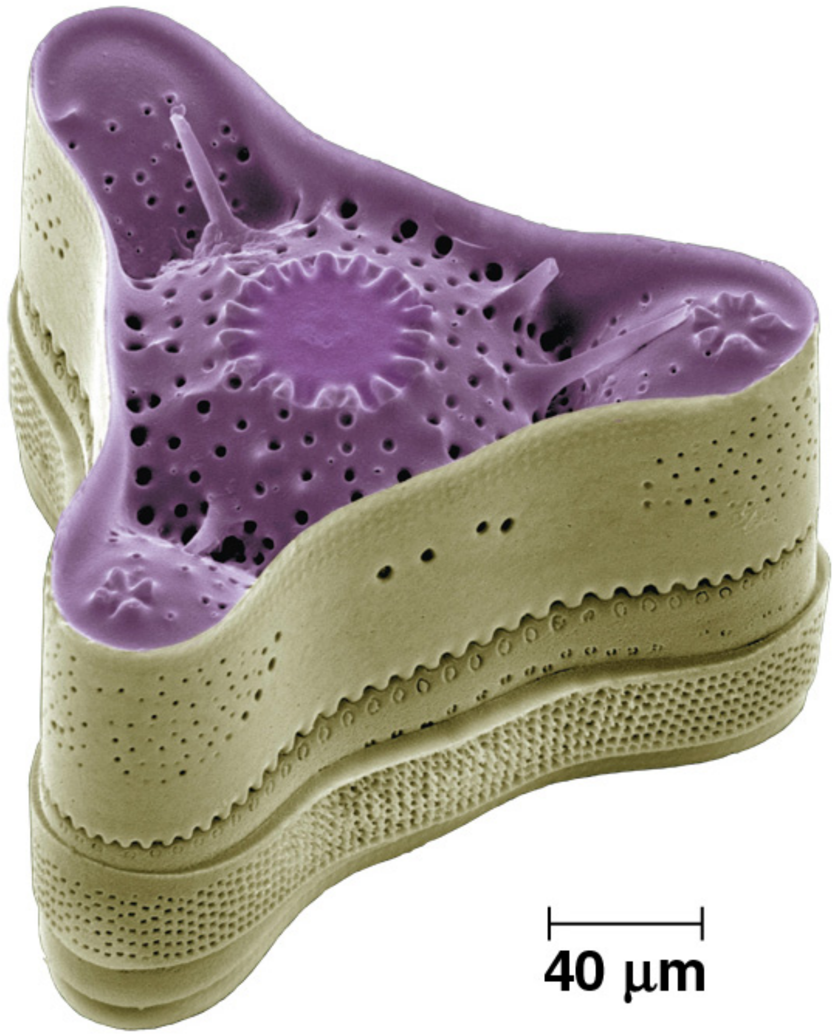
Figure 28.11



Diatoms

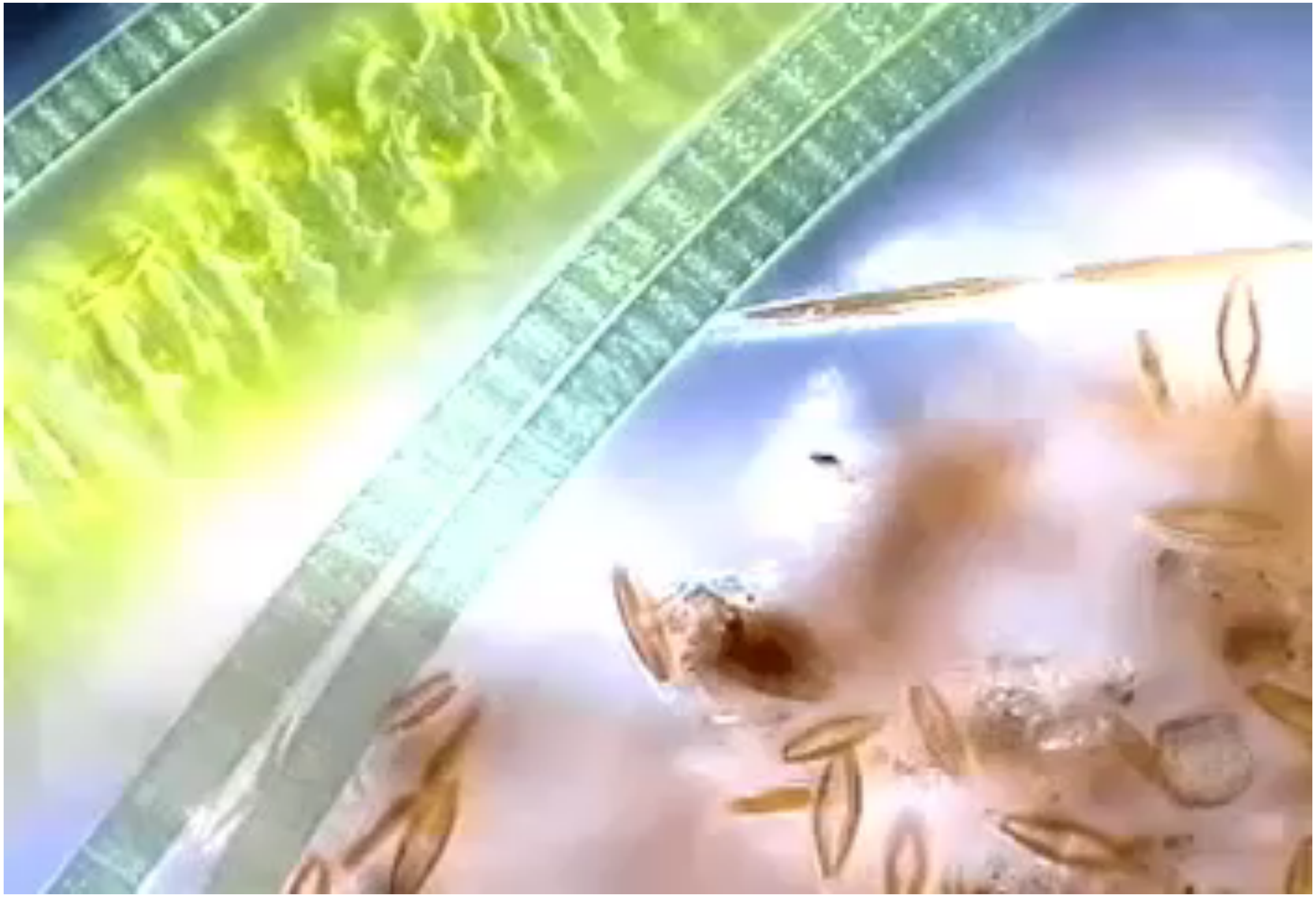
- **Diatoms** are unicellular algae with a unique two-part, glass-like wall of silicon dioxide
- The wall withstands pressure up to 1.4 million kg/m^2, protecting diatoms from the crushing jaws of predators

Figure 28.12



Video: Diatoms Moving

Video: Various Diatoms



- Including about 100,000 species, diatoms compose much of the phytoplankton in the ocean and lakes
- Diatoms are so abundant and widespread that their photosynthetic activity affects global CO_2 levels

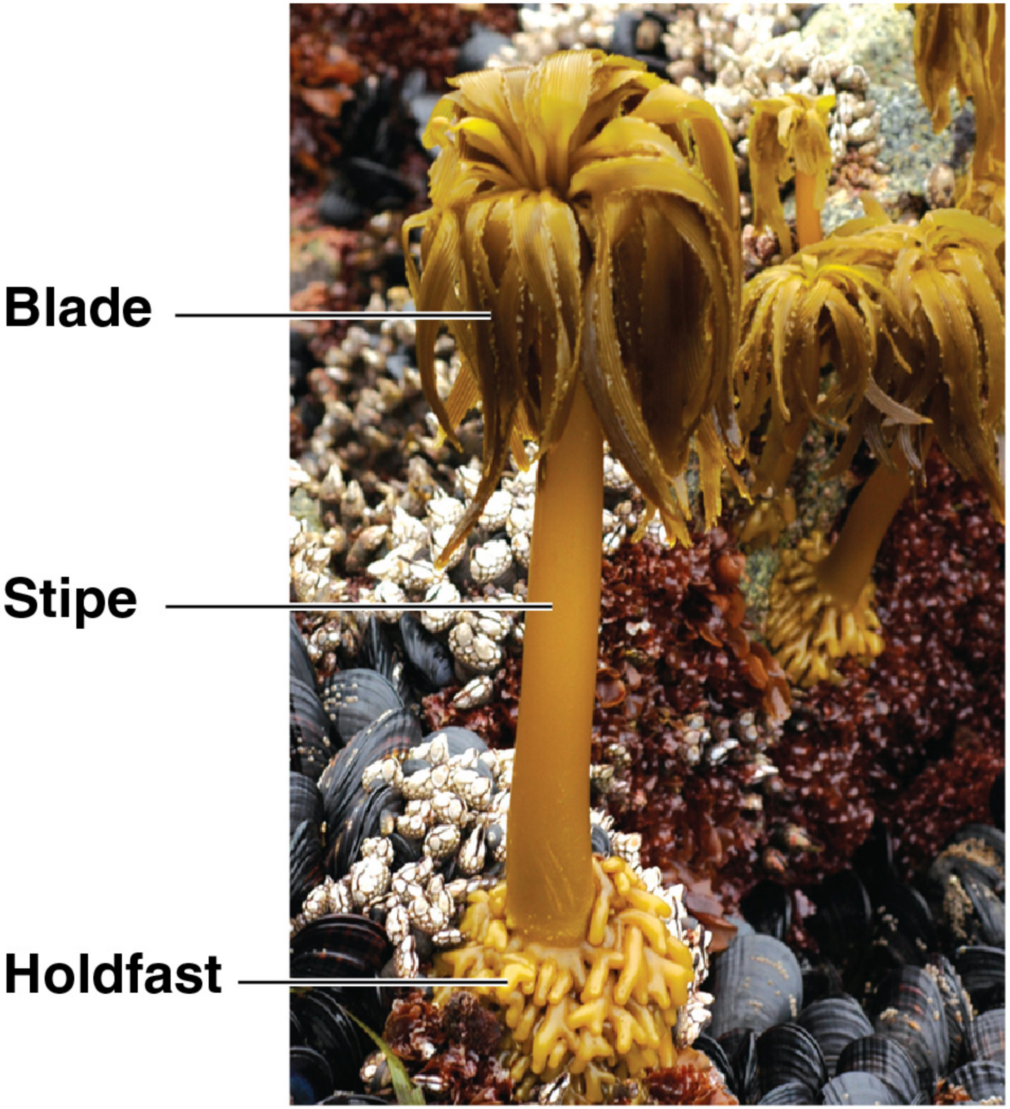
- After a diatom bloom, many dead individuals fall to the ocean floor, where decomposition is slow
- The breakdown and release of carbon stored in the diatoms on the ocean floor can take centuries
- Promoting diatom blooms by fertilizing the ocean with essential nutrients is a proposed approach to reduce atmospheric CO_2 levels

Brown Algae

- **Brown algae** are the largest and most complex multicellular algae
- Carotenoids in the plastids produce the brown color
- Most are marine, including many species commonly called “seaweeds”

- Brown algal seaweeds have plantlike structures: the rootlike **holdfast**, which anchors the alga, and a stemlike **stipe**, which supports the leaflike **blades**
- Some have gas-filled, bubble-shaped floats to keep photosynthetic structures near the water surface
- Brown algae lack the true tissues and organs found in plants

Figure 28.13



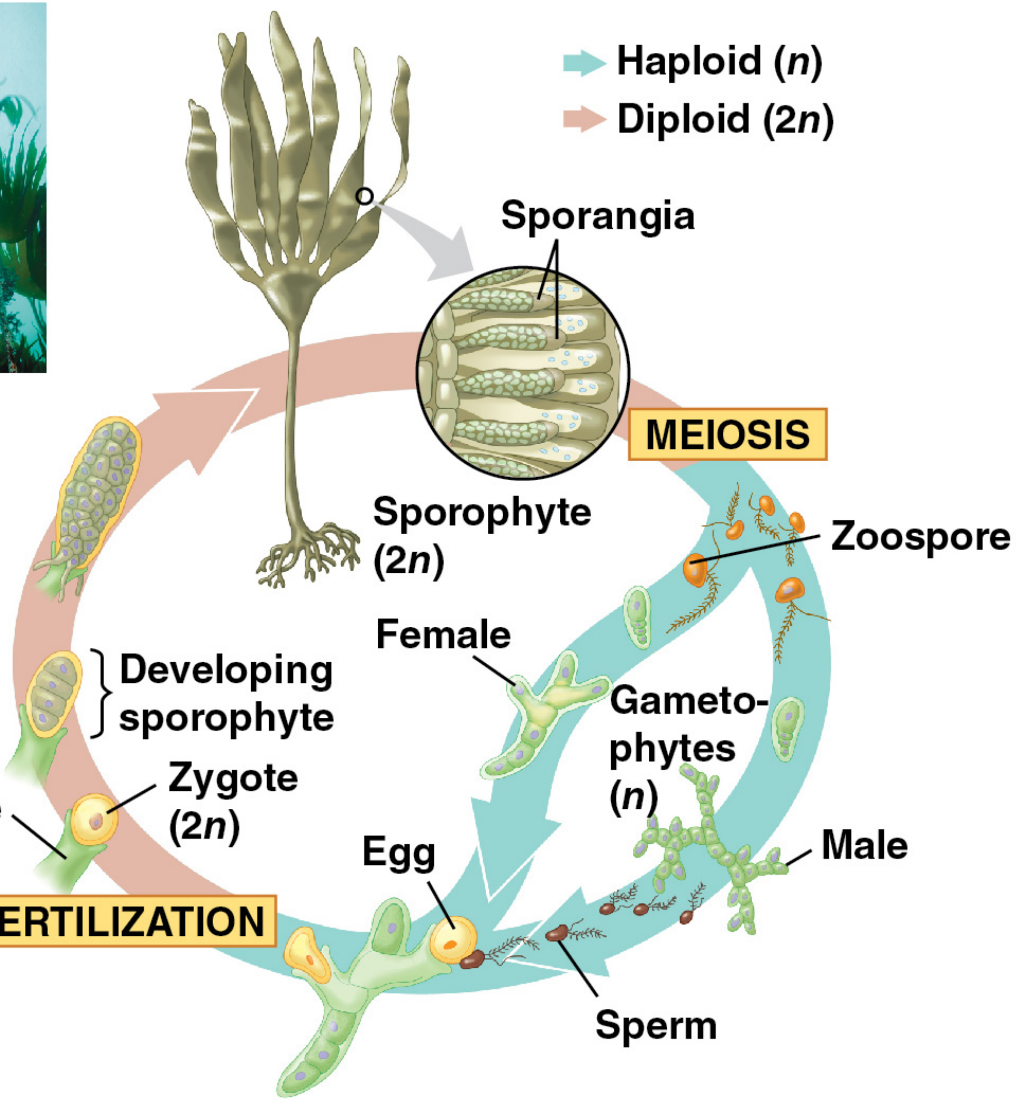
- Brown algae are important commodities for humans
  - For example, some species, such as *Laminaria* are eaten
  - Algin, a gel-forming substance found in the cell wall, is used as a thickener in many processed foods

Alternation of Generations

- A variety of life cycles have evolved among the multicellular algae
- Some have **alternation of generations**, in which both haploid and diploid stages are multicellular

- The diploid generation is called a sporophyte because it produces spores
- Haploid spores develop into multicellular haploid gametophytes that produce haploid gametes
- Fertilization of gametes results in a diploid zygote, which develops into a new sporophyte

Figure 28.14

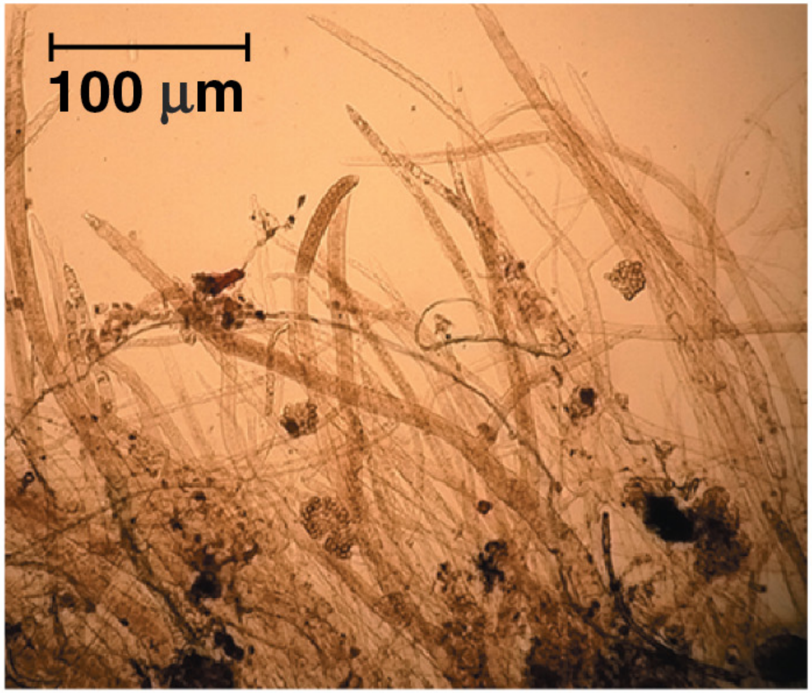


Haploid (n)
Diploid (2n)
Sporangia
MEIOSIS
Sporophyte (2n)
Zoospore
Female
Developing sporophyte
Gameto- phytes (n)
Zygote (2n)
Mature female gametophyte (n)
Egg
Male
FERTILIZATION
Sperm

- **Heteromorphic** species, such as *Laminaria*, have structurally different gametophytes and sporophytes
- **Isomorphic** species have gametophytes and sporophytes that look similar to each other

Oomycetes (Water Molds and Their Relatives)

- Oomycetes include water molds, white rusts, and downy mildews
- They were misidentified as fungi due to their multinucleate filaments that resemble fungal hyphae
- One key difference is that oomycetes cell walls are composed of cellulose, rather than chitin
- Based on molecular analysis, oomycetes and fungi are not closely related



(a) Closeup of oomycete hyphae (LM)

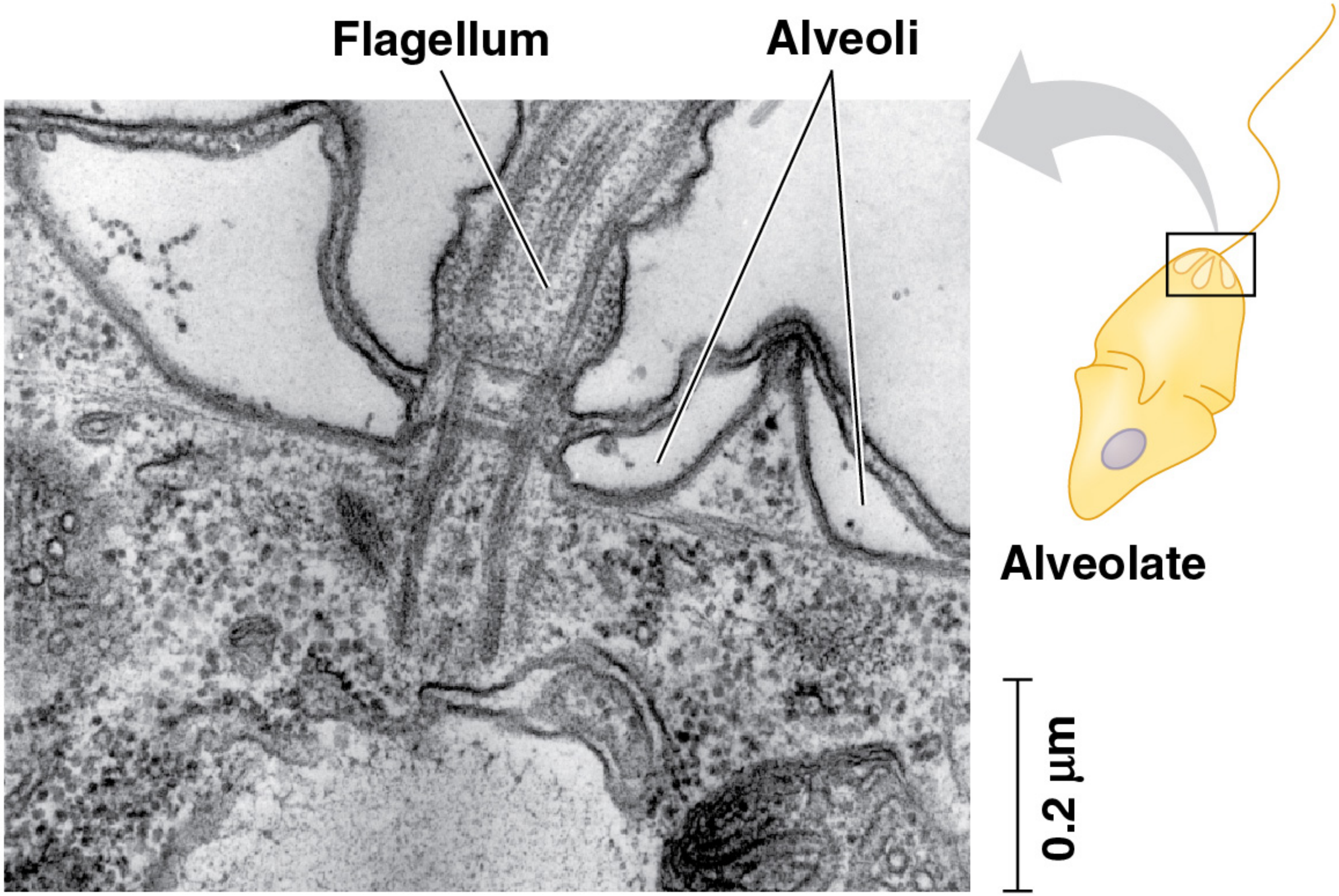
(b) Water mold hyphae growing on a goldfish

- Oomycetes are related to plastid-bearing groups, but do not have plastids or perform photosynthesis
- They acquire nutrients through parasitism or decomposition
  - For example, *Phytophthora infestans* is a parasite that causes potato late blight, a disease that kills potato crops

Alveolates

- **Alveolates** have membrane-enclosed sacs (alveoli) just under the plasma membrane
- Three clades included in the alveolates are the dinoflagellates, the apicomlexans, and the ciliates

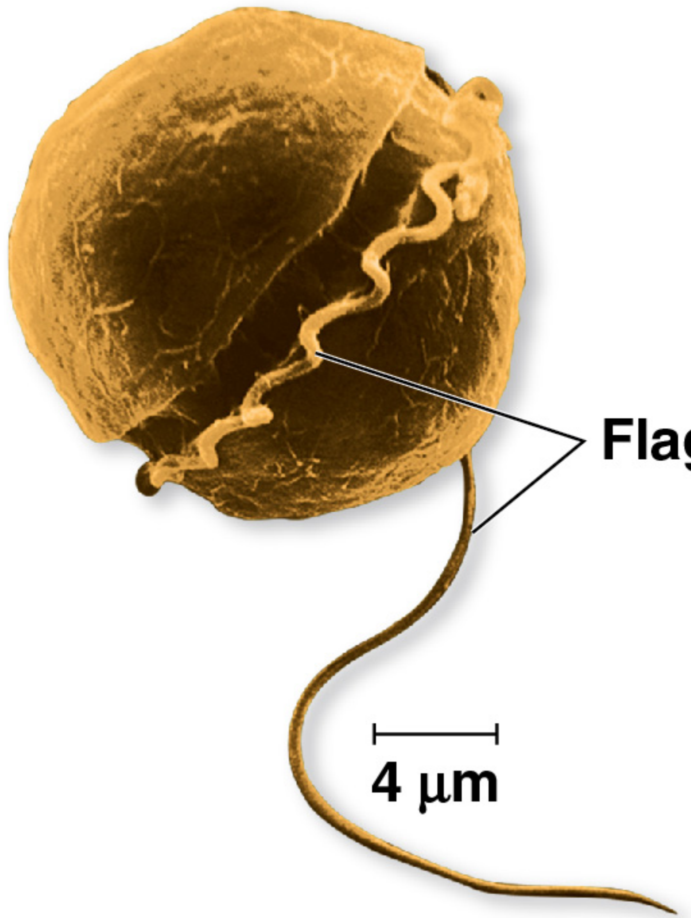
Figure 28.16



Dinoflagellates

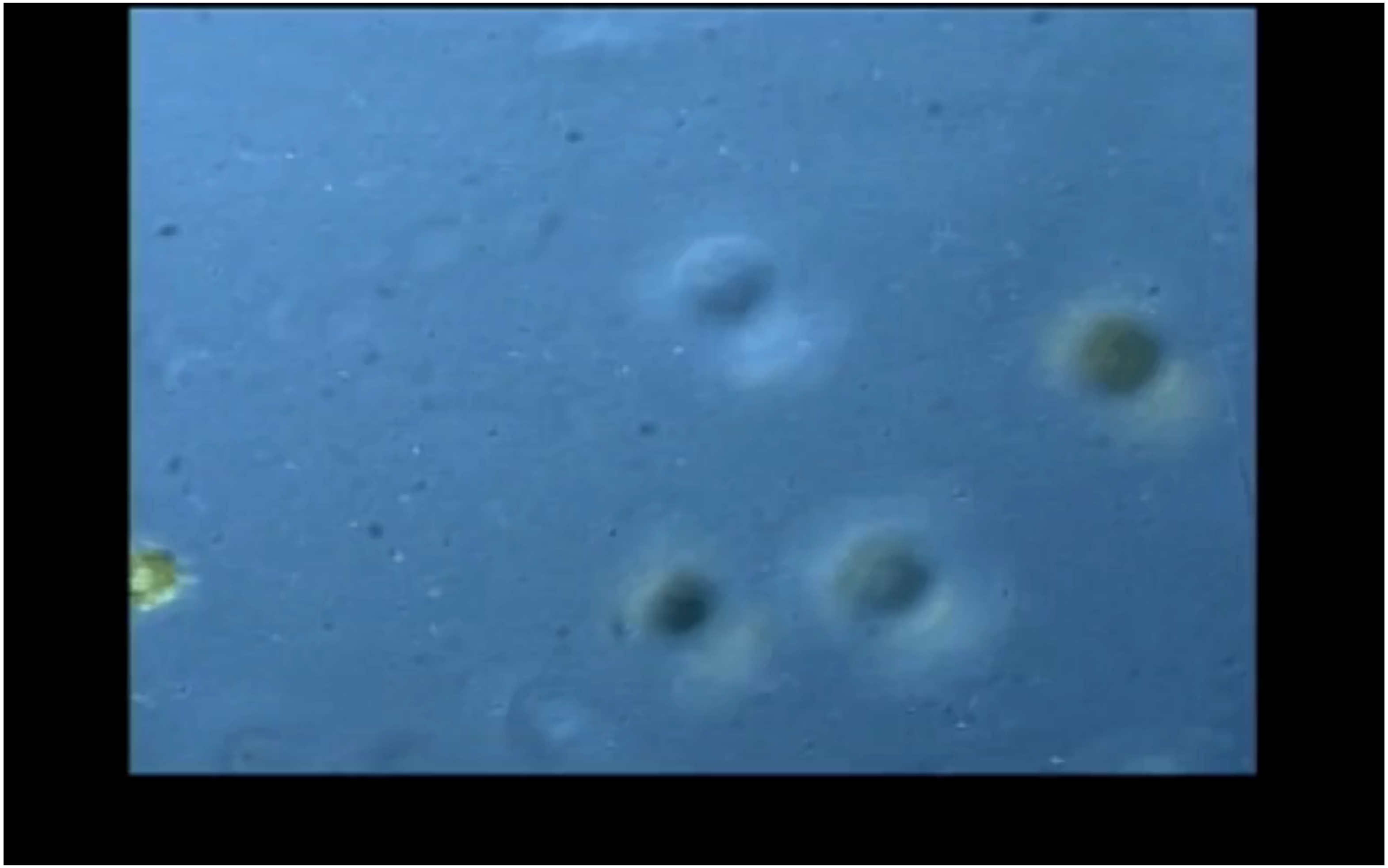
- **Dinoflagellates** are abundant components of marine and freshwater phytoplankton
- They have two flagella housed in the grooves of armor-like cellulose plates that surround the cell
- Beating of the spiral flagella causes dinoflagellates to spin as they move through the water

Figure 28.17



(a) Dinoflagellate flagella

Video: Dinoflagellate



- Dinoflagellate blooms cause “red tides” where the water appears brownish red or pink due to the carotenoids present in their plastids
- Red tides are toxic and can cause massive kills of invertebrates and fishes
- Ocean warming caused by climate change is facilitating more frequent red tides

Figure 28.17

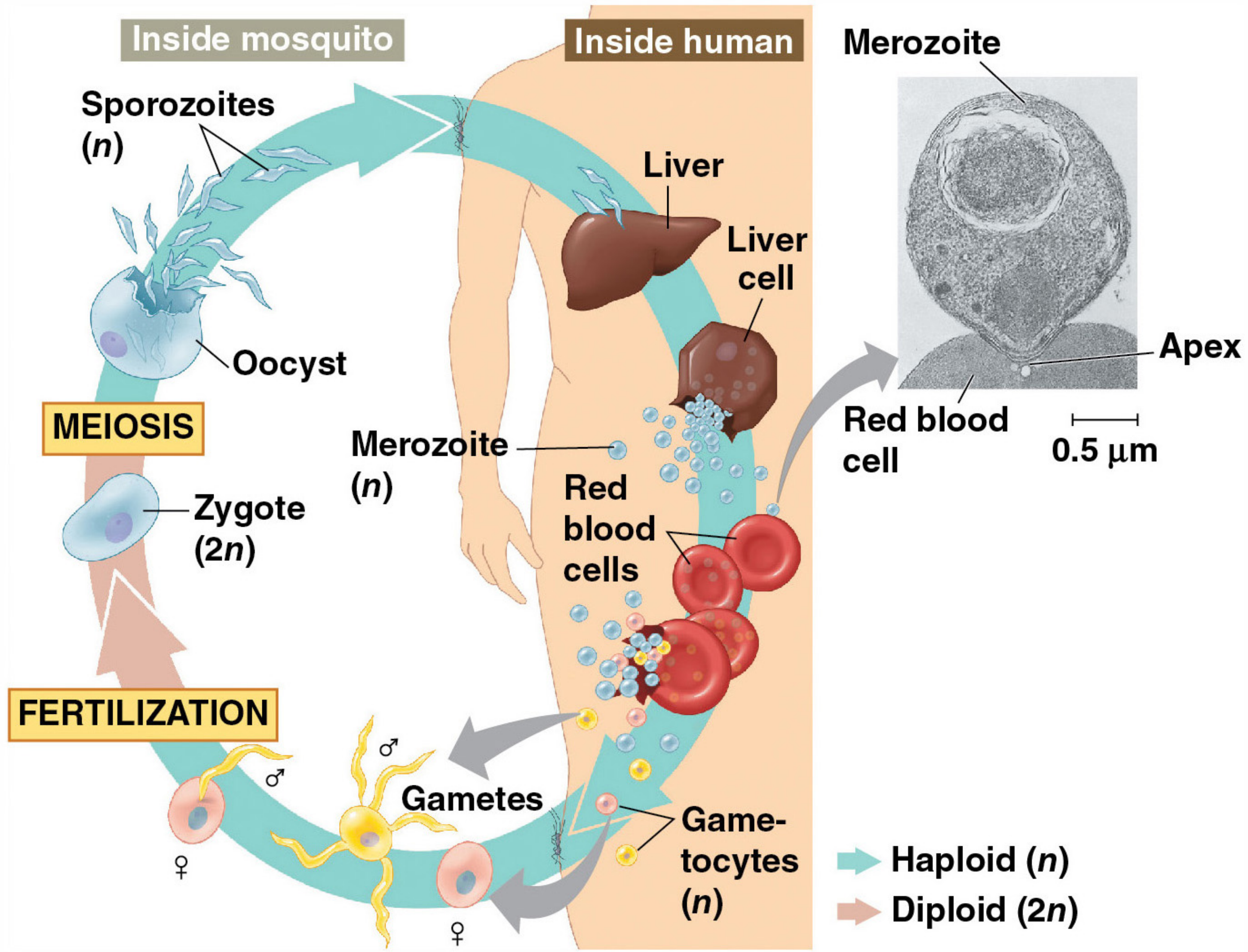
(b) Red tide in the Gulf of Carpentaria in northern Australia

Apicomplexans

- Nearly all **apicomplexans** are parasites of animals
- They spread through the host as infectious cells called sporozoites
- The apex (cell end) contains a complex of organelles specialized for penetrating host cells and tissues

- Most life cycles include both sexual and asexual stages, and require two or more different hosts
  - For example, *Plasmodium*, the parasite causing malaria, lives in both mosquitoes and humans

Figure 28.18


Inside mosquito
Inside human
Sporozoites (n)
Oocyst
MEIOSIS
Zygote (2n)
FERTILIZATION
Gametes
♂
♂
♀
♀
Liver
Liver cell
Merozoite (n)
Red blood cells
Game-tocytes (n)
Merozoite
Apex
Red blood cell
0.5 µm
Haploid (n)
Diploid (2n)

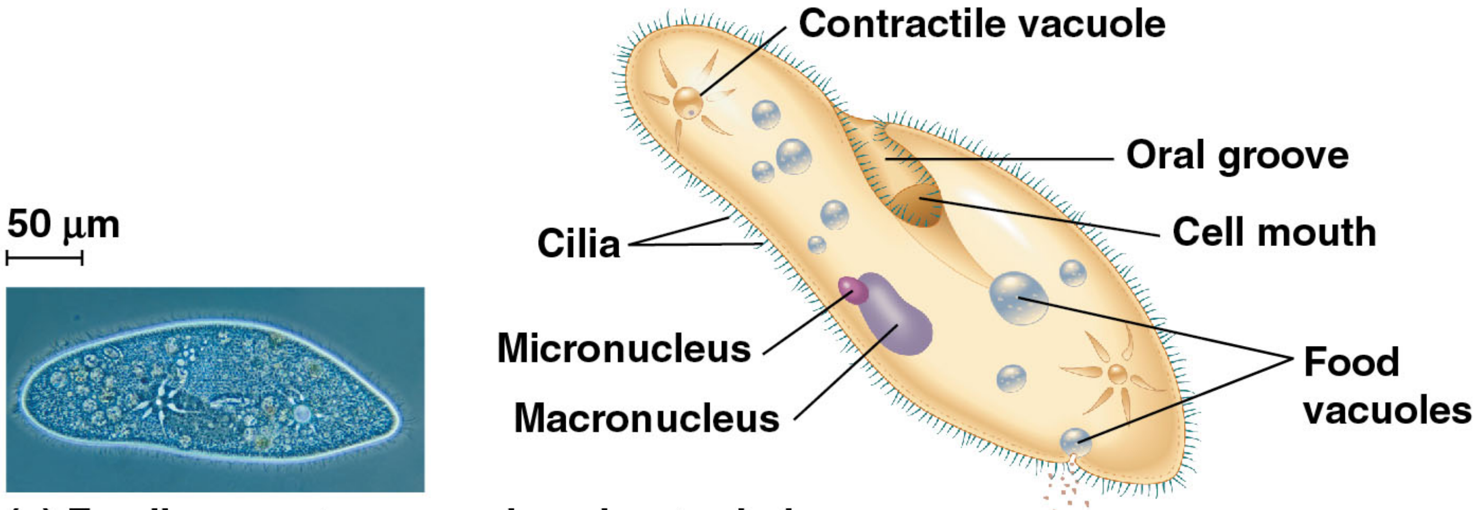
- *Plasmodium* evades the host immune system by living inside cells and continually changing its surface proteins
- Approximately 220 million people in the tropics are infected and 450,000 die each year from malaria

- The first licensed malarial vaccine was recently approved and routine use began in Africa in 2019
- The vaccine, which targets a protein on the surface of sporozoites, provides only partial protection
- Research into other potential vaccine targets is ongoing

Ciliates

- **Ciliates** are named for their use of cilia to move around and feed on bacteria or other protists
- The cilia may completely cover the cell surface or be clustered in a few rows or tufts

Figure 28.19



(a) Feeding, waste removal, and water balance

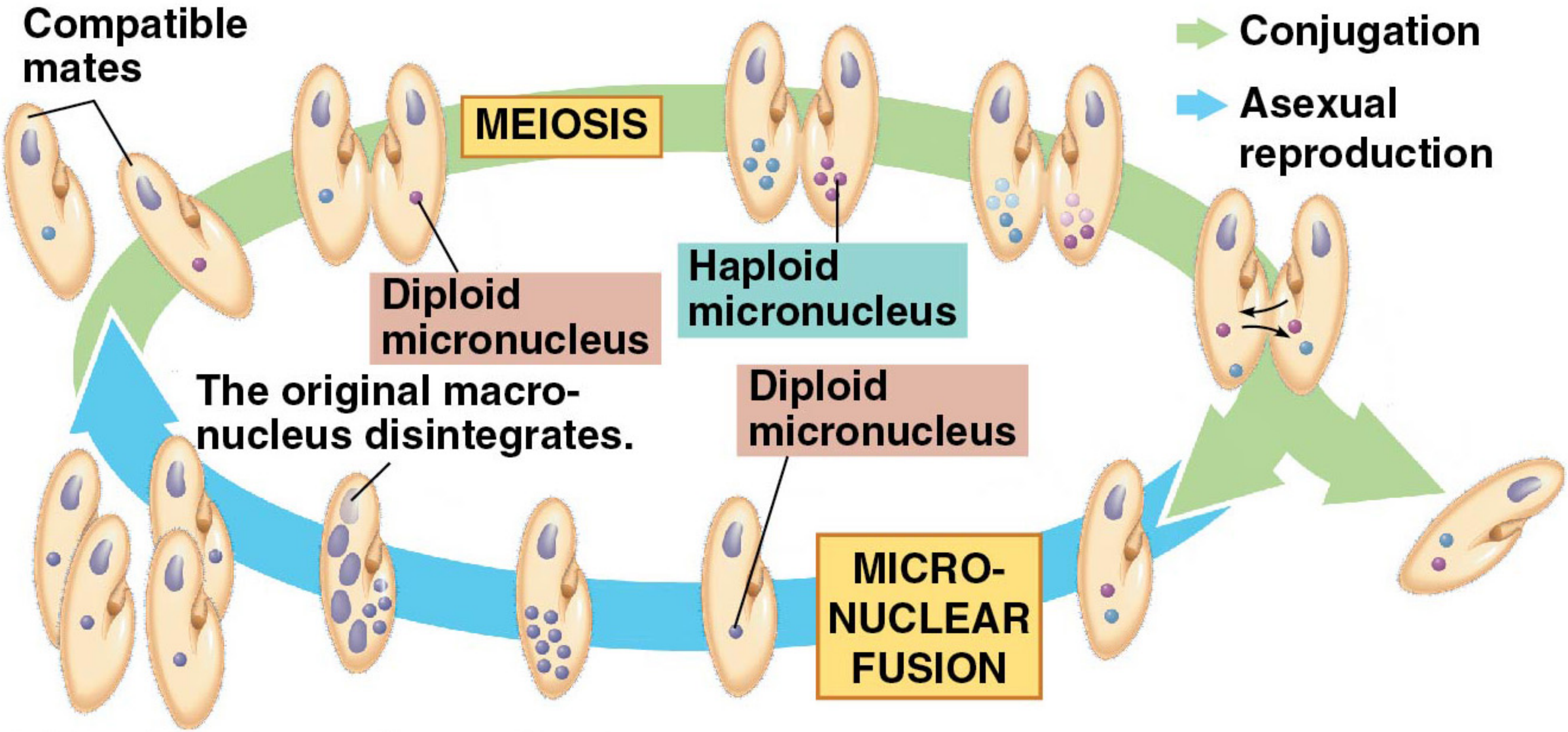
Video: Ciliate Movement in *Stentor*

Video: *Paramecium* Cilia

- Ciliates have two types of nuclei: tiny micronuclei and large macronuclei
- Each cell has one or more copies of each type
- Macronuclei have multiple copies of the genome
- Micronuclei may be diploid or haploid, depending on the life stage

- **Conjugation** produces genetic variation without reproduction through the exchange of micronuclei
- Asexual reproduction occurs by binary fission
- During binary fission, the macronucleus dissolves and a new one is formed from micronuclei

Figure 28.19



(b) Conjugation and reproduction

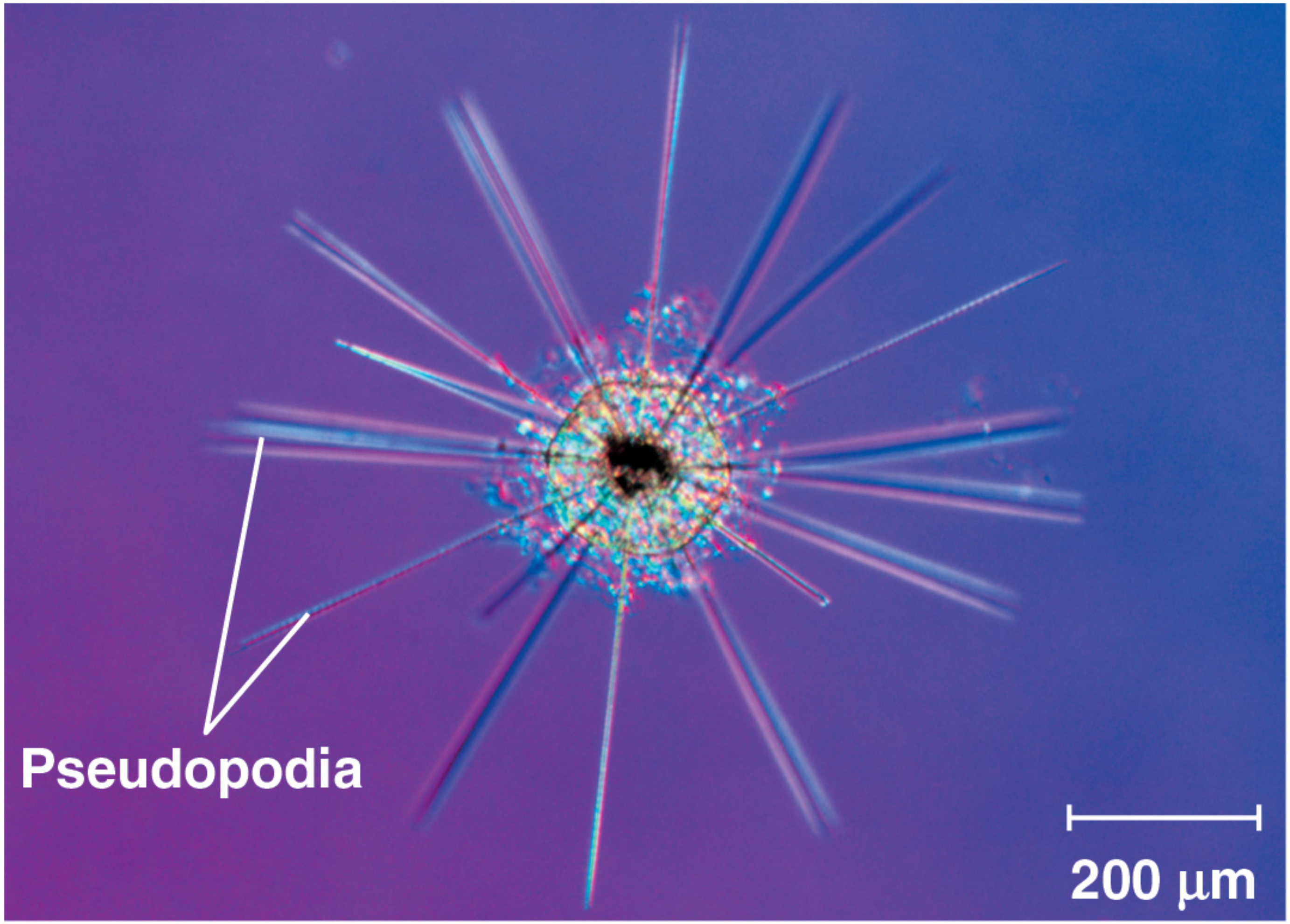
Rhizarians

- Many species of **rhizarians** are amoebas
- **Amoebas** are protists that move and feed using **pseudopodia**, extensions of the cell surface
- Rhizarian amoebas differ from amoebas in other clades by having threadlike pseudopodia
- Three clades included in the rhizarians are radiolarians, forams, and cercozoans

Radiolarians

- **Radiolarians** have delicate, symmetrical internal skeletons typically made of silica
- Pseudopodia reinforced by microtubules radiate from the central body
- Prey are engulfed by cytoplasm in the pseudopodia and carried into the cell by cytoplasmic streaming
- Most radiolarians are marine organisms

Figure 28.20



Forams

- **Foraminiferans**, or **forams**, are named for their porous calcium carbonate shells, called **tests**
- Pseudopodia that extend through pores in the test are used in swimming, test formation, and feeding
- Some host mutualistic photosynthetic algae within their tests

- Forams live in the ocean and fresh water, and their fossils make up part of the marine sediments
- Fossilized tests are used for correlating the age of sedimentary rocks in different parts of the world
- The magnesium content of fossilized tests is used to estimate the change in ocean temperature over time

Figure 28.21

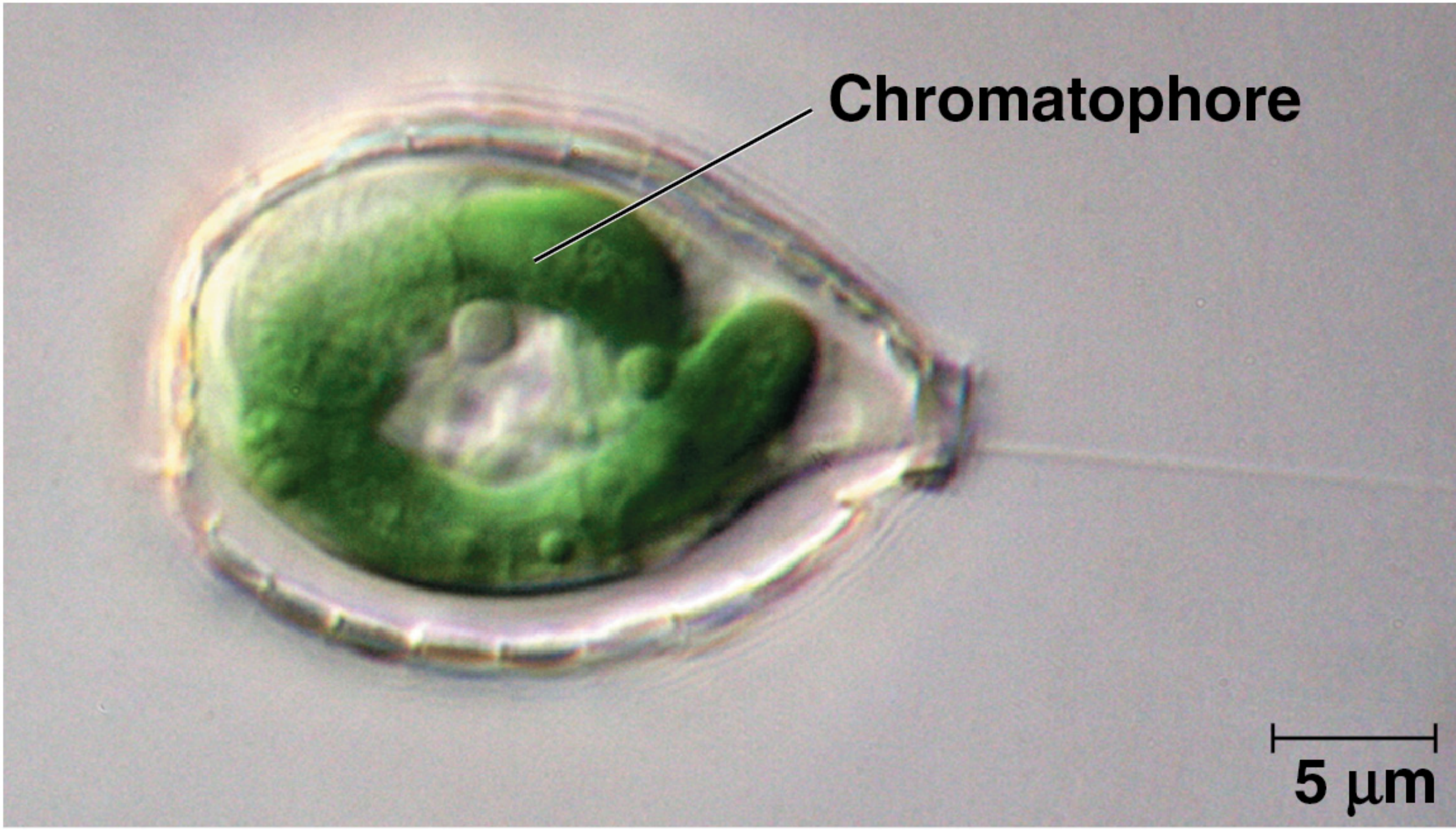
Cercozoans

- **Cercozoans** are amoeboid and flagellated protists that feed using threadlike pseudopodia
- They are common in marine, fresh water, and soil ecosystems

- Most cercozoans are heterotrophic parasites or predators
- Chlorarachniophytes are a small group of mixotrophs
- At least one species, *Paulinella chromatophora,* is known to be autotrophic

- *Paulinella chromatophora* has a unique photosynthetic structure called a chromatophore
- Chromatophores are derived from endosymbiosis with a cyanobacteria different from the one that gave rise to plastids

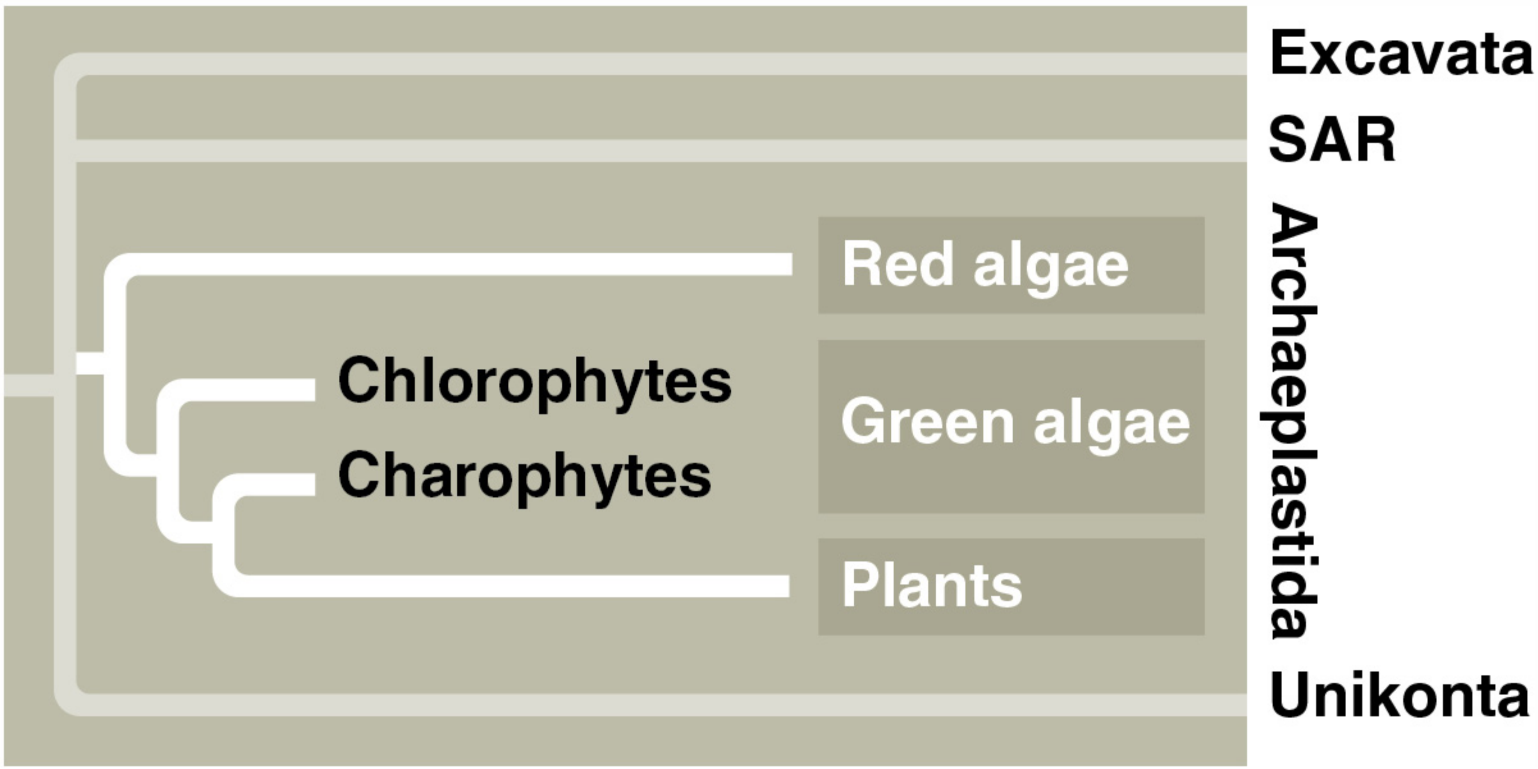
Figure 28.22



CONCEPT 28.4: Red algae and green algae are the closest relatives of plants

- Plastids arose when a heterotrophic protist acquired a cyanobacterial endosymbiont
- The photosynthetic descendants of this ancient protist evolved into red algae and green algae
- Plants are descended from the green algae
- **Archaeplastida** is the supergroup that includes red algae, green algae, and plants

Figure 28.UN03

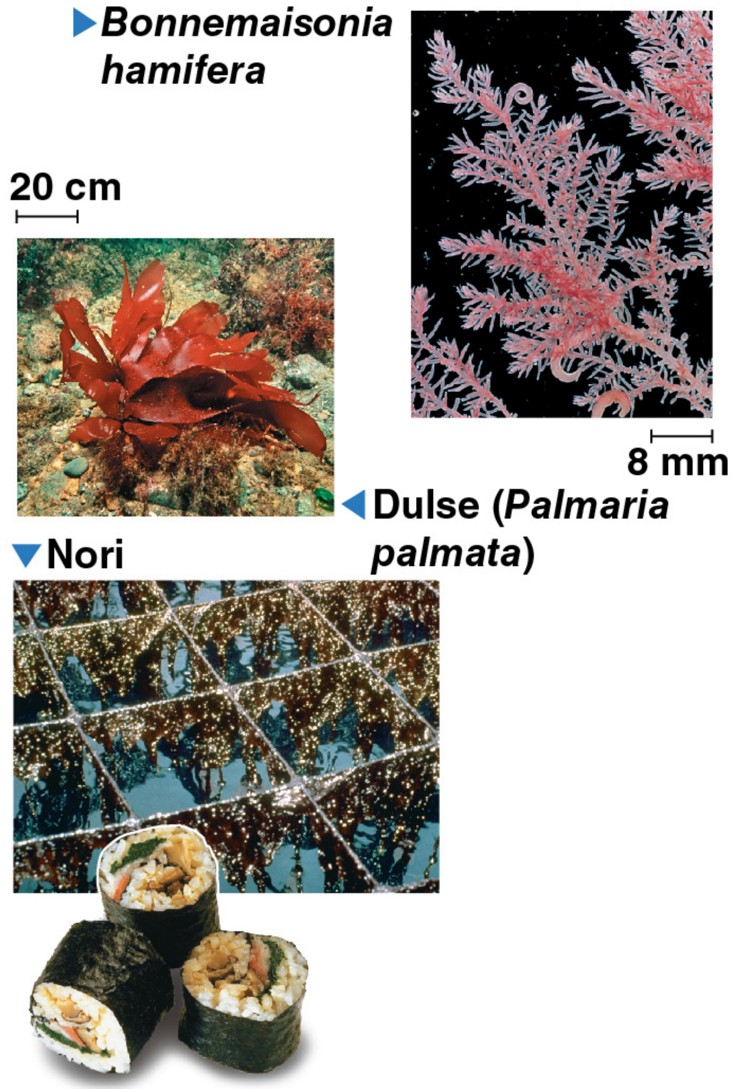


Red Algae

- An accessory pigment called phycoerythrin masks the green of chlorophyll giving **red algae** its color
- Color varies from greenish-red in shallow water to dark red or almost black in deep water
- Most are multicellular; the largest are seaweeds

- Reproduction is sexual in red algae and life cycles often include alternation of generations
- Red algae are common in coastal waters of tropical oceans
- Some species are consumed by humans, such as *Porphyra* (“nori”) that is used to wrap sushi

Figure 28.23


Bonnemaisonia hamifera
8 mm
20 cm
Dulse (Palmaria palmata)
Nori

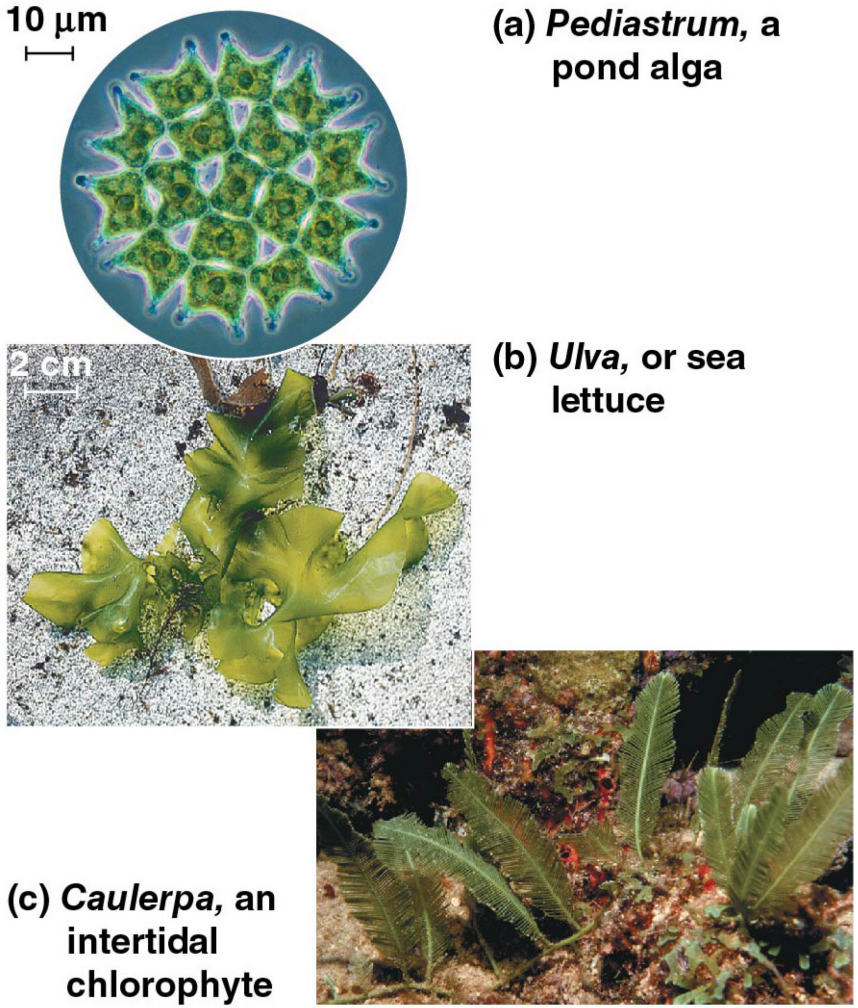
Green Algae

- **Green algae** are named for their green chloroplasts, which are structurally and chemically similar to those found in plants
- Green algae form a paraphyletic group that includes the charophytes and the chlorophytes
- Charophytes include the algae most closely related to plants

- Most chlorophytes live in fresh water, although there are many marine and some terrestrial species
- Various unicellular species are free-living while others live symbiotically with other eukaryotes
- Some live in environments exposed to intense visible and ultraviolet radiation

- Larger size and greater complexity evolved in green algae by three different mechanisms:
  1. Formation of colonies from individual cells (*Pediastrum*)
  2. Formation of true multicellular bodies by cell division and differentiation (*Volvox* and *Ulva*)
  3. Repeated division of nuclei with no cytoplasmic division (*Caulerpa*)

Figure 28.24



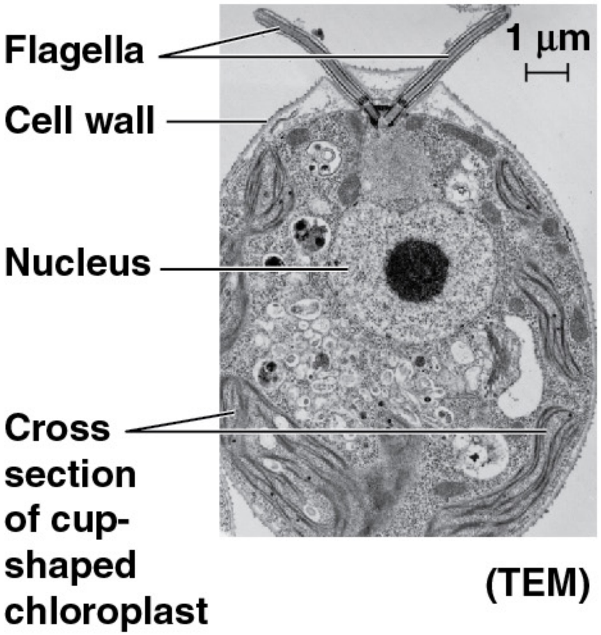
(a) ***Pediastrum,*** **a pond alga**

(b) ***Ulva,*** **or sea lettuce**

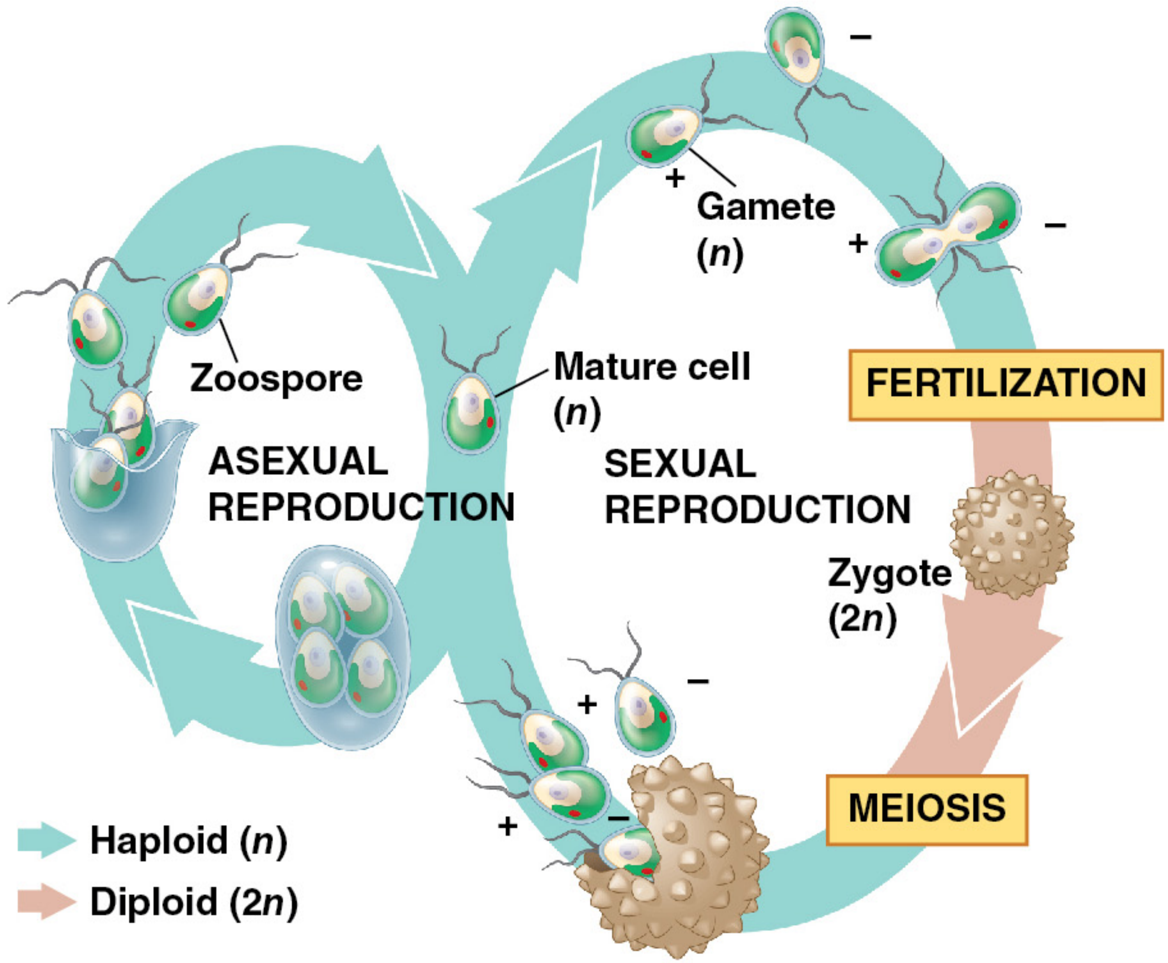
(c) ***Caulerpa,*** **an intertidal chlorophyte**

- Most chlorophytes have complex life cycles with both sexual and asexual reproductive stages
- Nearly all species have biflagellated gametes with cup-shaped chloroplasts
- Alternation of generations has evolved in some chlorophytes, including *Ulva*

Figure 28.25

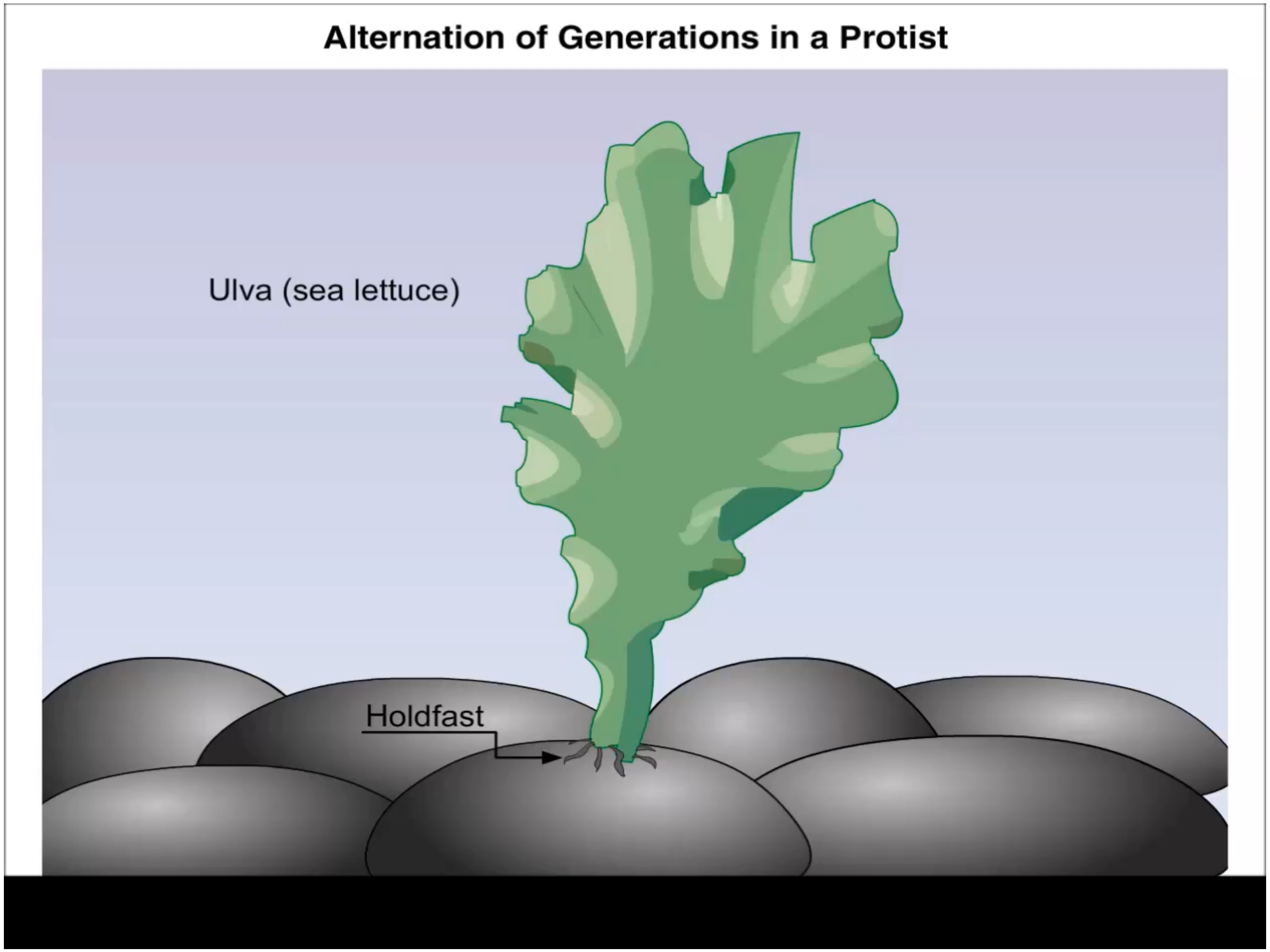


Flagella
1 µm
Cell wall
Nucleus
Cross section of cup-shaped chloroplast
(TEM)



Zoospore
ASEXUAL REPRODUCTION
Mature cell (n)
SEXUAL REPRODUCTION
Gamete (n)
FERTILIZATION
Zygote (2n)
MEIOSIS
Haploid (n)
Diploid (2n)

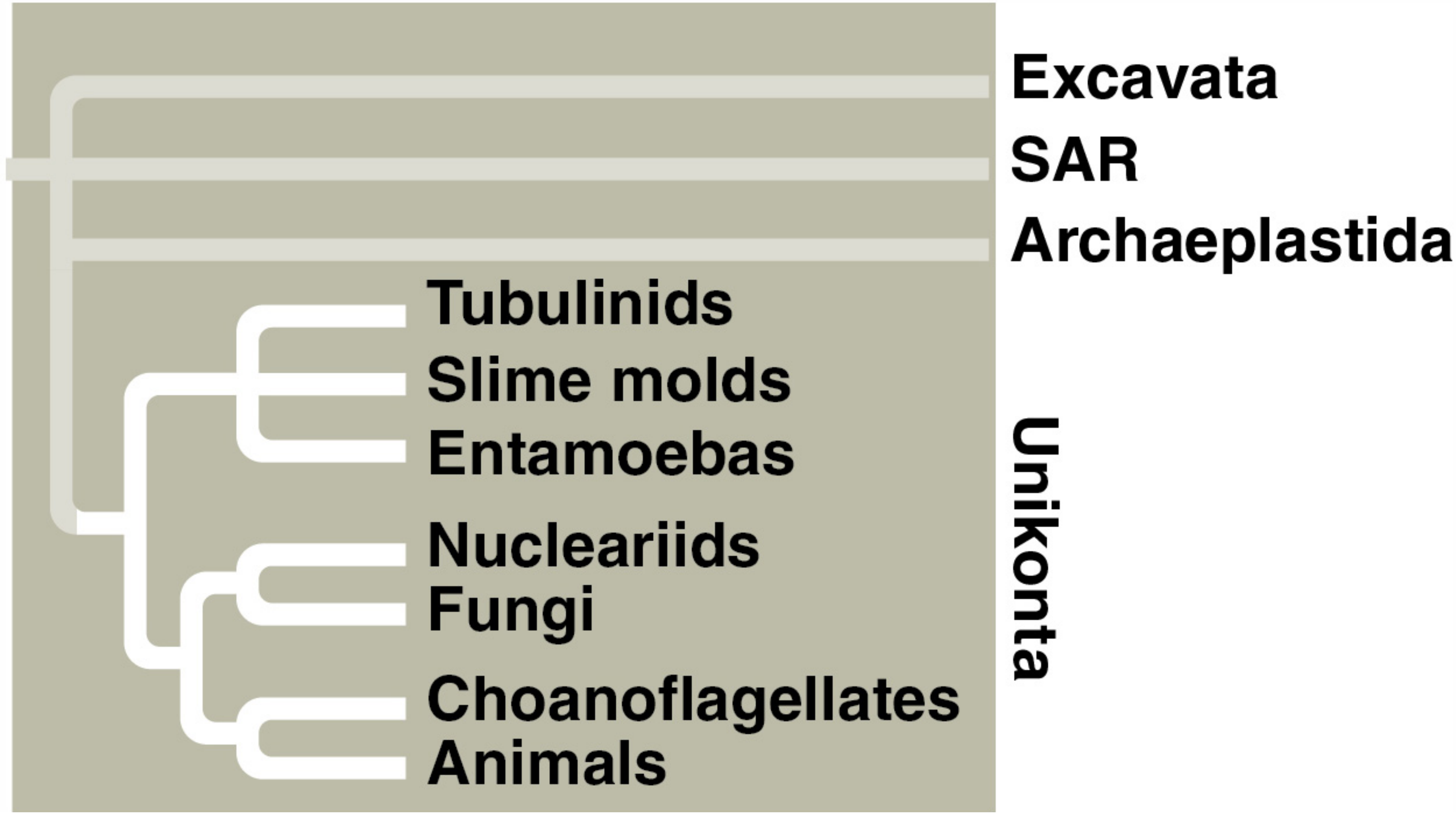
Animation: Alternation of Generations in a Protist



CONCEPT 28.5: Unikonts include protists that are closely related to fungi and animals

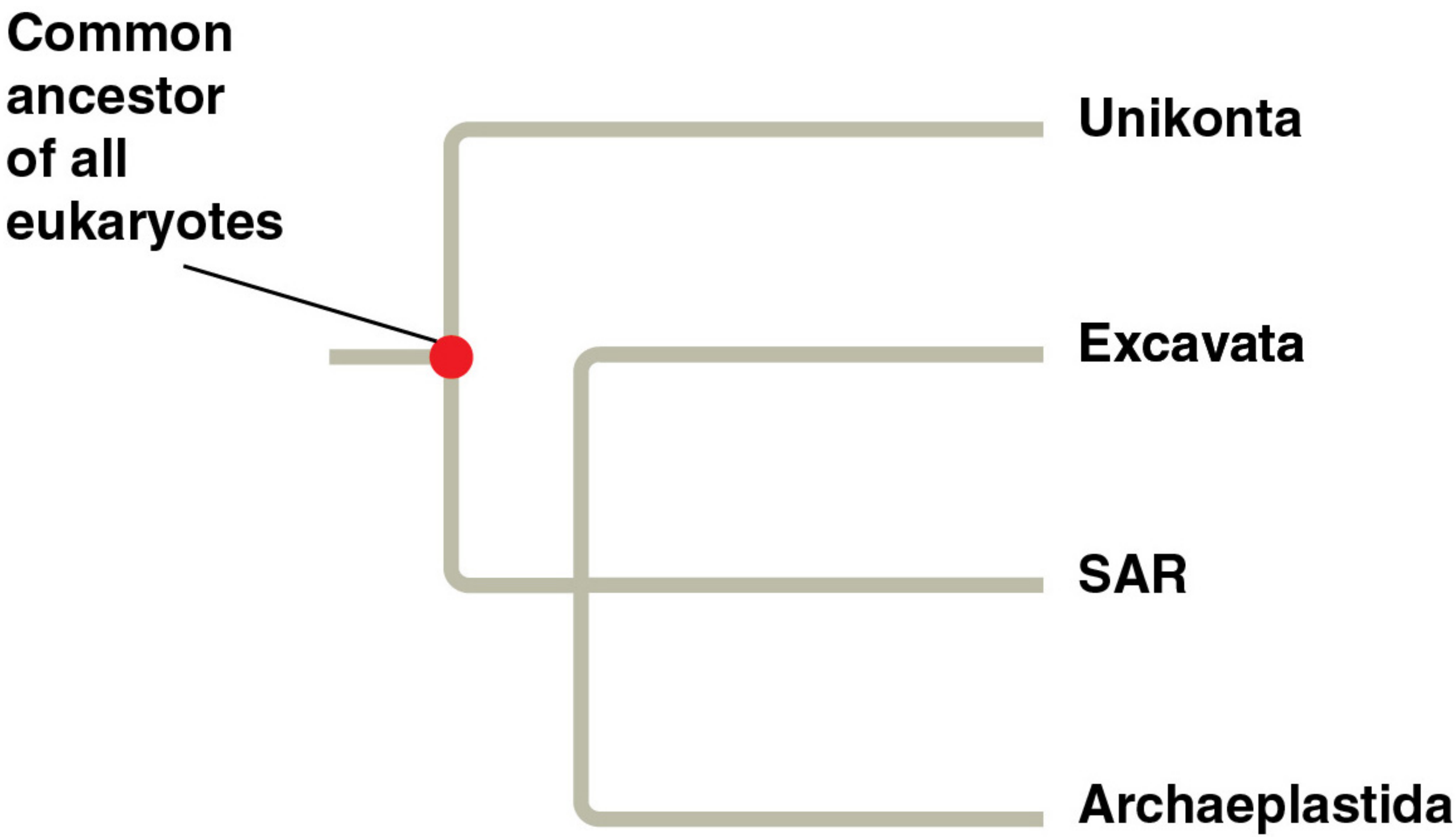
- The supergroup **Unikonta** includes animals, fungi, and some protists
- The two major clades of unikonts are the amoebozoans (tubulinids and relatives) and the opisthokonts (animals, fungi, and related protists)

Figure 28.UN04



- The root of the eukaryotic tree is uncertain
- One controversial hypothesis is that unikonts were the first to diverge from other eukaryote groups

Figure 28.26


Common
ancestor
of all
eukaryotes
Unikonta
Excavata
SAR
Archaeplastida

Amoebozoans

- **Amoebozoans** are amoebas that have lobe- or tube-shaped, rather than threadlike, pseudopodia
- They include tubulinids, slime molds, and entamoebas

Tubulinids

- Tubulinids are a diverse group of amoebozoans with lobe- or tube-shaped pseudopodia
- They are common unicellular protists in soil as well as freshwater and marine environments
- Most tubulinids are active predators of bacteria and other protists; others feed on detritus

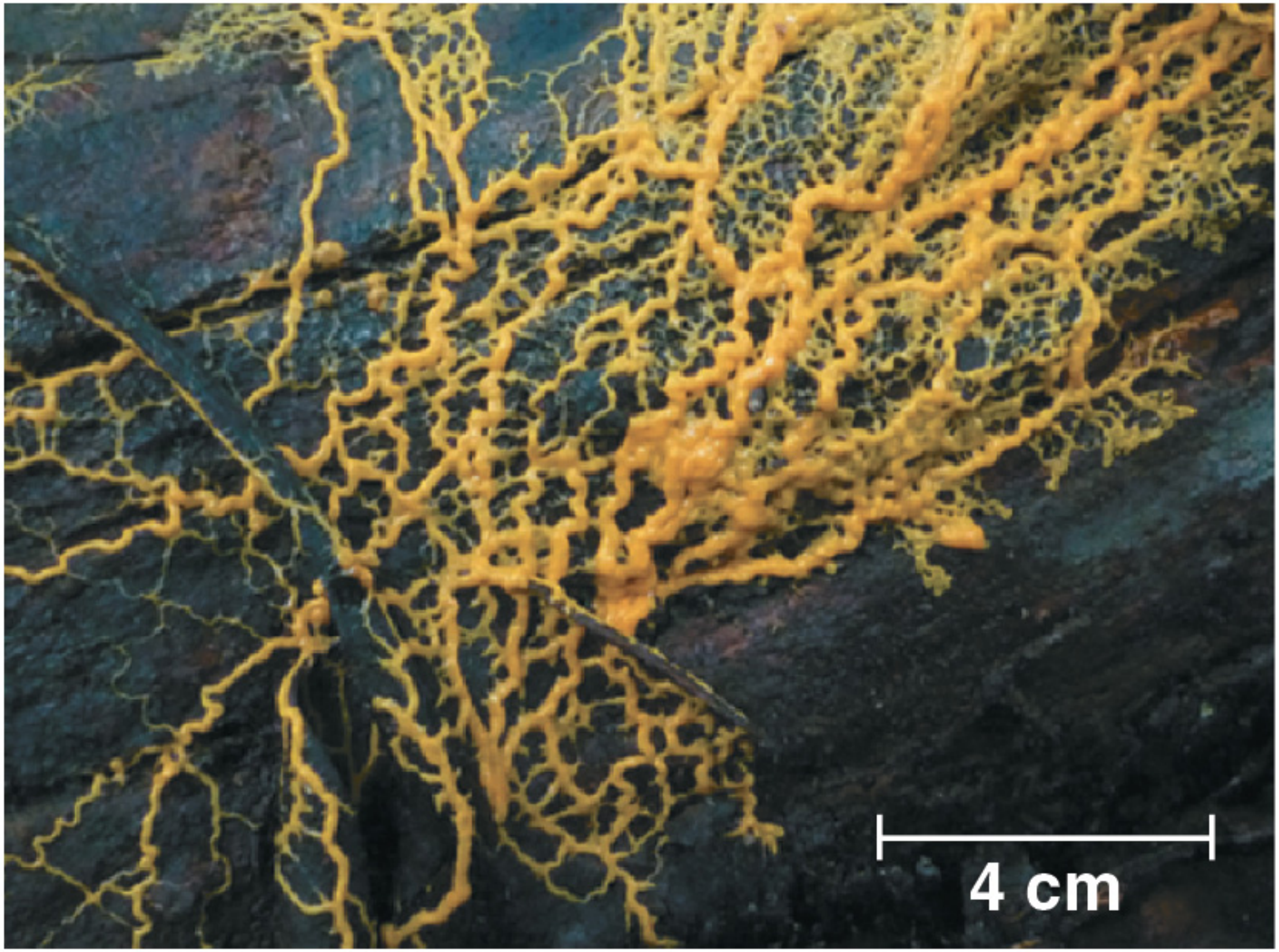
Slime Molds

- Slime molds, or mycetozoans, were once thought to be fungi due to their spore-producing fruiting bodies
- This resemblance is a result of convergent evolution
- Slime molds have diverged into two lineages, plasmodial slime molds and cellular slime molds

Plasmodial Slime Molds

- Many plasmodial slime molds are brightly colored, often yellow or orange
- They form a large feeding mass called a plasmodium
- The plasmodium is a single “supercell” that contains many diploid nuclei undivided by plasma membranes
- The plasmodium forms a fruiting body for sexual reproduction in unfavorable environmental conditions

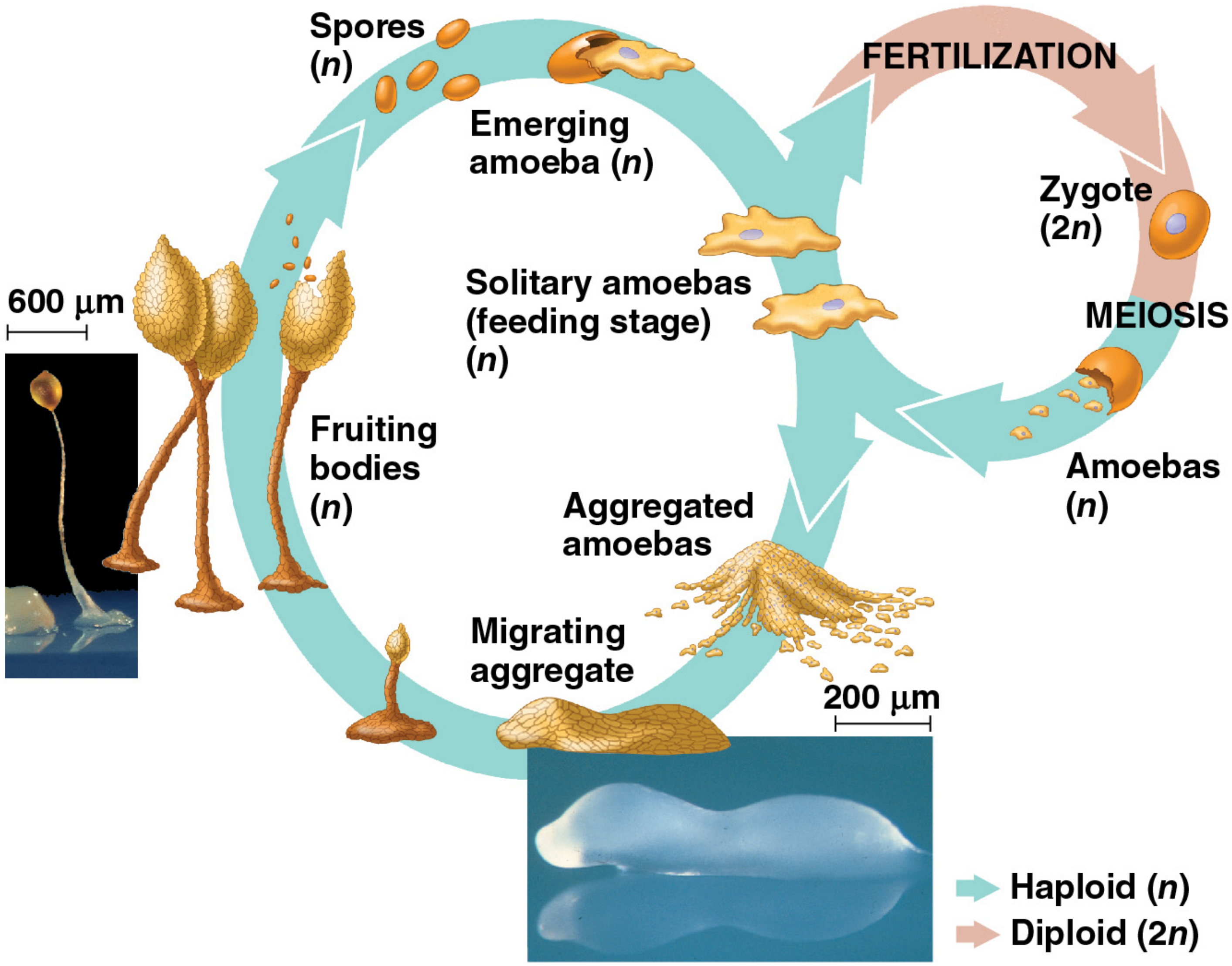
Figure 28.27



Cellular Slime Molds

- Cellular slime molds form multicellular aggregates in which cells are separated by plasma membranes
- The feeding stage consists of solitary cells
- Solitary cells unite to form a slug-like aggregate for migration when habitat conditions are poor
- Ultimately, the aggregated cells form a fruiting body

Figure 28.28


Spores
(n)
Emerging
amoeba (n)
FERTILIZATION
Zygote
(2n)
MEIOSIS
Amoebas
(n)
Solitary amoebas
(feeding stage)
(n)
600 µm
Fruiting
bodies
(n)
Aggregated
amoebas
Migrating
aggregate
200 µm
Haploid (n)
Diploid (2n)

Cellular Slime Molds

- *Dictyostelium discoideum* is a model organism for the studying the evolution of multicellularity
- Cells in the stalk of the fruiting body die without reproducing; cells at the top survive to reproduce
- Some cells have a “cheat” mutation, giving them the reproductive advantage of not forming the stalk
- Why don’t all *Dictyostelium* cells cheat?

Cellular Slime Molds

- Cheating cells lack a specific surface protein recognized by noncheaters
- Non-cheaters avoid exploitation by preferentially aggregating with other noncheaters
- Such a recognition system may have been important in the evolution of other multicellular eukaryotes

Entamoebas

- Members of the genus *Entamoeba* are parasites of all classes of vertebrates and some invertebrates
- Humans are host to at least six species, but only *E. histolytica* is pathogenic
- *E. histolytica* causes amoebic dysentery, the third-leading cause of death due to eukaryotic parasites

Opisthokonts

- **Opisthokonts** are a diverse group including animals, fungi, and several groups of protists

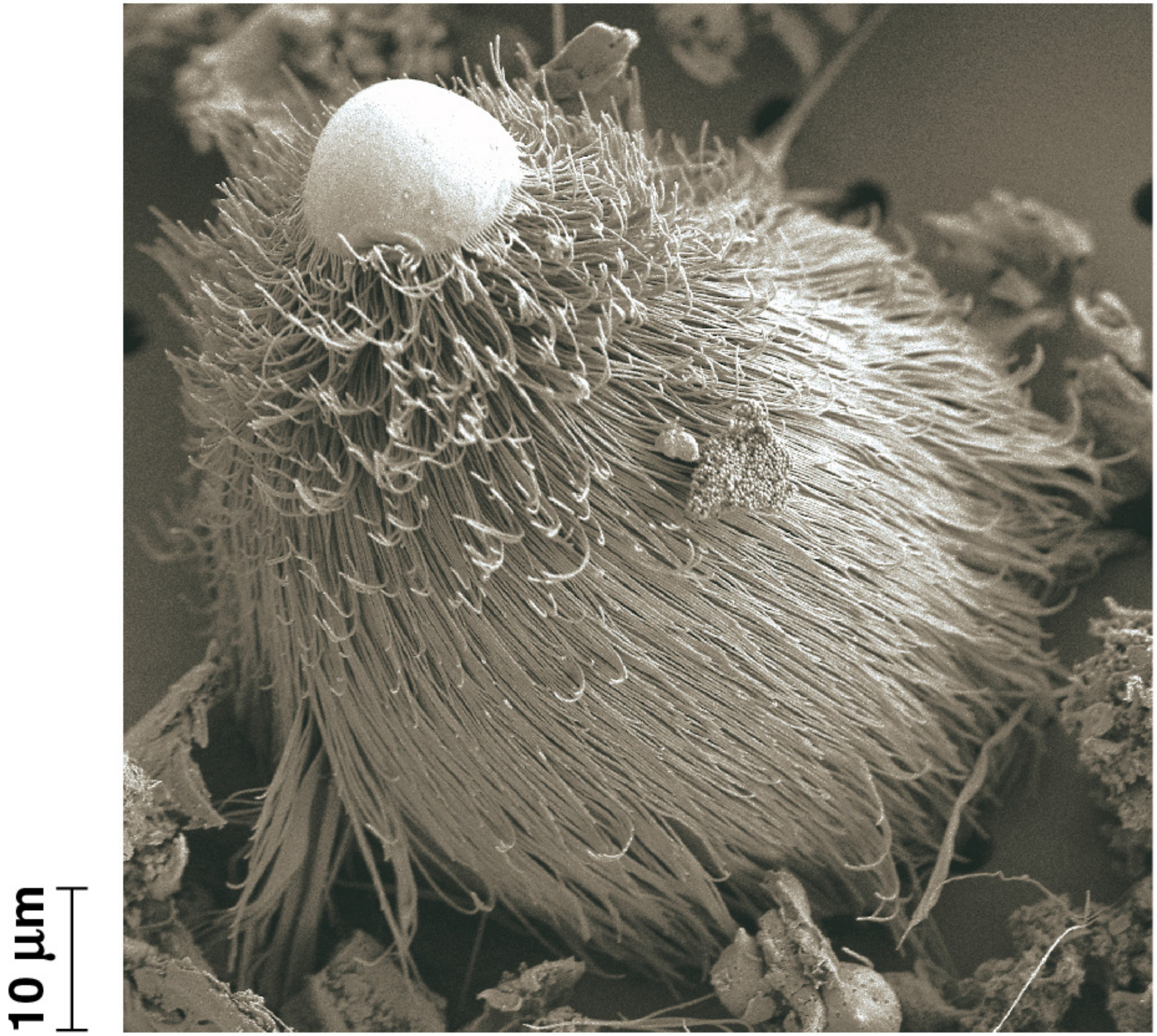
CONCEPT 28.6: Protists play key roles in ecological communities

- Protists are found in diverse aquatic and moist terrestrial environments
- Protists play two key roles in their habitats: that of symbiont and that of producer

Symbiotic Protists

- Some protist symbionts benefit their hosts
  - Some dinoflagellates live within the polyps and nourish reef-building corals
  - Some protists inhabit the guts of termites and aid with the digestion of wood

Figure 28.29



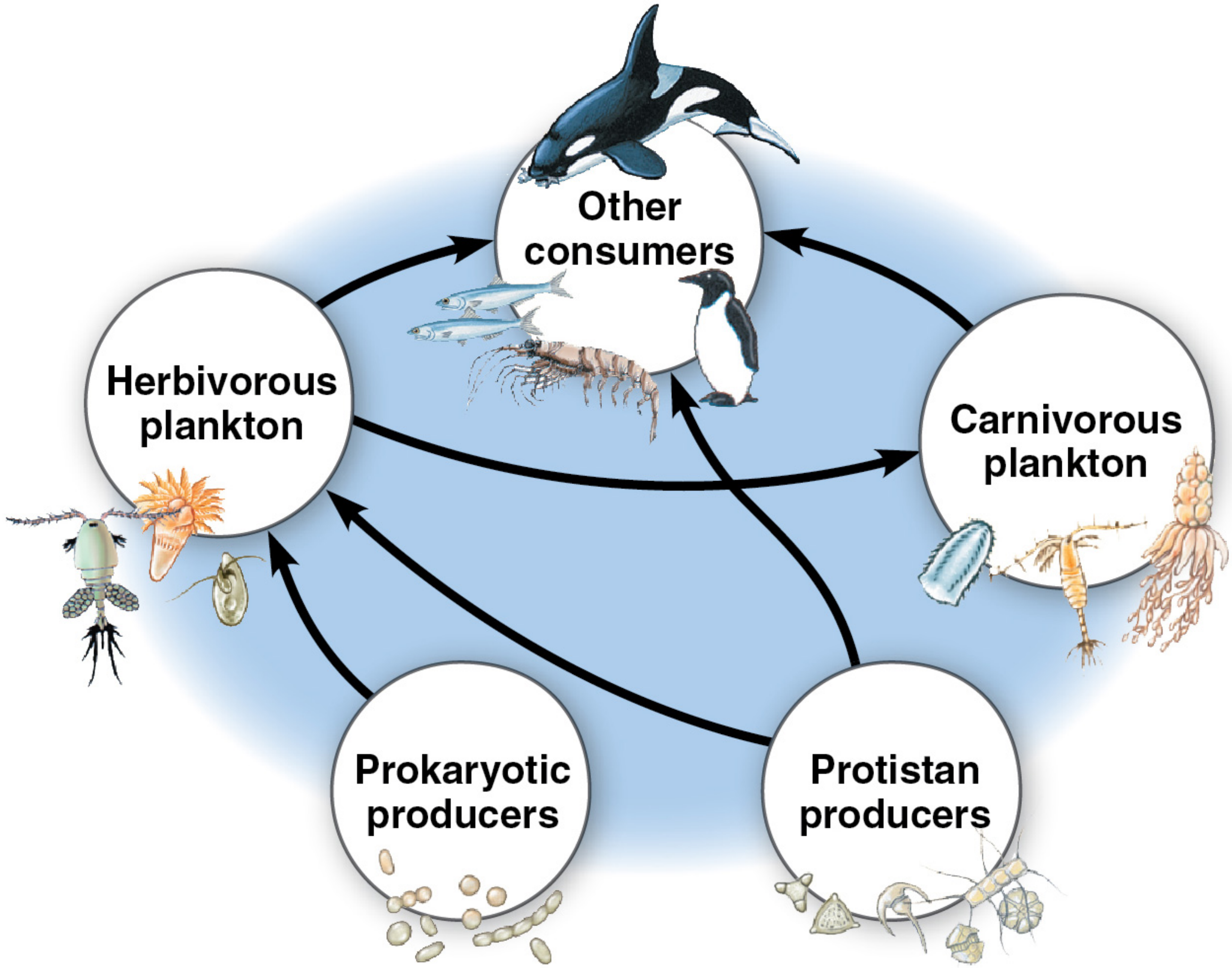
- Some protist symbionts are parasites
  - *Plasmodium causes* malaria in humans
  - *Pfiesteria shumwayae* is a dinoflagellate that attaches and feeds on the skin of fish
  - *Phytophthora ramorum* causes sudden oak death

Figure 28.30

Photosynthetic Protists

- Many protists are **producers**, organisms that use energy from light (or inorganic compounds) to convert CO_2 to organic compounds
- In aquatic communities, the main producers are photosynthetic protists and prokaryotes
- All other organisms are **consumers** that directly or indirectly depend on producers for food

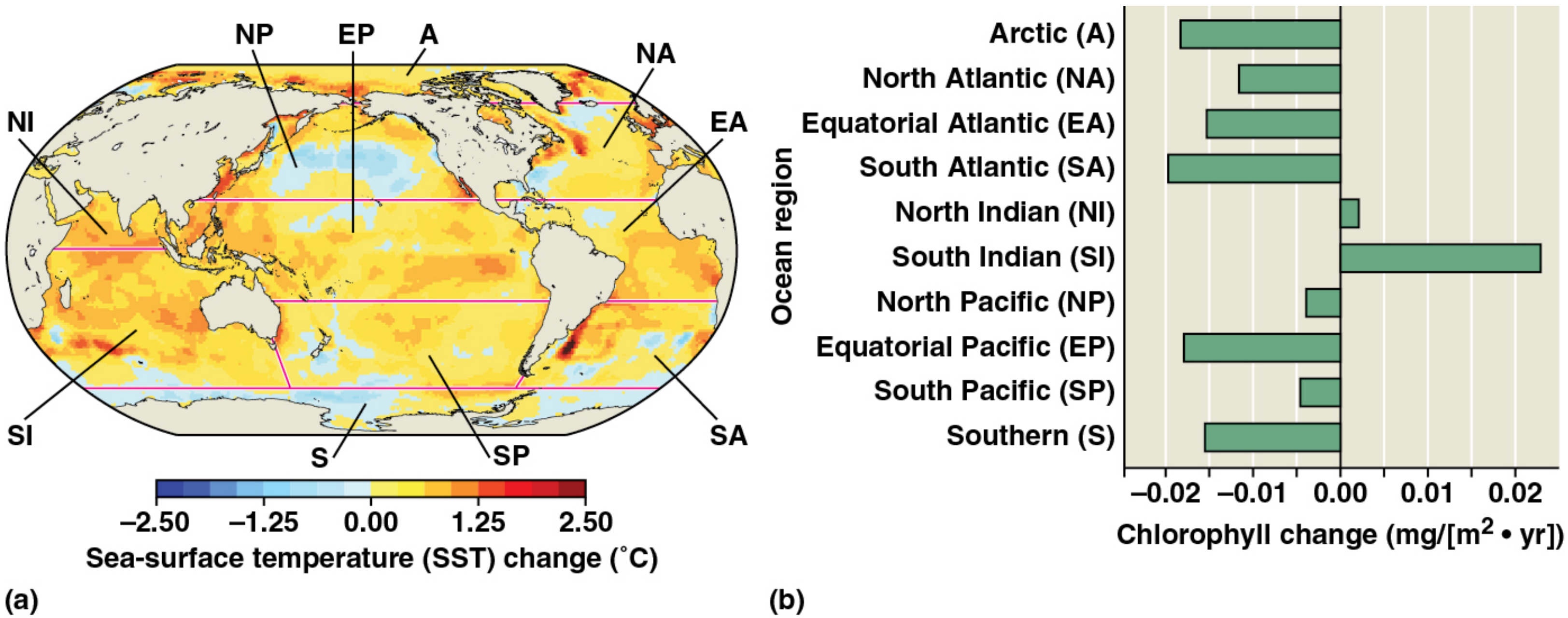
Figure 28.31


Other consumers
Herbivorous plankton
Carnivorous plankton
Prokaryotic producers
Protistan producers

- Photosynthetic protists are limited by nutrients; populations explode when nutrients are added
- Population booms can have major ecological consequences, such as the formation of marine “dead zones”

- Growth and biomass of photosynthetic protists and prokaryotes have declined with increasing sea surface temperature
- Phytoplankton communities rely on upwelling of cold, nutrient-rich water from the below
- Warm surface water acts as a barrier to upwelling

Figure 28.32



NP
EP
A
NA
NI
EA
SI
S
SP
SA
–2.50
–1.25
0.00
1.25
2.50
Sea-surface temperature (SST) change (˚C)
(a)
Arctic (A)
North Atlantic (NA)
Equatorial Atlantic (EA)
South Atlantic (SA)
North Indian (NI)
South Indian (SI)
North Pacific (NP)
Equatorial Pacific (EP)
South Pacific (SP)
Southern (S)
Ocean region
–0.02
–0.01
0.00
0.01
0.02
Chlorophyll change (mg/[m2 • yr])
(b)

- If sea surface temperature continues to warm due to global warming, this could have large effects on
  - marine ecosystems
  - fishery yields
  - the global carbon cycle

Figure 28.UN05

	Wheat mitochondrion	*A. tumefaciens*	*C. testosteroni*	*E. coli*	*M. capricolum*	*A. nidulans*
Wheat mitochondrion	–	48	38	35	34	34
A. tumefaciens		–	55	57	52	53
C. testosteroni			–	61	52	52
E. coli				–	48	52
M. capricolum					–	50
A. nidulans						–

Data from D. Yang et al., Mitochondrial origins, *Proceedings of the National Academy of Sciences USA* 82:4443–4447 (1985).

Figure 28.UN05

Wheat, used as the source of mitochondrial RNA

Figure 28.UN06

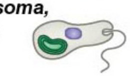
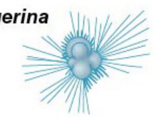
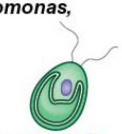
Eukaryote Supergroup	Major Groups	Key Morphological Characteristics	Specific Examples
Excavata	Diplomonads and parabasalids	Modified mitochondria	*Giardia*, *Trichomonas* 
	Euglenozoans Kinetoplastids Euglenids	Spiral or crystalline rod inside flagella	*Trypanosoma*, *Euglena* 
"SAR" Clade	Stramenopiles Diatoms Oomycetes Brown algae	Hairy and smooth flagella	*Phytophthora*, *Laminaria* 
	Alveolates Dinoflagellates Apicomplexans Ciliates	Membrane-enclosed sacs (alveoli) beneath plasma membrane	*Pfiesteria*, *Plasmodium*, *Paramecium* 
	Rhizarians Radiolarians Forams Cercozoans	Amoebas with threadlike pseudopodia	*Globigerina* 
Archaeplastida	Red algae	Phycoerythrin (photosyn-thetic pigment)	*Porphyridium*, *Palmaria* 
	Green algae	Plant-type chloroplasts	*Chlamydomonas*, *Ulva* 
	Plants	(See Chapters 29 and 30.)	Mosses, ferns, conifers, flowering plants 
Unikonta	Amoebozoans Tubulinids Slime molds Entamoebas	Amoebas with lobe-shaped or tube-shaped pseudopodia	*Amoeba*, *Dictyostelium* 
	Opisthokonts	(Highly variable; see Chapters 31–34.)	Choanoflagellates, nucleariids, animals, fungi 

Figure 28.UN07