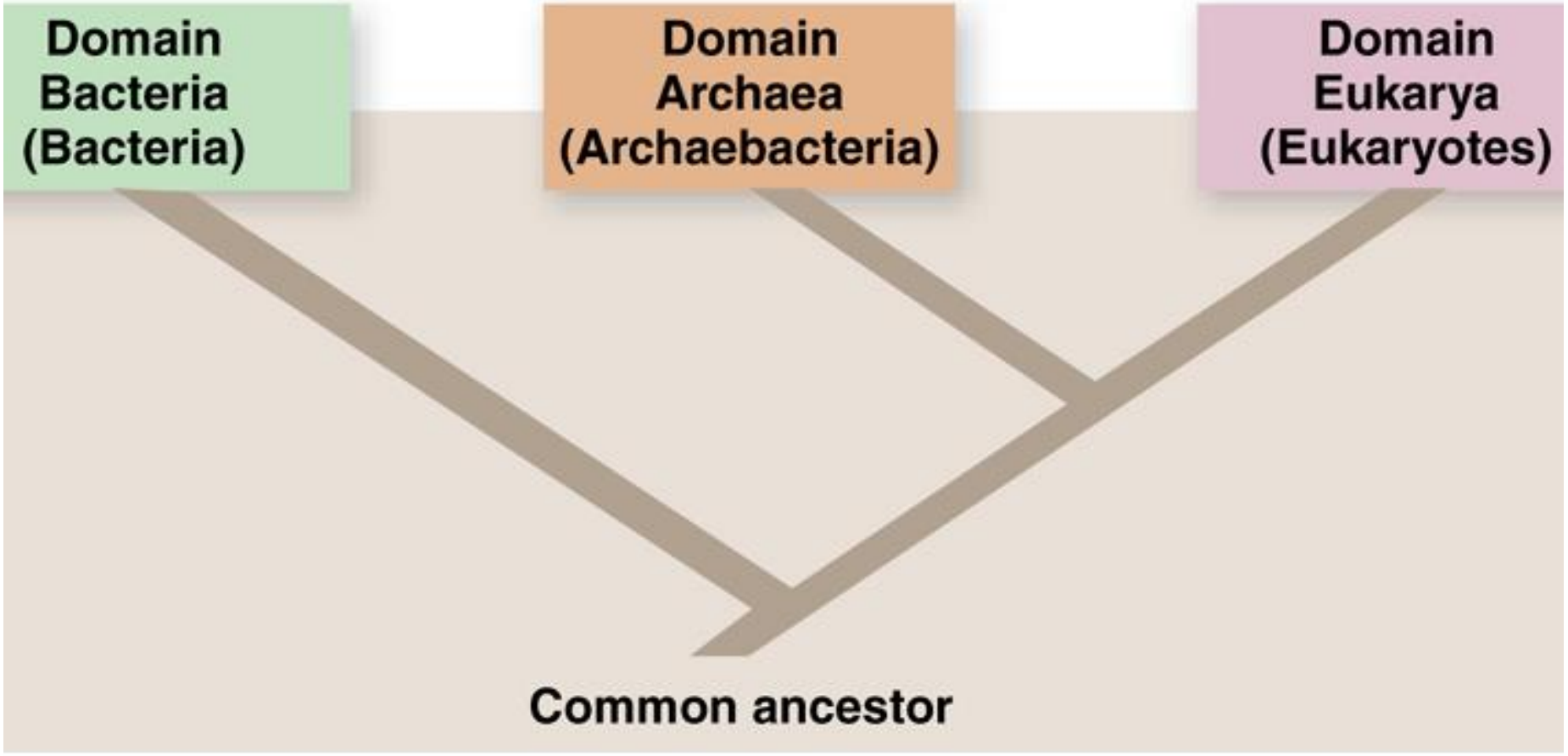
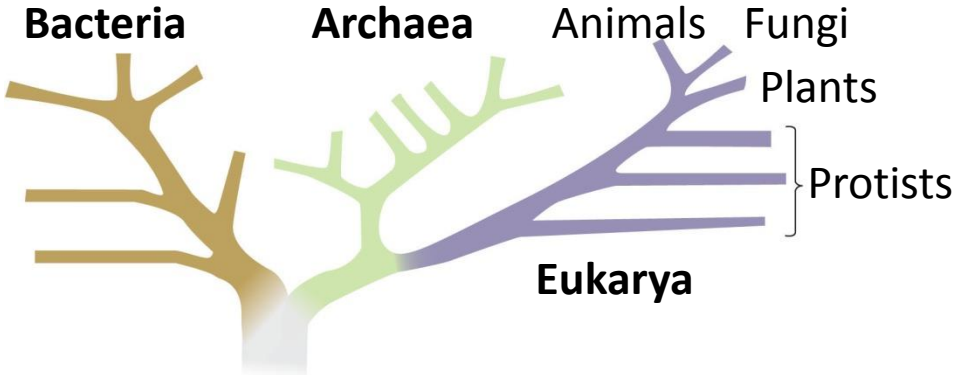
Three Domains of Life



The Microbial World

- All three biological domains include microbial organisms (or “microorganisms”)
- Although microorganisms include some of the smallest organisms, they play critical roles in the evolution of life on our planet and in the ecology of both terrestrial and marine environments



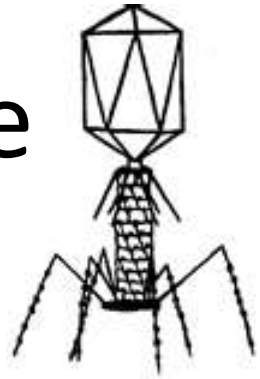
The Microbial World

- Microorganisms are the most important **primary producers** in many marine environments
  - Via photosynthesis and chemosynthesis, they manufacture organic matter from CO_2
  - As a result, they directly or indirectly feed most marine organisms
  - Microorganisms make essential nutrients available to other primary producers

Viruses

- Although they may not technically constitute a living organism (???), viruses are a critical component of the marine food web
- **Viruses are particles made up of nucleic acid** (RNA or DNA) protected by a protein coat
- They are parasites that reproduce and develop only with the aid of a living cell
- Viruses are minute, measuring 20-200 nanometers (a nanometer is one-billionth of a meter)!

You can swim, but you can't hide



- Viruses are everywhere in the marine environment
- They parasitize bacteria and plankton (and everyone else) releasing organic matter into the ocean
  - Provides organic compounds to be grazed upon by other members of the microbial community
  - Releases nutrients which may be used by photosynthetic organisms
  - May be responsible for half of the bacterial mortality in aquatic ecosystems and substantial amounts in phytoplankton

Viruses

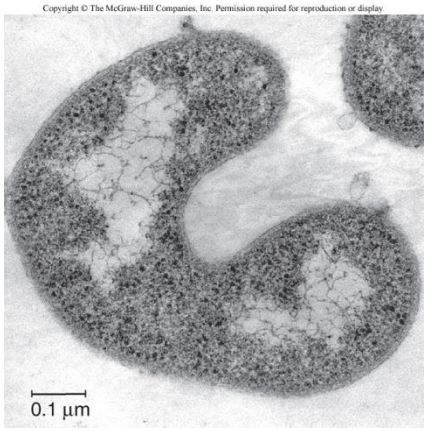
- The amount of viruses in a given environment is directly related to the abundance of the microbial life, which they invade
- Viruses are now recognized as the most abundant ‘biological’ organisms in the ocean
- For every liter of Long Island Sound water, there are 100,000,000,000 viruses!

Prokaryotes

- **Prokaryotes** are the smallest and structurally simplest true-living organisms, and the oldest life forms on Earth
- Prokaryotes are **unicellular** organisms which lack a nucleus and other membrane-bound organelles
- **Prokaryotes include all members of Domains Archaea and Bacteria**

Prokaryotes: Domain Bacteria

- Bacteria (Domain Bacteria) appear to have branched out very early on the tree of life and are genetically distinct from Archaea and eukaryotes (Domain Eukarya)
- They are abundant in all parts of the ocean
- Bacteria are vital to life on Earth because they ensure the recycling of essential nutrients in oceanic webs

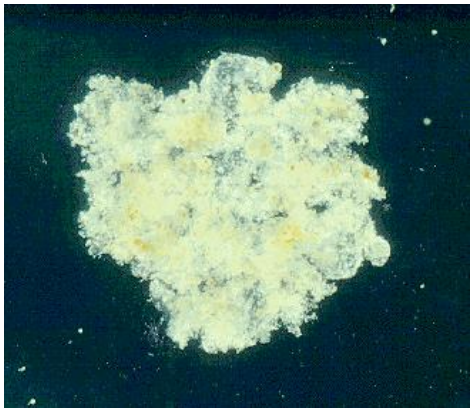


Bacteria

- Most organic matter is decomposed by bacteria
- Bacteria constitute a major part of the organic matter that feeds countless bottom-dwelling animals
- Organic particles sinking in the water column are composed mostly of bacteria!
  - Very important food source!

Marine Snow

- **Marine snow** is a continuous shower of mostly organic **detritus** falling from the upper layers of the water column
- Detritus is non-living particulate organic material, and is typically colonized by communities of microorganisms
- Includes dead or dying animals and plants, phytoplankton, fecal matter, sand, soot and dust



http://www.noc.soton.ac.uk/obe/personal/rsl/Rsl_web.htm

Marine Snow

- A single cell sinks at a rate of ~1-2 meters day^{-1}
- Aggregates sink ~150-200 meters day^{-1}
- Sinking cleanses pollutants from surface waters and brings much-needed nourishment to deep sea organisms
- Sediment traps capture sinking debris
  - Flux of particulate matter mirrors productivity at the surface; peak separated by 2 weeks

Feeling small?

- Particulate matter is defined as anything larger than 0.2µm
- Anything smaller is considered to be *dissolved*
- Particulate organic matter is only 10% of the total organic material in the ocean; *dissolved organic matter* makes up the rest (90%)
  - Of all the fish, all the whales, all the bacteria, all the organic debris in the oceans, 90% of it is dissolved
  - Viruses are considered to be *dissolved organic material*

Bac(k) to Bacteria…

- Bacteria feed primarily on dead organic material
- Some bacteria, however, are photosynthetic; the **cyanobacteria**
- Cyanobacteria have chlorophyll as well as a bluish pigment called phycocyanin
  - "blue-green algae"
  - Among the first photosynthetic organisms

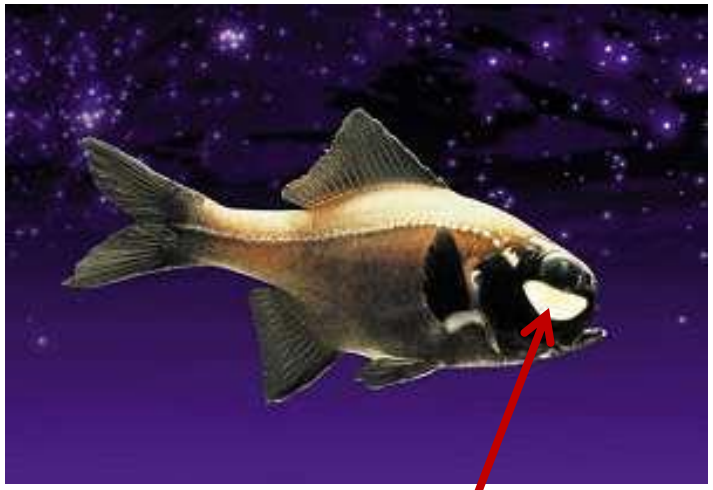
Bacteria

- Cyanobacteria are widely distributed
- Because of their size, cyanobacteria are believed to be the most abundant photosynthetic organisms in the ocean
- In addition to being free-living, some bacteria have evolved to live in close association with other marine organisms
  - **Symbiotic** bacteria

Symbiotic Bacteria

- Many of the organelles found in eukaryotic organisms evolved from symbiotic bacteria
- Examples of symbiotic bacteria include those involved in the digestion of wood by shipworms, those responsible for bioluminescence and those found in association with mussels, clams and tubeworms that live around hydrothermal vents

Symbiotic Bacteria



http://www.divernetxtra.com/biolog/pics/0900flash1.jpg

Bacteria sheltered in light-emitting photophores of flashlight fish

bioweb.uwlax.edu/zoolab/lab-5a/mollusca-bivalvia-7.htm

Shipworms (*Teredo)* are actually wood-eating bivalve molluscs!

Tetrodotoxin produced by bacteria in (immune) pufferfish

Prokaryotes: Domain Archaea

- **Archaea** (Domain Archaea) are among the simplest, most primitive forms of life
- Oldest fossils ever found (3.8 billion years old) appear similar to Archaea
- Archaea are prokaryotes, unicellular organisms that lack a nucleus and other membrane-bound organelles
- Thought to have had an important role in the early evolution of life

Archea - Extremophiles

- Some groups of Archaea were discovered only recently
- First in extreme environments on land – hot sulfur springs, saline lakes, and highly acidic or alkaline environments
- “Extremophiles”

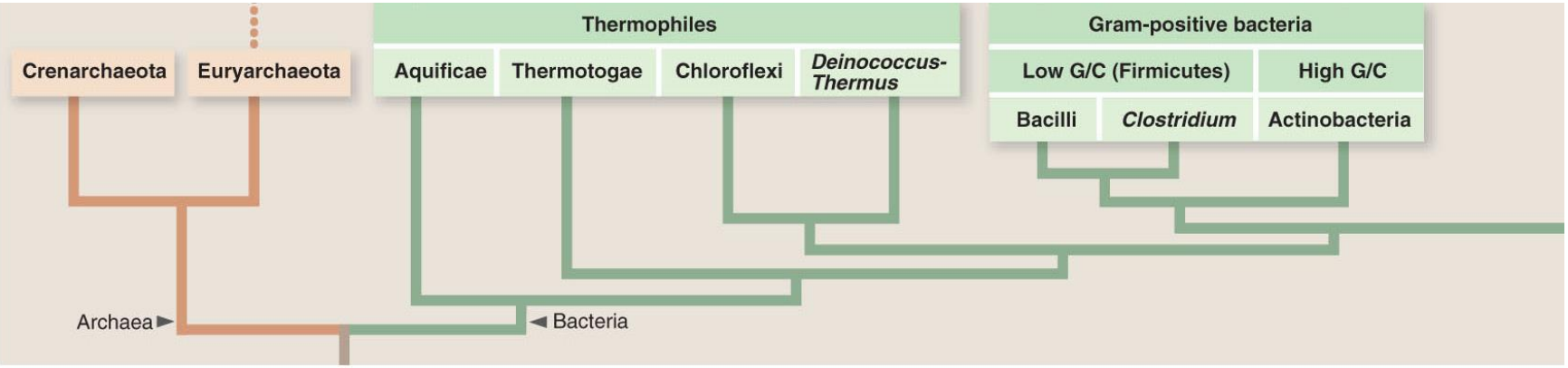
http://www.dpchallenge.com/image.php?IMAGE_ID=448561

Archaea

- Archaea were subsequently found in extreme marine environments, such as in very deep water, where they survive at pressures of 300-800 atmospheres
- Some archaea live at the high temperatures of hydrothermal vents, and *cannot* grow in temperatures under 70-80°C (158-176°F); 1 hydrothermal vent archaeum can live at 121°C (250°F) – the highest of any known organism

Evidence for life on Earth?

- Many of the harsh conditions which extremophiles require to survive were characteristic of our early Earth
- Likely that Archaea evolved to dwell in such conditions billions of years ago & survive today in similar (specific) environments

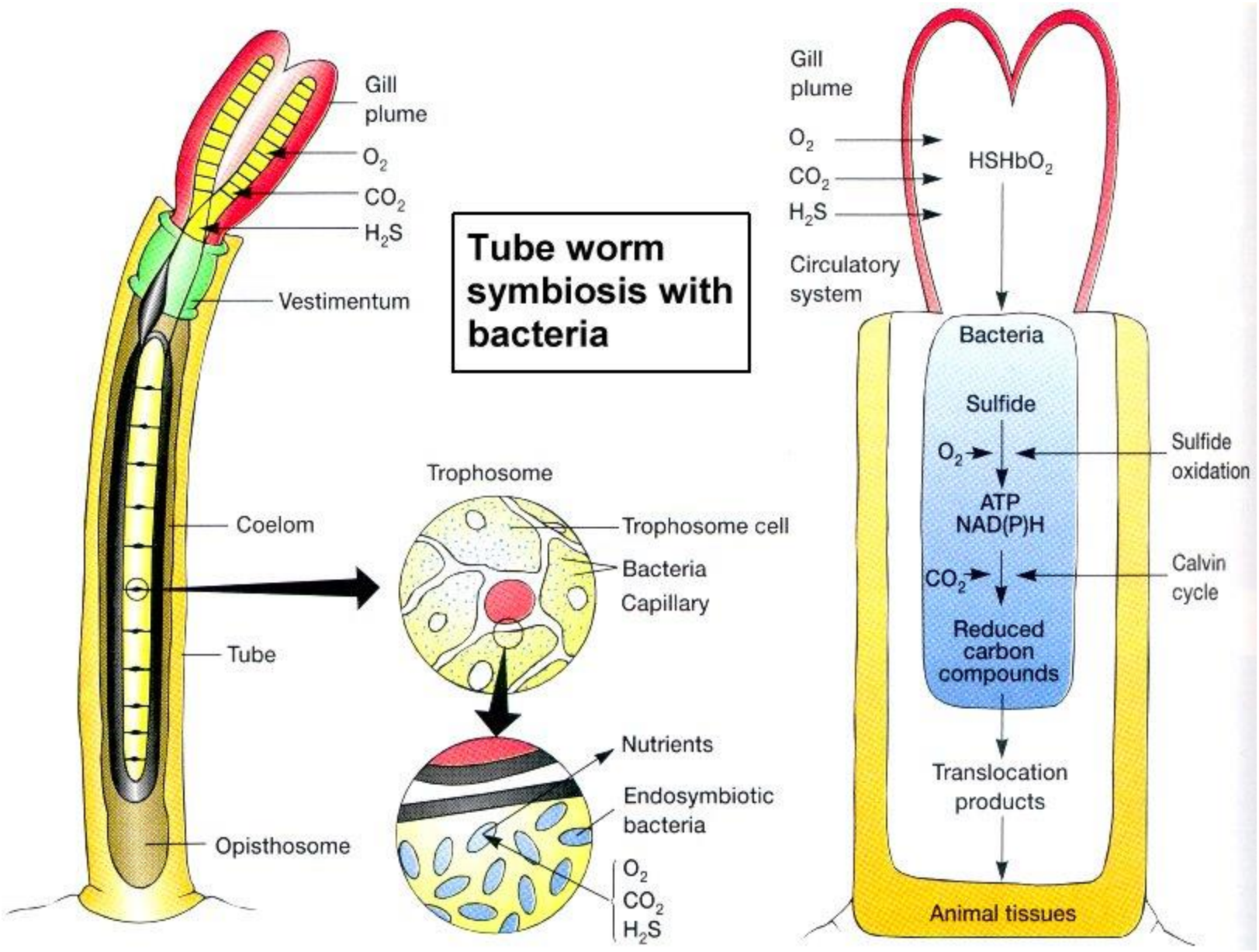


Got Chemosynthesis?

- Not all prokaryotic autotrophs derive energy from photosynthesis (although most do)
- Some bacterial autotrophs – called **chemosynthetic** – derive energy not from light, but from chemical compounds
- Hydrogen sulfide (H_2S) and other sulfur, nitrogen and iron compounds provide energy to convert CO_2 into organic matter
- Base of food web at hydrothermal vents

I need to vent about something here

- The hot water emerging from hydrothermal vents is rich in hydrogen sulfide (H_2S) which is toxic to most organisms, but an energy-rich molecule
- Water near the vents contain so many microbes that they cloud the water!
- Symbiotic and non-symbiotic



biology.kenyon.edu/sloncbio3/symbiosis.html

Anaerobics class

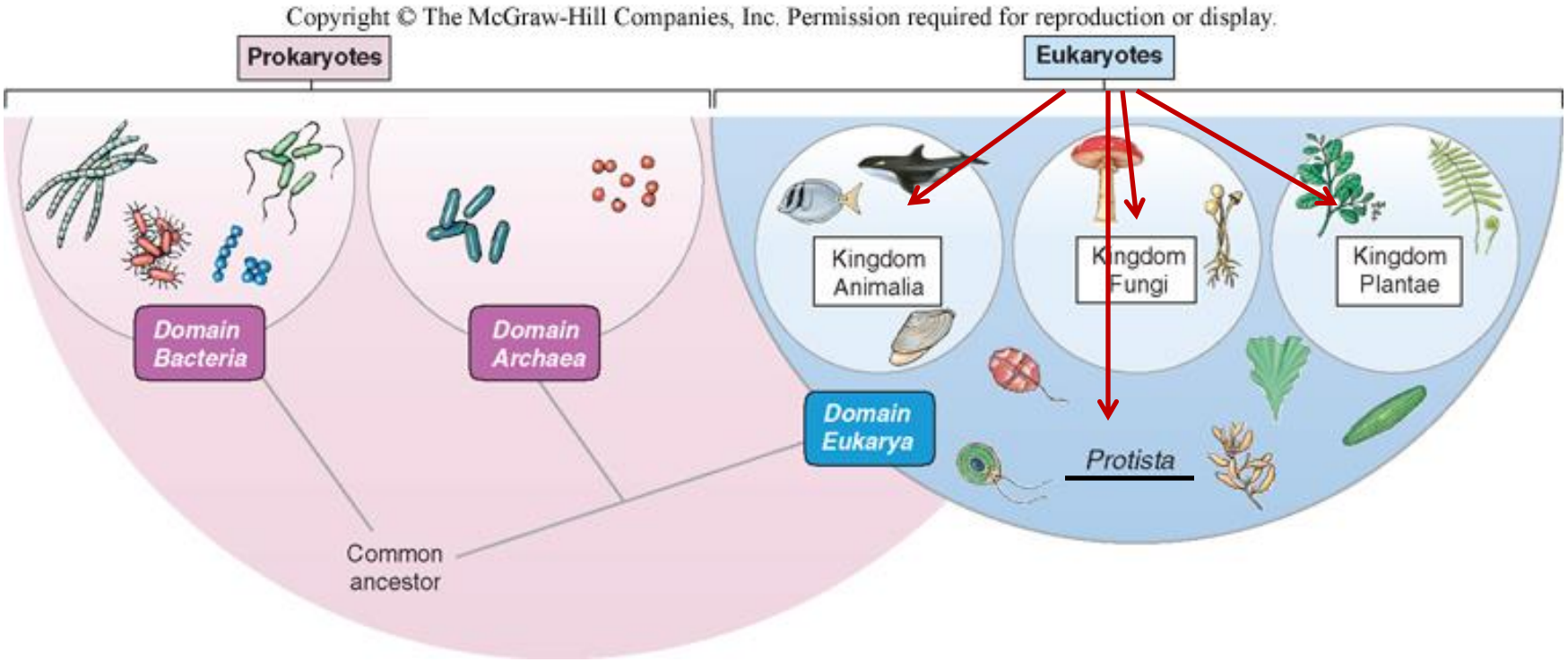
- Of the heterotrophic prokaryotes, not all use oxygen to respire
- **Anaerobic** bacteria and archaea grow where oxygen is *not* present, such as **anoxic** sediments, and are actually killed by even small doses of oxygen!
- These anaerobes use sulfate, and other reduced molecules instead of oxygen to respire
  - Responsible for ‘rotten-egg’ smell of some areas

Eukaryotes: Domain Eukarya

- Eukaryotes (Domain Eukarya) possess a nucleus, a membrane that encloses the DNA, in each of their cells
- While all prokaryotes (domains Archaea and Bacteria) are uni-cellular, eukaryotes include both uni-cellular and multi-cellular organisms
  - Kingdoms Protista, Fungi, Plantae, and Animalia

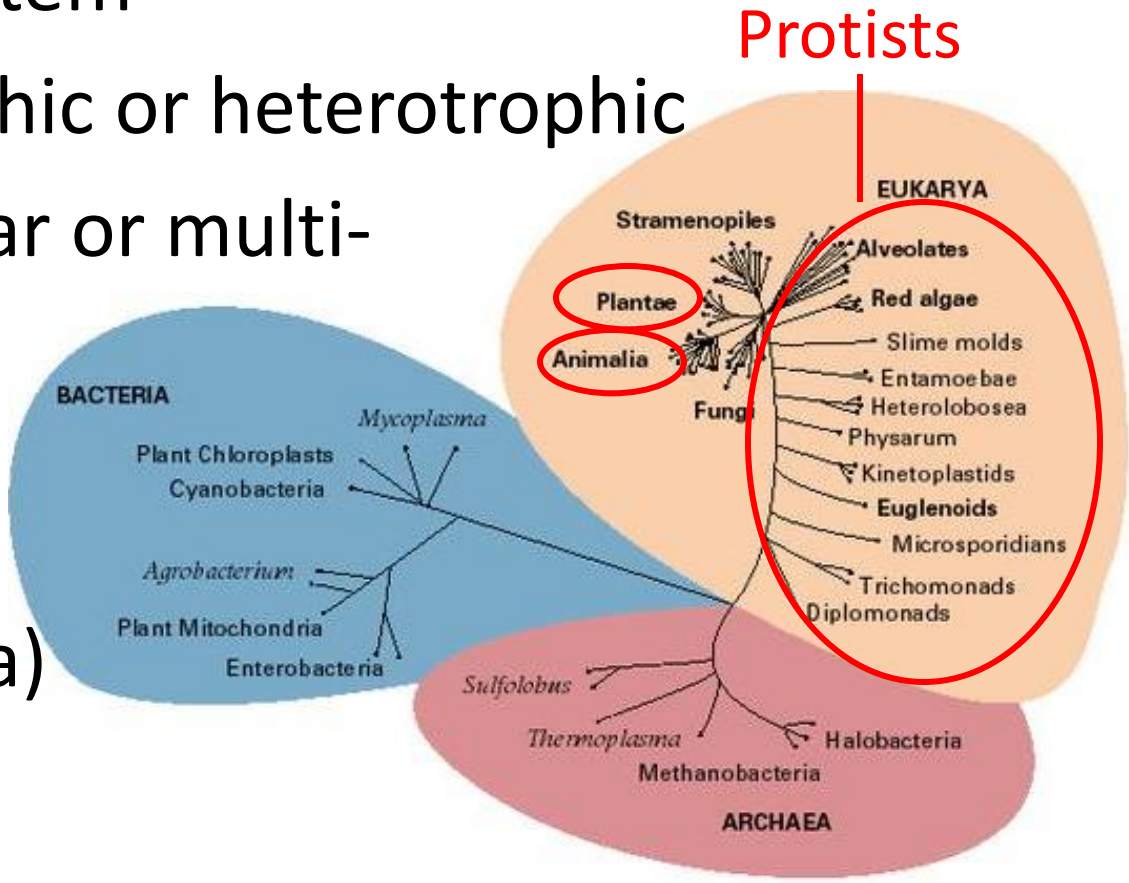
Microbial Eukaryotes

- Most microbial marine eukaryotes belong to the **Kingdom Protista**



Kingdom Protista (the Protists)

- Kingdom Protista is the 'trouble-maker' of the classification system
- Can be autotrophic or heterotrophic
- Can be unicellular or multi-cellular
- But all are eukaryotic! (Domain Eukarya)



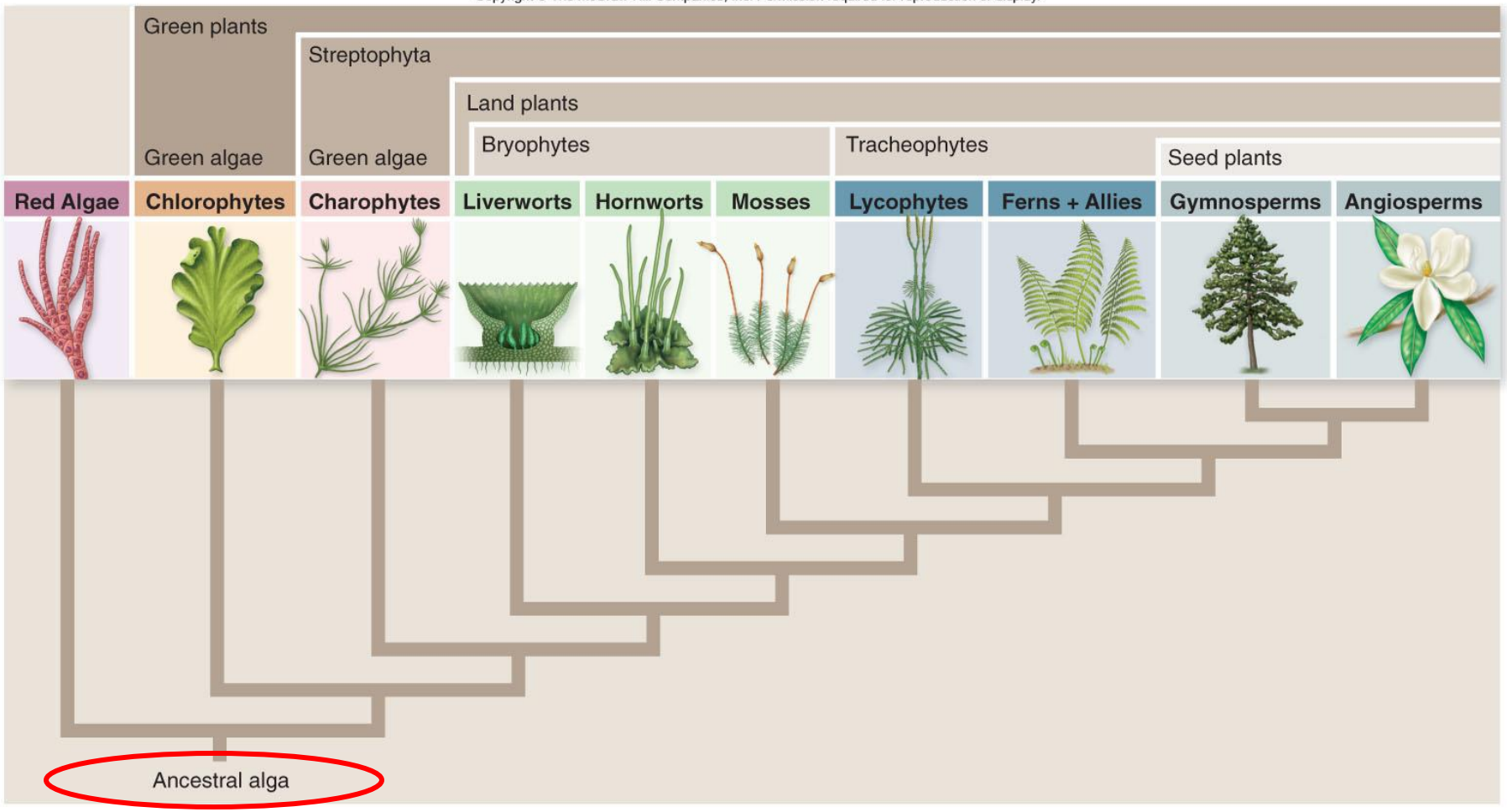
Protists

- Debates over classification persist
  - Different groups possess different evolutionary histories
  - Some are more plant-like (e.g., multi-cellular seaweeds)
  - Some are more animal-like (e.g., heterotrophic and mobile)
  - Some are photosynthetic *and* heterotrophic (what we call “mixotrophic”)

Algae

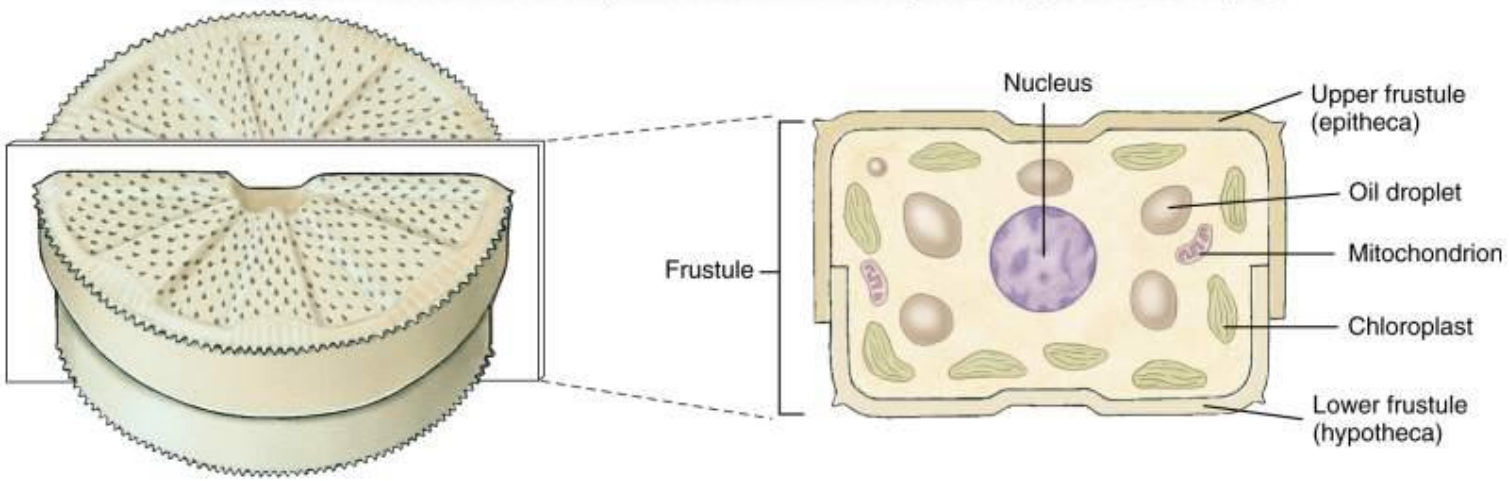
- **Algae** are a diverse group of protists
- Nearly all algae perform photosynthesis using photosynthetic pigments
- As protists, algae are distinct from plants and lack a cell wall, specialized tissues, and flowers
- They also lack true leaves, stems and roots
- **Unicellular or multi-cellular**
  - Multicellular algae are seaweeds!

Plants evolved from green algae (which is now considered a plant, not a protist!)



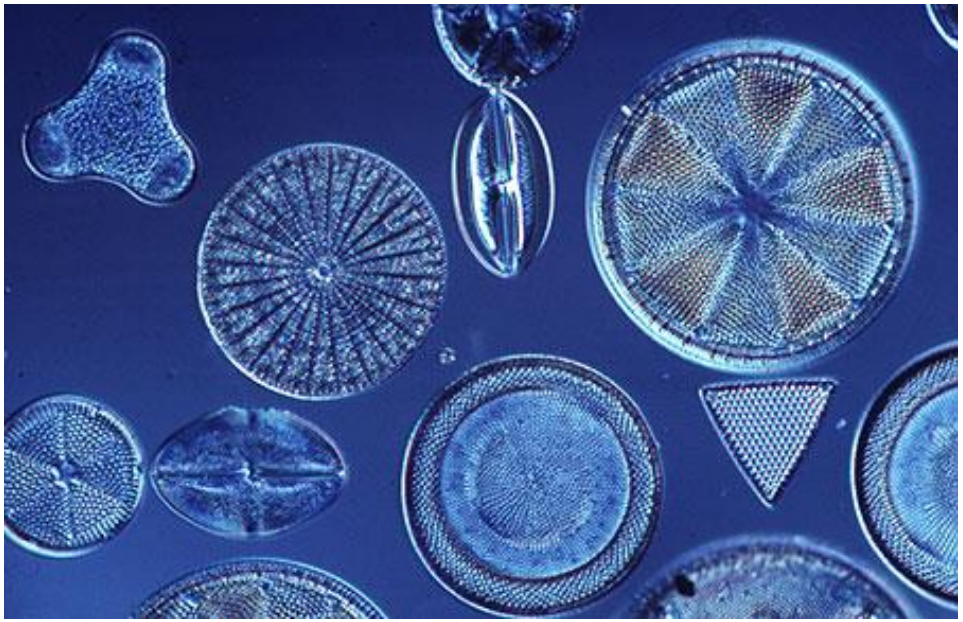
Unicellular Algae: The Diatoms

- **Diatoms** are unicellular, although many species aggregate to form chains
- Diatom cells are enclosed by cell walls made of **silica**; this glassy shell or *frustule* consists of 2-tightly fitting halves



Diatoms

- The glass frustule allows light to pass through so that photosynthetic pigments can capture light energy for photosynthesis



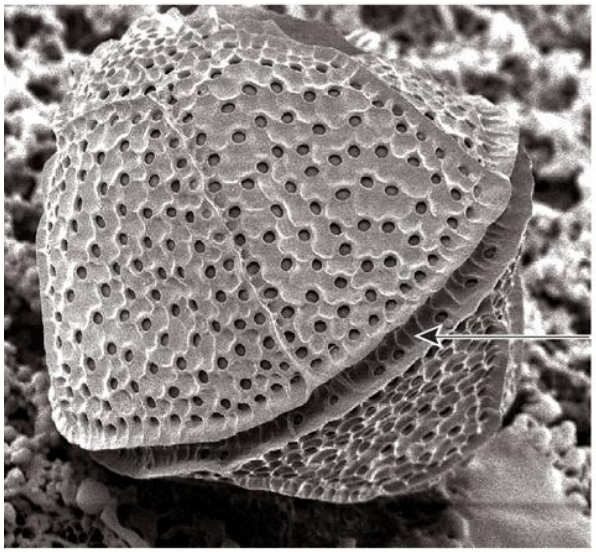
- UV protection?
- Aid in sinking?
- Protection from predation?

Diatoms

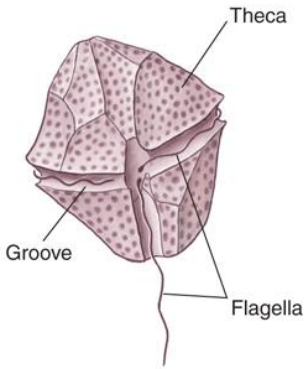
- Diatoms are very important primary producers in temperate and polar regions
- Account for a large share of the organic carbon produced on Earth
- Favorable environmental conditions (light and nutrients) promote periods of rapid reproduction known as **blooms**
- The glass frustules of dead diatoms eventually settle to the sea floor; diatomaceous ooze

Dinoflagellates

- **Dinoflagellates** are another important group of planktonic, unicellular protists
- Two flagella; one wrapped along a groove along the middle of the cell, the other trailing free



Courtesy of Lawrence Fritz, Northern Arizona University



Dinoflagellates

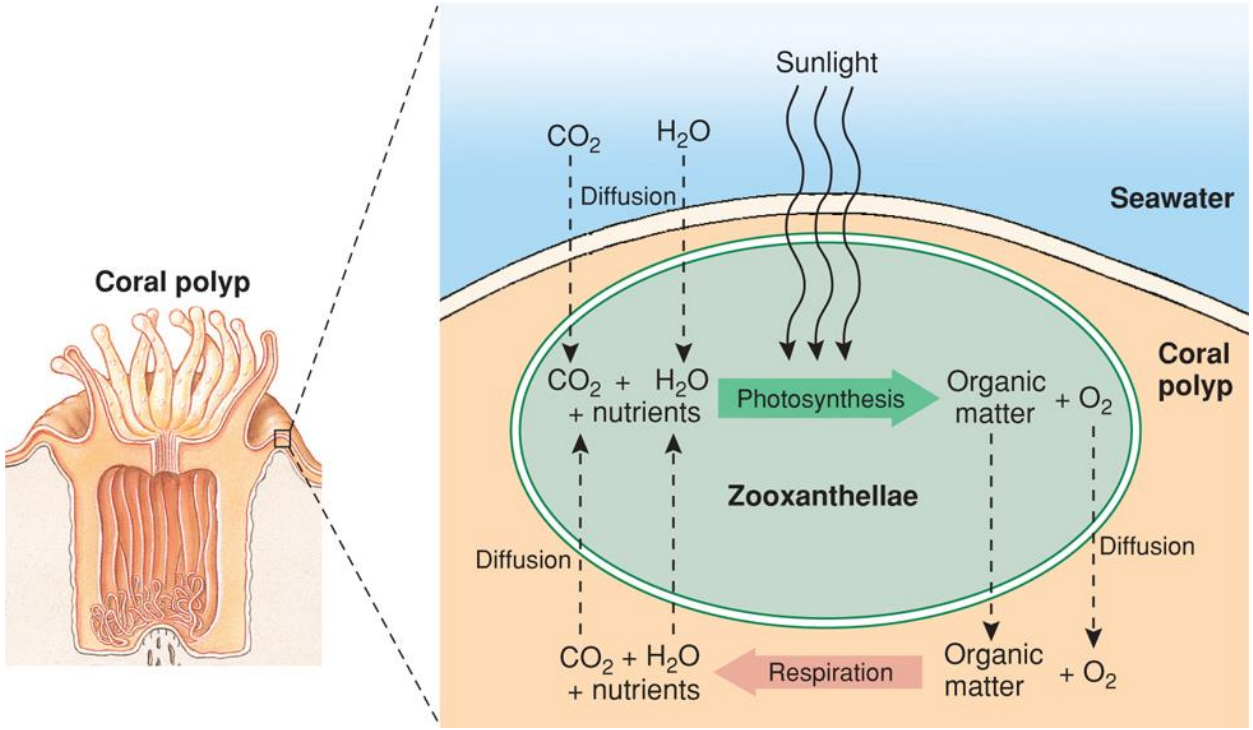
- Dinoflagellates may be autotrophic, heterotrophic or both (mixotrophic)!
- Nearly all dinoflagellates are marine
- Important primary producers, especially in tropical regions
- Some species release toxic substances and can cause harmful “red tides”
  - And some are bioluminescent

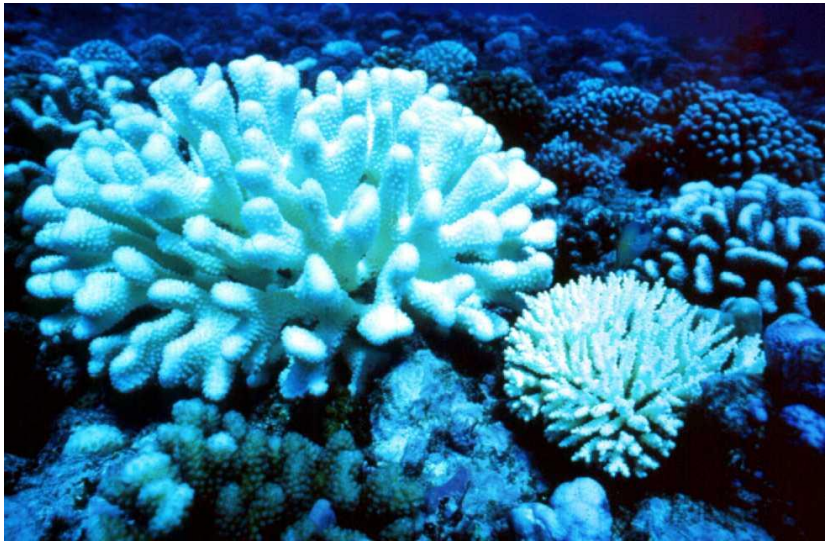
Dinoflagellates

- In addition to blooms of “red tide”, some dinoflagellates release toxins responsible for open sores on fish, crustaceans and bivalves

Zooxanthellae

- A group of dinoflagellates called **zooxanthellae** live in close association with animals such as coral, sea anenomes, sponges and giant clams
- Symbiotic: zooxanthellae photosynthesize within the body of an animal host, releasing organic matter and receiving nutrients (in the form of waste products) and shelter in return
- Loss of the colorful zooxanthallae is behind the phenomenon of *coral bleaching*





www2.watertown.k12.wi.us/pagesfifth_grade_websites.cfm

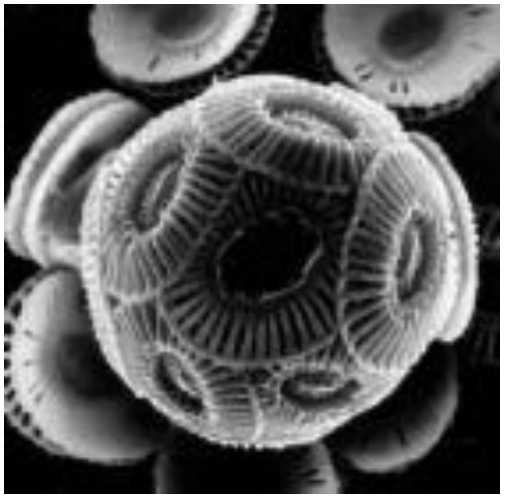
www.cgrer.uiowa.edu/peoplecarmichael/atmos_course/ATMOS_PROJ_99/jlmichfin/main.html

Corals (and zooxanthellae) are stressed by environmental change

- A water temperature change of only 1°C above the normal summer high temperature for a few weeks leads to coral bleaching
  - Coral expels zooxanthellae or the zooxanthellae expels itself
- El Niño events can drive coral bleaching
- May be reversible – corals can re-acquire new zooxanthellae if the stress is not too severe

Coccolithophorids

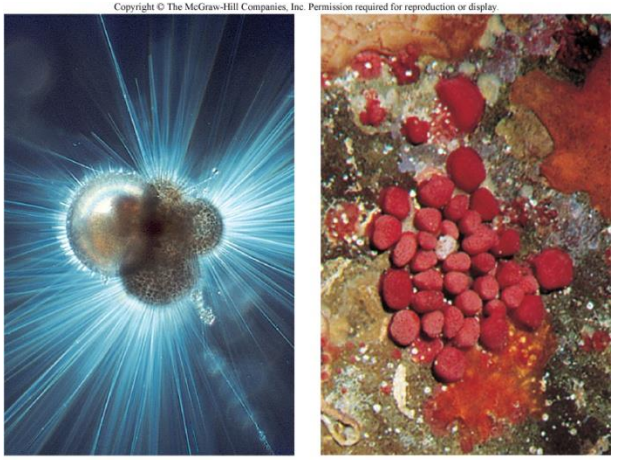
- **Coccolithophorids** are unicellular protists covered with ornamental plates made of **calcium carbonate** ($CaCo_3$)
- Form seasonal blooms in North Atlantic
- Produce dimethyl sulfide, which alters climate patterns!
  - Long considered to be the "smell of the sea"



Coccolithophorids from space!

Foraminiferans

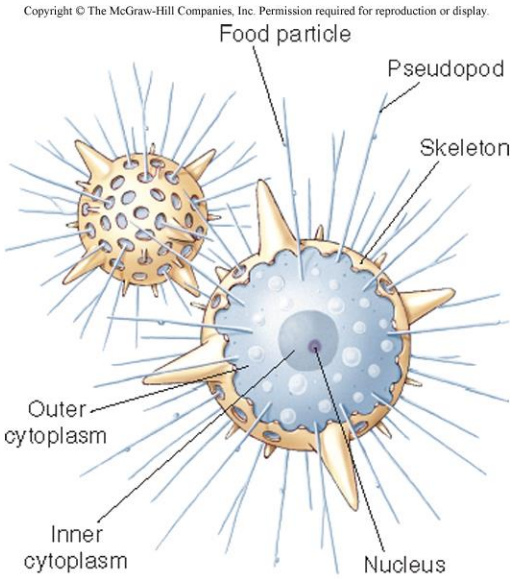
- **Foraminiferans** (“forams”) are marine protists that also have a shell made of $CaCo_3$
- Animal-like; possess *pseudopodia* – extensions of the cytoplasm used for trapping diatoms and other suspended material in the water
- Benthic or planktonic
- Important indicators of past climate change
- Form foraminiferous oozes

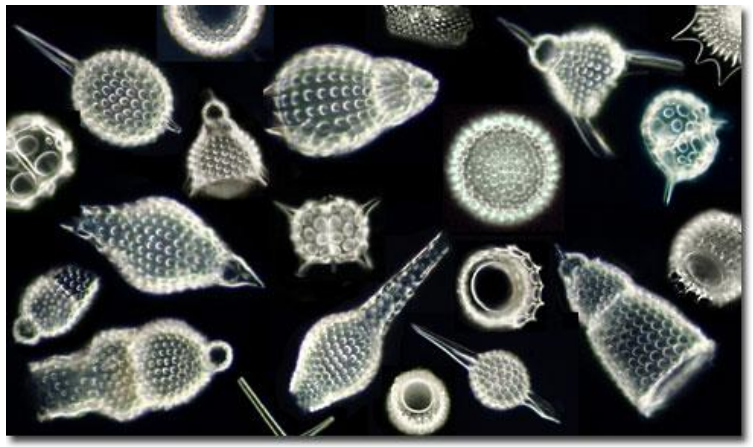


(a) (b)

Radiolarians

- **Radiolarians** are planktonic marine protists that secrete elaborate shells made of silica and other materials
- Cells are typically spherical with radiating spines
- Animal-like with pseudopodia
- Radiolarian ooze!

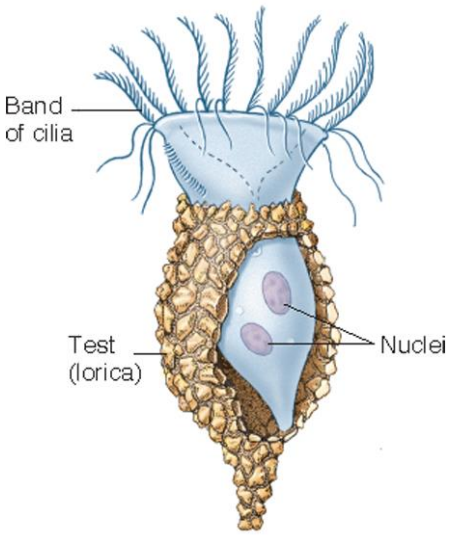




http://micro.magnet.fsu.edu/micro/gallery/radiolarians/radiohead.jpg

Ciliates

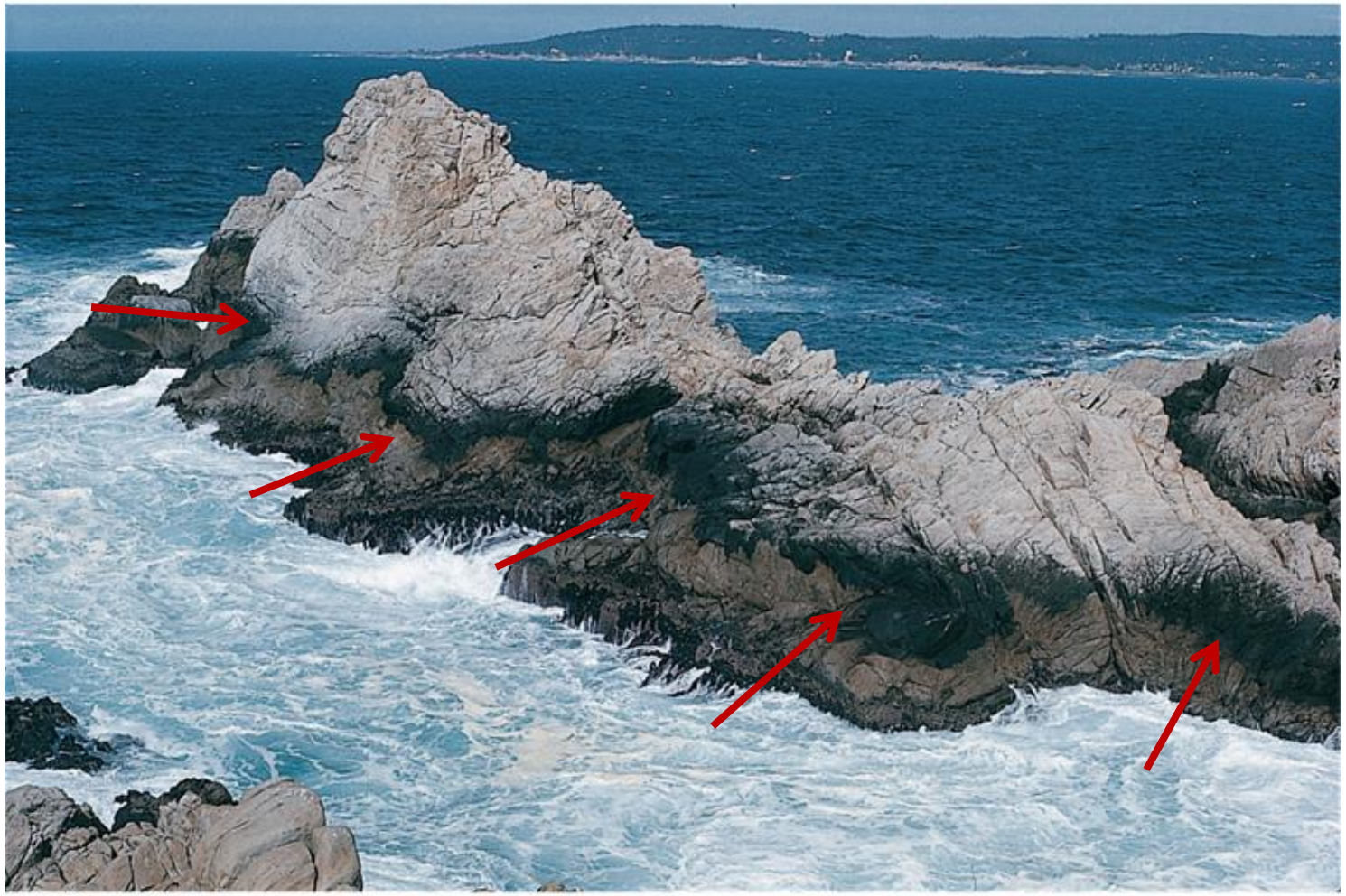
- **Ciliates** are protists with many hair-like **cilia** used in locomotion and feeding
- Planktonic or benthic
- **Tintinnids** are common ciliates that build vase-like cases or *loricas* made up tiny particles such as sand grains
- Important grazers in the microbial loop!



And finally…

- **Fungi** are eukaryotic organisms belonging to the Kingdom Fungi
- All are heterotrophic
- Can be unicellular or multicellular
- 1,500 known species of marine fungi
- *Absorb* nutrients from their environment
- Important decomposers in the marine environment, but also parasitic (disease-causing)

Marine Fungi



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