

# Chapter 2: Ancestral Plants

## Cyanobacteria



These living, pillow-like mounds, called “stromatolites,” are made by members of a group of photosynthetic bacteria called Cyanobacteria. They are extremely rare on Earth today, but they used to be much more common. These modern stromatolites were photographed in Shark Bay, Australia.

### *Taxonomy and Classification*

Domain: Bacteria

Kingdom: Eubacteria<sup>5</sup>

Phylum: Cyanobacteria

### *Fast Facts*

- Diverse, successful group of oxygenic photosynthetic bacteria
- Evolved at least 3.5 billion years ago; potentially the first life on Earth
- Globally distributed in aquatic environments
- Microscopic
- Come in many different shapes and sizes including mats, filaments, and even “strings of pearls”
- Some form pillow-like structures called “stromatolites”

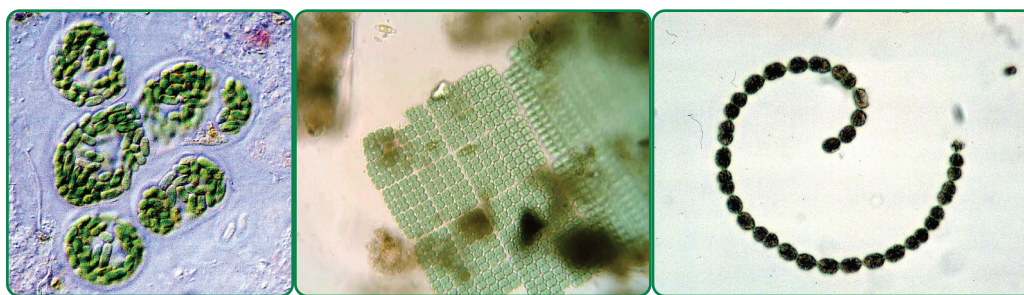
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<sup>5</sup> Please note that cyanobacteria are NOT plants. Rather, they have been included in this manual because ancestors of modern cyanobacteria likely gave rise to chloroplasts via endosymbiosis. (See “Endosymbiotic Theory,” below.)

- Likely the first oxygenic photosynthesizers
- Likely source of chloroplasts via endosymbiosis (see “Endosymbiotic Theory,” below)
- Some can fix nitrogen
- Nutrient-rich water or pollution can trigger a harmful cyanobacteria “bloom”

### *In-Depth Exploration*

Cyanobacteria is a phylum of photosynthetic prokaryotes that first evolved roughly 3.5 billion years ago and is therefore among the first life on Earth. Cyanobacteria come in many shapes including thick filaments, grids, and even “strings of pearls.” Some cyanobacteria even create structures easily seen with the naked eye called stromatolites. Stromatolites are among the oldest fossils discovered and can be billions of years old.



Modern Cyanobacteria in order from left to right: *Tolypothrix* sp., *Merismopedia* sp., and *Anabaena* sp. Note their diverse appearances and arrangements in spite of all being members of the same group of organisms.

Cyanobacteria live in aquatic habitats around the globe including oceans, lakes, rivers, and anywhere where standing water is exposed to sunlight. They obtain food via photosynthesis and were likely the first organisms on Earth capable of oxygenic photosynthesis (see “Photosynthesis,” above). Cyanobacteria probably formed the chloroplasts found in modern eukaryotes including plants (see “Endosymbiotic Theory,” below).

Some species of cyanobacteria can obtain nitrogen from the atmosphere in a process called “Nitrogen fixation.” Nitrogen fixation is very difficult to do, and only a few organisms can perform it. Nitrogen fixation gives these species of cyanobacteria an advantage that helps them survive, because nitrogen is essential to living organisms.

Although small, cyanobacteria can wreak havoc in large numbers. If a body of water is polluted or too nutrient-rich, cyanobacteria can explode in numbers in an event called a “bloom.”<sup>6</sup> This damages ecosystems, because the cyanobacteria outcompete other organisms for resources and

<sup>6</sup> Many other organisms can cause harmful blooms too; cyanobacteria are just one culprit.

space, can produce deadly toxins, and deplete oxygen in the water upon death and decomposition. This is one of the many reasons why it is unsafe to let pets swim in filthy water, and it is also why livestock water troughs should be changed regularly: cyanobacteria can pollute the water and make it unsafe to drink! Cyanobacteria blooms may even impact entire cities: in August 2014, for example, the city of Toledo, Ohio, found its water supply contaminated by toxins from cyanobacteria in Lake Erie due to a cyanobacteria bloom. The city found itself unable to drink its water for several days until conditions improved.



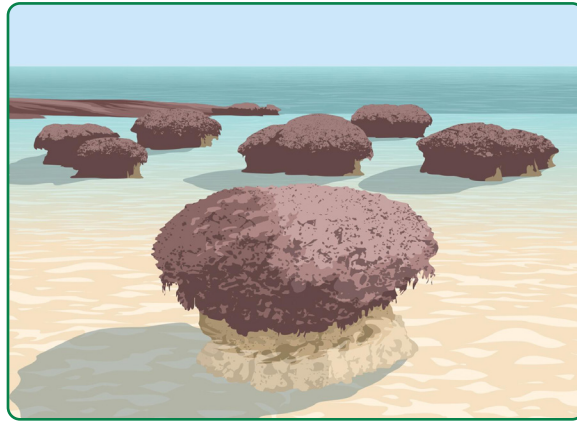
A bloom of cyanobacteria in a freshwater lake in Germany. Not only does it look gross; if it gets worse, then the other organisms living in this pond may die due to toxin buildup or oxygen depletion.

### *Find them!*

Cyanobacteria are relatively easy to find and view. To see them, you will need a microscope, glass slides and slide covers, a pipette, and test tubes or vials to collect samples. Use the pipette to collect a few milliliters of water from any permanently wet areas such as lakes, ponds, streams, or even bird baths or fountains. If the water is green and scummy looking, then there is a good chance that it will have cyanobacteria in it. Once you collect samples, place a single drop on a microscope slide, cover it with a coverslip, and use the microscope to see what you have. You may find many other organisms in addition to cyanobacteria such as green algae, protozoa, and invertebrates. If you do not find any cyanobacteria at first, then keep trying! Cyanobacteria usually thrive in warm, shallow, nutrient-rich water, so it may be easiest to find them in late summer or early fall.

**NOTE:** Microscopes are complex and expensive pieces of equipment that require a certain amount of expertise to take care of and use safely and effectively. If a microscope is not available or feasible for use, then it might be possible to collaborate with a local biology department at a university or high school instead.

## Stromatolites



### *Taxonomy and Classification*

Domain: Bacteria

Kingdom: Eubacteria

Phylum: Cyanobacteria

### *Fast Facts*

- Pillow-like structures made by certain types of cyanobacteria
- Have lived on Earth for at least 3.5 billion years
- Alternating layers of sediments, cells, and “glue” secreted by these cells create a banded pattern



Characteristic banding associated with stromatolites. Each layer is made of sediment, cells, and a “glue” secreted by the cyanobacteria. These stromatolites were made during the Cambrian Period and are therefore roughly 500 million years old.

- Used to be globally distributed but became relatively rare after the Cambrian Explosion (541 ma)
- Restricted today to mostly highly saline habitats such as Shark Bay in Western Australia

### **Manual Cross-References**

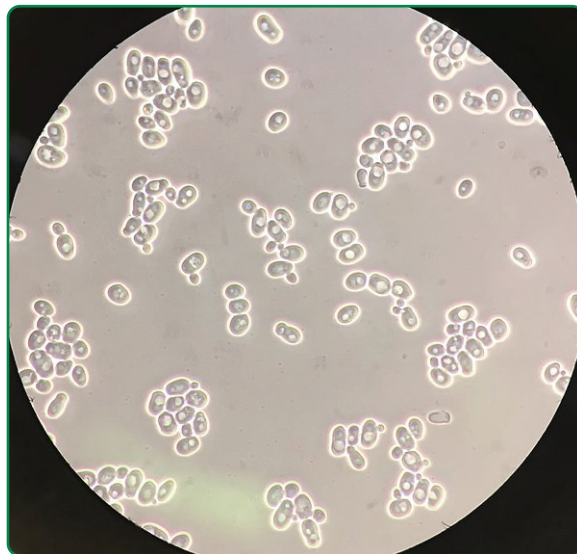
See the Topic Article “Endosymbiotic Theory” for a discussion of how these organisms likely gave rise to chloroplasts in plants.

See the Topic Article “Photosynthesis” for a discussion of how photosynthesis potentially evolved and how it functions.

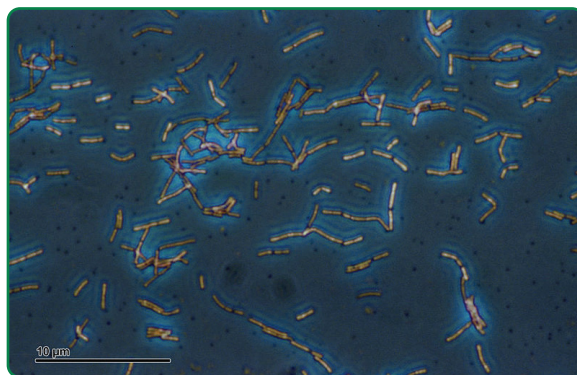
# Endosymbiotic Theory

“Endosymbiotic Theory” is a widely accepted explanation for how two types of organelles found within eukaryotic cells, mitochondria and chloroplasts, formed. To understand this theory, some background information is needed.

Scientists divide cells into two general groups: prokaryotes and eukaryotes. There are many differences between these two groups; as an example, eukaryotes are almost always much larger than prokaryotes. For instance, the organism used to make beer and bread, *Saccharomyces cerevisiae*, or “brewer’s yeast,” is a eukaryote, whereas the bacteria *Lactobacillus* sp., which also has many uses in the food industry, is a much smaller prokaryote.



The eukaryotic yeast *Saccharomyces cerevisiae* magnified 100× under a light microscope. This yeast is used to make beer and bread.



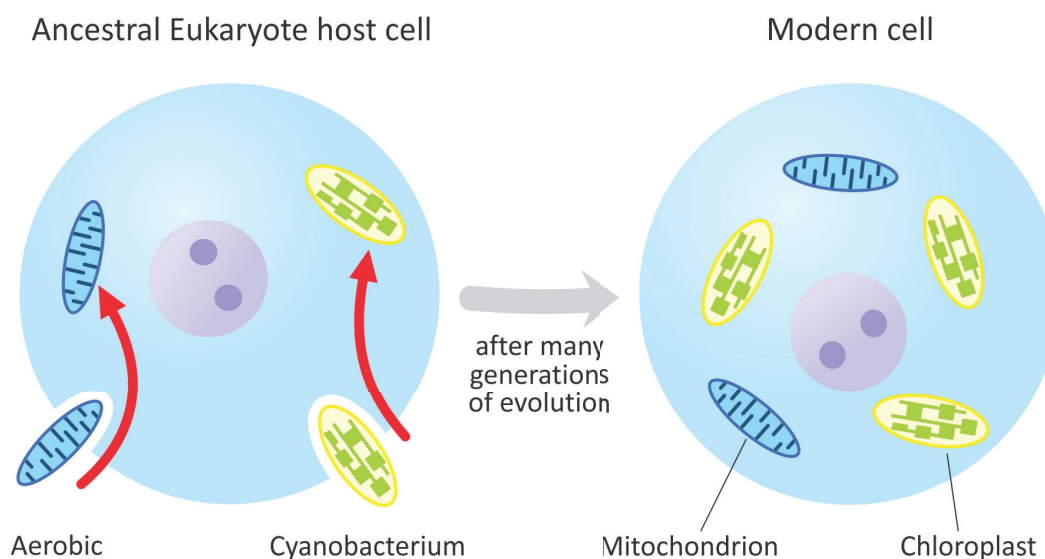
The prokaryotic *Lactobacillus acidophilus* magnified 6,000×. Notice how much more these organisms had to be magnified to be seen than the yeast pictured above. Similar to yeast, *Lactobacillus* sp. has many uses in the food industry too and can often be found in yoghurt and other probiotic-containing foods.

In addition to their differences in size, there are many other differences between eukaryotes and prokaryotes. One of the most important differences is the presence or lack of organelles: eukaryotes have organelles, whereas prokaryotes do not.

Organelles are intracellular “machines” that carry out specific functions such as moving materials, storing substances like food or water, and providing structural support. There are many types of organelles including chloroplasts and mitochondria. Chloroplasts produce chemical energy via photosynthesis, and mitochondria consume chemical energy via cellular respiration.

To explain how chloroplasts originated, the Russian biologist Konstantin Mereschkowsky proposed the theory of “endosymbiosis” in 1905; his theory was later adapted to include mitochondria as well. According to Mereschkowsky, chloroplasts (and mitochondria) formed when prokaryotic cells were engulfed by eukaryotic cells. Instead of being digested, however, the engulfed prokaryotes continued to live inside their eukaryotic hosts and provided essential metabolic functions in exchange for safety and nutrients. This gave the host cells a competitive advantage over other cells and helped ensure their survival.

### Endosymbiosis



A diagram showing how endosymbiosis likely happened. In the distant past, a eukaryotic cell engulfed prokaryotic cells and incorporated them into itself. Later on, the incorporated prokaryotes became mitochondria and chloroplasts in modern cells.

Unfortunately for Mereschkowsky, his endosymbiotic theory met with scorn from the scientific community and was largely forgotten until another biologist, Lynn Margulis, resurrected his theory in the 1960s and 70s. Endosymbiosis is now generally accepted as the best explanation for how mitochondria and chloroplasts formed and is supported by a wide array of evidence. Despite the general acceptance of endosymbiotic theory, however, there are many variations on endosymbiotic

theory and other, competing theories to explain organelle formation; some of these explanations may not necessarily be mutually exclusive, either.

It is likely that the first endosymbiotic event producing chloroplasts (called “primary endosymbiosis”) occurred only once. Scientists do not know when primary endosymbiosis occurred, however, but it was likely in the distant past. Because the first members of the plant kingdom, Viridiplantae, evolved at least 1.6 billion years ago, primary endosymbiosis must therefore have occurred before then.

## Discussion Questions

1. Are humans prokaryotes or eukaryotes? What about plants?
2. Where do scientists think chloroplasts and mitochondria came from?
3. What happened to Mereschkowski’s theory after he proposed it?
4. Extra challenge: in addition to size and organelles, what are some of the other differences between eukaryotes and prokaryotes? (Students will need to do research to answer this question.)
5. Extra Challenge: what are some of the pieces of evidence for endosymbiotic theory? (Students will need to do research to answer this question.)

## Answers

1. Humans and plants are eukaryotes.
2. Scientists think that chloroplasts and mitochondria came from prokaryotes that were engulfed by a eukaryote and continued to live in their new “home.”
3. Mereschkowski’s theory was scolded and forgotten by the scientific community until another biologist, Margulis, resurrected his ideas much later.
4. There are many differences between these groups including their method of reproduction (binary fission v. mitosis), sensitivity to certain drugs, ribosome size, chromosome structure, messenger RNA longevity, and much, much more.
5. Mitochondria and chloroplasts are sensitive to some antibiotics, have their own DNA and ribosomes, exhibit multiple membranes, and much more.

## Manual Cross-References

To learn more about photosynthesis, see the Topic Article “Photosynthesis.”

See the Write-Up on Cyanobacteria to learn about the organisms that gave rise to chloroplasts.