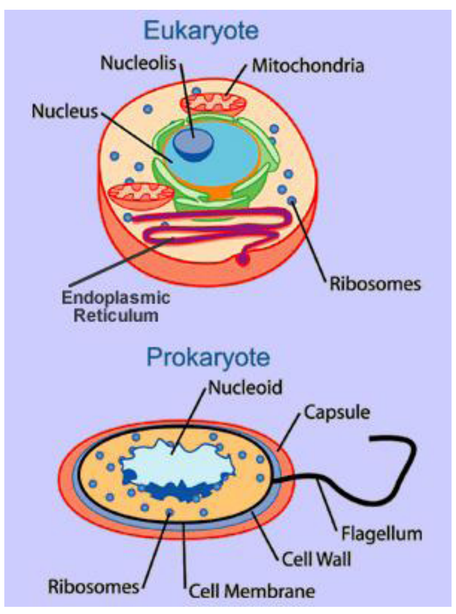
EUKARYOTES – 2.7 BILLION YEARS AGO

What's new with life?

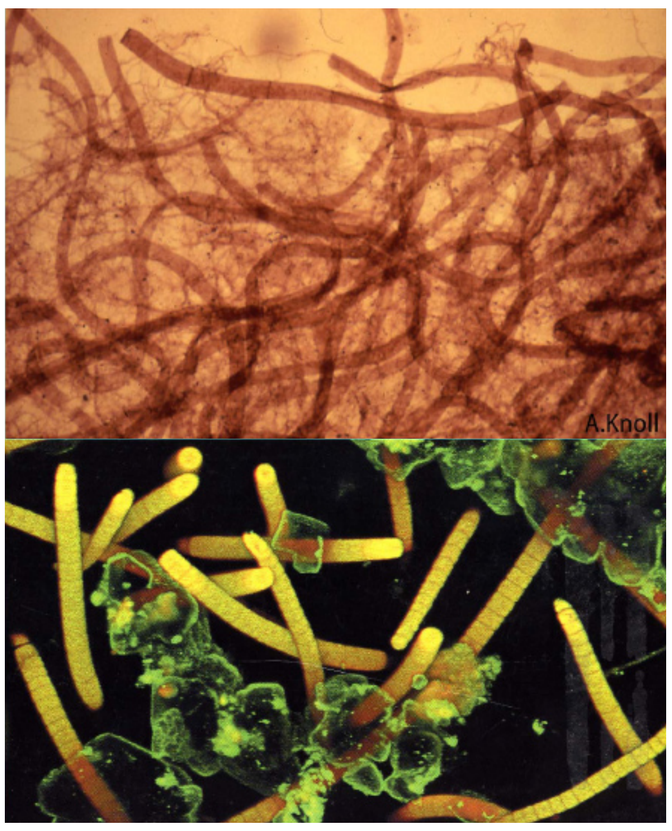
The first, simplest life forms were **prokaryotes**—organisms, like bacteria, that don't have a nucleus. Prokaryotes have existed on Earth since at least 3.8 billion years ago. **Eukaryotes** are organisms with a nucleus. The oldest evidence of eukaryotes is from 2.7 billion years ago. Scientists believe that a nucleus and other organelles inside a eukaryotic cell formed when one prokaryotic organism engulfed another, which then lived inside and contributed to the functioning of its host.

Eukaryotes differ from bacteria and other prokaryotes in many ways. Not only did the cell finally get a nucleus, but also DNA replaced what was likely RNA as a method of self-replication, bringing with it sexual reproduction.

- Eukaryotes are typically much larger than prokaryotes: > 60 microns compared to < 20.
- Eukaryotes contain DNA in a nucleus.
- Eukaryotes can reproduce sexually. Prokaryotes can reproduce only by cell division and, lacking sex, are essentially clones, making their early evolution proceed much more slowly than that of eukaryotes. *(Some eukaryotes can clone themselves in addition to sexually reproducing. They choose their method based on environment indicators.)*
- Eukaryotes have specialized organelles bound by double-layer cell membranes and possessing their own genome. Examples: chloroplasts in photosynthesizers and mitochondria in aerobic respirers.



The major differences between eukaryotes and Prokaryotes.



Lower picture: Modern cyanobacterium (prokaryotes). Greenish grains are $CaCO_3$. Upper picture: Eukaryotic algae (about 900 million years old) from Siberia. Fine threads are cyanobacteria (same size as those in lower picture). Photos by Andrew Knoll ©.

PROKARYOTES

ARCHAEA **BACTERIA**

EUKARYOTES

PROTISTS **PLANTS** **FUNGI** **ANIMALS**

All life resides within one of three domains: Archaea (prokaryote), Bacteria (prokaryote), and Eukaryotes. Eukaryotes consist of four kingdoms: Protists, Plants, Fungi, and Animals. The Protist kingdom consists of all single-celled eukaryotes as well as some multicelled seaweeds.

Just how long have eukaryotes been around?

The fossil record for eukaryotes goes back 2.7 billion years ago with the recovery of eukaryotic biomarkers in ancient oil. Among the many things that distinguish eukaryotes from bacteria and other prokaryotes is how their cell membranes are constructed. Eukaryotes stiffen them with a family of fatty acids known as sterols. In the mid-1990s, a group of geologists drilled 700 meters down into the ancient shales of northwest Australia to formations that have been dated with uranium and lead radiometric dating to 2.7 billion years old. Inside the shale, the geologists found microscopic traces of oil that contained sterols. Because eukaryotes are the only organisms on Earth that can make these molecules, scientists concluded that eukaryotes—probably simple, amoeba-like creatures—must have evolved by 2.7 billion years ago.

The oldest eukaryotic body fossil is the multicellular alga, *Grypania spiralis*. Coiled *Grypania* is found as thin films of carbon in the 2.1 billion-year-old Negaunee iron formation at the Empire Mine near Ishpeming, Michigan. The fossils are coiled forms of marine life that, if unwound, would stretch up to 9 cm (3.54 inches). Young specimens have been recovered from 1.1-billion-year-old rocks in China.

Oldest fossils of eukaryotes—the protist, Grypania spiralis. These fossils were found in 2.1-billion-year-old Banded Iron Formations in Michigan. Bottom image: Grypania spiralis ribbons on gray, finely-laminated, iron-rich shale (slab is 9.0 cm across). Each fossil ribbon is ~0.5 to 0.6 mm wide. Top and bottom photos by James St. John ©. Middle photo by TSU-MING HAN, CLEVELAND CLIFFS INC. ©.

What does oxygen have to do with it?

For eukaryotes to thrive, oxygen has to be present in the atmosphere in higher amounts than existed on early Earth. The more advanced the eukaryote (such as multicelled plants and animals), the more oxygen is required. Scientists believe that low levels of oxygen in Earth's early atmosphere is the major reason that it took so long for eukaryotes to evolve and also why they barely eked out an existence for so much of Earth's history, while their prolific prokaryotic cousins thrived.

Grypania is a photosynthetic eukaryotic algae that both produces and requires oxygen to function. Its discovery in 2.1-billion-year-old rock means that by then, oxygen must have been present in the atmosphere in concentrations high enough to support oxygen-using organisms. Eukaryotes with many cells—the ancestors of plants and animals—do not appear in the fossil record until a half billion years ago.

Scientists have examined sediments from the modern seafloor, including the rare locations that are oxygen-poor today. They learned that the chemical behavior of molybdenum's isotopes in sediments is different depending on the amount of oxygen in the overlying waters. As a result, the chemistry of molybdenum isotopes in sediments can be used to determine the oxygen content of the ocean water around it. Compared to modern samples, measurements of the molybdenum chemistry in ancient rocks from Australia point to ancient oceans with much less oxygen.

A world full of anoxic oceans would have serious consequences for evolution. These data confirm that there was virtually no oxygen dissolved in the oceans until about 2 billion years ago, and that the oceans have been oxygen-rich during the last half-billion years.

Header image shows algae from pond within Golden Gate Park, San Francisco.
Border image shows algae from Klamath Lake in Oregon. Photos by Francis Parchaso ©.