Algae transform the atmosphere

3.5 billion years ago, blue-green bacteria evolved as the first photosynthesizing prokaryotes. Otherwise known as cyanobacteria, these tiny microorganisms lived close to the surface of the oceans, so they could use energy from the sun to produce their food. They built large rock structures, called stromatolites, in shallow, saline coastal environments. Stromatolites are found throughout the fossil record from 3.5 billion years ago until today. Photosynthesis was a transformative process for our planet’s atmosphere, and hence for future life. Photosynthesis uses a pigment (in this case, a green one called chlorophyll) to capture sunlight, which is then converted into bond energy in a sugar crystal. Carbon dioxide and water molecules are the building blocks for the sugar molecule, but it takes energy to make them combine into sugar. This energy, taken from the Sun, is then stored in the sugar molecule, usable by biological organisms at a future date for their energy needs. Oxygen, a byproduct of this process, is released in the surroundings.

PHOTOSYNTHESIS

\[ 6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2 \]

Carbon dioxide + water + sunlight \( \rightarrow \) sugar + oxygen

Early Earth had no oxygen in its atmosphere, but it did have a lot of carbon dioxide. The early photosynthesizers had to perform anaerobic respiration (they got energy back out of the stored sugar molecules without using oxygen—a process that anerobic bacteria still use today). In fact, most of these bacteria couldn’t survive in high oxygen conditions. One challenge, though, was that to access sunlight, organisms had to be close to the surface of the oceans where light penetrates. But without an ozone layer to protect them from the UV radiation of the Sun, these early microorganisms would have fried. (Typical microorganisms found on Earth today would be killed in a matter of seconds if exposed to the full intensity of solar radiation in the UV spectrum.)

Bacteria overcame this challenge by producing a mucous layer within which mats of organisms lived. These mats trapped sand and the dead remains of previous populations. The mucous, sand, and dead organic matter absorbed most of the UV radiation. New mats formed over and buried the older ones.

What does iron have to do with it?

The first evidence of oxygen being released by photosynthesizing organisms comes in the form of Banded Iron Formations (BIFs), which exist in the geologic record from 3.8 to 2.0 billion years ago. These formations consist of alternating layers of red hematite (rust) and grey chert (silica). Both layers form as chemicals in the water combine and precipitate minerals on the seafloor. Earth’s oceans would have had a lot of dissolved iron, due to the accumulation of hundreds of millions of years of rock weathering and underwater volcanic eruptions. Newly formed oxygen, released from photosynthesis, would readily and quickly combined with the iron to form layers of rust. The chert would have been deposited between rust episodes. It’s thought that the banding results from cyclic variations in oxygen (due to climate perturbations). It’s also possible that the silica and rust deposited contemporaneously, but separated according to density in layers afterwards. Density separation can be seen today in seafloor muds.

Note: some scientists believe that stromatolite bacteria are also responsible for BIFs, not just because these bacteria produced the oxygen, but also because they might have been a catalyst in the chemical reaction that produced the rust. The bacterial genera Gallionella and Chromatium directly oxidize Fe\(^{2+}\) as an energy source, and both are likely to have existed in Precambrian oceans.

By 2.0 billion years ago, more oxygen was being produced than ions dissolved in seawater available for oxidation. Thus, for the first time, oxygen was free to leave the oceans and enter the atmosphere. It is only after 2 billion years ago that we see the first oxidized iron (rust) beds forming in land environments. The banded iron formations of the seafloor disappear from the fossil record, and the land-based Red Beds take their place. The Red Beds absorb most of the available oxygen until about 1 billion years ago, when the fossil record shows free oxygen finally beginning to accumulate in the atmosphere.

Life on planet Earth from 3.8 to 2.0 billion years consisted almost entirely of the simplest single-celled organisms with no nucleus and no sexual reproduction. But through their increased populations and almost 2 billion years of photosynthesis, the atmosphere on our planet transformed. Carbon dioxide steadily decreased. Oxygen slowly increased. Once there was enough oxygen for more advanced organisms to evolve, more efficient methods of photosynthesis made oxygen increase at even greater rates. Eventually enough oxygen accumulated in the atmosphere that UV radiation interacted with it in the upper atmosphere, split the molecules, and produced ozone, a gas that then acted as a UV shield, protecting life on Earth’s surface. Once life was able to move onto land, photosynthesis became even more efficient as sunlight was now more direct. At each of these major steps in evolution, we see a corresponding jump in the amount of atmospheric oxygen. Through the combined efforts of all the photosynthesizers over almost 4 billion years, eventually the oxygen levels rose to the stable value we see today, about 21% of our atmosphere. Note: It is estimated that the amount of oxygen locked up in earth’s Banded Iron Formations is about 10 times the amount contained in the atmosphere.

We humans are, in simple terms, bags of water filled with proteins and prokaryotic bacteria (the bacteria in our bodies outnumber our cells by about 10 to 1). We have descended from organisms that adapted to living in a prokaryotic world, and we conserve in our mitochondria the cellular machinery to power our cells that we inherited from the simplest single-celled bacteria of 3 to 4 billion years ago on Earth.

STROMATOLITES ARE AMAZING!

The bacteria that brought such fundamental changes to our planet’s atmosphere, paving the way for more advanced life to exist, are found throughout the entire history of the Earth. That they still exist today means that they’ve adapted to the very changes they’ve wrought. Over the last few hundred million years, they have evolved with an increasing number of diverse predators—one of the most voracious being the grazing mollusk—and they’ve lost their footholds in most places. Modern stromatolites, now a fragile rarity, were first discovered in Shark Bay, Australia in 1956. New stromatolite localities have since been discovered throughout western Australia in both marine and non-marine environments, the Bahamas, the Indian Ocean, and Yellowstone National Park, to name a few.

2.5-billion-year-old Banded Iron Formations in Australia in the Keeper’s Guide. Fireproof rock Publishing ©

Most modern stromatolites consist of three different bacterial layers:

- The uppermost layer is composed of photosynthetic cyanobacteria that use chlorophyll to trap sunlight and convert water and carbon into carbohydrates and oxygen.
- The middle layer is a mat of different bacteria that use photosynthetic processes and chlorophyll-like materials to convert hydrogen and carbon dioxide directly into carbohydrates or to convert hydrogen sulfide and carbon dioxide into carbohydrates by releasing oxygen.
- The lowermost layer contains anaerobic and sulfate-reducing bacteria, as well as methanogenic archaea, all of which use the energy present in the extracellular films of the above two layers.

The photosynthetic bacterial layer produces mucus that is designed to alleviate the effects of UV radiation. This layer also traps particles of calcium carbonate that are precipitated over the colonies due to the photosynthetic depletion of carbonate dioxide in the surrounding water. When combined with sediment grains and debris, these bacteria are forced to re-establish above the opaque layer and grow towards the light. The repetition of this cycle thereby forms numerous layers of cemented, carbonated rock. The bacteria themselves are occasionally preserved as fossils, where information of internal mineralization has occurred.

Flattened, layer stromatolites grow in quiet, isolated environments such as a saline pond or salt marsh. Dome and column stromatolites form in shallow, open water where the microorganisms are strong enough to build the mat-like structure, isolating individual stromatolites or disturbing the growth of adjacent colonies. Core stromatolites form in deeper water far beneath direct exposure to light—the cone shape is thought to be the product of photosynthetic bacteria congregating at the cone’s peak.