Cyanobacteria

Earth’s Extraordinary Organism

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Introduction:

Cyanobacteria are one of the oldest forms of life, having been found in fossils from 3.5 billion years ago. Also known as blue green algae or Cyanophyta, they are prokaryotes – single celled organisms with little internal structure – and grow in colonies that form filaments, hollow balls or sheets. (Little Things Matter A lot, 2005) They are mostly found in fresh water or marine water zones, but also in soils, and have also adapted to grow in extreme condition like deserts, hot springs, brine pools and salt ponds. (Cyanobacteria, n.d.)

People originally named Cyanobacteria blue green algae. Algae, however, are eukaryotic organisms, whereas further studies have shown that Cyanobacteria are prokaryotes. A better name for them is blue greens, but this remains a common mistake even today. Although they are named blue greens because they have color pigments, such as Phycocyanin, in them for photosynthesis, they can also have different colors. (Little Things Matter A lot, 2005) During the process of photosynthesis, Cyanobacteria convert sunlight into energy. At the same time, they release oxygen. This process was incredibly important in the history of life on earth. (Static Evolution, 1994) Cyanobacteria have helped the earth in three ways: by releasing oxygen, by fixing nitrogen and by capturing sunlight as energy that other species feed on, especially in the ocean.
Ancient History

Cyanobacteria appeared during the Archean era, 3.5 billion years ago (bya), in the primordial ocean. (Introduction to Cyanobacteria, 1993) This was identified from the fossil record: the oldest known fossils are Stromatolites, columns and mounds of Cyanobacteria fossilized together with minerals. (Introduction to Cyanobacteria, 1993) In fact, the oldest known rocks are only a little older, dating to 3.8 bya. Scientists were able to figure out that these fossils were Cyanobacteria because they are very similar to Stromatolites that form today. (The Cyanobacteria: Molecular Biology, Genomics and Evolution 2008)

There are two ways of calculating how old Cyanobacteria are: Fossil Record and Amino Acid “Clock.” (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) From the fossil record, scientist could tell the age of the fossil by counting the layers of minerals in the Stromatolites. (Introduction to Cyanobacteria, 1993) Researchers have found thousands of ancient fossils that look like 120 different living species of Cyanobacteria. It seems that 2 bya there were a wide variety of Cyanobacteria but fossils before that time are poorly preserved. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) Cyanobacteria have also left chemical fossils, which are colored pigments left as spots in the rock. (Introduction to Cyanobacteria, 1993)

The Amino Acid “Clock” method was about comparing proteins from different organism to find out the last common ancestor between bacteria and archaea. However this method was proven less effective. It predicted that Cyanobacteria appeared only 2 bya and we know this is wrong from the fossil record. To explain the difference between the two methods, some paleobiologists have suggested that life appeared 3.5 bya then disappeared and reappeared 2 bya. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008)
At the time when Cyanobacteria appeared, there was no oxygen in the atmosphere and therefore no life besides anaerobic bacteria (organisms living without oxygen). They grew in extreme condition with asteroids falling from the sky. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) The sun’s radiation was so intense that bacteria couldn’t survive on land. (Little things matter a lot, 2005) The primitive bacteria differentiated into many different kinds of species of bacteria. (The Rise of Slime, 2002) Among them were Cyanobacteria. They produced oxygen, which was toxic to anaerobic bacteria and so acted like a weapon or a means of defense. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) As their population increased they started producing oxygen that filled the earth’s atmosphere and transformed life on earth. This process took between 1 and 2 bya. This was known as the Great Turnover because the oxygen levels in the atmosphere increased from 0 to 20%. (Little things matter a lot, 2002) It was also called the Oxygen Catastrophe because it killed a lot of anaerobic bacteria. (See Oxygen) (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008)
Great Turnover

The first life forms on earth were anaerobic bacteria, the only organisms that can live without oxygen. (Static Evolution, 1994) Until 3 billion years ago there was no oxygen in the earth’s atmosphere. The development of oxygen was a particular process that took between 1 and 2 billion years. It all started with Cyanobacteria. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) As the bacteria multiplied, they started forming colonies. The increase in Cyanobacteria caused them to produce oxygen. They produced oxygen through photosynthesis. The oxygen levels increased from 0 to 20% in the earth’s atmosphere. This was known as the Great Turnover or the Oxygen Catastrophe. (Little Things Matter A lot, 2005)

When the earth was formed, its surface was filled with radiation from the sun. Species in the ocean weren’t a problem because the water would protect them but life on land was impossible. (Little Things Matter A lot, 2005) As the amount of oxygen began to increase, it produced a shield that blocked the radiation rays from the sun. (Introduction Cyanobacteria, 1993) Then, some species started leaving the ocean and inhabiting the land. (Cyanobacteria, 2008)

Plants started forming on land. Cyanobacteria helped plants in two ways. (Little Things Matter A lot, 2005) First Cyanobacteria absorbed nitrogen from the atmosphere and fixed it, giving plants an essential nutrient. (Static Evolution, 1994) More importantly, Cyanobacteria evolved into plant chloroplasts (See Evolution of Chloroplasts). The chloroplasts in the plants absorbed energy from the sun, turning carbon dioxide into oxygen in the process. These two species changed the atmosphere of the entire earth, allowing life to flourish. (Little Things Matter Alot, 2005)
Green Workers

In 1905, Mereschkowsky proposed that chloroplasts are stripped down Cyanobacteria like “little workers, green slaves” inside plant and algae cells. At first people didn’t think this was possible. They thought it was ridiculous. (Ancients Invasions, 2004) After years of studies, research proved him right.

The evolution of chloroplasts was a 1500 million year long journey. Chloroplasts are the solar panels of plant and algae cells. They’re pockets in the cells with their own membrane and DNA. (Ancients Invasions, 2004) They’re the parts of the cells that do photosynthesis. Photosynthesis is the ability to take sunlight and capture its energy into molecules that the cell can use. (Little Things Matter A lot, 2004) It also uses up carbon dioxide and releases oxygen. (Genome Biology, 2003) The other “power plant” in eukaryote cells is the Mitochondria. Like chloroplasts, they have their own membrane and DNA, but they collect energy in a different way, using sugar as a fuel and using up oxygen. They also have a similar history. (Ancient Invasions, 2004)

Chloroplasts are very similar to Cyanobacteria. Mereschkowsky’s idea was that, a long time ago, Cyanobacteria went into a cell and started living inside it. (Ancient Invasions, 2004) This is called “endosymbiosis”, from the words endo for “inside” and symbiosis for “living together while helping each other.” Over time, many of the Cyanobacterial genes are transferred to the nucleus, but at the same time some are lost entirely. (Genome Biology, 2003) The organelle now depends on its host cell because it doesn’t have all the genes it needs for survival. This
organelle that can’t live on its own is called the chloroplast. Mitochondria appeared in a similar way. (Ancient Invasions, 2004)

That means the history of eukaryote cells has two endosymbiosis events. (Ancient Invasions, 2004) The first endosymbiosis started with an Archaebacterium that absorbed a proteobacterium and turned into a eukaryote cell. This is the structure of the animal cells. The second endosymbiosis started with one of these eukaryote cells, which absorbed the Cyanobacterium and developed into plants and algae. (Genome Biology, 2003)

Scientists have several kinds of evidence for the endosymbiosis hypothesis. First, chloroplast and Cyanobacteria both have photosynthesis with two photosystems that split water and create oxygen, and they’re the only two kinds of organisms that have this type of photosynthesis. (Genome Biology, 2003) Second, chloroplast ribonucleic acid (RNA) is similar to Cyanobacteria rather than to its host cell. (Ancient Invasions, 2004) Mitochondrial RNA is similar to another bacterium. (Genome Biology, 2003) The third piece of evidence is the chloroplast DNA: chloroplast gene sequence, organization and expression support the idea that chloroplasts came from Cyanobacteria. (Ancient Invasions, 2004)

On the history timeline, there was enough oxygen for mitochondria to appear only 2.2 bya and we have fossils of eukaryote cells from 1.5 bya so mitochondria might have appeared during that time. (Genome Biology, 2003) We also have fossils of algae from 1.2 bya that suggest that chloroplasts appeared during that period. (Ancient Invasions, 2004)
**Water Blooms**

Although Cyanobacteria are important to life on earth they have a dark side as well. Cyanobacteria produce oxygen and fix nitrogen, two roles which are essential to our environment, but they can also release deadly toxins. They do this especially when they form water blooms. People say that it’s “blooming”, but actually Cyanobacteria float up to the surface in bright sunlight and spread. Cyanobacterial blooms are slimy, often colored mats of bacteria that rise to the surface of water to absorb energy from the sun. (Toxins of Cyanobacteria 1994)

For instance, Cyanobacteria can be seen growing on many ponds and lakes, as a green scum. They can also look very shocking. In Sweden in summer, blooms of Cyanobacteria turn the Baltic Sea into a stinking, yellow-brown slush called rhubarb soup. (The Rise of Slime, 2008) In calm weather, red colored colonies of a filamentous Cyanobacterium called Trichodesmium rise to the surface, creating the so-called Red Tide which gave the Red Sea its name. (Little Things Matter A lot, 2005) Animals or humans who drink the blooming Cyanobacteria become very sick and can show symptoms like passing out, convulsions, abdominal pain, nausea, vomiting, diarrhea and fever.

In 1878, George Francis discovered that pond scum (Cyanobacteria) in the Murray River poisoned cattle and other farm animals. (Toxins of Cyanobacteria, 1994) By the 1940s there were reports of animals dying from slimy pond water all over the world. In the 1950s, Theodore Olson fed samples of water blooms to animals and showed that Cyanobacteria were poisonous. (Rise of Slime, 2008) From the 1950s-1960s Gorham et al established cultures of toxic Cyanobacteria and isolated the poisons. (Toxins of Cyanobacteria, 1994)

Cyanobacterial toxins can be divided into two main groups: neurotoxins and hepatotoxins. Neurotoxins, like Saxitoxin and Anatoxin, are poisons of the nervous system.
They block connection between muscles and nerves and cause death by respiratory paralysis. In fact, anatoxin, a cocaine-like molecule, caused death within 1-4 min and so violently that it was first called “very fast death factor.” It causes muscle twitching and cramping, fatigue and paralysis, convulsions and death by suffocation. Hepatotoxins like Microcystin (“fast death factor”) and Nodularin causes liver damage including enlargement, congestion, necrosis and haemorrhage. Cyanobacteria also produce some less dangerous toxins that can cause horrible skin damage to people. One fisherman described the effect as follows: “It comes up like little boils. At night-time you can feel them burning.” Kenneth Weiss said that “Samples in a drying oven gave off fumes so strong that professors and students ran out of the building and into the street, choking and coughing.” Chronic exposure to toxic Cyanobacteria can also contribute to cancer.

Cyanobacteria that make the toxins can’t be distinguished from the ones that don’t. Scientists believe that Cyanobacteria secrete toxins only in the right environmental conditions. The toxic blooms form when wind is mild, water is 15°C to 30°C, water has pH 6-9 and there is an abundance of nitrogen and phosphorus. The Cyanobacteria involved in animal deaths grow free floating in the water. Unfortunately thirsty animals are not thrown off by the bad smell and taste, leading to sick and dying livestock. In the oceans the effects of blooms can have an even more severe impact. On the Florida gulf coast, algal blooms have killed hundreds of sea mammals. Overgrowing Cyanobacteria can choke or poison other species to death.

Our oceans are being overdosed with basic nutrients: nitrogen, carbon, iron and phosphorus. These essential nutrients come from crop fertilizers, sewage and detergents that are
being dumped in the ocean. As the bacteria feed on these nutrients they grow tremendously, they form toxic blooms and they choke out other organisms. (Toxins of Cyanobacteria, 1994) At the same time their natural competition is being removed because of over fishing and destruction of wet lands, throwing the chemistry of the ocean off balance. A marine ecologist named Jeremy BC Jackson has said that this uncontrolled growth will lead to “the rise of slime.” (The Rise of Slime, 2002)

In nature Cyanobacteria play many important roles and only sometimes produce harmful blooms or dangerous toxins. The balance is tilting more to harmful blooms, however, as we pollute the rivers, seas and oceans. (Toxins of Cyanobacteria, 1994) The dangerous toxins are becoming more of a problem both to human health and to the marine ecosystem. If we reduce our pollution then there will be a decrease in dangerous toxins and damaging blooms. (Rise of Slime, 2002)
Agriculture

Our world is going through a food crisis. There are over 6 billion people and the population is expanding faster than we can feed it. (Wikipedia, 2008) We need to develop new technologies that will increase the production of food. Cyanobacteria can be a useful fertilizer, giving crops the nutrients they need to grow. They can increase soil fertility and replace artificial fertilizers. (Blue Greens, 1983)

Cyanobacteria growing naturally in the soil convert the nitrogen in the atmosphere to a biologically useful form. The Cyanobacteria do this in order to use the nitrogen in their own cells. (Blue Greens, 1983) This is called Nitrogen fixation. Very few organisms can fix nitrogen. Most plants can’t. (Static Evolution, 1994) Nitrogen, however, is an essential nutrient and plants can’t grow without it. That’s why fertilizers, including artificial fertilizers or natural ones like manure, play an important role in growing plants: they’re a source of nitrogen. (Blue Greens, 1983) Since Cyanobacteria have relationships with plants and algae, they provide nitrogen to their hosts in exchange for a place to live on. (Blue Greens, 1983) That means they can replace or supplement artificial or organic fertilizers. (Wikipedia, 2008) The reason why we would want to replace fertilizers with Cyanobacteria is that fertilizers are expensive, whereas Cyanobacteria grow on their own. Having both Cyanobacteria and fertilizers in a soil might increase the plant growth more than either one alone. (Blue Greens, 1983)

Cyanobacteria, for instance, are helpful in the rice paddy fields. (Toxins of Cyanobacteria, 1994) These paddy fields are maintained by blue greens which grow significantly in the waterlogged field. They fix nitrogen and then secrete nitrogenous substances into the soil. (Wikipedia, 2008) In India, the Philippines and China, Cyanobacteria are specially grown to be spread out in the rice paddy fields. Some studies in India show that adding Cyanobacteria results
in a 10 to 15% increase in crop yield. (Blue Greens, 1983) Growing rice fields with water ferns (Azolla) and Cyanobacteria will increase yield up to 38%. The ferns provide a place for Cyanobacteria to grow in their leaves in exchange for fixed nitrogen. (Blue Greens, 1983) It’s not enough to add Cyanobacteria to soil: in order for them to grow in a soil, it’s important to have the right conditions. (Little Things Matter A lot, 2005) The Azolla and Cyanobacteria in the soils and paddy fields depend on a delicate balance of environmental conditions. Therefore a better understanding of using Cyanobacteria in agriculture could be part of the solution to the world’s food crisis. (Blue Greens, 1983)
Food Source in the Ocean

Between 1970 and 1980, scientists discovered that a type of Cyanobacteria called picoplankton was the most abundant life form on the planet. (Little Things Matter A lot, 2005) This tiny organism, which didn’t seem much to a lot of people, was in fact the biggest food source in the ocean. When you scoop up a handful of ocean water, you don’t realize that it’s full of this microscopic organism and that the entire ocean is filled with it. Since the ocean covers ¾ of the earth’s surface, all that picoplankton adds up to a huge mass.

Many organisms in the ocean feed on picoplankton. (Little Things Matter A lot, 2005) Even huge whales use it as their main food, needing to eat huge amounts every day. Like plants, picoplankton is known as a primary producer because it’s the one that captures energy from the sun supplies it to organisms in the food chain. This process is called photosynthesis. (Introduction to Cyanobacteria, 1993) It involves capturing energy from the sun and using it to transform carbon dioxide to a sugar that behaves as a chemical way of storing energy. (The Cyanobacteria: Molecular Biology, Genomics and Evolution, 2008) Since Cyanobacteria can also fix nitrogen, they can use it to transform sugars into proteins. Every organism requires sugar to grow and to make other important building blocks, like protein and fat. (Little Things matter a lot, 2005)

In the same way, humans need sugar to maintain their metabolism. If people take too much sugar, then their fat will increase rapidly, whereas if they take less sugar then they get tired, weak, their muscles will start breaking down for energy and eventually they’ll die. (Toxins of Cyanobacteria, 1994) Humans and other animals can’t use sunlight directly, so they have to feed on primary producers to get their energy or on other animals that feed on primary producers.
Energy is passed through the food chain as molecules made of carbon. (Little Things Matter A lot, 2005) This places primary producers at the base of the food chain. Without picoplankton the whole food chain of the ocean would collapse.

Just like Cyanobacteria are in the nitrogen cycle where they fix nitrogen they can also play a part in the carbon cycle by fixing carbon. (Little Things matter A lot, 2005) The carbon cycle involves movement of carbon between the atmosphere, the freshwater and soils, the ocean and the sediments (like fossil fuels). (Rise of Slime, 2002) In the very long run carbon from the atmosphere gets trapped in carbonate rocks in the bottom of the ocean and as fossil deposits of oil, coal and gas. At the same time volcanoes break down these carbon traps and release carbon dioxide back into the atmosphere. (Micro Worlds, 2004) On a much shorter time scale, living organisms affect how much carbon dioxide there is in the atmosphere. (Little Things Matter A lot, 2004) In the day time plants and algae like Cyanobacteria capture carbon dioxide during photosynthesis. When other animals eat them the trapped carbon gets passed on. The trapped carbon gets released when organisms breathe out carbon dioxide and when they die and decay. (Micro Worlds, 2004)

On the other hand humans have found of a way of affecting the carbon cycle in a bad way. When we burn coal, oil or gas we release the carbon trapped in it quickly, much faster than volcanoes would naturally. (Rise of Slime, 2002) This puts lots of carbon dioxide in the atmosphere. Carbon dioxide is a green house gas: it heats up the earth’s surface by trapping the sun’s energy. (Micro World, 2004) This leads to global warming and other effects like melting glaciers and rising ocean levels, and changes in the weather.
Cyanobacteria are a huge carbon dioxide sink in the ocean. (Rise of Slime, 2002) That means they take in a lot of more carbon dioxide then they breathe out. They are essential to the survival of the ocean’s organisms and also for keeping the carbon dioxide levels in the atmosphere stable. (Micro World, 2004) The health of Cyanobacteria is important to maintain both the oceans and the air healthy.
Other uses

Humans are always on the lookout for new uses of Cyanobacteria. Cyanobacteria, such as Spirulina, are a food source which is high in protein (55-75%) and can be easily cultivated in ponds. (Ecology of Cyanobacteria, 2000) It has been eaten in tropical countries for hundreds of years especially in places where it grows in high concentrations.(Unbound Medline, 2007) These places are usually mineral rich lakes often near volcanoes, like Lake Texcoco in Mexico, Lake Chad in central Africa and the Great Rift Valley in east Africa. (Ecology of Cyanobacteria, 2000; Toxins of Cyanobacteria, 1994)

Scientists are studying ways to use Spirulina as part of the solution to the food crisis. These days it is sold as a pill and as powder and is considered a health food. (Unbound Medline, 2007) For example Booster Juice carries Spirulina as a healthy supplement for their shakes. Spirulina is attractive to many people because it contains all the essential amino acids, minerals like potassium, essential fatty acids, and many vitamins (especially the B complex) in unusually high concentration.(Unbound Medline, 2007) Due to its high nutritional value, Spirulina has been recommended by NASA and the European Space Agency as one of the main foods for space missions. (Ecology of Cyanobacteria, 2000)

In 1981 the US Food and Drug Administration confirmed that Spirulina is a source of nutrients and approved it as a health food. A 2007 clinical study showed that people who took 4.5 g of Spirulina for 6 weeks had many health benefits like decreased cholesterol and lowered blood pressure. (Unbound Medline, 2007) Several studies have shown that Spirulina has had some small benefits in helping people with HIV. Some people have said that Spirulina is a miracle cure and others say that its benefits are overstated. (Ecology of Cyanobacteria, 2000) There is even concern that it could contain Cyanobacterial toxins, because there are no good
guidelines for its safety, but there is no evidence of it causing harm to humans yet. (Toxins of Cyanobacteria, 1994) Therefore there are still ongoing debates about the health benefits of Spirulina.

Another creative use of Cyanobacteria is in making new drugs for Alzheimer’s disease from the toxins. Alzheimer disease is a brain disorder during old age that causes amnesia and finally death. (Unbound Medline, 2007) Scientists have taken neurotoxins and have been working on them to produce a viable drug to treat the disease in a non toxic way. Edson Albuquerque at the University of Maryland School of Medicine is trying to modify anatoxin-a to reduce its toxicity so that the drug could be useful in slowing mental degeneration. Anatoxin-a is useful because mimics acetylcholine, a neurotransmitter, that is affected in Alzheimer’s. (Ecology of Cyanobacteria, 2000) For that reason it could also be useful for another disease, myasthenia gravis (a disease that causes muscle weakness). (Ecology of Cyanobacteria, 2000)

Finally, our world has a major problem with green house gas emissions. We are using a lot of fuels and gases to run cars and other industries. Recently, in Texas, a company called Vertigro has found a way to use algae scums as a way of collecting energy from the sun to use it as car fuel. (CNN, 2008) This is a great way to reduce our pollution levels and cut down on our use of fossil fuels. (Rise of Slime, 2002) In 1996, oil was very cheap - about $20 a barrel. By comparison, algal oil seemed expensive at the time - but now, oil is over $100 a barrel and algae seem to be a more affordable choice and great for our environment too. (CNN, 2008)
Conclusion

In our everyday world Cyanobacteria play an important role in the conservation of our planet. In fact for more than 3.5 billion years it has improved the state of the earth, allowing life to prosper. They’re the oldest known form of life that has left a mark in our fossil record. The history of Cyanobacteria is a fabulous discovery that has shed light on the evolution of life itself. This tiny organism did so much that we can barely imagine it. It created the most important part of the very air we breathe, the requirement for life on land: oxygen. It also became the energy source for plants, evolving into chloroplast. Without plants, the earth’s land surface would be uninhabitable. There would be no food for animals, no clean environment and there would be no food chain on land at all.

As much as Cyanobacteria have done for us in the past, we need to figure out ways of using them in the future. Research has shown that Spirulina can be a very nutritious food supplement. It’s got important health benefits, and can also be a solution to the world’s food crisis. NASA and the European space agency have been using Spirulina as food for space missions. Scientist’s are looking at Cyanobacteria for their potential as drugs: Cyanobacterial toxins are helpful in producing a drug capable of treating Alzheimer disease. And finally Cyanobacteria can be a viable and clean source of energy: from only sun and water they can create a clean fuel to replace our polluting fossil fuels that are quickly running out. Changing to this cleaner and renewable energy can make our world a better place to live. With this marvellous history and great chances for the future, Cyanobacteria really are Earth’s Extraordinary Organism.
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