How vast those Orbs must be, and how inconsiderable this Earth, the Theatre upon which all our mighty Designs, all our Navigations, and all our Wars are transacted, is when compared to them. A very fit consideration, and matter of Reflection, for those Kings and Princes who sacrifice the Lives of so many People, only to flatter their Ambition in being Masters of some pitiful corner of this small Spot.

Christiaan Huygens, 1690

Cornucopia

Greetings AST 111. In this module we'll explore when and how life arose on Earth.

When did life arise on Earth? Well, the direct fossil evidence puts the origin of life at least 3.5 billion years ago. Carbon isotope abundances in rocks pushes this to about 3.8 billion years ago when life got started on Earth. To remind you, the solar system and Earth is about 4.5 billion years old. So life arose within a few hundred million years after Earth was formed, and possibly in a shorter time.

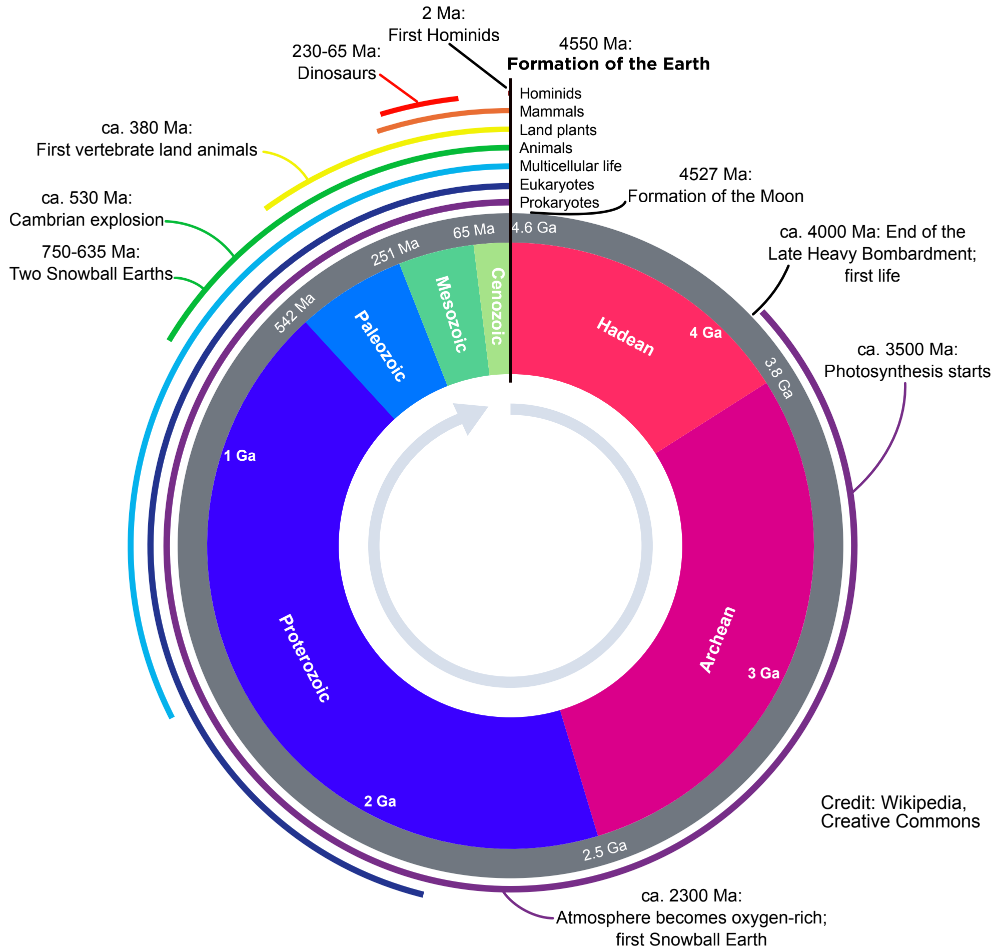
One way that you get at fossils and rocks that are 3.5 billion years old is where you will have some sedimentary process -- a river, a lake bed-- that deposits different layers of sediment over the eons. Later ,there might be another river formed that cuts right through these old sedimentary layers. Then you get a nice free sample of the different layers with fossils and rocks preserving the carbon isotope ratios that existed at that time.

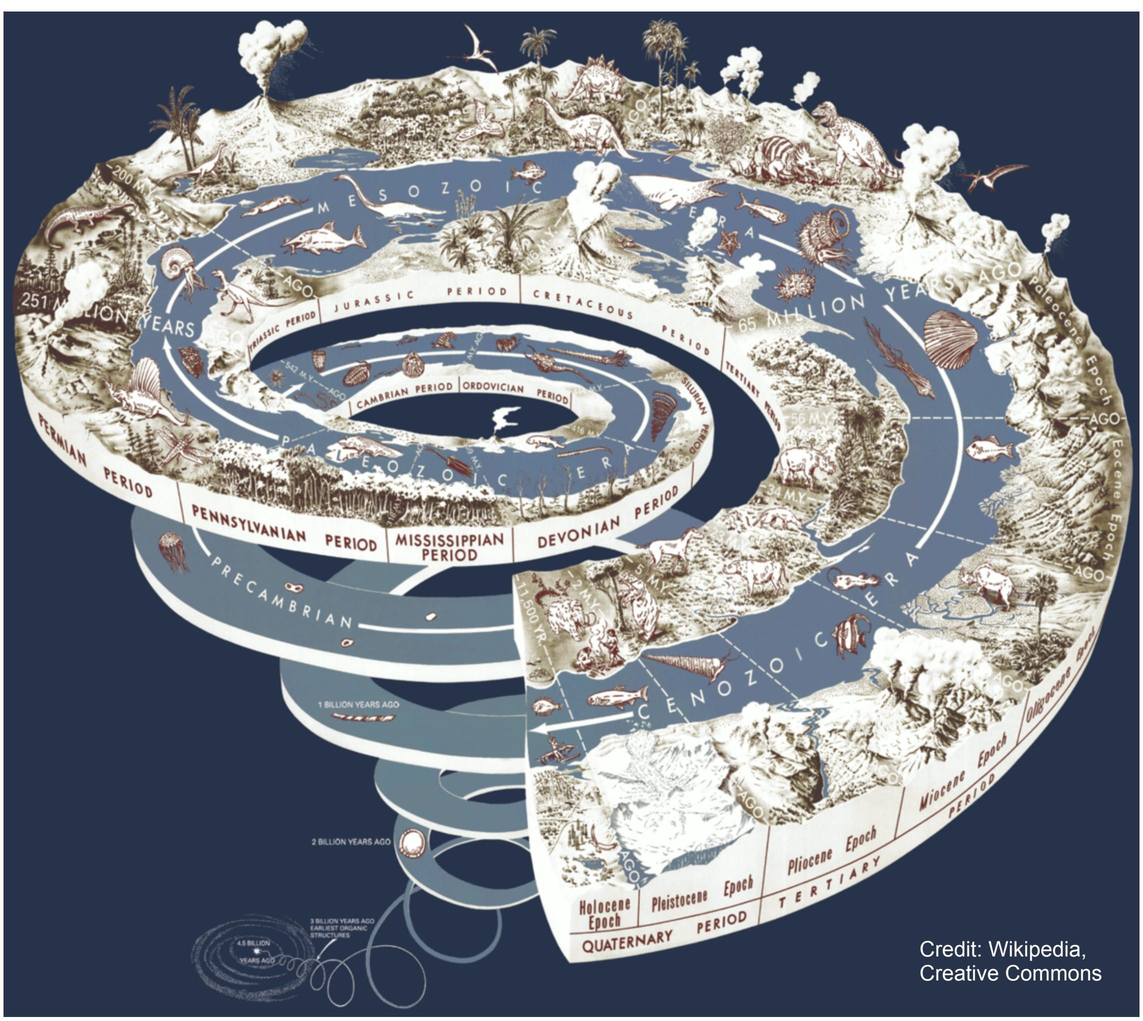
We have a fantastic example of this process in Arizona, the Grand Canyon. In the image above you can see some of those different layerings. At the lowest layers of the Grand Canyon the exposed rock is about 4 billion years old.

The illustrations below shows the geological time scales as a clock. Different spans of time are separated by changes in the composition of the rocks. These changes correspond to defining geological or paleontological events, such as mass extinctions. For example, the Hadean eon represents the time before fossil record of life on Earth. The unit of time “Ma” is millions of years. So 1000 Ma is 1 billion years. Of course you get the absolute ages coming from radioactive dating with, say, potassium-40 or uranium-235 or any of the other radioactive isotopes pairs that we explored earlier in this course.

Another, perhaps more artistic, version of the geological timescales is shown by the spiral illustration below. Notice the change from the Cretaceous period and the Tertiary period, marked around the world by the iridium layer that we also discussed earlier.

Spend a bit of time going through these history of Earth figures. Its worth it.


2 Ma:
First Hominids
230-65 Ma:
Dinosaurs
4550 Ma:
Formation of the Earth
Hominids
Mammals
Land plants
Animals
Multicellular life
Eukaryotes
Prokaryotes
ca. 380 Ma:
First vertebrate land animals
ca. 530 Ma:
Cambrian explosion
750-635 Ma:
Two Snowball Earths
4527 Ma:
Formation of the Moon
ca. 4000 Ma: End of the
Late Heavy Bombardment;
first life
ca. 3500 Ma:
Photosynthesis starts
65 Ma
251 Ma
542 Ma
4.6 Ga
Cenozoic
Mesozoic
Paleozoic
Hadean
4 Ga
3.8 Ga
1 Ga
Proterozoic
Archean
3 Ga
2 Ga
2.5 Ga
Credit: Wikipedia,
Creative Commons
ca. 2300 Ma:
Atmosphere becomes oxygen-rich;
first Snowball Earth


MESOZOIC
ERA
251 MILLION YEARS AGO
65 MILLION YEARS AGO
TRIASSIC PERIOD
JURASSIC PERIOD
CRETACEOUS PERIOD
TERTIARY
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
SILURIAN
PALEOZOIC ERA
PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISSIPPIAN PERIOD
DEVONIAN PERIOD
PRECAMBRIAN
CENOZOIC ERA
1 BILLION YEARS AGO
2 BILLION YEARS AGO
Paleocene Epoch
Eocene Epoch
Oligocene Epoch
Miocene Epoch
Pliocene Epoch
Pleistocene Epoch
Holocene Epoch
QUATERNARY PERIOD
TERTIARY PERIOD
Credit: Wikipedia,
Creative Commons

Rocks known as stromatolite offer evidence of microbial life existing 3.5 billion years ago. Living stromatolites still exist! Wow. Your can find them in places like Shark Bay in Australia, Lagoa Salgada in Brazil, and Cuatro Ciénegas in Mexico. Below are some examples from Shark Bay and Exuma Caysin the Bahamas.

Credit: Wikipedia, Creative Commons

Credit: Wikipedia, Creative Commons

Credit:University New South Wales, public domain

The upper image shows a bed of living stromatolite in Shark Bay, Australia. The lower left image is a close up of a colony in Exuma Caysin the Bahamas. The lower right image shows a cross section of a living stromatolite. In 2010 a new form of chlorophyll was discovered in such cross sections. Chlorophyll is what allows plants to harvest energy from the sun through the process of photosynthesis. The new form is cool because it can use the low energy photons of infrared light. This means that photosynthesis use a wider spectrum of sunlight than we realized and can sustain primitive life even under very poor lighting conditions. Maybe this is why stromatolite has been around for some 3.5 billion years! Speaking of, the image below shows an example of stromatolite from Bolivia that is 3.5 billion years old.

Credit: Wikipedia,
Creative Commons

So it's organisms like stromatolite that give us direct fossil evidence for life existing at least 3.5 billion years ago on a very young, relatively hot planet.

So how did life arise on Earth? Well, the genetic evidence suggests that all life on Earth evolved from a common ancestor. It was likely similar to the microbes living today in hot water near undersea volcanoes - the black smokers - or hot springs because the Earth was fairly hot when it was first born. For example, the image below shows the Morning Glory Pool in Yellowstone. The distinct colors of the hot springs is due to bacteria which inhabit the water at different depths, different temperatures, which on average is a toasty 70 °C or 160 °F.

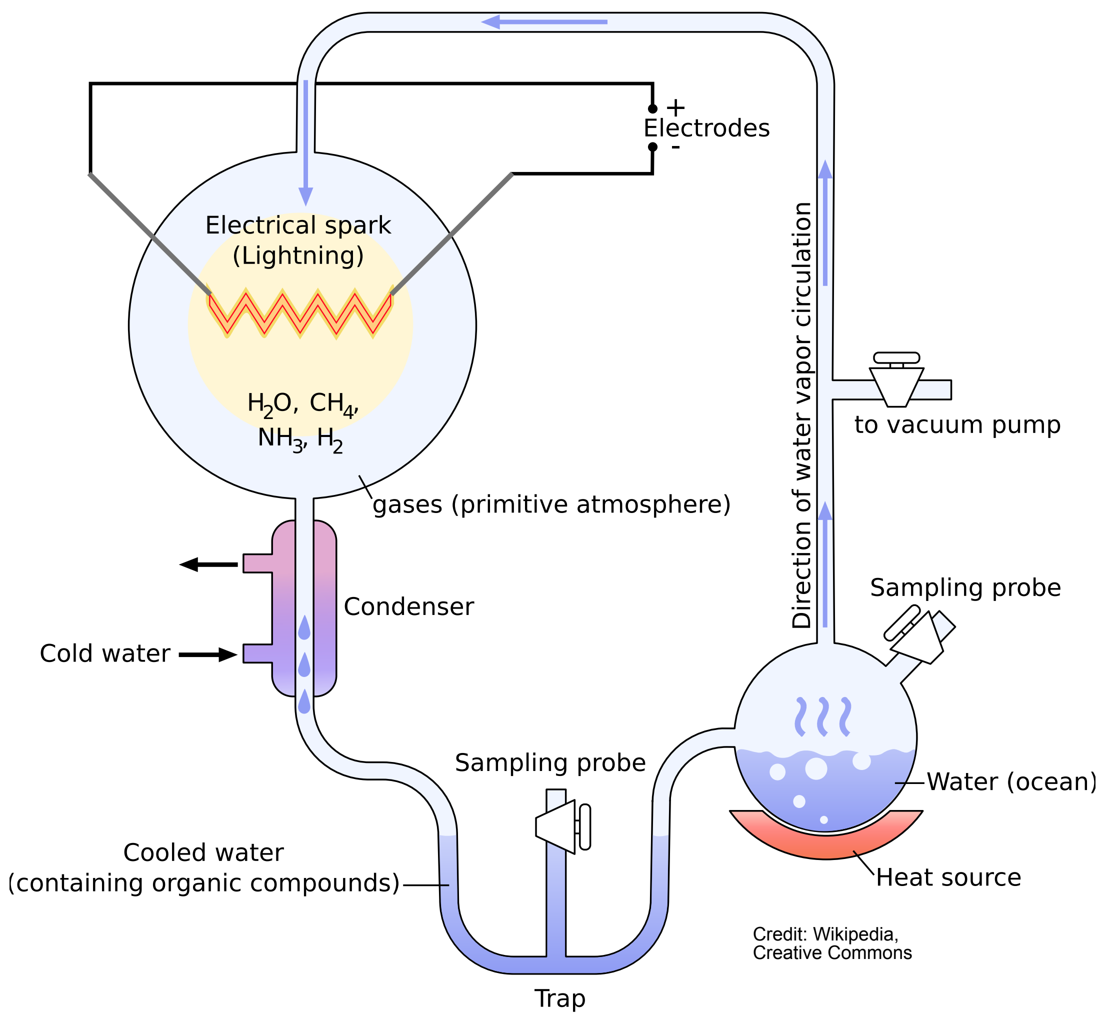
Credit: Wikipedia,
public domain

Let’s be clear: we don't know how the first living organism arose. We can't answer that yet.

But laboratory experiments suggest that it may have been the result of a natural chemical processes on an early Earth. One of the most famous ones and fascinating experiments was by Stanley Miller and Harold Urey at the University of Chicago in the early 1960s.

Their experimental setup is illustrated below. They took a glass chamber and filled it with the gases thought to exist in the early Earth. No oxygen here. Oxygen comes later. This is pretty much a water, methane, ammonia and hydrogen atmosphere. They simulated lightning - an energy source - by putting sparks in the chamber. They also circulated the gasses to simulate the ebb and flow of an atmosphere. Turn it on and let it run for a couple of days.

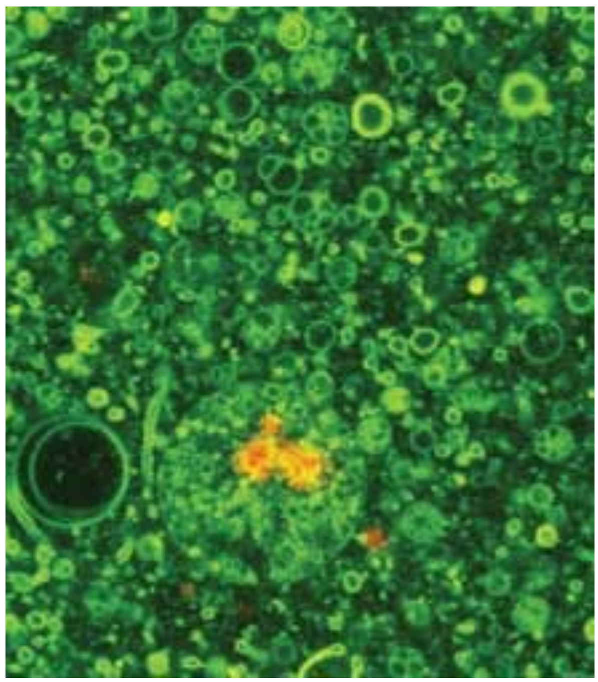
Note there is nothing inorganic in there. You've just got circulating primitive gases and you're sparking it with energy. At the end of a couple of days you’ll fine the glass vessel is coated with this black, gooey stuff. Analyze this tar-life stuff and you find it has over 20 different amino acids. Wow! Of course, other folks since then have done similar prebiotic experiments and they also find mixtures of simple to complex organic compounds.



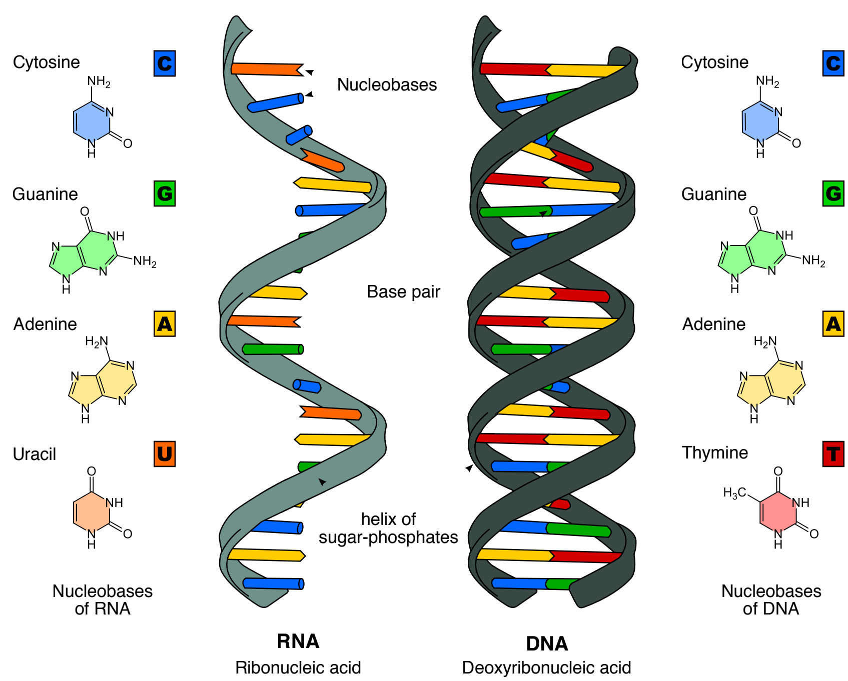
Credit: Wikipedia,
Creative Commons

Experiments since then have shown how clay - perhaps near hot springs on black smokers on the ocean floor - may have spurred the formation of these early cells. The image below shows the results of such experiments. Its a microscope image showing short strands of RNA, colored red here, contained within an enclosed membrane. Both the RNA and the cell membrane formed spontaneously with the aid of clay material beneath them.

Now this is RNA, not DNA. RNA is a precursor to DNA. See the illustration below for the difference between the two. What these experiments suggests is that process of self-organizing into an RNA-like structure complete with a protective cell around it is a natural process resulting from interactions between inorganic materials and an energy source.

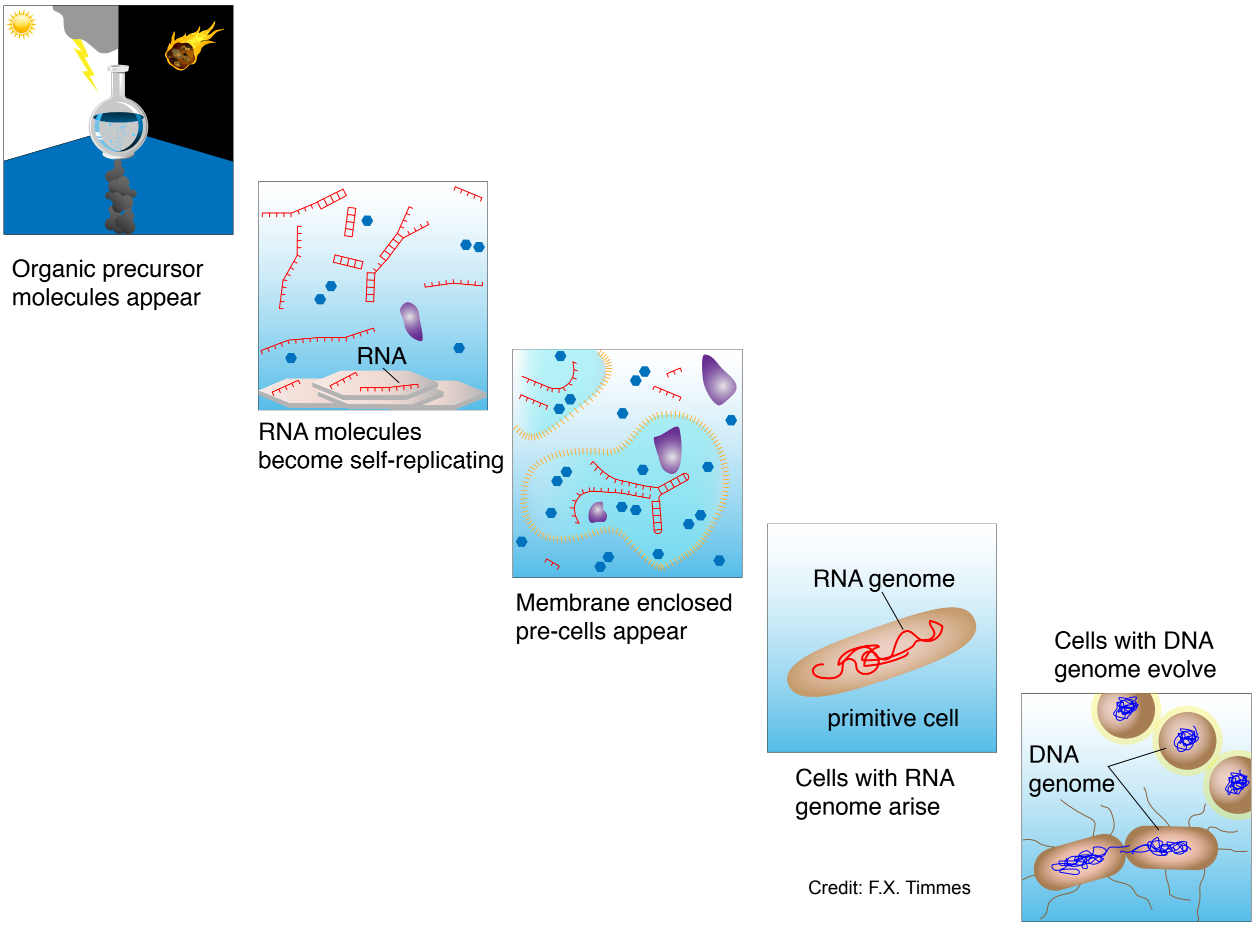


Credit:Science News, Oct 2003.



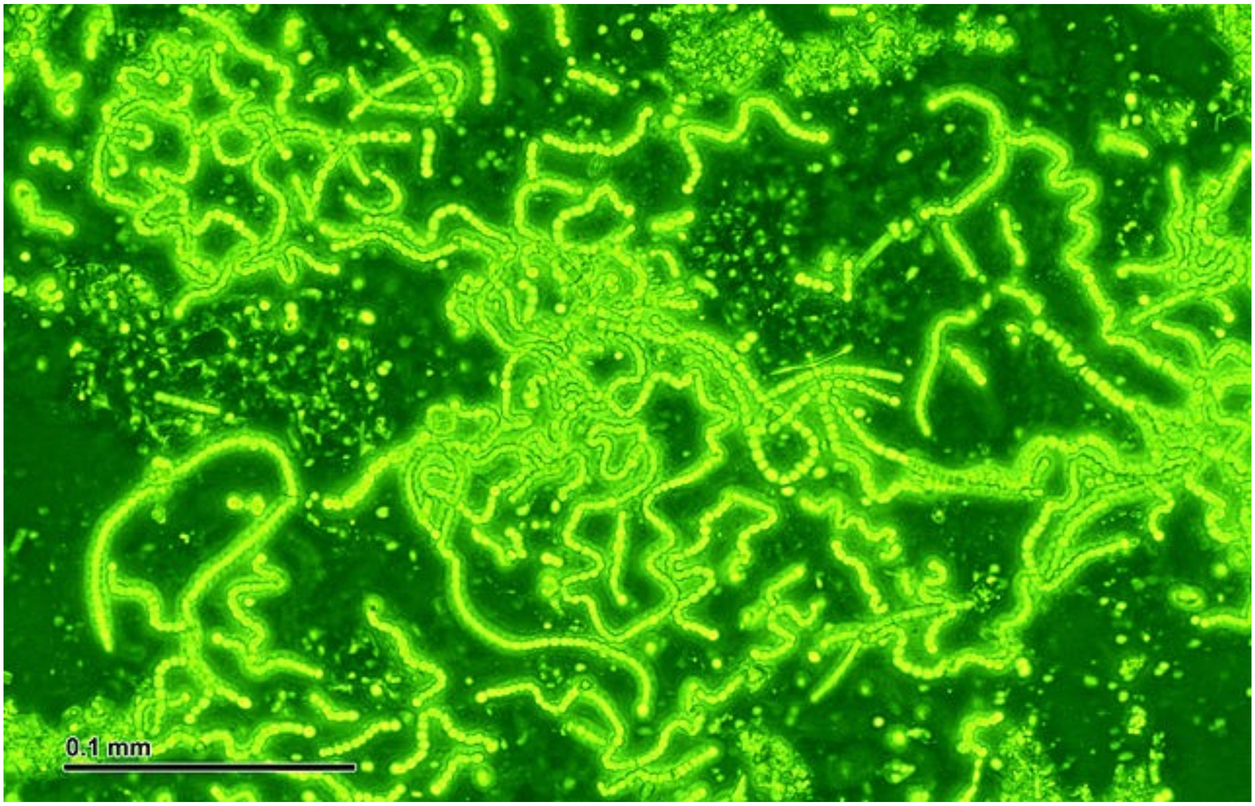
Credit: Wikipedia, Creative Commons

The total story of how life may have first arisen on Earth is outlined in the illustration below. Once life arose, it rapidly diversified and evolved through the process of natural selection.



Where did all the oxygen in our atmosphere come from? Answer: Life! The image below shows microscopic chains of modern cyanobacteria or blue-green algae as they are sometimes called. By producing gaseous oxygen as a byproduct of photosynthesis, ancient cyanobacteria are thought to have converted the early oxygen-poor atmosphere into an oxygen-rich atmosphere. This great oxidation event fundamentally changed Earth. For one, it caused the rusting of the Earth - oxidizing the iron in the crust. For two, it caused a mass extinction of organisms for whom oxygen is a poison. For three, it stimulated extensive biodiversity among organisms who could use oxygen.

So oxygen wasn't always in the Earth's atmosphere. The oxygen came from biological processes about 2.5 billion years ago. It fundamentally changed of evolution on Earth.



Credit: Wikipedia,
Creative Commons

So what are the necessities of life? Well, life on Earth thrives in a wide range of environments from the very hot to the very cold, from the very acidic to the very alkaline, from the very light to the very dark. Life on Earth only seems to require three things: a source of nutrients (food!), a source of energy, and liquid water.

Whether that's a necessity for life that might exist on other planets, we don't know yet.

Thanks! Bye Bye.