Life in the Universe 11/4/2019

Chapter 6: The Origin and Evolution of Life on Earth

Prior knowledge: Chapter 4 - the conditions on Earth and how they're suitable for habitability since relatively quickly after Earth's formation; Chapter 5: how life has taken advantage of Earth's habitability and all the different environments it can strive in

This Chapter: we'll discuss the origin of life on Earth, its evolution and how we came to be

1. Searching for Life's Origins

How do we begin to search for the origins of life on Earth?

- The geological record → incomplete, many rocks didn't survive the first 500 million years of Earth's formation
- Evolution → tells us how different life forms evolve from one another, but not how the first life organisms were formed

→ We need to look for clues regarding the origin of life on Earth and conduct experiments that simulate the conditions in which life might have arisen on early Earth

***When** did life begin?*

The only way we can determine when life began if by dating fossils and organic material embedded in rocks. The estimate we get on the time of origin of life is as old as the oldest found fossil. However, we need to know where exactly to look for these potentially very old fossils.

- *Stromatolites* - meaning "rock beds" in Greek are rocks with typical, layered structure. Living stromatolites today are formed by colonies of microbes that are intermixed with sediment. The microbes at the top generate energy through photosynthesis, while those below feed off of the waste produced by the ones in higher layers. As sediments are deposited over the microbial colonies, they need to migrate higher up to remain in conditions to which they're adapted to. This creates the layered structure of the rocks. There are ancient stromatolites that do not contain any living microbes, but are similar in structure to the living stromatolites, which has led scientists to believe their origin is also organic, which would make them fossils of ancient life. The structure of stromatolites and chemical analysis, offers strong evidence for the existence of life on Earth 3.5 billion years ago. If some of these ancient microbes were also using photosynthesis for generating energy, then it suggests that simpler life might have existed a long time before that too. → stromatolites: 3.5 billion years ago

- *Microfossils* - individualized fossilized cells. We know that ancient life was entirely microbial and microscopic, so recognizing and isolating microfossils from rocks is not an easy task. Most have been probably destroyed by geological processes. And they're not completely "obvious" and sometimes are indistinguishable from mineral structures in rocks. Therefore, discovery of "the oldest microfossils" is usually accompanied by a controversy of whether those are actual microfossils. How do we confirm that a found structure is of biological or mineral nature? - we look for clear cellular structure and metabolic byproducts. Oldest microfossils: 3.426 billion years (strong evidence), 3.465 billion years (controversy over biological origin)

- *Isotopic evidence* - living organisms can change the ratios of isotopes from their non-organic values. The most prominent one is carbon, whose isotopes in nature can be found in constant ratio (C13 accounts for 1 out of every 89 carbon atoms). The metabolic processes in living organisms favor C-12 (easier to incorporate in organic material, stronger bonds, etc), therefore when carbon is taken up from the atmosphere or inorganic material and incorporated into living organisms, there's always more C-12 atoms because of life's preference towards them. Analysis of the ratios of C-12 and C-13 isotopes can reveal the existence of ancient organic life in old rocks. The oldest found rocks believed to contain evidence for life are found in Greenland and dated to 3.85 billion years ago. There is controversy over their biological origin as well, however other rocks have been found with the life ratios of C in other places on Earth, also dating to 3.8 billion years ago. C is also not the only element whose isotope ratios are different in living organisms - iron, nitrogen, sulfur follow the same rule and their living organism ratios have been measured in these ancient rocks as well.

Conclusions: stromatolites (3.5 billion years ago), microfossils (3.4 billion years ago) and isotope ratios (3.8 billion years ago) all offer evidence that life on Earth existed relatively early in its history. For us to be able to find and measure all of these different indicators, life on Earth must have been widespread by then, suggesting it may have originated even much earlier than that, which would mean that life on Earth arose quite early in its history.
What does this tell us about life elsewhere? - either Earth was really lucky or life is quite common in the Universe.

What *did early life look like?*
To determine what early life looked like, we resort to mapping the tree of life through DNA sequencing. We know that organisms evolve through mutations in their DNA, therefore the closer their DNA sequences are, the more recently they have evolved from a common ancestor. DNA mutations "add up" so we can trace this evolution to earlier and earlier ancestors by tracking back the similarities and differences in the DNA sequences of all organisms on Earth. DNA sequencing: bacteria, archaea, eukarya and their branching. Organisms on the roots of the branches are closer to the common ancestor of all life. We know that early life was obviously microscopic, but not much can be said at the moment. Scientists believed that most early life was extremophiles, but the DNA sequencing studies show some non-extreme archaea that are genetically similar to earliest life forms.
http://www.onezoom.org/
https://www.sciencemag.org/news/2015/09/first-comprehensive-tree-life-shows-how-related-you-are-millions-species

Where *did life begin?*

It's unlikely that life began on land. During the early days of Earth, there was no ozone layer to protect Earth from harmful UV radiation. Although some extremophiles today can survive high radiation, it is much more likely that life could thrive in places where it was protected from it and had sources of energy.

One hypothesis (Darwin) claims that early life could have arisen in shallow ponds, where the organic compounds for life can be spontaneously formed. Because they need to be close to each other to give rise to more complex organisms and metabolic processes, this hypothesis uses the fact that the Moon was closer to Earth, causing more prominent tides, which would push the organic compounds closer to the edges of the ponds. There, though energy from volcanic hot springs, life could have arisen. Problem: shallow water does not offer much protection from UV. Also more susceptible to destruction from impacts and geological events.

Deep sea or underground life near volcanic vents - provide enough chemical energy, as well as the reactions between minerals and rock. Deep sea life would be better protected and have better chances to survive. Therefore, even though the earliest life might have arisen in shallow ponds, it is most likely that life that has migrated to deep sea or originated there that has survived the early days of Earth.