Astrophys Space Sci (2008) 317: 267–278
DOI 10.1007/s10509-008-9876-6

INVITED REVIEW

Origin of Life

Ashwini Kumar Lal

Received: 16 April 2008 / Accepted: 15 July 2008 / Published online: 10 October 2008

Abstract The evolution of life has been a big enigma despite rapid advancements in the field of astrobiology, microbiology and genetics in recent years. The answer to this puzzle is as mindboggling as the riddle relating to evolution of the universe itself. Despite the fact that panspermia has gained considerable support as a viable explanation for origin of life on the earth and elsewhere in the universe, the issue, however, remains far from a tangible solution. This paper examines the various prevailing hypotheses regarding origin of life-like abiogenesis, RNA world, iron–sulphur world and panspermia, and concludes that delivery of life-bearing organic molecules by the comets in the early epoch of the earth alone possibly was not responsible for kick-starting the process of evolution of life on our planet.

Keywords Abiogenesis · Panspermia · LUCA · Microbes · Thermophiles · Extremophiles · Cyanobacteria · DNA · RNA · RNA world · Iron–sulphur world · Miller–Urey experiment · Comets

1 Introduction

The question of the evolution of life on the earth and elsewhere in the universe has ever been as challenging as the question of evolution of the universe itself. Science does not provide authentic explanation regarding the origin of the universe in the controversial “Big Bang” (Arp et al. 1990) theory for evolution of the universe, nor does it provide any satisfactory explanation regarding the origin of life despite considerable advancements in the fields of astrobiology, genetics and microbiology in recent years. The “Big Bang” model for evolution of the universe is not secure enough to serve as a foundation for beliefs about the origin of life, which is exemplified very much by the fact that the most distant galaxies we can see today look as rich and fully evolved as our own, even though they are theoretically only 5% as old as revealed in the Hubble Ultra Deep Field (HUDF) images taken with Hubble’s advance camera for surveys and near infrared camera. Among the several factors leading to beginning of life on this planet, “panspermia” appears to provide the most favoured hypothesis for emergence of life on our planet. This paper examines the various prevailing hypotheses regarding origin of life on this planet. It also hints at a very interesting and crucial inference that probably delivery of life-bearing organic molecules by the comets in the early history of earth alone was not sufficient to provide the requisite trigger mechanism for initiation of life on our planet.

A.K. Lal (✉)
Ministry of Statistics and Programme Implementation,
Sardar Patel Bhawan, Parliament Street, New Delhi 110001, India
e-mail: akl1951@yahoo.co.in

2 Early earth and beginning of life

Earth formed as part of the birth of the solar system about 4.6 billion years ago. It was then very different from the world known today (Rollinson 2006; Ehrenfreund et al. 2002). There were no oceans and oxygen in the atmosphere. During the period 4.3–3.8 billion years ago (the Hadean Epoch), it is believed to have undergone a period of heavy meteoric bombardment for about 700 million years. It was bombarded by planetoids and other material leftovers from the formation of the solar system. This bombardment, combined with heat from the radioactive breakdown, residual heat, and heat from the pressure of contraction caused the

planet at this stage to be fully molten. Heavier elements sank to the center while the lighter ones rose to the surface producing earth's various layers. The early earth was lifeless and simply inhospitable with its atmosphere dominated by the surrounding materials from the solar nebula, especially light gases such as hydrogen and helium. The planet is believed to have cooled quickly with formation of solid crust within 150 million years, and formation of clouds in about 200 million years. The subsequent rains gave rise to the oceans within 750 million years of earth's formation, making it a habitable planet for the first time in its history. It may not be out of place to mention here that liquid water is the most essential ingredient to trigger the beginning of life. Water provides an excellent environment for the formation of complicated carbon-based molecules that could eventually lead to the emergence of life. Steam escaped from the crust while more gases were released by volcanoes, creating the second atmosphere in earth's early history. Life on earth may have emerged during or shortly after the early heavy bombardment phase, perhaps as early as 3.90–3.85 billion years ago, but the precise timing remains uncertain. A prebiotic reducing atmosphere, if present, predicts that building blocks of biopolymers—such as amino acids, sugars, purines, and pyrimidines would be formed in abundance (Ehrenfreund et al. 2002). Recent modeling of the earth's early atmosphere, however, suggests that the new atmosphere probably contained ammonia, methane, water vapor, carbon dioxide, nitrogen, and a trace of other gases. It is generally believed that until 2.4 billion years ago, the earth's atmosphere was generally devoid of oxygen. Volcanic activity was intense and without an ozone layer to hinder its entry, ultraviolet radiation flooded the surface. Thus, the early earth was just one big chemical evolution experiment (Rollinson 2006). Many scientists now believe that dust particles from comets and meteriorites—rich in organic compounds, rained down on early earth which are believed to have provided an important source of molecules that gave rise to our life on our planet.

As per the conventional hypothesis, the earliest living cells emerged as a result of chemical evolution on our planet billions of years ago in a process called "abiogenesis" connoting generation of life from nonliving matter. The term is primarily used to refer to theories about the chemical origin of life, such as from a primordial sea, and most probably through a number of intermediate steps, such as nonliving but self-replicating (biopoiesis). The first indications of life on the earth come from fossils and carbon inclusion in rocks. The western Australian greenstones, together with similar rocks from Greenland and South Africa are some of the oldest rocks on the earth. As per the palaeontogical findings relating to the beginning of life on earth, "stromatolites," the oldest microfossils (dome-shaped clumps of bacteria) relating to 11 species of bacteria found in the archaean rocks from western Australia date back to around 3.5 billion years (Schopf et al. 2002). They are colonial structures formed by photosynthesizing "cyanobacteria" (blue-green algae) and other unicellular microbes, and are believed to be the "last universal common ancestor" (LUCA). Cyanobacteria produced oxygen as a by-product of photosynthesis, like today's plants, and played a vital role in the history of our planet. This "LUCA cell" is the ancestor of all cells, and hence all life on earth. Even older rocks from Greenland, believed to be more than 3.8 billion years old, contain isotopic fingerprints of carbon that could have belonged only to a living being.

In a 1996 paper published in *Nature*, Mojzsis and his-coworkers had reported controversial evidence of ancient life dating back to some 3.86 billion years ago found in a rock formation on Akilia Island in west Greenland (Mojzsis et al. 1996). Scientists look for evidence of life in ancient rocks like those from Akilia Island by searching for chemical signatures and isotopic evidence. The carbon isotope change on the Akilia Island rock sample, analyzed with high-resolution microprobe, gave an indication of emergence of life on earth at least 3.86 billion years ago. This was at the end of the period of heavy bombardment of the earth by comets and meteorites. The researchers found that the ratio of carbon-12 to carbon-13 was 3% higher than would be expected if life were not present. Since living organisms use the lighter carbon-12, rather than the heavier carbon-13, a lump of carbon that has been processed by a living organism has more carbon-12 atoms than one found in other places in nature. Recently, Manning et al. (2006) at the UCLA Department of Earth and Space Sciences have mapped an area on the Akilia Island where ancient rocks were earlier discovered by Mojzsis and his teammates to preserve carbon-isotope evidence for life at the time of their formation. Their findings, as reported in the *American Journal of Science*, lend credibility to the fact that these rocks are 3.86 billion years old and contain traces of ancient life (Penny and Poole 1999). At the time of the 1996 *Nature* paper, there was no reliable map showing the geology of the area.

The earliest form of life was a prokaryote, unicellular bacteria possessing a cell membrane and probably a ribosome, but lacking a nucleus or membrane-bound organelles such as mitochondria or chloroplasts that thrived in aquatic environments, and ruled the earth in its early history (3 billion to 1.5 billion years ago). Like all modern cells, it used DNA as its genetic code, RNA for information transfer and protein synthesis, and enzymes for catalyzing reactions (Penny and Poole 1999). For a long time in the history of earth, the land remained barren of eukaryotes—complex multicellular organisms comprising plants and animals including us humans. Eukaryotic cells developed about 1.5 billion years ago in a stable environment rich in oxygen. The oldest fossils of land fungi and plants date to 480 million to 460 million years ago, though molecular evidence suggests the fungi may have colonized the land as early as