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Review Article: Origin of Life on the Planet Earth: A Brief Review

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ABSTRACT

Understanding the beginning of life on planet Earth has always been a captivating and scientifically very important and dynamic topic. The purpose of this study is to provide a concise review of some issuesrelated to the origin of life (OoL) on early Earth and stimulate further research into this important area of science. This brief review highlights the significance of the primordial soup as a nutrient-rich chemical mix in Earth's early oceans, and the Stanley Miller and Harold Urey experiment. Furthermore, it provides a brief description of the fundamental building blocks of life, such as lipids, nucleic acids (deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)), proteins, and the role of entropy in chemical evolution. The results indicated that our understanding of the OoL continues to advance through interdisciplinary research and innovative experiments. As scientists delve deeper into the origins of life, we can anticipate further breakthroughs that will deepen our understanding of our own existence and the possibilities of life beyond Earth.

Introduction

Life as a relationship between the living and the non-living-this divine bestowal-is flowing on the mysterious planet Earth, and nowhere in the universe like it has been discovered yet. On the other hand, throughout history, the origin of life (OoL) has captivated the minds of philosophers and scientists as an important and very challenging subject [1,3]. From ancient Greece to the present day, humanity has been intrigued by the mysteries surrounding the emergence of life on Earth.Moreover, studying the OoL is a complex and fascinating scientific pursuit that involves multiple disciplines, including prebiotic chemistry, biology, and geology [3-7]. Life on Earth began through non-living processes after the formation of our solar system approximately 4.6 billion years ago[8,9]. The incredible diversity of life we see today is the result of the gradual and intricate process of evolution by natural selection, which has been unfolding over billions of years [10-12].However, to understand the OoL itself, which is one of the unsolved scientific questions of the century, we should explore a different concept called abiogenesis (see Scheme 1). In fact, abiogenesis deals with how living organisms first emerged from nonliving matter [1,13-17].

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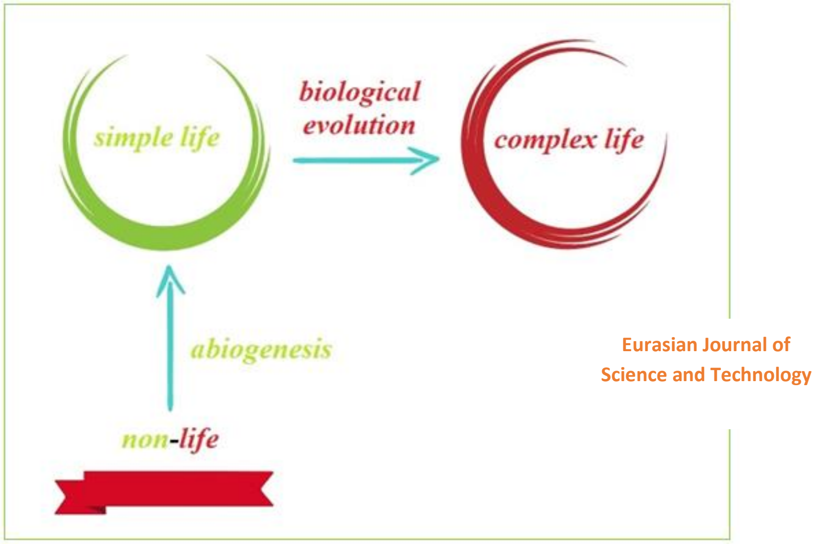


Scheme 1 The abiogenesis and biological evolution [1,8,18]

It is important to note that life arose only once in a markedly different environment from what we experience today. Therefore, understanding the conditions of early Earth is crucial in unraveling the OoL [3,19]. Various hypotheses have been proposed by scientists regarding the primary sources of life on Earth. Some suggest that organic molecules originated near hydrothermal vents on the ocean floor, where heat from the Earth's core facilitated chemical reactions that could have produced diverse organic compounds. Others suggest that mineral-rich tidal pools provided optimal conditions for diverse stimulation to occur on solid surfaces, contributing to the OoL.

In addition, the panspermia theory, which was advanced in 1865 by German physicist Hermann E. Richter, contends that the first organic molecules were brought to Earth by meteorites from space. Although there is no universally accepted theory on the OoL, credible proposals indicate that a combination of chemical and molecular evolution over a significant period may have led to the emergence of simple life forms [20-29].

The primary objective of this article is to provide a concise overview of some issuesrelated to the OoL on early Earth. By doing so, readers can gain a clear understanding of this important and fascinating scientific issue (OoL). Furthermore, its secondary purpose stimulates further research into this important area of science.

The Primordial Soup

The environment of early Earth was tumultuous, with frequent volcanic eruptions and meteor impacts shaping the landscape. In such a chaotic setting, the concept of the primordial soup emerged. In fact, the aqueous solution of organic compounds that accumulated in primitive water bodies of the early Earth due to endogenous chemical syntheses and extraterrestrial delivery through cometary and meteoritic collisions is known as the primordial soup. In the 1920s, Russian biologist Alexander Oparin and British evolutionary biologist and geneticist John Haldane proposed the theory of primordial soup. According to this theory, Earth's oceans contained a nutrient-rich chemical mixture that created favourable conditions for the emergence of life. This idea suggests that the essential building blocks of life, such as amino acids, could have formed within this vast array of chemical possibilities [18,23,30-43].

However, the OoL on Earth most likely occurred through countless natural experiments, in which various combinations of organic molecules mixed and recombined to form complex interacting systems [9,31,44,45].

The Miller and Urey Experiment

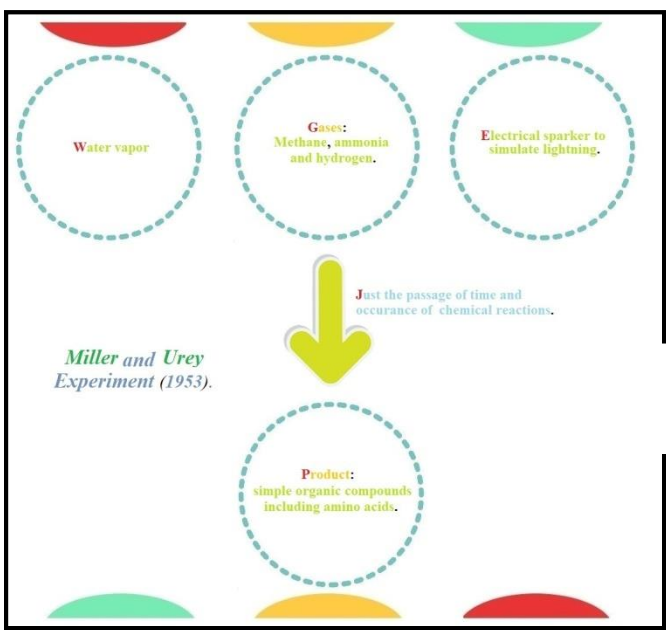
The publication of Stanley Miller and Harold Urey's experiment in 1953 marked a significant milestone in the scientific exploration of the OoL [46].

Their findings sparked further speculation about the formation of the first primitive cell.Miller and Urey aimed to shed light on life's origins by recreating early Earth conditions in a laboratory. They created an apparatus that replicated the environment that emerged after Earth cooled sufficiently for liquid water to be present. Their experiment involved combining water (H_2O), methane(CH_4), ammonia(NH_3), and hydrogen (H_2), which they then subjected to heat and an electric current to simulate lightning (Scheme 2).

Surprisingly, after just one week, they discovered the presence of various amino acids-a vital building block of proteins (all living things contain the extremely complex material known as protein, which is directly engaged in the chemical reactions necessary for life). Since proteins contain enzymes that catalyze the formation of nucleic acids (are biomolecules that contain genetic information) like deoxyribonucleic acid (RNA) and deoxyribonucleic acid (DNA), this experiment provided compelling evidence that the necessary materials for life could be spontaneously generated [8,47-55].

The Essential Components of Life

Lipids (which provide the foundation for the structure and function of living cells), nucleic acids, and proteins are the three essential components of all living things, and understanding them is very important to understanding abiogenesis. These components had to be present in the primordial soup from which life originated. Lipids, which form the cell membranes, play a significant role in abiogenesis. Their unique structure enables them to assemble into spherical structures when immersed in water. These structures



Scheme 2 Stanley miller and Harold Urey experiment (1953) [33, 46]

create boundaries within the primordial soup that could facilitate self-replication. Previously, it was believed that lipids only came from living cells. However, experiments have shown that lipids can be formed through the heating of carbon monoxide and hydrogen with minerals commonly found in the Earth's crust. These components were readily available in the early Earth and could have been produced in hydrothermal vents found in underwater environments. The presence of certain ions, such as salts or magnesium, poses a challenge as they disrupt lipid structures. Recent research has discovered a solution: lipid spheres can remain intact in the presence of amino acids, the building blocks of proteins. Amino acids can be encapsulated within lipid membranes, allowing them to interact and potentially form proteins. This finding sheds light on how lipids and proteins may have played a role in the abiogenesis, relying on each other's presence to survive in ion-rich environments [23,31,45,56-60].

The second crucial component for life is nucleic acids, particularly RNA [8,50]. RNA is thought to have been the essential precursor leading to the first living matter, with DNA assuming the role of storing and replicating genetic information later. However, the exact process of the first RNA molecule's formation from nonliving chemicals remains uncertain. Researchers have been able to demonstrate the formation of RNA-like molecules on clay surfaces, which act as catalysts for bringing RNA bases together. Similarly, they have proposed that RNA building blocks could have polymerized in the early Earth's shallow ponds through organic molecules from meteorites and interplanetary dust [31,61-68]. In addition, proteins, consisting of amino acids, are the third crucial component of life. Scientific experiments have demonstrated that under the atmospheric conditions of the early Earth, amino acids and other organic compounds can naturally arise [70-74]. The precursors for proteins were likely present from the early stages of Earth's formation. Nevertheless, the challenge lies in comprehending how these intricate molecules come together to form self-replicating living cells. While the precise mechanism remains elusive, it is important to acknowledge that life likely evolved gradually through simpler incremental steps, increasing the chances of occurrence. Indeed, the evolution process through natural selection provides an explanation for life's journey from simple organisms to the diverse array of species that currently inhabit planet Earth. The early Earth's diverse range of environments presented numerous opportunities for chemical interactions and the formation of life's fundamental building blocks [8,10,13,18,19, 75-82].

The Role of Entropy in Chemical Evolution

The concept of entropy emerged in the physical sciences during the nineteenth century, particularly in thermodynamics and statistical physics. It serves as a measure of equilibria and evolution of thermodynamic systems [5,82,83].

The entropy may be the driving force behind chemical evolution that results in biological functioning. This concept could provide further insights into the connection between thermodynamics and biological functioning. In fact, entropy is a term that initially came from thermodynamics and describes a system's propensity to gravitate towards disorder and a higher energy state. This concept suggests that when molecules are exposed to an external source of energy, they rearrange themselves to dissipate more energy. This process of energy capture and conversion distinguishes living organisms from nonliving entities and could be the driving force behind chemical evolution [8,84-89].

Conclusion

The results of the current study led to the following conclusions:

(1) The OoL on Earth remains a captivating and very complex scientific inquiry. Although

the exact mechanisms and processes by which lifeemerged are not yet fully understood, significant progress has been made in unraveling the mysteries surrounding this subject.

(2) The study of abiogenesis, which focuses on the emergence of living organisms from nonliving matter, provides valuable insights into the early Earth's conditions and the potential sources of organic compounds.

(3) The concept of primordial soup, an aqueous solution of organic compounds, has shed light on the possibility of life's emergence through natural chemical interactions.

(4) Scientists have proposed various theories, including the hydrothermal vent hypothesis, the tidal pool hypothesis, and the panspermia hypothesis, each presenting compelling arguments for the OoL.

(5) The Miller and Urey experiment demonstrated the spontaneous generation of essential building blocks of life, such as amino acids.

(6) Lipids, nucleic acids, and proteins have been identified as essential components in the OoL.

(7) Entropy may play a crucial role in chemical evolution leading to biological functioning.

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