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GSF Focus

The naked planet Earth: Most essential pre-requisite for the origin and evolution of life

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A B S T R A C T

Our blue planet Earth has long been regarded to carry full of nutrients for hosting life since the birth of the planet. Here we speculate the processes that led to the birth of early life on Earth and its aftermath, finally leading to the evolution of metazoans. We evaluate: (1) the source of nutrients, (2) the chemistry of primordial ocean, (3) the initial mass of ocean, and (4) the size of planet. Among the life-building nutrients, phosphorus and potassium play a key role. Only three types of rocks can serve as an adequate source of nutrients: (a) continent-forming TTG (granite), enabling the evolution of primitive life to metazoans; (b) primordial continents carrying anorthosite with KREEP (Potassium, Rare Earth Elements, and Phosphorus) basalts, which is a key to bear life; (c) carbonatite magma, enriched in radiogenic elements such as U and Th, which can cause mutation to speed up evolution and promote the birth of new species in continental rift settings. The second important factor is ocean chemistry. The primordial ocean was extremely acidic (pH = 1–2) and enriched in halogens (Cl, F and others), S, N and metallic elements (Cd, Cu, Zn, and others), inhibiting the birth of life. Plate tectonics cleaned up these elements which interfered with RNA. Blue ocean finally appeared in the Phanerozoic with pH = 7 through extensive interaction with surface continental crust by weathering, erosion and transportation into ocean. The initial ocean mass was also important. The birth of life and aftermath of evolution was possible in the habitable zone with 3–5 km deep ocean which was able to supply sufficient nutrients. Without a huge landmass, nutrients cannot be supplied into the ocean only by ridge-hydrothermal circulation in the Hadean. Finally, the size of the planet plays a crucial role. Cooling of massive planets is less efficient than smaller ones, so that return-flow of seawater into mantle does not occur until central stars finish their main sequence. Due to the suitable size of Earth, the dawn of Phanerozoic witnessed the initiation of return-flow of seawater into the mantle, leading to the emergence of huge landmass above sea-level, and the distribution of nutrients on a global scale. Oxygen pump also played a critical role to keep high-PO_2 in atmosphere since then, leading to the emergence of ozone layer and enabling animals and plants to invade the land.

To satisfy the tight conditions to make the Earth habitable, the formation mechanism of primordial Earth is an important factor. At first, a 'dry Earth' must be made through giant impact, followed by magma ocean to float nutrient-enriched primordial continents (anorthosite + KREEP). Late bombardment from asteroid belt supplied water to make 3–5 km thick ocean, and not from icy meteorites from

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Kuiper belt beyond cool Jupiter. It was essential to meet the above conditions that enabled the Earth as a habitable planet with evolved life forms. The tight constraints that we evaluate for birth and evolution of life on Earth would provide important guidelines for planetary scientists hunting for life in the exo-solar planets.

1. Introduction

The origin of Universe, and the birth and evolution of life on Earth finally leading to the human race constitute important topics in natural science. Since the first successful synthesis of amino acids and related organic compounds by Miller (1953), a number of laboratory experiments have been performed which revealed the importance of catalyzers, role of nutrients, and physical and chemical environments on the primordial Earth to bear life (e.g., Dyson, 1982; Nisbet et al., 1995; Nisbet and Sleep, 2001; Nisbet, 2002; Russell and Arndt, 2005; Russell, 2007).

On the standpoint of planetology, the concept of habitable planet defines it as water-covered, depending on the distance from the central star to the particular planet in the star-planet system. The Earth fits in this framework as only one rocky planet; Mars is frozen, and Venus is too hot for liquid water (Fig. 1). A habitable planet must automatically yield life, which eventually leads into evolved life such as animals in the case of Earth. The hunt for planets outside our solar system (exoplanets), where blue oceans with dense oxygen-bearing atmosphere must be present, is now a frontier area with the speculation that large animals may be surviving on other planets and that such life could be a common phenomenon in the Universe. Our Milky Way Galaxy is composed of 100,000,000,000 stars; among these if 1% of stars acquire planets, presumably more, our Milky Way Galaxy may be full of rocky planets with ocean, and at least more than a few million Earth-like planets can be predicted.

This contribution evaluates the evolution of life on Earth and speculates the scenario of life on other planets, and derives conclusions that contradict the more optimistic views. Our arguments arise from long-term multi-disciplinary research on the origin and history of life on the Earth and the identification of the most critical factors relating to the initial condition of Earth when the planet was born at 4.56 Ga. The most important initial conditions were the size of the planet and a small amount of water contained within only 3–5 km thick ocean; we therefore call the Earth as naked planet in this paper.

2. Nutrients supply: where from?

The key functions for the origin and evolution of life are nutrients and mass of ocean. Life cannot be synthesized under nutrient-free conditions in an atmosphere as shown in the famous experiments of Miller (1953). Life can be considered to comprise three major systems with super-molecules (molecular number as large as 10^9) enclosed by membrane (Fig. 2). These three components are C (carbon)-centered sugar for fuel, P (phosphorous)-centered metabolism, and N (nitrogen)-centered information coding by basic pairs (DNA). For life to function, these three components are critical. Among these, P (negative ion) is a centered nutrient, which, coupled

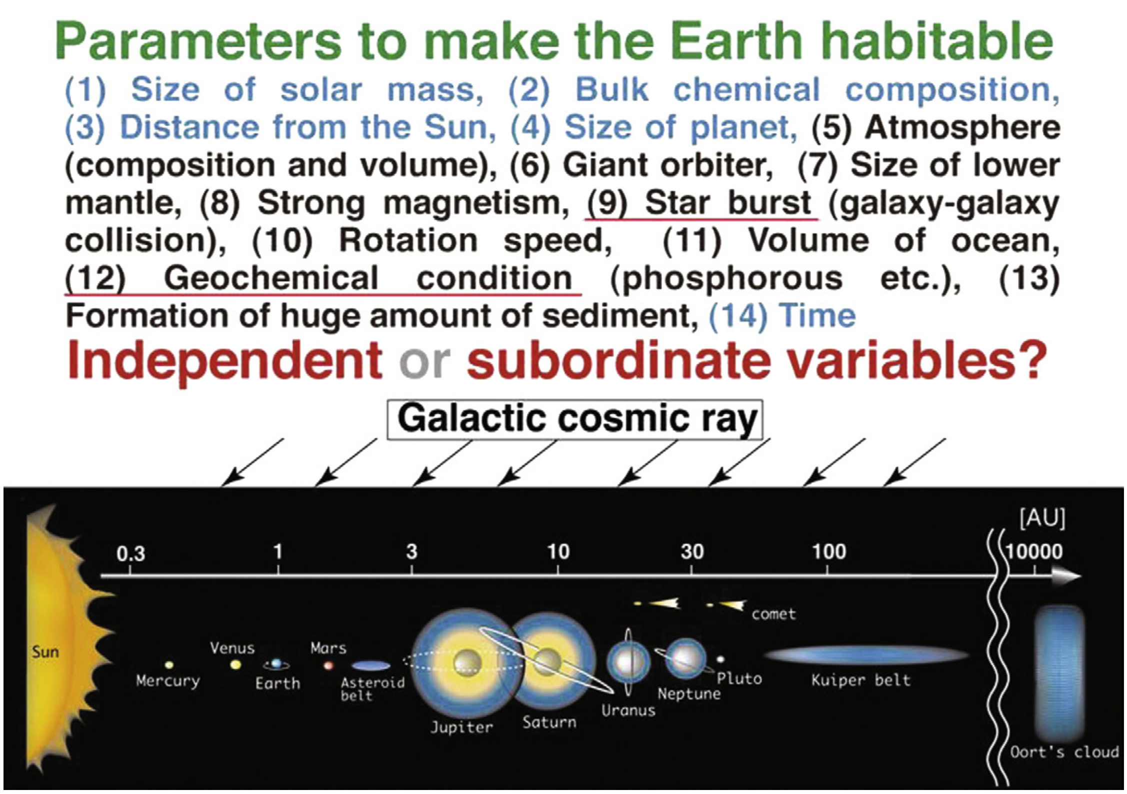

Figure 1. Habitable planets as a function of distance from the central star, Sun, in our solar system. The upper portion shows the parameters to make the Earth habitable. Fourteen major parameters are identified. Note that all of these are not independent functions.