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Habitable Trinity: a new concept of a habitable environment beyond Earth

J.M. Dohm and S. Maruyama
Earth-Life Science Institute, Tokyo Institute of Technology, Meguro, Tokyo, Japan 152-8551 (jmd@hwr.arizona.edu)

Abstract

Habitable Trinity, which is a newly proposed concept of a habitable environment for searching for life beyond Earth, is the coexistence of an atmosphere (consisting largely of C and N), an ocean (H and O), and a landmass (supplier of nutrients). It is the minimum requirement for the beginning of life as we know it.

1. Introduction

A habitable planet has largely been defined as having an adequate climate, which includes a sufficient atmosphere [1,2], as well as the presence of liquid water on its surface [3]. In addition to these parameters, planetary radius, density, escape velocity, surface temperature, and bulk composition have formed the basis for developing indexes to search for potential habitable exoplanets; over eight hundred exoplanets have been confirmed to date, and of those nearly ten potential habitable planets have been identified (based from PHL@UPR Arecibo). Recently, icy satellites such as Europa have been the foci to discuss the possibility of the presence of life under ice sheets, and even the possible presence of evolved multi-cellular organisms, such as fish-like life [4].

The presence of an atmosphere (C and N), an ocean (H and O), and a landmass (nutrients) are minimum chemical-composition requirements for life. In addition, steady-state material circulation is necessary to bear life. On the surface of the Earth, the Sun drives a steady-state supply of energy circulated among the atmosphere, ocean, and landmass, which we call Habitable Trinity. The Habitable Trinity, a triple point for life through the interface among water, solids, and gas (**Fig. 1**), which can maintain organic radical reactions, is proposed as a new definition of a habitable environment.

In order for life to persist, energy circulation must be maintained between the atmosphere, ocean, and landmass (dynamic equilibria for life-sustaining environment). The sun drives the hydrological cycle, which includes precipitation and resulting chemical weathering of the continental rocks, as well as erosion and transport of rock materials via far-reaching (from orogenic continental divides to the oceans), first as boulders and rocks and finally as ions for life to ingest (**Fig. 1**). Aeolian activity also supplies the oceans with nutrients, but to a much lesser degree when compared to the river systems that concentrate huge volumes of nutrient-enriched sediments along the continental shelf, slope, and rise. A continuous nutrient supply is critical for life to originate, develop, duplicate, and evolve.

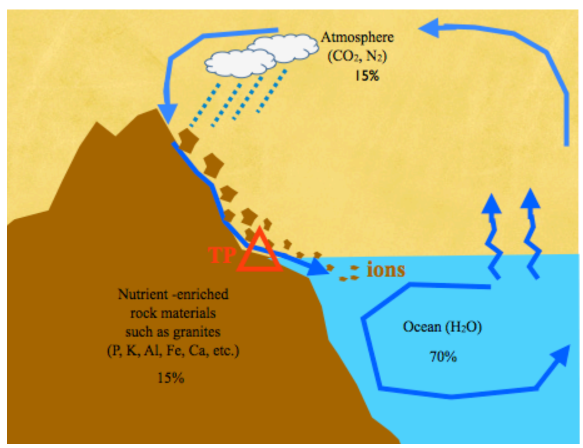

Figure 1. Life is composed of: (1) water (ocean = 70%), (2) C and N (atmosphere = 15%), and nutrients (solid Earth = 15%). All of these combined enables organic radical reactions. For life to exist and flourish, a triple point among the atmosphere, ocean, and landmass (nutrient-enriched rocks such as granite) must exist. Energy/material circulation is driven by the Sun, including hydrological cycling, which includes chemical weathering, erosion, and transport of nutrient-enriched materials to the oceans (boulders to rocks to eventually ions ingestible for life).

The Habitable Trinity concept goes beyond the "follow-the-water-approach", providing an index in the quest for life-containing planetary bodies beyond our solar system as the reconnaissance systems become increasingly autonomous and at higher resolution, affording greater perspective during this golden age of international and interdisciplinary exploration and discovery.

2. Discussion

The concept of Habitable Trinity, which is based on the geologic and biologic evolution of the Earth informed through [5, 6], can be applied to any planet and satellite to optimize the search for life beyond Earth. As such, an index of parameters to optimally search for life on the planetary bodies of our solar system and exosolar planets must start with the three primary Habitable-Trinity components: landmass, atmosphere, and ocean. In the following, going beyond the "follow-the-water-approach", we apply Habitiable Trinity to Mars and Europa.

2.1 Mars

Likely concurrent with the shut down of the dynamo, Habitable Trinity vanished from the surface of Mars a long time ago (nearly 4 Ga); the most Earth-like planet of our solar system once had an interfacing ocean, atmosphere, and landmass with energy circulation driven by the Sun and possible plate tectonism [7]. Mars is therefore a prime candidate target for testing the hypothesis of whether life exists beyond Earth in our solar system.

If life was born on Mars, could it have evolved into large animals? The answer is no. Life would have remained relatively simple as recorded on early Earth. This is because of its size and rapid cooling, when compared to the Earth, and thus an ocean and atmosphere were lost before life could evolve into more complex organisms. However, this does not mean that Mars is dead, both in terms of internal heat energy and aqueous activity, highlighted in the Tharsis-Elysium corridor region where geologically recent volcanism, tectonism, and hydrologic activity is observed [8]. Thus, life may have a chance to persist through time for at least parts of Mars.

2.1 Europa

Is there life under the ice sheet that totally envelops Europa, a satellite of Jupiter? Europa is mainly composed of an ice-covered ocean [9]. The possibility of the presence of life under an ice sheet which envelops a planetary body such as Europa is derived from the traditional concept of habitable planet because liquid water is present. However, Habitable-Trinity conditions do not exist on Europa, as it is composed of an ice-covered ocean with no nutrient-enriched continental crust and a tenuous atmosphere of mostly O_2. In such an environment, amino acids and proteins are difficult to form as there is not a steady-state supply of nutrients; there is no landmass to source nutrients, and even if there was a sufficient atmosphere composed of elements such as C and N, which is not the case, there would not be input to the ocean due to the ice barrier. Without a sufficient supply of elements, life is unlikely to be born. Such a planetary environment is consistent with an extraordinary Snowball Earth that would totally envelop the Earth in ice, shutting down the circulation of nutrients among the components of the Habitable Trinity; a total ice cover which would lead to a much greater mass extinction of life beyond that recorded during Snowball-Earth events during which time there was subaerially exposed landmass (i.e., volcanoes and associated hydrothermal systems) [5,6]. In fact, could life have persisted at all following such conditions?

3. Summary

A new approach is proposed here which we call "Habitable Trinity", a new paradigm in the hunt for prime life-containing objects (solar planets/satellites and extrasolar planetary bodies), including providing an index for the life-hunt. The index must include mass of an ocean, atmospheric composition, and landmass including its geochemistry (e.g., granite and/or KREEP). Mars is the best option in our solar system to test the hypothesis of whether life exists beyond Earth based on Habitable Trinity.

The Habitable-Trinity-based index, founded on the geologic and biologic evolution of the Earth [5,6], will inform future reconnaissance systems of much greater resolution than current exoplanet-seeking missions. The optimal search for life beyond our solar system would be exoplanets that at least contain an ocean, a landmass, and an atmosphere of sufficient compositions.

References

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