GLACIERS AND ICE SHEETS AS ANALOG ENVIRONMENTS OF POTENTIALLY HABITABLE ICY WORLDS

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Abstract

Icy worlds have attracted a remarkable attention as possible habitats for life [1]. On Earth, glaciers and ice sheets have been considered uninhabited for a long time as they seemed too hostile to harbor life. However, these environments are unique biomes dominated by microbial communities which maintain active biochemical routes. Thanks to techniques such as microscopy and more recently DNA sequencing methods, a great biodiversity of prokaryote and eukaryote microorganisms have been discovered. These microorganisms are adapted to a harsh environment, in which the most extreme features are the lack of liquid water, extremely cold temperatures, high solar radiation and nutrient shortage. Here we compare the environmental characteristics of icy worlds, and the environmental characteristics of terrestrial glaciers and ice sheets in order to address some interesting questions: (i) which are the characteristics of habitability known for the frozen worlds, and which could be compatible with life, (ii) what are the environmental characteristics of terrestrial glaciers and ice sheets that can be life-limiting, (iii) What are the microbial communities of prokaryotic and eukaryotic microorganisms that can live in them, and (iv) taking into account these observations, could any of these planets or satellites meet the conditions of habitability? In this review, the icy worlds are considered from the point of view of astrobiological exploration. With the aim of determining whether icy worlds could be potentially habitable, they have been compared with the environmental features of glaciers and ice sheets on Earth.

1. Introduction

Although possible life elsewhere may be different than it is on Earth, several minimum conditions of habitability have been defined: a solvent (water), a source of energy, a group of biologically essential elements (on Earth they are H, C, N, O, S, and P) [2-4] and some physicochemical conditions (temperature, pH, water activity, etc.) (Fig. 1). The icy worlds of the solar system and beyond meet these conditions of habitability, but their magnitudes are different. It is necessary to know what the intervals of these values are to make them habitable.

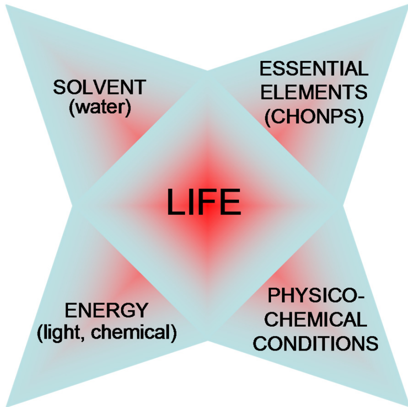

Figure 1. *Characteristics of habitability. Minimal conditions of habitability have been defined as: a solvent (water), a source of energy, a group of biologically essential elements (on Earth they are H, C, N, O, S, and P) and some physicochemical conditions (temperature, pH, water activity, etc.) [2-4].*

To know the limits of life, we must first establish what these limits are on Earth, since it is the only case we know. One of the most life limiting features on Earth is low temperature. Actually, the Earth can be considered a cold place. For instance, 90% of the Earth's oceans have a temperature of 5ºC or less. When terrestrial habitats are included, over 80% of the Earth's biosphere is permanently cold. Among terrestrial environments, 85% of Alaska, 55% of Russia and Canada, 20% of China, and the majority of Antarctica are permanently cold. In our solar system, six of the other eight planets are permanently cold, and hence understanding life's adaptations to cold environments on our planet should be useful in the search for and understanding of life on other planets. Living organisms that inhabit the more extreme environments on Earth are microorganisms. Among them, microorganisms inhabiting glaciers and ice sheets could be those that support the environment more similar to the conditions found in icy worlds [5].

2. Microbial communities living in glaciers and ice sheets

The discovery of cold-tolerant microorganisms in glaciated and permanently frozen environments has broadened the known range of environmental conditions that support microbial life. In glaciers and ice sheets, three different ecosystems have been considered: the supraglacial ecosystem, the subglacial system and the englacial ecosystem. These three ecosystems differ in terms of their solar radiation, water content, nutrient abundance and redox potential [6].

In icy satellites such as Europa, a similar environment could exist. Liquid water could be present in the subsurface ocean, containing materials derived from the original formation of the satellite. In addition, new compounds may have been produced by chemical reactions in the interior, reaching the surface by endogenic processes such as cryovolcanism or extensional tectonics. Additional material may be brought by comets or meteorites. N species could come from the surface crust; and CO2, SO42- and organic compounds could be expected due to meteoritic delivery. Other compounds such as HCN have been detected in other icy satellites such as Enceladus, Triton and Titan.

3. Environmental life-limiting characteristics of terrestrial glaciers and ice sheets

On Earth, three environments maintain very low temperatures throughout the year: poles, oceans and glaciers. Considering that a great diversity of microorganisms belonging to the three main domains (Bacteria, Eucarya and Archaea) has been discovered inhabiting glaciers, they have been considered biomes that should be recognized as such in their own right. The inhabitants of the glaciers have to be polyextremophiles, due to the diverse extreme conditions in which they live. Most of the microorganisms isolated from cold environments are psychotolerant and psychrophiles. In addition to the low temperatures, microorganisms from glaciers generally tolerate high solar radiation (radiophiles), scarce availability of water (xerophiles), and sometimes they can also bear extremely acidic media (acidophiles).

4. Conclusions

a) The icy worlds of the solar system most likely to harbor life are Europa and Enceladus. They are the only two recognized moons where liquid water could be in contact with rocks.

b) Other icy worlds could also contain a water ocean below the surface, but it would be included between layers of ice.

c) In the pursuit of life in other planets, it is widely recognized that the presence of liquid water is requirement for habitability. The existence in Earth glaciers of microbial communities that maintain active biochemical routes in englacial and subglacial ecosystems can broaden the scenarios in which life might be possible.

These findings open new questions to research: i) as the studies of enzymatic activity at very low temperatures (up to -196ºC) have mostly been carried out in the laboratory, could these metabolic activities be detected in situ in the coldest regions of Earth?, ii) are we using the best techniques to detect biosignatures on icy worlds?, iii) what will we find in upcoming missions to Europa and Enceladus?, iv) are there other new potential candidate worlds to be habitable?, iv) what characteristics of habitability can be found in exoplanets?

5. References

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