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The microbial case for Mars and its implication for human expeditions to Mars

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Abstract

Mars is considered as key target for the search of life beyond the Earth. As well as carbon based chemistry and an adequate energy source, water in liquid phase has been considered a prerequisite for habitability. By analogy with terrestrial extremophilic microbial communities, e.g., those thriving in arid, cold, salty environments and/or those exposed to intense UV radiation, potential oases on Mars are suggested. They are connected with areas where liquid water still exists under the current conditions, but also sulfur rich subsurface areas for chemoautotrophic communities, rocks for endolithic communities, permafrost regions, hydrothermal vents, soil or evaporite crusts are of interest. The presence of humans on the surface of Mars will substantially increase the research potential; however, prior to any human exploratory mission the critical issues concerning human health and wellbeing as well as planetary protection issues need to be investigated.
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1. Introduction

The quest for life on Mars has received increased attention within the current space exploration programs [1,2]. Mars with a mean distance to the Sun of 1.52 astronomical units is located at the outer border of the habitable zone encircling the Sun, which is estimated under the premise of the presence of liquid water on the planet's surface at some time during its 4.5 billion years lasting history [3]. Furthermore, there is now growing evidence that the physical and chemical surface properties of early Earth and Mars were very similar [4]. Geological erosional features, observed from Mars orbit and from landers, suggest that prior to 3.5 Ga ago the climate on Mars was wet and more temperate allowing the presence of large quantities of water on its surface [5,6]. At that time life had already started on Earth. Fossil record reveals that microbial autotrophic ecosystems existed on the early Earth already by 3.5 Ga or even 3.8 Ga ago [7]. Under the assumption, the life emerges at a certain stage of planetary evolution, if the right environmental physical and chemical requirements are provided, it is legitimate to assume that conditions on early Mars were as favorable for life to emerge as on early Earth.

2. Water and habitability of Mars

As well as carbon based chemistry and an adequate energy source, water in liquid phase has been considered

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as one of the prerequisites for habitability. Therefore, understanding the history of water on Mars appears to be one of the clues to the puzzle on the probability of life on Mars (reviewed in [6]). With the Mars Exploration Rover (MER) mission of NASA, the story of water on the red planet has been further unraveled. Especially in the Meridiani Planum, the landing site of the rover Opportunity, distinct layering in some rocks showed that water once flowed there on the surface of Mars, leaving ripple-like curves in the outcrop rocks. Bead-like objects, the so-called "blueberries", turned out to be rich in hematite, a mineral that requires water to form. The detection of sodium chloride which only forms when water has been present is another indication of liquid surface water in the past of Mars [8]. More insight into the history of water on Mars has been obtained from measurements with the OMEGA (Observatoire pour la Mineralogie, l'Eau, les Glaces et l'Activité) instrument of the Mars Express mission of ESA [9]. The global mineralogical data provided further support to the supposition of an aqueous environment on early Mars, i.e. during the Noachian period (up to 3.5 billion years ago) indicated by the formation of clay minerals. This period, probably alkaline, was followed by a more acidic one in the Hesperian period (up to 1.8 Ga ago), as indicated by the massive occurrence of hydrated sulfate minerals. These conditions were driven by extensive outgassing of volatiles coupled with a rapid drop in atmospheric pressure. Liquid water was probably still present during transient and local events, such as volcanic activity, impact release or melting of ice deposits. During the last Amazonian period (up to present) Mars has been cold and dry, as also indicated by the presence of anhydrous ferric oxides [9].

The estimates of the total amount of water that may have existed at the surface of Mars range over two orders of magnitude. A low amount of water ranging from 3.6 to 133 m is suggested from the composition of the contemporary atmosphere, e.g. the D/H ratio [10]. On the other hand, the geological flow features provide evidence of abundant water at the surface of Mars, at least at some time in the past, assuming a global inventory of water of at least 440 m [11,12]. From the global neutron mapping of the Mars Odyssey mission, the present distribution of water in the shallow subsurface was divided in four types of regions: (i) regions with dry soil with a water content of about 2 wt%; (ii) northern permafrost regions with a high content of water ice (up to 53 wt% of water); (iii) southern permafrost regions with high content of water ice (> 60 wt% of water) covered by a dry layer of regolith; and (iv) regions with water-rich soil at moderate latitudes (about 10 wt% of water) covered by a dry layer of soil [6,13]. These water-rich regions are well separated from the Martian atmosphere by a rather thick layer of desiccated regolith. Therefore, it was supposed that they were formed long time ago, when the climate allowed liquid water at the surface.

The present atmosphere of Mars is too cold—the average surface temperature is $-65\,^{\circ}\mathrm{C}$—to support liquid water on the surface for long and too thin—the average surface pressure is 560 Pa—to support ice; especially at the equatorial regions any ice that does form will quickly sublimate into water vapor. Therefore, the current surface conditions of Mars do not allow liquid water to persist over longer periods. The search for putative extant Martian life must therefore concentrate on subsurface biological oases where liquid water still exists under the current conditions. More information has been provided by the on-board measurements of the spacecraft Mars Express and Mars Reconnaissance Orbiter, currently orbiting Mars. Prominent results of the current Mars Express mission are the detection of deep underground water-ice at the South Pole by the Mars advanced radar for subsurface and ionospheric sounding (MARSIS) instrument estimating a total volume of $1.6 \times 10^6\,\mathrm{km}^3$ of water, which is equivalent to a present global water layer of about 11 m [14], the discovery of large-scale explosive volcanism on recent Mars (about 350 Ma ago) [15], indications of relatively young volcanic activities in the north polar ice regions [16], and the global distribution of anhydrous and hydrated minerals [9].

3. Terrestrial extreme habitats as relevant for putative microbial oases on Mars

If life once started on Mars, the gradual decreasing pressure and temperature might have forced the emerging biota to retreat to some protective oases [17], where it might persist even today. Potential oases, to which putative life on Mars might have withdrawn are inferred from terrestrial analogues, such as deep subsurface rocks inhabited by cryptoendolithic microbial communities [18], the polar ice caps and permafrost regions [19], submarine or sub-ice hydrothermal vents [20] or other hydrothermal areas in connection with volcanic activities, or endoevaporites, i.e. microbial communities that live in salt crystals, e.g., halite or gypsum [21,22]. In the following terrestrial extreme habitats will be investigated, namely extremely dry environments, extremely cold environments, extremely salty environments, and those exposed to an intense flux of solar UV radiation, which may be considered as analogues for putative Martian oases.

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