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Heterogenous microbial habitability on Mars and its implications for the search for life

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Abstract

Using the term "habitability" only for conditions necessary for the origin of life and the proliferation of life, we discuss the heterogeneity of martian habitability in space and time ("punctuated" habitability), the implications for the level of evolution of putative martian life, as well as for *in situ* strategies to search for life on Mars.

1. Microbial habitability on Mars

Extraterrestrial habitability is a complex notion and, within this context, we use the term "habitable" only for conditions necessary for the origin of life and the proliferation of life. Not covered by this term would be conditions necessary for pre-biotic chemistry and conditions that would allow the recognition of extinct or hibernating life [1]. In principle, life should be able to emerge on any rocky planet having water in contact with rocks and an abundant supply of prebiotic molecules, hence constituting a universal phenomenon. However, a closer look at the conditions supporting prebiotic chemistry, the origin and evolution of life and its survival shows just how delicate this conclusion can be. On Mars, there is plenty of evidence indicating water in contact with rocks [2-5]. Additionally, early Mars had the same inventory of exogeneous prebiotic molecules as the young Earth-although today a number of surface physical and chemical agents are likely responsible for degrading at least the more volatile organic components. Nevertheless, there is a major difference in the habitable conditions of early Earth and Mars in terms of spatial and temporal scales. For life to emerge, favourable conditions and ingredients need to be present for up to a couple of million years [6]. The specific conditions for the appearance of life may have been met at various times and various places on Mars. For established life, the temporal and spatial scales are less restrictive. Conditions on Mars related to changes in obliquity may potentially allow for active metabolism and replication on a time scale of a few hundred or thousand years at spatial scales as reduced as some tens of microns to perhaps decimetres. Following a relatively short period during which life may have gained a foothold on the red planet, when conditions may have been similar to those on the young Earth, the number of potentially habitable environments for established life throughout Mars' history was probably very large. Suitable conditions may still exist in the subsurface where extant or dormant cells could occur, but they may not necessarily be inhabited [7]. Smaller, shorter-lived habitats hosting established life forms could have co-existed with spatially-distant habitats in which life was emerging.

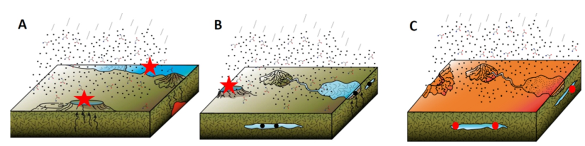


Figure 1: Variable conditions favouring life on Mars. A. Sketch representing early Mars with two types of non-connected habitable environments that could have supported the emergence of life (indicated by the red stars)-a lake in an impact crater and a larger water body. B. Changing hab-itability on Mars. In one location a crater lake could host conditions conducive to the emergence of life while, simultaneously in another unconnected habitat, extant life may be flourishing in the sediments at the bottom of an ice-covered body of water (black dots). Extant life is also present in the subsurface. C. No habitable conditions at the surface of Mars. The frozen cryosphere may still host dormant cells (red dots). In all scenarios there is a continuous rain of extraterrestrial organics.

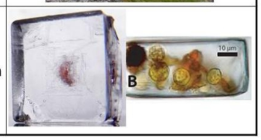
Habitability scales	Time	Space	
Origin of life	10^5-10^6 y?	10^1-10^3 km	
Established life	Day-weeks	10^2-10^3 µm	
Survival	10^{-1}–n10^6 y?	10^2-10^3 µm	

Figure 2: Spatial and temporal scales of the different categories for microbial habitability

2. Evolutionary implications

The extreme heterogeneity of the habitats and their general lack of inter-connectivity for most of Martin history, the latter depending however on the efficiency of the subsurface hydrological system and the opportunities of transient fluvial activity, impose severe constraints on the possibility of evolution of martian life forms. The lack of continuously hospitable conditions would inhibit evolution and it is possible that martian life, necessarily chemotrophic, remained, and still remains, in a very primitive state and very small (< 1 μm) [8]. Its remains would be preserved in the same way as microbial remains on Earth, possibly as physical structures, possibly as complex carbon molecules with specific isotopic signatures, or possibly as other types of biosignatures. Their small size means that, if present as physically-preserved structures, they will be too small to identify using in situ instrumentation (unless they form large colonies). In terms of quantity of organic compounds, these will be diluted by the preserving mineral medium. It would be preferable to search for biosignatures at a location where they could have been concentrated, as in a sedimentary, hydrothermal or palaeosol environment. To ensure better chances of preservation, the geologic units should have undergone no or very limited diagenesis and metamorphism and the rocks should have not been in contact with the surface and the atmosphere for extended periods of time (for example, a recently eroded outcrop, or rocks recently excavated by an impact) [9]. If organic compounds were to be preserved (at least the heavier fraction of the compounds), the in situ instrumentation on Curiosity and ExoMars may be able to identify them.

Identification of a potential organic biosignature in a bulk sample would be of the greatest importance [9]. At least we would have an indication that life could have existed on the planet. Such a discovery would pave the way for the more arduous, follow-up investigations into the exact nature of the biosignature, its distribution and the implications for the mode of life of the original microorganisms. However, because of the probable degradation of any potential organic biosignature, it would be necessary to return such sample to Earth for detailed analysis and verification.

3. Implications for missions to Mars

The heterogeneity in the distribution of environments supporting the origin, evolution and survival of life over Mars' history has a significant impact on the planning of missions seeking to find traces of life, in particular because locations supporting one habitable element, for example the initial conditions giving rise to life, might not support another element, such as ephemeral habitats that might host life for very brief periods of time. These considerations have a profound impact on the nature and distribution of eventual traces of Martian life, or any precursor, and must therefore inform our search for life strategies.

References

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