CRATER LAKE SETTING FOR MACROBIONTS ON MARS: HOW AND WHERE TO SEARCH.

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Introduction: The natural setting where life originated on Earth may be forever beyond reach, but the planet Mars may be used as a proxy for sites which are analogs to what happened on our home planet.

The "macrobiont" is defined as the setting under which life first formed [1, 2]. Such a site must include all necessary ingredients and be susceptible to the variety of conditions which facilitate prebiotic syntheses to enable the rise of the first reproductive molecules, i.e., the cradle for the cross-over from inanimate matter to living entities for the Origin of Life (OoL).

Within the nascent macrobiont, proto-cells may eventually develop and incorporate the reproducing molecules, to provide additional metabolic capabilities as well as protection of precious components from external influences. This can be followed by further evolution to produce cells competent to colonize suitable niches in the broader planetary environment once they leave the macrobiont.

Alternatively, the macrobiont may *not* successfully create life which can spread. Or, the macrobiont may not survive sufficiently long for this evolution to occur, only to be extinguished by the ravages of time (weather, volcanism, flooding, aeolian blanketing, evaporation to dryness, etc.).

Crater Lake Macrobionts: Previously we examined formation of a macrobiont as a consequence of a rare survival of an organic-rich fragment from a cometary nucleus [2]. Other proposed settings have included suboceanic vents and surface hydrothermal settings; tidal flats; sea ice; cave pools; meteorite ponds; etc.

Here, we examine the prospect that lakes in impact craters, and also perhaps calderas, provide ideal settings in which macrobionts can form. Discovery of sites which are putative proto- or extinct macrobionts could provide the glimpse into a past which has been erased on Earth, and help establish the likelihood of favorable sites for the OoL on exo-planets.

Properties of a Macrobiont: Distinguishing a proto- or full macrobiont from an extinct microbial community may be challenging. Macrobiont requirements include an environment which provides essential resources: a solvent (liquid H_2O); critical atoms (CHNOPS) plus bioavailable Fe and trace elements (e.g., Zn, Ni, Cu, Co); and feedstock organics (especially heteroatomic molecules with N and O). The Sutherland scheme of prebiotic synthesis emphasizes cyanides and Cu catalysts [3]. Borates are identified as a key constituent by the Benner group [4]. Cu and B are enriched in certain locations on Mars [5, 6].

Laboratory researchers have discovered the difficulty of achieving the abiotic polymerizations of informational macromolecules and proteins except by removal of H_2O, via wet/dry or freeze/thaw cycling. For this reason, we believe macrobionts are likely to be small in size, with a multi-faceted, fluctuating environment to provide for an array of reactions and the sequestration of key products

Example Crater-Lake Macrobiont: We have therefore chosen as example a lake which feeds proximal ponds, as shown in Fig. 1. For large craters, an impact into ice-laden martian permafrost will create long-lived hydrothermal conditions. As available H_2O in the lacustrine environment decreases, the evaporation reduces the amount of water, while infalling aeolian dust increases its sedimentary load. Martian dust is salt-laden, which increase salinity and also availability of soluble catalytic ions. The dust will also include meteoritic organics, mostly as extremely fine-grained particles, and these may become further concentrated if transported as suspended load by fluvial activity from afar. The macrobiont will interact with the environment through solar heating, UV irradiation, and chemical reactions with atmospheric constituents. Organics produced will separate according to particle size and density, to produce surface scum, suspended particulates, and bottom sludge. Geochromotography [7] can also separate organics into chemical groups.

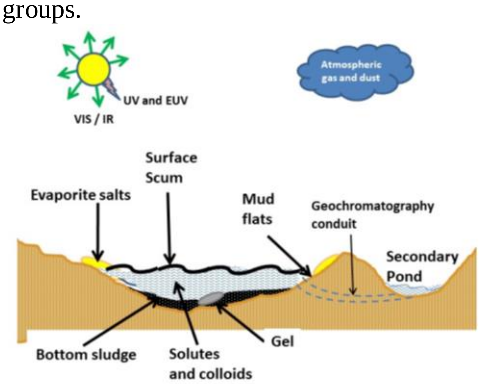

Fig. 1. Schematic Macrobiont Properties (Crater Lake is located off-figure, to the left)

Time and Size. The macrobiont must be of sufficient size and lifetime to accomplish the tasks of hosting informational molecules, proto-cells, and eventually cells competent to survive in external environments. Because optimal cellular configurations are micron-sized, even a small pond can provide ample opportunity for evolution. For example, in a bowl-shaped pond 5 meters in diameter and only 1 m deep (max), and a modest cell density of $10^3/cm^3$, the total population could exceed 10^{10} cells, providing ample opportunities for cellular evolution. This can proceed quickly compared to pond lifetime. Thus, even with a long division time of 24 hr per generation, the time to fully populate this example pond is only five weeks.

Exploring for Macrobionts: A hallmark of scientific exploration of the surface of Mars has been the conscious attempts to understand the recent history and provenance of the various geologic settings encountered. Although compositional analyses are part of this endeavor, there is also considerable emphasis on extensive imaging for panoramas and walkabouts. These efforts are major consumers of exploration time (sols) and data (bandwidth). Past existence of water or present existence of hydrated minerals or H_2O ice are afforded high priorities. Organics are also high priority, but how to "follow-the-organics" has been neither obvious nor pursued to the extent it could be.

The chlorinated and sulfurized organics that have been discovered on Mars so far [8] are at trace concentrations and do not qualify as unique bio-markers or of obvious relevance to prebiotic synthesis.

Compositional Indicators. Silica, clays, and salts have been identified as potential preservers and protectors of organic matter [9, 10]. These all are, of course, products of aqueous alteration of the original igneous progenitors. As noted above, they are also mineral categories which may play an important role in macrobiont activities. For these reasons, emphasis could be placed on attempting to find major deposits of these materials. Mars is already endowed extensively with salts and often clays. However, we have yet to discover a full evaporite sequence or bedded deposits consisting only of clay. The only high-silica occurrence was in a putative hydrothermal area explored by the MER Spirit rover, but no capability for analyzing organics is operational on the MER rovers.

Enrichments of trace elements over nominal values in the expected igneous minerals allows another method of detecting candidate macrobiont sites. Those elements commandeered by extant life on Earth (e.g., Zn, Ni, Cu, Co, Mn) are of particular interest because of their putative involvement in the prebiotic evolution process. Their enrichment can also be indicative of deposition at a redox front. Analysis of trace elements by x-ray fluorescence and LIBS requires special attention and is typically performed on the ground well after the rover has moved to a new location, but with special effort and the benefits of past experience, these elements could be targeted for detection, hopefully eventually automatically onboard.

Operational Imperatives. In searching for macrobionts, compositional signatures could be more conclusive than geomorphological features. For understanding sedimentation and distinguishing between aeolian and fluvial activity, the opposite seems true.

In an exploration mission, there is always tension between the objectives of "understanding" and "discovery." These result in counter-posed objectives of devoting sufficient time and resources to thoroughly exploring a site or formation, versus "drive, drive, drive" to seek new and different settings. Exploration is further hindered by practicalities, such as the necessity (so far) for the rovers to "bump" to get into position to analyze targets of interest (i.e., after driving perhaps 50 meters to reach an identified next target, additional sols are needed to plan then execute a small maneuver of cm's to reach a selected target). Subsequent sols are then spent deciding on where to go next.

One new capability, pioneered by MSL Curiosity rover, is autonomous targeting for the ChemCam laser instrument to analyze nearby bedrock candidates. Interpretation of the results, however, is still ground-based. With onboard capability to autonomously decide which samples are "more of the same" versus "new and different," the likelihood of discovering unusual outliers could increase significantly.

Conclusions: The imperative to continue the exploration of Mars should include the search for life, especially the settings where the OoL could have occurred. In contrast to what some science advisors once recommended, an imperative to understand well a given site before progressing to the next can be counter-productive to the overall search. Clay, silica, and salt deposits should be of special interest, but a highly sensitive capability for detection of organics is also needed, ideally as local remote-sensing but without time-consuming, complex sampling and analysis.

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