MARTIAN CRATER-LAKE ENVIRONMENTS AND THEIR POTENTIAL RANGE OF BIOLOGICAL DEPOSITS.

C. Gross[1*], A. Airo[1], M. Al-Samir[2], M. Sowe[1], S. Nabhan[1], J.L. Bishop[3], S. van Gasselt[1]
[1]Freie Universität Berlin, Inst. of Geological Sciences, Malteserstr. 74-100, 12249 Berlin, Germany, *christoph.gross@fu-berlin.de.; [2]German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, [3]SETI Institute & NASA Ames Research Center, Moffett Field, CA, USA

Introduction: We present here a range of potential crater-lake deposits that could form under abiotic and biotic settings. For our analysis we have considered different crater-sizes, distinct mineralogical basement compositions, various detrital inputs, and phototrophic or chemotropic microbial populations. We conclude that any prolonged photosynthesis-based ecosystem would likely create sediments in which biomarkers could be found by MSL-type technology, whereas chemosynthetic-based ecosystems with high detrital input would greatly reduce the chances of biomarker detection.

Mars' early history appears to have been suitable for the origin of life. During the Hesperian, Mars appears to have transitioned into a periglacial climate with sporadic fluvial events creating morphologies such as the large outflow channels or small seeps. If microbial life did exist on Mars during or before the Hesperian it is reasonable to assume that microorganisms could have remained viable within the subsurface or at least exist as dormant spores until today. In the event of an impact of sufficient magnitude in post-Noachian times, however, the formation of crater-lakes is at least in some cases likely and could have served as a temporal habitat for a microbial ecosystem. Modeling studies predict that the surficial ice layer would protect the underlying crater-lakes from evaporation for up to a few 100s of thousands of years [1]. Furthermore, it can be assumed that the lake water would be hydrothermally recycled as a consequence of the impact-related heating and fracturing of the basement.

Approach: We assume here that the Martian subsurface contains dormant or active microorganisms that are able to populate their specific niche of the crater-lake to the maximum level within less than a thousand years. Hence, the total amount of biomass will be limited by either energy availability or nutrient supply. Although it is entirely possible that growth of Martian lake microbes is limited by nutrients supply or uptake ability, we assume here for the following discussion that the only limiting factor is availability of energy. We consider chemo- and photoautotrophic organisms that grow without nutrient limitations and have the ability of C- and N-fixation. Also, we discuss different metabolisms that are separate from each other, although it is entirely possible that various microbial species with different metabolic activities populate the crater-lake simultaneously as this is common on Earth. An overview of the different scenarios is given in Figure and Table 1.

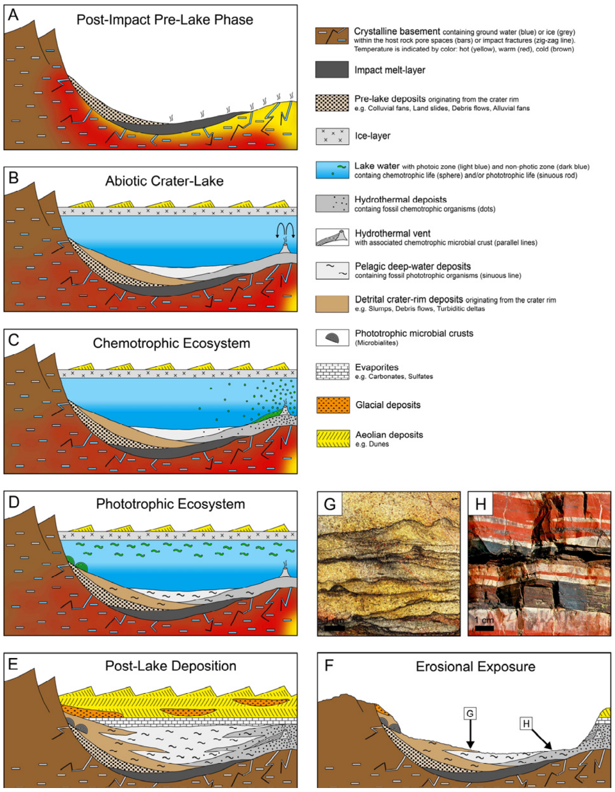

Figure 1: [A-F] Formation of biotic and abiotic crater-lake deposits shown in schematic cross-section of an impact crater with crater-rim (left) and central peak (right). **G:** Archean sandstone from the Moodies Group containing microbial biofilms visible as dark laminae (Barberton Green-stone Belt, South Africa). **H:** Banded Iron Formation outcrop at the Archean Fig Tree Group (Barberton Greenstone Belt, South Africa).

Ice-covered lakes: In analogy to ice-covered lakes of the McMurdo Dry Valleys, McKay and Davis [1] developed a model for early Mars and concluded, that liquid water habitats could have been maintained under relatively thin ice cover for extended time spans after mean global temperatures fell below the freezing if a source for meltwater is present. Newsom et al. [2] show, that also in later epochs of Martian history lakes could have formed even though the availability of surface water progressively decreased and climatic conditions approximated today's values. Heat sources, viable to the maintenance of an ice-covered lake on Mars, include hot impact melt on the crater floor and a central peak (if present), flowing groundwater, and latent heat developed by freezing of lake water at the ice-water interface while freezing to form new ice [1;3]. The new ice developed below the ice layer replaces ice lost at the surface by ablation, creating a balance in ice thickness. Heat is only lost by conduction [2]. Calculations suggest that a Martian crater lake with a melt sheet of roughly 200 m will maintain an ice layer of less than 50 m for several thousand years.

Once a lake has formed, the lacustrine sediments will be dominated by (1) siliciclastic detrital input originating from the crater-rim, (2) mineralization driven by hydrothermalism, and (3) aeolian sediments passing throught the surficial ice-layer.

These aeolean deposits would initially accumulate on top of the ice-layer but could migrate through the ice as it is known from Earth's lakes in Antarctica. However, the rate at which such sediments would traverse an ice-layer of different thicknesses remains largely unknown, particularly in the context of the Martian environment. It remains also unknown whether the entry of the aeolean sediment into the liquid lake water and subsequent final deposition at the lake bottom occurs at a slow but continuous sedimentation rate or rather in a short-lived sporadic and rapid event where a large amount of sediment breaks through the ice at once.

Hydrothermal Input: Since the formation of an impact structure is a high-energy, high-temperature event which introduces large amounts of heat into a limited area, the development of hydrothermal circulation systems within impact craters is inevitable if water is present. Even impacts into arid environments will potentially result in the release of volatiles through shock dissociation of hydrated minerals [4]. The interaction of aqueous solutions and other volatile components with hot, shocked rocks will result in hydrothermal activity, leading to effective alteration processes and potentially large-scale hydrothermal overprint on shock- metamorphic rocks, as well as deposition of secondary minerals from hydrothermal solutions.

Evidence for hydrothermal activity on terrestrial impact structures can be found in various locations: Vredefort [5] Sudbury [6], Noerdlinger Ries [7], Haughton [8] and many more. Large impact structures such as Sudbury and Vredefort are associated with important mineral and ore deposits but the age of large craters like Sudbury (1.84 Ga) or Vredefort (2 Ga) [9] restricts the study of phyllosilicates and other key-minerals, due to major metamorphism and the effects of erosion under terrestrial atmospheric conditions and variations. Younger but therefore also smaller craters like the Noerdlinger Ries impact (14.4 Ma and 24 km diameter) [10] and Haughton (22.4 Ma and 23 km diameter) [11] offer a better insight for understanding post impact hydrothermal environments.

Summary: Our analyses considered crater-lake deposits resulting from a range of crater sizes, distinct mineralogical basement compositions, various detrital inputs, and phototrophic versus chemotropic microbial populations (Table 1). Development of prolonged photosynthesis-based ecosystems would likely create sediments and biomarkers readily identifiable by MSL-type instruments, whereas chemosynthetic-based ecosystems with high detrital input would greatly reduce the chances of biomarker detection.

Table 1: Crater-lake deposits forming under biotic and abiotic conditions.

	Detrital crater-rim deposits	**Pelagic deep-water deposits**	**Hydrothermal deposits**
Abiotic	Siliciclastic sediments originating from the crater-rim and containing little to no organic material.	Dominated by aeolian sediment input , occasional turbidity currents, and pelagic precipitates. Small amounts of organic material can originate from cometary input and/or in-situ pre-biotic chemical reactions.	Largely hydrothermal input associated precipitates forming either fine-grained suspension deposits (mud) or cemented vent systems (smokers). Under favorable chemical conditions substantial amounts of pre-biotic organics could be formed.
Chemotrophic Ecosystem	If local hydrothermal systems are lacking and the input from distal hydrothermal systems is minimal the deposits would be comparable to those under abiotic conditions.	Overall similar to the abiotic deposits but potentially containing a larger fraction of organic-rich pelagic precipitates originating through microbially induced mineralization.	In close proximity to the hydrothermal vents the microbial population can be high and develop biofilms and microbialites.
Phototrophic Ecosystm	Within the shallow-water photic zone the siliciclastic deposits are interbedded with benthic biofilms, biomats, and microbialites.	Overall similar to the abiotic deposits but with a high content of organics derived from the deposition of dead planctonic organisms.	If the hydrothermal system is below the photic zone the deposits would be similar to those under abiotic conditions, with the exception of pelagic inputs.

Acknowledgements: This work has been supported by the Helmholtz Association through the research alliance "Planetary Evolution and Life". We thank C. Heubeck and M. Homann for providing imagery of Archean rock samples.

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