MICROBIAL TAPHONOMY AND ITS IMPORTANCE IN MARS EXPLORATION

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Introduction:

Our present strategy for the astrobiological exploration of Mars emphasizes the search for a *fossil record* preserved in aqueous lithologies that were deposited during earlier clement periods in Martian history, when habitable conditions could have existed at the surface. A fundamental starting point for properly implementing a strategy for Mars *"exopaleontology"* is to understand the combination of factors that enhance the capture and preservation of fossil biosignatures, or which alter fossil biosignatures in ways that make their detection difficult.

What is Taphonomy?

Taphonomy studies the conditions and processes by which organisms become fossilized. Taphonomic processes include changes that occur following the death, burial and diagenesis of fossil organisms. The main motivation of such studies is to identify preservational biases in the fossil record- information that can also be used to guide biosignature search strategies on Earth, or elsewhere.

General Principles: It has long been recognized that in detrital sedimentary systems, fossil preservation is favored by: 1) rapid burial in fine-grained, organic-rich sediments (mudstone and shale), particularly those deposited under anoxic conditions, and which undergo early cementation, and 2) rapidly-mineralizing sedimentary systems (e.g. hot and cold springs, evaporites, paleosols, etc.) where the capture and preservation of biosignatures is enhanced by rapid entombment in fine-grained chemical precipitates [1].

Over the past two decades, strategies to explore for a Martian fossil record have been supported by paleobiological / taphonomic studies of the terrestrial fossil record to document processes of microbial biosignature capture and preservation [e.g., 2-4]. Such studies have been carried out over a broad range of modern and ancient geological environments considered potential analogs for early Mars. These studies have generally shown fossil preservation to be strongly influenced by *microscale* physical, chemical, and biological factors that collectively determine the nature of information captured and retained. In addition, different environments appear to exhibit unique *"taphonomic modes"* that can provide important clues for assessing biogenicity.

Impacts of Diagenesis: An important, yet often overlooked factor in the long-term survival of fossil biosignatures are the textural and mineralogical changes that accompany burial and diagenesis of the host rock. Long-term preservation is enhanced where rocks are composed of stable minerals that resist chemical weathering and that form tight, impermeable matrixes that promote a closed chemical system. Examples include rocks made up of highly ordered, chemically stable mineral phases, like silica (e.g., chert), or phosphate (e.g., "phosphorites"), or less stable carbonate lithotypes (e.g., limestones) and shales (e.g., mudstones). Owing to their abundance and relative stability, such lithologies tend to have long crustal residence times and are the most common host rocks for the Precambrian fossil record on Earth [1].

Types of Fossil Information: The most compelling biosignatures are often highly specific, macromolecular biomarker compounds that can be tied to known biological functions. Such biomarkers are often labile compounds that are rapidly degraded during early diagenesis, forming more stable geopolymers, most notably kerogen, that can persist for billions of years [5].

Scale-Integrated Observations: The microbial fossil record encompasses a range of information, including biosedimentary structures (e.g., microbialites), cm-scale, biomediated microfabrics, micrometer-scale cellular organic remains, biominerals and chemical biomarkers (inclusive of isotopic signatures). This indicates the importance of investigations (both on Earth and Mars), integrated across spatial scales.

Earth versus Mars: An important difference between the Earth and Mars, that may enhance the potential for preserving a fossil biosignature record on the Red Planet, is the absence of plate tectonics and the destructive effects of deep burial metamorphism. Other factors that may act in favor of long-term preservation at shallow depths on Mars are low water activities and a pervasive shallow cryosphere with subfreezing temperatures. In contrast, other factors, such as the destructive effects of ionizing radiation and high oxidant concentrations, constitute taphonomic factors on Mars that could reduce preservation potential at the surface. Targeted subsurface drilling/coring may be required to get to depths that exceed destructive effects of radiation.

References: [1] Farmer and Des Marais 1999, *JGR-Planets,* doi:10.1029/1998JE000540; [2] Schopf et al. 2012, *Astrobio,* doi:10.1089/ast.2012.0827; [3] Parenteau et al. 2013, *Astrobio,* doi:10.1089/ast.2013.1122; [4] Hofmann et al. *Astrobio*, doi: 10.1089/ast.2007.0130; [5] Summons et al. 2011, *Astrobio*, doi: 10.1089/ast.2010.0506.