Exploring for a Martian Fossil Record: Lessons from Earth

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Introduction: Strategies to explore for Martian life involve two basic exploration pathways: The search for extant life (exobiology) and the search for a fossil record of past life (exopaleontology). Each of these pathways involves distinctly different strategic approach [1]. In the first instance, we follow the requirements for life as we presently understand them, with the search for liquid water leading the way. Because liquid water is a limiting and ephemeral resource at the surface of Mars today and deep drilling being beyond our present technological reach, the focus of the current Mars program has been to find ancient sites where water was present in the past and interrogate the geologic record of those past habitable environments to search for fossil biosgnatures. The exploration for potential fossil repositories on Mars can be informed by the principles and approaches developed by paleontologists who study Earth's Precambrian fossil record. Going to the Precambrian Earth is in many ways like going to another planet and no less challlenging. The exploration for fossil microbial biosignatures in old rocks is a risky business, but worth the effort. The discoveries to date have transformed our views of the earliest history of our biosphere and placed that history in the broader context of planetary evolution. At the heart of these discoveries are some basic principles drawn from the field of taphonomy [2], the subdiscipline of paleontology that seeks to understand the factors and interactions that control fossil preservation.

"Rules" of Preservation: NASA's "Follow the water" strategy has been astonishingly successful for Mars in pointing us to compelling astrobiological targets for landed missions and eventually, for sample return [3]. At this point, however, locating and mapping aqueous minerals and water-formed geomorphic features from orbit, or on the surface with rovers, are not the only things we need to consider to properly implement and effective strategy for Mars exopaleontology. Since the early 1990s, there has been a growing awareness of the importance of assessing the *preservation potential* of specific Mars-relevant sedimentary environments, through focused studies of microbial fossilization. Such studies are challenging because to be done correctly requires a marriage of geology and microbiology. With the detection and mapping of important aqueous mineral deposits from orbit [4], including such aqueous indicators as phyllosilicates, sulfates, silica and carbonates, analog studies have entered a new wave of activity. While we continue to follow the water at Mars, in the selection of targets for exploration, I hope this illustrates that we also need to consider *presevation potential* in setting landing site priorities.

Best Places to Explore: Factors that favor the capture and presevation of fossil biosignatures include the rapid burial of organisms and/or their byproducts, in either fine-grained (clay-rich) detrital sediments, or in chemically precipitated sediments [5]. Depositional settings where these processes are common include [1]: A) marine or lacustrine basins (e.g. foredeltas), where the rapid, physical sedimentation of fine-grained sediments occurs; B) *mineralizing springs* (e.g., sinter-depositing thermal springs in volcanic terrains, tufa-depositing cold springs in alkaline lake settings, seafloor hydrothermal systems, etc.), where chemical disequilibrium processes cause rapid mineral precipitatation in the presence of organisms, entombing biological materials before they can be degraded; C) *evaporite basins* (e.g., terminal lake basins, impact crater and volcanic crater paleolakes, and arid shorelines where evaporite deposits, inclusive of carbonates, sulfates, halide salts precipitate in the presence of microorganisms; D) *mineralizing soils* (e.g., surface duracrusts and sub-soil hard pans where minerals precipitate in the zone of accumulation (e.g. as silcretes, calcretes, and ferricretes); E) *subsurface sedimentary systems*, including caves, where groundwater preciptates cements, or fracture fills, often entombing chemostrophic organisms; and F) *glacial ice and permafrost* (frozen soils, glacial ice) which capture and cryopreserve microbial biosignatures within ice crystals, fluid inclusions, or interstitial brine pockets.

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