ENVIRONMENTAL AND MINERALOGICAL CONTROLS ON FOSSILIZATION: KEY ELEMENTS IN A STRATEGY FOR MARS EXOPALEONTOLOGY. Jack D. Farmer, Arizona State University, Dept. of Geology, P.O. Box 871404, Tempe, AZ 85287-1404; jfarmer@asu.edu

Introduction: One cannot expect to land just anywhere on Mars and discover a fossil record. What are the important factors that should guide the search? While the potential range of fossil information preserved in rocks of all ages is quite broad, including actual cellular remains (1), various classes of chemofossils (2), biominerals, biofabrics, and stromatolites (3), studies of fossilization processes in modern environments on Earth, as well as the terrestrial fossil record, indicate that the preservation of biosignatures is strongly influenced by the physical, chemical and biological factors of the environment (4). Acting together, these factors determine the types of deposits and range of information preserved.

Important Fossilization Processes: On Earth virtually all of the well-preserved cellular microbiotas in the Precambrian were preserved by either 1) early diagenetic infusion of silica or phosphate into organic materials and sediments, or 2) by rapid burial of organic materials in fine-grained, clay-rich shales. These two situations comprise a very narrow taphonomic window that greatly restricts opportunities for preserving cellular level biosignatures in rocks (4). Of course, there are also intrinsic properties of organisms that promote their preservation, such as the presence of recalcitrant cell walls or extracellular elements. While fossilization requires very special conditions, still we have documented an extensive Precambrian fossil record on Earth. It is crucial that such preservational constraints be considered carefully before mounting an expensive and time-consuming campaign to explore for an ancient Martian biosphere. Environments where the sedimentary processes defined above commonly operate in the presence of biology include: arid marine or lacustrine shorelines (5), evaporite basins (6), mineralizing springs (7), and subsoil hardpans (8).

Long-term Preservation: Rock type (e.g. the mineralogy and texture of the host sediment) is also a fundamental factor influencing the long-term preservation of biosignatures. In this context, most important is the rapid reduction of permeability following sedimentation and burial. This typically follows the compaction of fine-grained sediments, along with secondary mineralization (cementation). The reduction of permeability during early diagenesis serves to isolate and protect organic remains from later oxidation. A second critical factor is the microstructural and chemical stability of the enclosing sedimentary matrix. This promotes long-term retention of biofabric and chemofossil information which may remain even when organic materials have been lost. Long-term microstructural and chemical stability to a large extent depends on mineralogy.

While the best preservation of fossil information is typically in sedimentary silica or phosphate, most of the Precambrian fossil record on Earth is actually hosted in carbonates (primarily as stromatolites). These provide primary mineralogical targets in the search for fossil record on Mars. However, the tendency of carbonate minerals to undergo recrystallization during diagenesis often leads to the loss of important microstructural details.

Crustal Residence Time: Evaporite minerals provide another potential target for a Martian fossil record (9). During precipitation from supersaturated brines, terrestrial evaporites typically capture numerous halophilic microorganisms present as biofilms on accreting mineral surfaces, or within fluid inclusions. However, where an active hydrological system is present, evaporites are easily dissolved and lost from the rock record. Hence, evaporites are quite rare in ancient sequences on Earth. The same may not hold true on Mars where the hydrological cycle has been far less active.

Ice provides another potential target for a fossil record (10). However, by geological standards, the crustal residence time is exceedingly short for ice. Although ice provides an excellent medium for preserving organic materials (11), it tends to be easily lost from the crust during cycles of climatic warming (12). This suggests that on Mars, ground ice is likely to be unimportant as a target for exopaleontology, with the exception of situations where subsurface aquifers have recently replenished the near surface cryosphere. In that case, upflowing ground water may have carried representatives of an extant subsurface biota into the near-surface environment, cryopreserving their remains in ice.

Conclusions: Observations drawn from terrestrial paleontology comprise crucial elements in the present strategy to explore for a fossil record on Mars. In the most detailed sense, the strategy has yet to be applied. At the bottom line, successful application to the problem of site selection will involve more than just identifying sites where water was present. However, there are many sites on Earth where water is abundant but fossils rare or absent. In selecting landing sites on Mars we must be able to take the strategy to the next level of application by asking crucial questions about the early diagenetic mineralization, and the other factors of the sedimentary systems that are required for microbial fossilization. From an exploration standpoint, the first step in the process is to identify and locate the right kinds of deposits. Mineralogy provides the most reliable information for properly assessing the potential for capturing and preserving of a fossil record. In meeting this important requirement, high spatial resolution mineralogical mapping should be given the highest priority in future missions (13).

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