TRACES OF LIFE: MACRO- AND MICROSCOPIC EVIDENCE OF PAST AND PRESENT BIOGENIC ACTIVITY POTENTIALLY PRESERVED IN EXTRATERRESTRIAL SEDIMENTS AND ROCKS. S. T. Hasiotis, J. R. Rogers, and R. H. Goldstein, The University of Kansas, Department of Geology, 1475 Jayhawk Blvd., 120 Lindley Hall, Lawrence, KS 66045-7613; hasiotis@ku.edu; jrrogers@ku.edu; gold@ku.edu

Introduction: If life were once or still part of the Martian landscape, an excellent chance exists for the preservation of evidence of life via its interaction with, and entrapment within, various substrates (=substratum). Martian soils, rocks, and ice may contain micro- to macroscopic evidence in the form of burrows, borings, inclusions, or biofabrics that can confirm the presence of Martian life even if no body fossils or living material are found. Martian trace fossils could also corroborate biogeochemical evidence that may be found in the substrates examined.

Most people are familiar with fossils as evidence of life in the geologic record on Earth. Body fossils of micro- and macroscopic organisms are preserved in sedimentary rocks, which were derived from sediments deposited in numerous environments. The earliest known fossils on Earth are those of prokaryotic organisms in 3.8 Ga (billion-years old) stromatolites [1].

On the other hand, trace fossils, such as stromatolites, are the result of organism-substrate and organism-organism interactions that are preserved in the rock record [2]. Traces that can be produced by micro- to macroscopic organisms (Bacteria, Archaea, and Eucarya) include tracks, trails, burrows, nests, borings, and biologically mediated fabrics (sediments, laminae, etc.=biofabrics). Trace fossils can occur in lithified sediments, including borings in hard substrates (rocks and minerals) where the organism mechanically or chemically penetrated the substrate [3]. Biochemical signatures in the form of fractionated isotopes (e.g., C, S, Fe) can also be thought of as trace-fossil evidence of organisms that were once part of the environment. Some trace fossils contained in sedimentary rock were produced by bioturbation (mixing) of the sediment prior to lithification; traces produced in hard substrates are referred to as borings and result in the bioerosion of the substrate [3].

Much information on environment, evolution, ecology, and climate can be gained from studies of modern trace-making organisms that produce tracks, trails, burrows, nests, and borings analogous or homologous to ancient trace fossils [1, 2]. The recognition of distinct patterns of bioturbation and bioerosion depends on comparative studies of modern and ancient forms. These patterns can be used as proxies to identify the possible tracemaker and also record the presence of an organism if the body fossil is not preserved [2].

Here, we review the possible traces of life that might be found in samples retrieved from Mars pending the tentative 2011 launch and 2014 return of NASA’s Mars’ lander-retrieval mission. The potential Martian types of trace fossils and patterns of biofabrics, bioturbation, and bioerosion are based on bioturbation-structure presently found on Earth and in its geologic record [i.e., 1, 3-8 and references therein].

Trace Fossil Patterns and Fabrics: The following section describes the different types of trace fossils, biofabrics, and biologically mediated substrates that occur on Earth. The smallest and most likely types of trace fossils are described first; these are structures produced by prokaryotes and simple eukaryotes and include microendolithic borings, organic remains as inclusions in minerals, chemical traces, biologically modified surfaces, precipitates and fabrics, and macroscopic structures produced by microorganisms. These types of biofabrics must also be verified by thin-section and SEM (scanning electron microscopy) analyses to ensure they are not abiotic. Several types of meso- and macroscopic trace fossils produced by metazoans are also briefly described. If life on Mars evolved to the point where metazoans were present, then it is necessary to discuss distinguishing features of their trace fossils.

Microendolithic Borings. Bacteria, Cyanophyta, Actinomycetes, Fungi, Lichens, Rhodophyta, and Chlorophyta are just some of the organisms that produce microborings. These structures include borings as isolated pits, fine threads, trails, and/or strings of beads (e.g., linked spheres) that range in size from < 2-25 µm in diameter to 25+ µm in length. They occur as branching networks of tunnels, sack-like side-branches, swellings, and spherical chambers. These structures can be formed in detrital, organic, and chemical (carbonates and evaporites) sedimentary rocks, and likely occur in igneous rocks (i.e., basalts, sulfides) [3].

Inclusions of Organic Remains in Minerals. It is well known that as minerals precipitate from an aqueous fluid, tiny volumes of fluid can be trapped along irregularities in the growing crystal. These fluid inclusions are commonly preserved in minerals precipitated in near-surface settings such as springs, evaporative lakes, and caves. Commonly such materials contain organic remains trapped within fluid inclusions. Similar remains trapped in Martian samples could preserve degraded organic material, and with exceptional preservation, could even contain viable materials.

Chemical Traces. C, S, and Fe isotopes are some of the major elements fractionated by life on Earth,
concentrating the lighter elements in their tissues. Biomolecules, such as sterane and alkane biomolecules, are also indicative of prokaryotic and eukaryotic organisms and can be preserved in sediments.

**Biologically-Modified Surfaces.** Microbiological weathering of minerals has been widely documented. With this process, microorganisms attach to mineral surfaces and directly impact mineral surface chemistry and solution chemistry. While microorganisms dissolve a variety of minerals, such as phosphates, sulfides, oxides, etc., the rapid dissolution kinetics of these minerals does not allow preservation of traces of biological activity. However, silicate minerals, which have slower dissolution kinetics, preserve microbiologically induced etching more often. Many etch pits resemble colonizing cells in size and shape and may contain high concentrations of C, P, and N as well as traces of DNA and RNA, where cells have been entrained in the rock [9].

**Biologically-Mediated Precipitates and Macrofabrics.** Microbial precipitation of minerals is also common. Microorganisms can directly precipitate or mediate the precipitation of oxides, carbonates and clays. For examples, the Fe-oxidizing bacterium Gallionella sp. precipitates a distinctive, spiraling stalk of iron oxide, while dolomite precipitation in low temperature environments has been linked directly to the presence of anaerobic bacterial metabolism. The presence of these precipitates may be indicators of biological activity and, in some cases, they may even entomb the colonizing cells as they act as nucleation sites.

Larger scale structures are built by single or multi-layered, monospecific to ecologically diverse communities of prokaryotes and simple eukaryotes. The structures include stromatolites, thrombolites, tufa, and travertine. All are accretionary, organosedimentary structures composed of biogenically derived sediment formed by microbial mat-building communities. They can have laminated or clotted fabrics that are built in standing or flowing water. Internal features should include thin, wavy, spongy, or clotted textures with or without tubular structures, radiating or branching microfabrics, or concentrically layered granules deposited in layers. These textures form macroscopic structures that range from millimeter- to meter-scale and can be areally wide-spread [7, 10].

**Metazoan Trace Fossils.** Based on photographs from past and recent Mars’ landers, there is very little chance of macroscopic metazoan life on Mars. However, if life reached the size and shape of simple slime molds, nematodes, and the like, then small, simple horizontal and vertical burrows and trails might be found. If life advanced further and was slightly more complex, then relatively large, flattened sack-like features similar to Earth’s Vendian biota could occur in sediments or sedimentary rocks. These are body fossils that are nearly bilaterally to radially symmetrical and are preserved mainly as casts [4, 6].

**Preservation Potential of Trace Fossils:** The preservation potential of these and other micro- to macroscopic trace fossils is likely much greater than that for body fossils or organic remains. For most of Mars, the surface and near-surface sediments and rocks have not experienced significant burial heating. Over the last 1Ga or so, there has been very little water affecting the Martian landscape, so chemical weathering of the sediments and rocks is minimal. On the other hand, enough water and heat may have existed in some areas (mostly subsurface and around volcanos) to support metabolic processes for primitive microscopic life.

**Issue of Contamination:** If evidence of life were to be found, some researchers might point to contamination of microbes from Earth-derived landers. The trace fossils briefly discussed here would offer irrefutable evidence that life did indeed exist on Mars in the past, preceding the time period of Earth-derived contamination.

**Conclusions:** Our cursory review of hypothetical fabrics preservable at the micro- and macroscale in Martian sediments and rocks will prepare paleontologists and biologists for exploration of extra-terrestrial planetary bodies.

**References:**