SCIENCE PRIORITIES FOR MARS ASTROBIOLOGY

Jack D. Farmer (Arizona State University, School of Earth and Space Exploration)

Introduction. This abstract summarizes concepts presented in a Decadal Survey White Paper submitted to the community by Farmer, J.D. M. Allen, T. Hoehler and M. Mischna. 2009. Astrobiology Research and Technology Priorities for Mars.

In a planetary context, the term "habitability" refers to the potential for an environment to support life. At the heart of the current Mars Exploration Program (MEP) are the questions: Have habitable environments have ever existed on Mars? If so, did life ever arise there and does it still persist today? An important objective for the next phase of of exploration will be to refine our understanding of what actually constitutes a habitable environment on Mars. The discussion of habitability that follows is organized around what are perceived to be the fundamental requirements for terrestrial life: 1) liquid water, the solvent for all known bio- logical processes, 2) sources of biological elements and compounds, which comprise the basic building blocks of organisms and 3) sources of energy needed to sustain metabolism, growth and the replication of living systems. An important focus for future exploration efforts, will be to discover discover places on Mars where liquid water has co-existed, both in time and space, with the critical elements and potential energy sources required for life.

Expand the Search for Past or Present Water: A fundamental astrobiological goal of Mars exploration is to understand the past and present distribution of water in all its forms. Based on recommendations first articulated in "A Strategy for the Exobiological Exploration of Mars" (NASA 1995), the MEP has systematically pursued a phased program of exploration designed to "follow the water", alternating orbital reconnaissance missions, with landed missions targeted to specific sites of high interest for astrobiology. This strategy has been remarkably successful. But there is still much to understand about the past and present distribution of Martian water, as a context for targeting the best places for life detection missions in the coming decade. This knowledge will also be critical for future human exploration of Mars.

Modern Subsurface Water: While there is abundant evidence for liquid water at the surface of Mars earlier in the planet's history, a key question for assessing habitability on Mars today is the potential for zones of liquid water to exist in the subsurface. While the surface habitability of Mars has varied over the geological history of the planet, it is possible that the subsurface has provided continuously habitable conditions over the whole history of the planet. Orbital mapping by the ODY GRS experiment showed water (as both ice and hydrated mineral phases) to be a widespread component of the upper half-meter of the Martian regolith. However, there is also geomorphic evidence for past reservoirs of subsurface liquid water, both as large (seemingly deeply sourced) outflow channels formed during earlier epochs of Martian history and as small (geologically young) spring-and seep-carved channels, from locally sourced aquifers, or snow melt. Still direct observations of a subsurface hydrosphere have remained elusive. Future needs to continue this exploration for subsurface water on Mars to more fully assess the potential for habitable subsurface environments that might support an extant Martian biosphere, or future human occupation.

Ancient Surface Water: The Mars Odyssey (ODY) THEMIS, and MRO's HiRISE and CRISM experiments have revealed a wide variety of water-formed geomorphic features at the surface of Mars, covering terrains of all ages, and in many cases associated with spectral signatures of water-deposited minerals (e.g. sulfates, halides, phyllosilicates, silica and Fe-oxides). This suggests that liquid water was once widespread over the Martian surface and was, at times, actively cycled between the surface and shallow subsurface hydrosphere, cryosphere and atmosphere, similar to Earth's hydrological cycle. The highly successful Mars Exploration Rovers, Spirit and Opportunity, were targeted to sites previously assigned a high priority for past water activity based on orbital observations. This led to the discovery of extensive outcrops of bedded, hematite-bearing sulfates at Meridiani Planum by Opportunity and water-formed Fe-oxides, sulfates and silica in the Columbia Hills of Gusev Crater by the Spirit rover. The Mars Science Laboratory mission, is scheduled to land at Gale Crater in early August, 2012 and will continue our exploration of past water on Mars at a site that spans a significant part of Martian history.

Follow the biological elements – Life as we know it requires carbon, along with the bioessential elements H, N, O, P, and S. Terrestrial life also requires a number of transition metals, that have well understood catalytic roles in enzymes. Understanding the processes that control the distribution of bioessential elements on Mars is considered key for a more refined understanding of habitability. In the coming decade, we must improve our understanding of how geological processes (e.g. hydrothermal circulation, evaporation, weathering, etc.) may have shaped surface and subsurface habitats on Mars, potentially creating conditions favorable for the origin and persistence of life. This includes a characterization of carbon reservoirs in the crust (e.g. carbonates, CO_2 clathrates, etc.), as well as atmospheric fluxes of key carbon containing volatiles (CO, CO_2, CH_4, etc.) needed to better constrain the carbon cycle and how it has changed over time. These fundamental compound also hold importance as resources to support human exploration.

Distribution and abundance of carbon compounds: We need to refine our understanding of carbon sources and sinks (organic and inorganic) on Mars, including the endogenic processes that synthesize carbon molecules *in situ* and exogenic processes that deliver carbon compounds to Mars via IDPs, meteorites and comets. This will require the detailed characterization of both the molecular structure and isotopic composition of organic compounds present in soils and ices, as well as biogenic gases in the atmosphere.

Nature, distribution and concentration of oxidants. The failure of the Viking experiments to detect measurable carbon in the Martian regolith is consistent with a highly oxidizing surface environment, although the exact nature of the oxidants and their interactions are, as yet, poorly constrained. In addition, it has been pointed out that the Viking GCMS experiments would have been unable to detect certain recalcitrant carbon compounds derived from the diagenesis of meteoritic organics (e.g. nonvolatile salts of benzene carboxylic acids, and perhaps oxalic and acetic acids). Thus, such compounds are likely to be present in the Martian regolith today, a concept in part confirmed by the recent Phoenix lander mission. Redox is considered to be a fundamental dimension of habitability. To understand the processes that have controlled the distribution and availability of carbon and the biogenic elements in the Martian crust, it will be necessary to understand basic redox processes and pathways.

Follow the energy - To advance Mars Astrobiology in the coming decade will require models for habitability that are both inclusive (with respect to alternative possibilities for life) and quantitative. In particular, we need models that predict not only whether life could exist in a particular environment, but *how much life* could be supported. In most chemotrophic biological systems on Earth, energy availability constrains biomass abundance over many orders of magnitude. Characterizing and quantifying energy sources on the Martian surface may thus, provide a key observation for prioritizing future landing sites, based on the potential magnitude of the energy “signal” they may harbor. For organisms on Earth, the relationship between energy flux and biomass abundance varies with the physicochemical environment (e.g. temperature, water activity, pH). For example, the amount of biomass supported at steady state by a given energy flux can be expected to decrease as temperatures increase, as water activity decreases, or as pH deviates from an optimal range. This observation presents a means for weighing, on a common basis, the individual and compounded effects of a variety of physical and chemical factors that influence habitability. To take such factors into account requires a means for constraining the effects of these factors over a range of environmental conditions. This may be particularly challenging when assessing the habitability of ancient surface environments on Mars. Nonetheless, the rock record may preserve evidence of paleoenvironmental conditions in the mineral assemblages and elemental signatures present, which, in turn, can help constrain the temperature, water activity and pH of ancient environments on Mars.

Mars Sample Return. The technology challenges associated with gaining access to deep (100s to 1000s of meters) subsurface zones of liquid water on Mars by robotic drilling are formidable. At this stage, progress on the question of Martian life is likely to come more quickly through the search for fossil biosignatures preserved in ancient, surface exposed sedimentary rocks. While it possible that compelling evidence for fossil biosignatures may be obtained through *in situ* missions, the definitive identification of putative Martian life forms may prove to be impossible using remote, robotic methods. For this reason, targeted Mars Sample Return (MSR) has been broadly advocated as an essential step for the definitive detection of past Martian life. On this basis, MSR provides a logical step in the exploration for an ancient a Martian biosphere, provided that the samples returned have been highly targeted by precursor *in situ* missions.

While MSR will provide opportunities for highly sophisticated analyses of Martian materials in terrestrial labs, it will also require the implementation of extensive planetary protection protocols to address international concerns over planetary back-contamination. This reality will add significantly to the cost and complexity of astrobiology missions and may require international partnering to be affordable. Thus, the value of MSR should be carefully weighed against the value of additional *in situ* mission investments. Logically, MSR should come in advance of human exploration of Mars and will provide an important information needed to assess risks and plan for such missions. Given the cost and complexity, MSR should be discovery-driven based on discoveries by precursor robotic missions, particularlt those focused on *in situ* life detection.