Are There Signs of Life on Mars?
A Scientific Rationale for a Mars Sample-Return Campaign As The Next Step in Solar System Exploration

Bruce M. Jakosky (University of Colorado at Boulder)
Richard W. Zurek (Jet Propulsion Laboratory, California Institute of Technology)
with
Jan Amend (Washington University in St. Louis)
Michael H. Carr (U.S. Geological Survey)
Daniel J. McCleese (NASA Jet Propulsion Laboratory)
John F. Mustard (Brown University)
Kenneth Nealson (University of Southern California)
Roger Summons (Massachusetts Institute of Technology)

A White Paper Submitted To The NRC Planetary Science Decadal Survey

September 13, 2009
(updated from September 7 submittal)

Compelling Reasons To Explore Mars

There are three compelling reasons for having a vigorous program to explore Mars: Mars has clear potential for biological activity, it has a well-preserved record of climate and geologic evolution, and it is accessible enough that a series of spacecraft missions could be used to systematically address some of the most important questions in solar-system science.

Conditions on Mars, particularly early in its history, were conducive to prebiotic chemistry and potentially to an origin and the continued evolution of life. It meets, or has met in the past, all of the requirements that are thought to be necessary for an origin of life or for life's continued existence.

Mars has preserved physical records of its early environment. This means that records of geologic history and climate change, as well as of possible prebiotic and biotic processes, throughout its history are accessible. Thus, there is a means to address questions about whether life ever existed on Mars, about planetary evolution processes, and about the potential coupling between biological and geological history.

Mars is accessible. Its atmosphere, surface, and interior can be explored from orbit and from the surface. Frequent launch opportunities provide the means to take a step-by-step approach to even the most challenging questions, as well as the means to respond relatively quickly to new discoveries. We also have seen the tremendous value of having an infrastructure (i.e., orbital assets for relay, critical event coverage, and site reconnaissance) in place at Mars as a means of enhancing the quantity and quality of returned data.

This combination of biological potential, of a well-preserved record of planetary evolution, and of ready access for exploration makes Mars a unique place in our solar system. Progress on issues that are important to both the science community and the public could be made more readily at Mars than anywhere else in the solar system.

Substantial Progress Enables The Next Steps

The science-driven approach of “follow the water” and the existence of a program emphasizing Mars exploration have allowed us to make substantial progress over the last two decades toward understanding the key disciplines at Mars — life, climate, geology, and preparation for human exploration.

This approach has included orbiters that were increasingly able to identify sites containing morphological and mineralogical evidence for water-related materials and processes. It includes surface vehicles of increasing capability that have now explored four sites at which water and ice have played important roles in shaping the surface (with a fifth site to be explored by MSL). This combination of global, regional, and local exploration has led us to a broad understanding of the history of water and of its relationship to the evolution of surface materials.

The evidence for water having had a complex history is unambiguous and makes Mars a possible abode for life. The highest-priority science questions for Mars now relate to habitability of Mars through time and thus to whether there ever was life on the planet.

Sample Return As The Next Step In Mars' Astrobiological Exploration

A definitive answer to whether there is or has been life on Mars or, if not, why not, can only be done rigorously through the analysis *of carefully selected samples returned* from one or more well-characterized, high-priority sites.

It is exceedingly difficult to address these questions *in situ* due to the limited measurements possible in even a series of landed missions. On an *in situ* mission, only an extremely limited set of experiments can be performed, based on the difficulty of packaging cutting-edge analytical tools for spacecraft and on the limited payload capacity of a lander or rover. Analysis of returned samples would allow measurements using complex analytical techniques (i.e., occupying large laboratories), provide necessary opportunities for follow-up measurements, and enable subsequent analyses using techniques not yet developed at the time of sample return.

Properly interpreting evidence related to life requires multiple approaches, and it is not possible to select discrete and unique criteria ahead of time. Answers would come only through multiple analyses of returned samples.

The greatest scientific progress in the search for life and in understanding the history of Mars as a potential habitat for life would be made by returning carefully chosen samples to Earth for detailed analysis.

The Broader Case For Mars Sample Return

Analysis of returned samples would contribute to most disciplines at Mars and is necessary for advancing our understanding of many of them, including through comparison with Earth. There is high relevance to topics including planetary formation, geophysical evolution, surface geology, climate and climate history of all the terrestrial planets.

Based on previous returned samples and sample analyses (meteorites, Moon, Stardust), sample return is expected to revolutionize our understanding of Mars in ways that simply cannot be done *in situ* or by remote sensing. This greater understanding of Mars would result in part from physical clues of processes that also operated on early Earth, but whose signatures are no longer accessible here. In this way the return of samples from Mars would provide a new perspective on evolution of the terrestrial planets generally.

Sample return is also thought to be a necessary step along the path toward potential human missions to Mars, in order to understand the environment prior to human arrival.

Progress By The Mars Exploration Program Has Made Sample Return Possible

The "follow the water" approach, as implemented through an integrated program of Mars exploration, has provided the context and the scientific justification for sample return:

- Recent missions have validated our ability to extrapolate orbital measurements to surface characteristics;
- A diversity of water-active environments has been revealed; many of these have the potential to preserve key biogeochemical signatures;
- MSL in particular is designed to test the "habitability" of a site chosen from multiple candidates.

The Mars Exploration Program has also made great strides in developing the technologies needed for sample return:

- MPF and MER have demonstrated surface mobility, and MER has utilized much of the basic instrumentation needed to identify high-priority samples.
- MER and PHX have provided valuable experience in sample handling and surface preparations; MSL will go further.
- The MSL EDL system design could fully support MSR. It could deploy caching rovers and could accommodate an MSR Lander with a Fetch Rover and Mars Ascent Vehicle (MAV).
- The assets needed to identify sites for potential sample return (instruments on ODY, MEX, MRO) and to certify site safety (MRO HiRISE) are operating now.
- Experience with operating multiple missions at the planet in the same period has been demonstrated. Orbital relay assets have been utilized to support routine operations by landed craft and for critical events.

The tremendous productivity of the Mars missions, and the successful and productive interplay between missions, has resulted from the Program approach to Mars exploration. In addition, the missions flown in the last two decades (MPF, MGS, ODY, MER, MRO, MEX, PHX) and those planned for future flight (MSL, MAVEN, ExoMars) are remarkable in adhering in detail to the "seek, *in situ*, sample" approach outlined in the 1995 Mars Exobiology Strategy.

A Site For Sample Return Can Be Selected

Exciting sites for potential sample return have been identified based on orbiter imaging and remote-sensing analysis. A site optimized for potential sample return could be chosen from the data now being collected, augmented with additional data obtained prior to when a site needs to be locked in.

The sample return site needs to be well characterized *in situ*. This could be done by returning to a previously visited site (e.g., the MSL site) or by going to a new site. Characterization of a new site would not require exploration by a precursor mission that would be as sophisticated as MSL. It could be done with an upgraded MER-class vehicle and instruments that would be a part of the proposed sample-return exploration. A choice between a previously visited site (e.g., MER or MSL) or a new site could be made for a potential caching rover prior to the 2018 launch opportunity; the same instrumentation and system capabilities could be used in either case, simplifying planning.

While the *in situ* detection of complex organics or other biosignatures would be highly motivating to return to that same site, such a detection is not required. The approaches to both life questions and other disciplines are much broader than, for example, the single litmus test of detecting complex organics, which may not be accessible at the surface today *even if life had developed in the past.* To further "buy down scientific risk" with additional precursor missions would not be necessary. Orbital data, validated by MSL and the preceding missions, should be sufficient to select a productive site, one with great potential to address both astrobiological and geochemical science.

A program to select the sample return site could be initiated now. We would want to assess the best site based on current information, to recommend observations of additional sites with the assets still available, and to consider new information as it becomes available.

Remaining Steps To A Mars Sample Return

A strategy that would conduct sample return as a campaign with a caching rover (MSR-C), followed by a sample return lander/rover (MSR-L) that would fetch the sample cache and loft it into orbit for rendezvous and return by an orbiter (MSR-O), would provide flexibility to return to a previously visited site (e.g., if motivated by an MSL discovery) or to go to a new site.

The recent program of frequent flights to Mars and operations on its surface demonstrates that samples could be collected from a well-chosen site and returned to Earth for study in a reasonable time even if that should require, as suggested here, several flight elements and launch opportunities.

In this way, a relatively modest (but still challenging) lander/rover would prepare an appropriate cache while the technology development needed for the proposed MSR-L (with its MAV) would proceed in parallel. Thus, the site for caching and subsequent potential sample return would be chosen after MSL results are available, but before the proposed MSR-C is launched.

This plan proposes that, within the next decade:

- The successful flight of MSL would validate the Entry, Descent and Landing capability needed in subsequent landed elements that would be part of a sample return campaign;
- The next mission in a sample return campaign would be a caching rover, with MER-class capabilities for characterizing the site and selecting samples;
- An intensive flight technology development for the proposed sample return lander, particularly for its MAV, would soon be started and sustained;
- Means of meeting planetary protection and contamination requirements, including advance work for the proposed sample receiving facility, would be integrated into planning from the beginning.

Mars Exploration Program

Sample return would be an implementation required to address specific, fundamental science goals that have been identified as the highest-level science goals for Mars. If we do not do MSR, then these science goals cannot be addressed adequately.

Compelling questions in other disciplines — present-day atmosphere and climate, deep interior, etc. — could and should be pursued as resources and international partnering opportunities permit. Example mission concepts are:

- <u>Trace Gas Mission</u>: Would follow up on recent discoveries pointing to modern day geological or biochemical processes;
- <u>Surface Geophysical Network</u>: Would fill in present void in our understanding of interior processes, including how they have affected the Mars climate;
- <u>Mars Scouts</u>: Many focused, low-cost mission concepts having high science value that would be complementary to the core program have been developed.

Summary

Mars is unique in solar-system exploration in terms of the breadth and depth of science goals, the relative ease of implementing missions, the importance to the highest-priority science objectives such as the life question, and in terms of public fascination. Mars has preserved the history we seek and holds the potential that we could find the signs of life or the reasons why life never started there. In doing so, we would learn much about the change over time of climate and of planetary processes on the terrestrial planets.

A sample return from a single site, no matter how carefully chosen, would not address all of the high-priority scientific objectives for Mars. The diversity of Martian environments, now and in the past, and the complexity of the processes at work will require a broader program of exploration. ***However, the first sample return from a well-characterized site is the means to make the greatest progress at this point in understanding solar-system exploration.***

While other solar-system objects are compelling destinations — with tantalizing possibilities even for the life question — the effort, time and expense required to investigate them *at comparable levels of detail and of scientific risk* is much greater than for Mars.

There is no doubt that the remaining steps to a sample return are both challenging and expensive. The campaign strategy outlined above, with multiple elements, would spread the risk — both scientific and technical — and the peak funding required. Accomplishing this campaign would likely require international cooperation and even then would take several launch opportunities to implement. But we could reasonably take the first steps now and in the coming decade.

Analysis of returned samples would revolutionize our understanding of Mars, both across multiple disciplines and as the integrated understanding of a complex planet and of solar-system processes, including astrobiology. We need to go forward with this challenging step.