Seeking Signs of Life on a Terrestrial Planet: An Integrated Strategy for the Next Decade of Mars Exploration

A white paper submitted to the National Research Council as input to the Planetary Decadal Survey.

Prepared on behalf of the Mars Exploration Program Analysis Group (MEPAG) by the MEPAG Executive Committee (Jack Mustard, chair)

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All references and acronyms used in this document are defined in *Compiled Bibliographic Citations and Acronym Glossary for the Mars-Related White Papers Submitted to the NRC's Planetary Decadal Survey*, which may be accessed at:
http://mepag.jpl.nasa.gov/decadal/index.html <http://mepag.jpl.nasa.gov/reports/index.html>

Mars: A Laboratory for Solar System Processes

The Mars Exploration Program Analysis Group (MEPAG) has maintained since 2001 a prioritized listing (referred to as the "Goals Document") of the most important currently open scientific goals and objectives about Mars that could be addressed using the flight program (MEPAG, 2008). The broad and ambitious nature of this list reflects the complexity of Mars itself and, amongst the terrestrial planets and Moon, the nearly unique physical record on Mars of geological, climatic and pre-biotic, if not biological, processes that have occurred over four billion years of its history. The MEPAG (2008) list has more objectives and investigations on it than can be addressed in the one-decade period being considered by the Planetary Decadal Survey. Given the resource constraints, how can we determine the subset of the MEPAG list that will become the specific scientific objectives for the next decade? What strategies will connect the different lines of scientific inquiry?

Although we have learned many things about Mars from recent and ongoing missions, Mars remains a compelling target for planetary exploration for four primary scientific reasons (summarized in MEPAG, 2009). The objectives for Mars of the next decade can be framed in the context of these broad scientific drivers.

1. Early evolution of the terrestrial planets, including our own Earth;
2. A means to approach, and possibly answer, questions about the origin and evolution of life elsewhere in the Universe and, by comparison, on our own world;
3. The nature of short- and long-term climate change as driven by orbital variations;
4. The internal structure and origin of the terrestrial planets.

In addition, Mars is a long-term strategic target for the human exploration program (MEPAG, 2009). The compelling rationale for the human spaceflight program is partly driven by science, and partly by other considerations.

Finally, in considering scientific objectives for the flight program, it is critically important to consider a number of factors related to mission implementation, including technical readiness and political and financial realities.

Proposed Science Objectives for the Next Decade

Specific high priority questions that could be addressed in the next decade are (enumerated goals refer to the MEPAG Goals listing; this specific list was vetted at the July 2009 MEPAG meeting (Mustard et al., 2009)):

- How does the planet interact with the space environment, and how has that affected its evolution? (Goal II)
- What is the diversity of aqueous geologic environments? (Goal I, II, III)
- Are reduced carbon compounds preserved and what geologic environments have these compounds? (Goal I)
- What is the complement of trace gases in the atmosphere and what are the processes that govern their origin, evolution, and fate? (Goal I, II, III)
- What is the detailed mineralogy of the diverse suite of geologic units and what are their absolute ages? (Goal II, III)
- What is the record of climate change over the past 10, 100, and 1000 Myrs? (Goal II, III)

- What is the internal structure and activity? (Goal III)

Mission Concepts and Architecture

Missions can be proposed that would address the above scientific objectives, which encompass those previously defined goals from the last planetary decadal survey (NRC, 2003) not yet fulfilled for Mars. That SSE decadal survey and subsequent assessments (NRC, 2006) suggested the following missions: 1) a sample return mission to make progress on a broad front of fundamental scientific questions; 2) a Mars Science Laboratory (MSL) to explore a water-modified environment identified from orbital data; 3) an aeronomy mission to understand the processes of atmospheric composition, evolution and loss of volatiles to space; and 4) a network mission to characterize the interior structure / activity and to address meteorological objectives. The continued pursuit of these suggested missions, taking into account new discoveries and lessons learned, is an integral part of the exploration strategy for the coming decade.

The success of the MEP to date shows the value of mission interdependencies that could leverage resources and reduce risk, both technical and scientific, to achieve the highest priority scientific objectives. Outstanding examples of the benefit of interdependencies are site selection (for PHX and MSL), critical event coverage (for ODY, MRO, MER, PHX), and data relay (MER, PHX). (See Edwards et al., 2009.) Furthermore, all mission concepts must balance the firmness of the scientific foundation, the technical feasibility, and the cost/risk implications of the proposed mission concepts. For Mars, in the past and as advocated here for the next decade, these mission factors have been explored and assessed by MEPAG, particularly through their Science Analysis Groups (Murchie et al., 2008; Pratt et al., 2009; Banerdt et al., 2009), and by groups chartered by NASA, including the Mars Architecture Tiger Teams (Christensen et al., 2008, 2009) and the Mars Architecture Review Team (MART; S. Hubbard, chair).

The mission building blocks (concepts and plans) and the architecture linking them are described here in further detail. Together, they form an integrated strategy for the next decade of Mars exploration that would address the highest priority science objectives for Mars and planetary exploration.

Steps in Progress

Here we describe briefly the steps that the NASA Mars Exploration Program is already taking to address some of the scientific objectives outlined earlier.

Mars Science Laboratory **– *MSL***

Motivated by its growing body of orbital reconnaissance and *in situ* findings, the MEP is developing the Mars Science Laboratory rover to investigate *in situ* a water-modified environment. MSL is not designed as a life detection mission, although MSL brings a more sensitive detector of organic material than was flown on Viking. MSL will explore the habitability of the site by using its analytical laboratories to analyze powdered material drilled from rocks and by imaging geologic structures and surface textures at a variety of scales. MSL will generally characterize the stratigraphic and compositional context of the landing site, taking advantage of the rover's mobility. MSL will go to a site where orbital reconnaissance has established both morphologic and compositional evidence for the action of water and where the potential for preservation of biosignatures, should they exist, is high. In doing so, MSL will also utilize a new landing system capable of placing a metric ton safely on the surface of Mars, thereby demonstrating a feed-forward technology that can be exploited in future missions. The MSL spacecraft, now in development, is scheduled to launch in 2011.

Mars Atmospheric and Volatile Evolution Mission - MAVEN

MAVEN, currently in the formulation phase, is NASA's second Mars Scout mission. It directly responds to the recommendation of the last planetary decadal survey to understand the loss of volatiles to space. Planned for launch in 2013, MAVEN would orbit Mars to observe and quantify current atmospheric escape processes and thus to provide a firm basis for modelling what may have happened in the past. Ancient water not frozen into the planet's surface may have been lost to space, especially after the demise of the global magnetic field permitted the solar wind emanating from a bright UV early Sun to sweep through the atmosphere. Understanding the volume of water lost to space as compared to the volume locked in subsurface ice and surface alteration is one key to understanding the evolution of water on Mars.

Mars Mission Objectives for the Next Decade

Given the questions that could be addressed by the MSL and baselined MAVEN missions, the remaining science objectives call for the following specific actions:

- Given the diversity of sites revealed by recent Mars missions, explore a new site with high potential for habitability and geological discovery. At that site, evaluate past environmental conditions, the potential for preservation of the signs of life, and seek candidate biosignatures.
- Test hypotheses relating to the origin of trace gases in the atmosphere, and the processes that may cause their concentrations to vary in space and time.
    - Also extend the current record of present climate variability
- Establish at least one (and preferably more) solid planet geophysical monitoring station with a primary purpose of measuring seismic activity.
- Take specific steps to achieve the return of a set of high-quality samples from Mars to Earth as early in the 2020's as possible:
    - Fund MSR technology development program early in the next decade
    - Identify a safe, high-priority site suitable for caching samples for possible return
    - Establish a potentially returnable cache of samples on Mars.

These steps are not mutually exclusive and provide opportunities for mission synergies.

Proposed Mars Mission Architecture for the Next Decade

The above mission concepts could be achieved through four mission concepts, for which measurement objectives, mission linkage, and science rationale are now briefly described.

Trace Gas Mission Orbiter Concept – 2016 (TGM; see Smith et al. & Edwards et al., 2009)

- *Detect remotely a suite of trace gases with high sensitivity (e.g., <ppb)*
- *Characterize their time/space variability over the planet for 1 Mars year & infer sources*
- *Replenish for several years the orbiter infrastructure needed for future mission support*

Ground-based and MEX detections of methane in the Mars atmosphere introduced a new cross-cutting element addressing both astrobiology and geoscience goals. Methane's presence and reported variability requires active subsurface sources and unknown chemical sinks. To understand the nature of the subsurface source and whether it is biochemical or geochemical requires detection of a broad suite of trace gases (e.g., higher-order hydrocarbons, sulfur and nitrogen bearing gases, water vapor and isotopes) in addition to methane. Identification of localized sources could further define their nature and could provide targets for future exploration. Even if methane is not as variable as reported, establishing a much improved trace gas inventory would help in understanding volatile loss in the atmosphere and the potential role of trace gases in past climates, particularly as reflected in isotopic ratios. This relatively low cost orbital mission (~$750M, including launch vehicle, spacecraft, instruments) is possible in the energetically challenging 2016 launch opportunity. Its early flight would provide vital mission support for later missions and a timely follow-up of an important discovery about Mars today.

Network Mission Concept – 2020 (NET; see Banerdt et al., 2009)

- *Determine the planet's internal structure & composition, including core, mantle & crust*
- *Collect simultaneous network meteorological data*

The established existence of an early global magnetic field and the possible transition in chemical alteration of the surface following its demise brings new emphasis to understanding interior structure and processes. The priority would be to emplace 3-4 seismic stations on the surface to make critical measurements of internal activity and structure. Measurements of heat flow and surface-based meteorological measurements have also been proposed. The latter could be highly leveraged by atmospheric sounding of temperature and dust (plus trace gases) from the proposed 2016 orbiter, and data from even a few stations would provide valuable ground truth for the remote sensing data. The network geophysical science would benefit from the relay capabilities required of the proposed 2016 orbiter. Depending on implementation, preliminary estimates of the total mission cost suggest that a 3-4 station network might cost ~$1B.

Sample Return Campaign Concept – 2018 and beyond (see Borg et al., 2009)

- *Make a major advance in understanding Mars, from both geochemical and astrobiological perspectives, by the detailed analysis of carefully selected samples of Mars returned to Earth*

Of the Mars missions needed to address the objectives outlined earlier, the proposed sample return is the most challenging. ***The return of carefully selected samples even from a single well-chosen site would be the means to make the greatest progress at this point in planetary exploration***. The recognized challenges of definitively detecting biosignatures, especially when attempted *in situ*, has raised the priority of sample return for astrobiological studies (NRC, 2007) to the same high level given sample return for geochemistry, including geochronology. For both science areas, the return of samples would provide the opportunity for repeated experimentation with the latest analytic tools, including the all-important ability to follow-up on preliminary discoveries with new or revised analytic approaches. Knowledge of the samples' context on Mars, including detailed knowledge of the environment from which they were selected, would also be crucial for defining the laboratory analyses and interpreting their results.

The pursuit of the proposed sample return campaign in a step-by-step approach now appears to be within the international community's grasp, both scientifically and technically. Orbital reconnaissance, experience with surface operations and the development of the MSL Entry/Descent/Landing system have reduced both the scientific and technical risks of sample return, in accordance with the NRC desires (NRC, 2003, 2006) that NASA take steps to implement a sample return mission as soon as possible. The next mission steps in the proposed sample return campaign would be:

- Collection of appropriate samples and caching them at an appropriate site;
- Acquisition of the cache and launch of it into Mars orbit;
- Rendezvous with the cache in Mars orbit and return to Earth.

The activities for the next decade with regard to the proposed sample return are:

- Identification of the sample return site;
- Deployment of a caching rover, preferably launched in the 2018 opportunity; and
- Initiation of a technology development program for the proposed sample return cacher, Mars ascent vehicle, and Earth-return orbiter.
- Planning for sample handling and analysis facilities for the proposed return of samples.

Sample Return - Technology Development (see Hayati et al., 2009)

Major challenges include the development of the Mars Ascent Vehicle (MAV), sample acquisition/handling/caching, and back planetary protection procedures. While still challenging, development of a fetch rover, more modest advances in the orbiter capture and return mechanisms, and tweaking of the MSL delivery system would be building on the current program's investment in flight articles. Development of contamination control procedures and planning for the proposed future sample handling facilities also needs early investment. Early investment in these areas would reduce mission risks and help control costs.

Sample Return – Caching with a 2018 Rover Concept (see Pratt et al., 2009)

Site Selection (see Grant et al., 2009): The existence of environments where (liquid) water has reworked the morphology and composition of the surface has been established with data from orbital and landed spacecraft. A number of sites were revealed that had the potential that compositional and geomorphic signatures of past ancient life—or that evidence of how far the pre-biotic chemical evolution went—would be preserved. MSL will explore the habitability of one such site with its sophisticated analytic laboratories, but it does not have the type of sample coring and caching apparatus needed to produce the cache itself.

A caching rover proposed here for launch to a new site in 2018 could be directed back to the MSL site *if MSL were to make a sufficiently compelling discovery*. (This addresses the concern raised in previous assessments of insufficient time to respond to MSL results; NRC, 2006.) In any case, whether from a new site or one previously visited (e.g., MSL or MER), the sample cache prepared there would be extracted from a well-characterized environment.

Furthermore, there are distinct advantages of going to a new site for the caching rover. First, another aqueous environment could be explored, as the instrumentation needed for sample selection for a cache could also conduct high priority *in situ* science. Second, and perhaps more importantly, all possible objectives for sample return could be weighed in the selection process; this differs from the MSL site selection process in that access to non-sedimentary rock types and landforms were (by design) not given high priority. Thus a new site would be chosen based on existing orbital data and future directed observations (Grant et al., 2009), guided by experience gained with MER and MSL, but with broader criteria focused on a potential sample return.

2018 Mars Astrobiology Explorer-Cacher Concept ***(MAX-C rover; see Pratt et al., 2009)***

- *Explore Mars habitability in the context of diverse aqueous environments provided by a new site; characterize the explored environment suitable for potential sample return*
- *Select and prepare samples for possible return*

To provide flexibility while building on the MSL technical heritage, the next landed mission proposed after MSL would have sufficient instrumentation to characterize the site and to select samples for caching at a new site. It would not need the MSL onboard analytical laboratories, but would have the ability to core into rocks at carefully selected points. It should have the range needed to get the diversity of samples that would greatly enhance the value of the returned material and to park in an area potentially accessible by a fetch rover from the proposed sample return lander. Launch in 2018 would leave ample time to respond to an MSL discovery but also would take advantage of the favorable entry conditions during that opportunity.

While launch of the proposed rover in 2020 is still possible technically, such a launch would be almost 10 years after the MSL development. Building sooner on the personal and technical expertise developed by MSL would reduce both technical and cost risk.

It is reasonable to ask what would be this mission's contribution if a sample return were delayed indefinitely. The answer is there is great value in exploring a new site, especially with rock coring capability. The diversity of Mars, now and early in its history, is quite remarkable—nearly a dozen geologic/ climatic unit types have been identified (Murchie et al., 2008), many with habitability potential. The proposed 2018 rover, delivered by the MSL system, could carry instruments whose remote sensing and contact science capabilities go beyond the MER capabilities, even without the MSL analytic capabilities. Much could be learned about Mars from its *in situ* exploration even as it prepares a cache for the future. Fortunately, there is enormous overlap between the capabilities required for sample selection and those able to support high-value *in situ* science. Preliminary estimates of the total mission cost of this rover concept suggest that it is in the range ~$1.5 - 2B.

<u>Possible NASA-ESA Collaboration</u>

This suite of proposed missions is a challenging program and, with the proposed sample return, an expensive one. A promising development is that NASA and ESA are co-aligned in their interests for the next decade (i.e., a Trace Gas Mission, a landed rover mission, and network mission concepts) and beyond (a sample return in the early 2020's). In recent discussions, there is general agreement on a suite of options to consider, although much work remains to finish definition of the international program's elements and to get commitment from the agencies involved. Since the discussion of those commitments is ongoing at this time, potential collaborations are not discussed further here.

<u>A New Theme: Seeking Signs of Life on Mars</u>

The "Follow the Water" theme served Mars exploration well by connecting discipline goals in our investigations of Mars just as those processes (geological, geophysical, meteorological, chemical and potentially biological) have been connected through Mars history. As the numerous missions to Mars have revealed the diversity of its environments and the complexity of its history, other themes have emerged which MEPAG has considered and which NASA, to some extent, has adopted:

- Introduced in 2000: Follow the Water [MGS, ODY, MER, MEX, MRO, PHX]
- Introduced in 2004: Understand Mars as a System [All]

- Introduced in 2005: Seek Habitable Environments [MSL, MSR]

In 2008, MEPAG began debating a new theme that would focus on the MEPAG Life Goal as first amongst equals (see e.g. Murchie et al., 2008). The issue was how to capture in a phrase the essence of the MEPAG goal (including Solar System Exploration decadal survey quests) without jumping prematurely to a mission of life detection—a lesson learned from Viking.

The Mars Architecture Tiger Teams (MATT), chartered by NASA to address the direction and feasibility of Mars mission architecture, followed the MEPAG MSS SAG by concluding (Christensen et al., 2008): "*The focus on future missions should be "explore habitable environments" of the past and present, including the "how, when and why" of environmental change"*. Although quantitatively assessing environmental habitability is the objective of MSL, the growing body of information about the diverse aqueous environments of Mars indicates that we are ready for more ambitious next steps, in concurrence with the major findings of the NRC (2007): "*The search for evidence of past or present life, as well as determination of the planetary context that creates habitable environments, is a compelling primary focus for NASA's Mars Exploration Program*". Furthermore, "*The greatest advance in understanding Mars, from both an astrobiology and a more-general scientific perspective, will come about from laboratory studies conducted on samples of Mars returned to Earth."*

In June, 2009, the Mars Architecture Review Team proposed the following strategy for the next decade of Mars exploration: "*Seeking Signs of Life"*. The Mars science community discussed and accepted this specific proposal at the July 2009 MEPAG meeting.

Summary: Seeking Signs of Life on Mars

The following mission building blocks are proposed for the coming decade:

- **TGM** to determine the abundances and spatial/temporal variations of trace gases and isotopes in the present atmosphere and their implications for life
- **NET** to explore the nature and history of the interior and the implications for the surface and atmospheric environments
- MSR [**MAX-C** + Return Lander & Orbiter] to return diverse suites of carefully chosen samples from a well-characterized site to Earth for detailed geological and astrobiological study.

These proposed program elements would address high priority science objectives for both Mars and Solar System exploration by tapping into the virtually unique physical record of large body evolution that Mars provides, even while examining the dynamic processes still at work on the planet today. 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.

This strategy would implement missions of high scientific priority as recommended by previous NRC reports, while responding to new discoveries. The proposed step-by-step approach to sample return would provide a credible path with defined way-points, while conducting important *in situ* science.

This integrated strategy does not address all of the high-priority scientific objectives for Mars—no one strategy could within the projected resources. However, these steps would make the greatest progress to answering fundamental questions of Solar System science, including the age-old question of whether Mars is today—or ever was—an abode of life.

REFERENCES

Posted online by the Mars Exploration Program Analysis Group (MEPAG) at:
.http://mepag.jpl.nasa.gov/decadal/index.html .