Mars Astrobiology Explorer-Cacher (MAX-C): A Potential Rover Mission for 2018

Prepared on behalf of the Mars Exploration Program Analysis Group (MEPAG) by the Mid-Range Rover Science Analysis Group (MRR-SAG)

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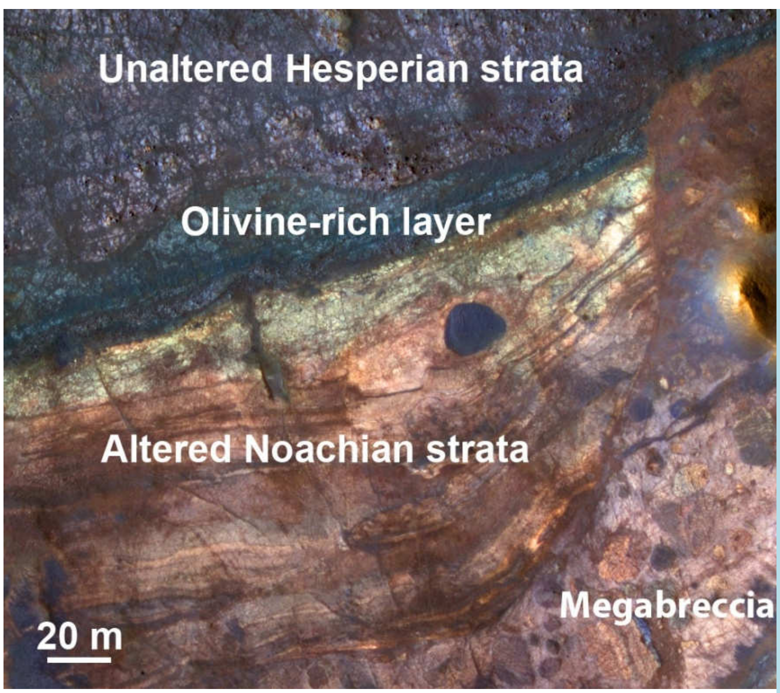

Example candidate MAX-C landing site, Nili Fossae region (22.2 N, 77.1E).

Noachian-Hesperian sedimentary stratigraphy. CRISM has detected phyllosilicate minerals in a megabreccia (lower right) and adjacent Noachian strata and olivine in overlying layers which are possibly lava flows. Unaltered Hesperian strata (upper left) are inferred to outcrop near the top of this sequence.

Portion of HiRISE image PSP_002176_2025. Credit: NASA/JPL/University of Arizona.

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INTRODUCTION[1]

Significant discoveries and landmark technical achievements with recent orbiting and landed missions have overturned the image of Mars as a forbidding red planet lacking resources to sustain life as we know it. Landscapes cut by gullies and channels, spectral maps of sedimentary minerals, detection of water in surface deposits, shallow-radar images of cyclically layered polar deposits, and plumes of atmospheric methane are all part of the emerging picture of Mars as a dynamic and habitable planet. The search for preserved evidence of life is now the keystone concept for a new generation of Mars rovers capable of exploring, sampling, and caching suites of rocks. Drawing on the reconnaissance heritage of Spirit and Opportunity and the extraordinary analytical instrument suite of the Mars Science Laboratory (MSL), the proposed rover mission would target landing sites with the highest potential for preservation of biomarkers in the forms of minerals, organic molecules, and sedimentary features.

The purpose of this white paper is to describe a potential rover mission that could be launched in 2018. This mission was first envisioned by the MAPG team (McCleese et al. 2006; Beaty et al. 2006), and the possible strategic importance of this mission was subsequently refined by the MEPAG MSS-SAG team (Murchie et al. 2008) and the MATT team (Christensen et al., 2008, 2009). The authors of this report were charted by MEPAG to produce a much more refined definition of this mission concept. Based on programmatic and engineering considerations as of April, 2009, we have assumed that the mission would use the MSL sky crane landing system, would include a single solar-powered rover, would have a targeting accuracy of ~ 7 km (semi-major axis landing ellipse), and would have a mobility range of at least 10 km. In addition, it would have a lifetime at the martian surface greater than one Earth year, and both cost and cost risk that would be lower than those of MSL. The proposed mission is conceived to address two general objectives: conduct high-priority *in situ* science and make concrete steps towards the potential future return of samples to Earth. The proposed means of achieving these two primary goals while balancing the trade-offs between them are described in detail in MRR-SAG (2009), and are summarized in this white paper. We propose the name Mars Astrobiology Explorer-Cacher (MAX-C) to best reflect the dual purpose of the potential mission.

POTENTIAL CONTRIBUTIONS OF THE PROPOSED MAX-C ROVER MISSION TO THE *IN SITU* EXPLORATION OF MARS

The Mars Exploration Program Analysis Group (MEPAG) actively maintains a prioritized, consensus-based list of broad scientific objectives that could be achieved using the on-going flight program (MEPAG, 2008). The first among equals of these objectives is to determine whether life ever arose on Mars. Searching for signs of life on another planetary body requires a detailed understanding of the diversity of life as well as the environmental limits and evolutionary adaptations of life for different physical and chemical settings on Earth. Exploration for life on Mars requires a broad understanding of integrated planetary processes in order to identify those locations where habitable conditions are most likely to exist today or to have existed in the past and where conditions are or were favorable for preservation of the evidence of life if it ever existed. Such an approach would require investigation of the following in addition to life detection:

- The geological and geophysical evolution of Mars,

[1] All 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.

- The history of Mars' volatiles and climate,
- The nature of the surface and subsurface environments,
- The temporal and geographic distribution of liquid water, and
- The availability of other resources (e.g., energy) necessary for life.

Over most of the last decade, the Mars Exploration Program has pursued a strategy of “follow the water” (formally introduced in 2000; see documentation in MEPAG, 2008). While this strategy has been highly successful in the Mars missions of 1996-2007 (MPF, MGS, ODY, MER, MEX, MRO, and PHX), it is increasingly appreciated that assessing the full astrobiological potential of martian environments requires going beyond the identification of locations where liquid water was present (e.g., Knoll and Grotzinger, 2006). Thus, in order to seek signs of past or present life on Mars, it is necessary to characterize more comprehensively the macroscopic and microscopic fabric of sedimentary materials, identify the presence of organic molecules, reconstruct the history of mineral formation as an indicator of preservation potential and geochemical environments, and determine specific mineral compositions as indicators of oxidized organic materials or coupled redox reactions characteristic of life. This type of information would be critical in identifying and caching relevant samples intended for study in sophisticated laboratories on Earth.

With the above context, we considered and debated a broad range of specific possible ways to advance towards the above long-range science goals. Three related possible mission concepts emerged as highest priority: (1) Early Noachian (> 4 Ga) Astrobiology addresses early planetary evolution and crustal composition during the critical time when climatic conditions and processes such as a magnetic field and impact cratering potentially enabled prebiotic conditions leading to life; (2) Noachian-Hesperian Stratigraphy addresses whether life arose and, if so, how it was affected by changes in surface conditions during a global decline in erosion, aqueous weathering, fluvial activity, and magnetic field; and (3) Astrobiological Exploration of a New Terrane seeks to broaden the diversity of explored astrobiology-relevant environments by visiting a site that is both promising and qualitatively distinct from previously visited sites.

After considering the measurements and the investigation strategies necessary for each of these kinds of exploration targets, we concluded that a rover with the same general capabilities would be capable of exploring a wide range of landing sites of relevance to all of them. Each of these three lines of scientific inquiry relate to astrobiology, they all entail understanding paleo-environmental conditions, understanding preservation potential would be important for all of them, and they all are of interest for assessing possible evidence of past life and/or pre-biotic chemistry. This single general mission implementation would allow the Mars Exploration Program to respond to discoveries over the next several years in any of the above areas with the distinction between these scenarios resolved in a landing site competition.

On Earth, minerals differ in their effectiveness as agents of preservation. Phyllosilicates are often associated with organic accumulation (e.g., Kennedy, et al., 2002; Wattel-Koekkoek et al., 2003), but they are less effective for preserving morphological fossils. In contrast, precipitated minerals, such as silica, sulfates, and carbonates, can preserve diverse types of biosignatures, but the specific setting in which these minerals originally formed also has a substantial impact upon the preservation of key evidence. Efforts by orbiter missions, MER, and MSL to map the distribution of such minerals at various spatial scales will influence substantially the way they are viewed as indicators of aqueous activity and habitability and also as preservation media for biosignatures.

Implementing the above objective would require interpretation of the origin and subsequent modification of rocks with as-yet unknown mineral composition, macro-scale structure, and degree of heterogeneity. Given these unknowns, it is challenging to specify the critical measurements required by a rover mission. Relevant experience from studies of ancient terrestrial strata, martian meteorites, and from MER indicates that the proposed rover's interpretive capability should include: meter to submillimeter texture (optical imaging), mineral identification, major element contents, and organic molecular composition.

For three primary reasons, we propose that the measurement strategy focus on interrogation of surfaces: 1). We know from the results of MER that a variety of microscopic textures are present on Mars (Herkenhoff et al. 2004; 2006; 2008); 2). We know that surface analysis techniques have significantly lower cost and risk in comparison to acquiring rock chips or powders (comparative experience from MER and MSL); and 3). A number of suitable instruments are either already developed or are under development (at least Technology Readiness Level-3) in each of these four areas identified (MRR-SAG, 2009 for references). This class of instruments makes use of a relatively smooth, abraded rock surface, such as is produced by the Rock Abrasion Tool (RAT) grinder on MER (Gorevan et al., 2003).

For measurements of mineralogy and chemistry, instruments used to directly interrogate smoothed rock surfaces typically cannot match the analytical accuracy and precision attained by instruments that ingest samples. However, the data quality is sufficient to meet key science objectives, and the ability of such instruments to characterize intact outcrops offers substantial advantages. Although in the past we have used instruments that average the analytic data over an area at least centimeters in size (e.g. Christensen et al., 2004; Morris et al., 2006; Gellert et al., 2006), with newer instrumentation spatial resolution down to scales of 10s of microns is readily achievable (see e.g Wang et al., 2003; Ohzawa, 2008; Bhartia et al. 2008). Some instruments can produce data in a 2-D scanning mode, which would be exceptionally powerful. If observations of texture, mineral identification, major element content, and organic materials are spatially co-registered, they can interact synergistically to strengthen the ultimate interpretations. This 2-D micro-mapping approach is judged to have particularly high value for evaluating potential signs of ancient microbial life, which are likely to be manifested at relatively small scale. We conclude that the 2-D micro-mapping investigation approach is an excellent complement to the data anticipated from MSL, which will have higher analytical precision but lower spatial resolution.

If it were possible for the proposed rover mission to include additional instruments, they could support astrobiological objectives by measuring volatile constituents and light stable isotopes, potentially including elements in addition to C in organic materials. We have additionally recognized several possible high-priority secondary payloads, including atmospheric monitoring instruments (the most important of which is a pressure sensor, Rafkin et al., 2009), and a magnetometer (see Weiss et al. 2008).

POTENTIAL CONTRIBUTIONS OF THE PROPOSED MAX-C ROVER MISSION TO A POSSIBLE FUTURE SAMPLE RETURN

Returning samples from Mars is essential to meeting the Mars Exploration Program's highest priority scientific objectives (NRC, 2007; ND-SAG, 2008; iMARS, 2008; MRR-SAG, 2009; Borg et al., 2009; MEPAG, 2009; and references therein). A sample return campaign would entail comparatively high cost and scientific risk, so in comparison to other mission approaches, it must also deliver unprecedented value. In order to address the kinds of scientific questions that are highest priority, we would need what we refer to as "outstanding samples." We agree with the position (most recently summarized by NRC, 2007) that there is no such thing as "the right sample" and that delaying a potential MSR campaign until one is discovered is illogical. However, even though any sample returned from Mars would be useful for some line of scientific inquiry, it is also true that not all samples would be equally useful for detailed scientific investigation. Some of our highest priority questions could be addressed only with samples that record the effects of critical martian processes. The scientific productivity of returned-sample investigations would be dependent on the effectiveness by which the samples were selected. This is the concept of "outstanding samples," which undoubtedly exist in many places on Mars but which could only be identified and collected with planning and effort.

As our knowledge of the martian surface has increased, there has been a parallel increase in the number and nature of sites that are believed to contain outstanding samples. The NRC (2007) recently summarized one set of high interest astrobiology sites. At Mars-related sessions in major recent conferences (e.g., LPSC, EPSC, AGU, Mars-7, EGU), the global Mars science community has developed multiple additional site-related astrobiological hypotheses, the testing of which could substantially address the life question.

To date, we have explored six landing sites on the martian surface. Four of these (MPF, V-1, V-2, and PHX) stimulate only limited interest in returning samples. Although there is significantly more interest in the kinds of materials that have been discovered by the rovers Spirit and Opportunity, and new discoveries could be revealed as those missions progress, there is a widespread feeling amongst the science community that better samples (particularly for addressing the high-priority life-related questions) exist elsewhere on Mars. The landing site selection competition associated with MSL clearly revealed a number of sites with excellent potential (Grant et al., 2008; Golombek et al., 2009). A key outcome of relevance to a possible future sample return relates to what MSL discovers.

- If, at the MSL landing site, we do <u>not</u> recognize a way to put together an outstanding sample suite, we would want to send a rover to an alternate site selected from orbital data and for which an argument could be made that there is better science or access potential. Such a rover should be equipped with adequate scientific instrumentation to support sample selection decisions and document sample context.
- If MSL <u>does</u> discover outstanding samples, we would presumably want to send a rover back to collect them for return. ND-SAG (2008) pointed out that it is theoretically possible for a sampling rover that revisits a previously explored route at a well-characterized site to carry reduced instrumentation (relative to a rover sent to a new site). However, this might require revisiting exact positions, and possibly even the same RAT holes. At the very least, sampling would have to take place in a nearby and demonstrably equivalent geological unit. Because such a pared-down mission would lack the ability to select or document samples, the risk of not being able to reoccupy previous sites would be a critical science vulnerability with enormous potential consequences to the science return. We concluded that the consequences would be too severe to accept this risk.

The same kind of proposed rover, with similar analytical capabilities, would be needed by a potential future sample return campaign to select and document its samples, regardless of whether it would be sent to the MSL site (or any other previously explored site) or to a new site selected from orbit.

The potential future return of samples from Mars would require delivery to the martian surface of a rover that could collect samples and a future ascent vehicle (referred to as the Mars

Ascent Vehicle, or MAV) that could lift them into martian orbit. In all sample return mission scenarios, an orbiter would also be required). However, as discussed in more detail by MRR-SAG (2009), for mass, cost, and/or risk reasons it might be either impossible or undesirable to land the sampling rover and MAV at the same time. This leads to discussion of the so-called "2-element" architecture (the sampling rover and the MAV landed together), and the so-called "3-element" architecture (the sampling rover and the MAV landed on separate flights). The return orbiter is the remaining mission element.

By far the most important contribution of the proposed rover mission to a potential future sample return would be the assembly of a returnable cache of samples. If this proposed rover discovers outstanding samples, it would be most efficient to collect and cache them while the rover that first identifies them is still active. It would be challenging and risky for a mission to attempt to reoccupy specific sampling sites of an earlier mission. The assembly of a compelling cache of samples would by definition place the program on the pathway of a 3-element Mars sample return campaign concept.

If the cache created by the proposed MAX-C rover mission were recovered by a subsequent mission that lands the MAV, the complexity of that subsequent mission would be greatly reduced. It would not need to carry out the complex and time-consuming tasks of identifying and prioritizing candidate samples, acquiring them, and packing them for the return trip to Earth. This would therefore reduce the cost and technical risk of that follow-on mission. This reduction in mass may in turn be a critical factor in keeping a potential future sample return mission's landed mass within heritage (MSL) entry, descent, and landing capabilities. Even if the proposed MAX-C cache is not recovered, for one reason or another, the action of building the cache would demonstrate and refine the mission-critical sampling, encapsulation, and sample management technologies, which would reduce the "number of miracles" needed for a future MSR.

SUMMARY OF THE PROPOSED *MARS ASTROBIOLOGY EXPLORER-CACHER* (MAX-C) ROVER MISSION

Summary of Science Vision

Our planning activity over the past five months has concluded that the capabilities needed for a rover to carry out compelling, break-through science at the martian surface are the same as those needed to select samples for potential future sample return, and to document their context. This proposed rover would have the following attributes:

- Mast- or body-mounted instruments capable of establishing local geologic context, and that would be capable of identifying and prioritizing targets for close-up investigation. This could consist of an optical camera and an instrument to remotely determine mineralogy (the same considerations applied to the design of both MER and MSL). Documenting the field context of the landing site would include mapping outcrops and other accessible rocks, characterizing mineralogy and geochemistry, and interpreting paleo-environments.
- A tool to produce a flat abraded surface on rocks.
- A set of arm-mounted instruments capable of interrogating the abraded surfaces by creating co-registered 2-D maps of visual texture, major element geochemistry, mineralogy, and organic geochemistry. This information would be used to understand the diversity of the samples at the landing site, to formulate hypotheses for the origin of

that diversity, and to seek candidate signs of past life preserved in the geologic record. This information could also be used to select an outstanding set of samples.

- A sample acquisition, encapsulation, and caching system of the standards specified by ND-SAG (2008). This cache would be left in a position (either on the ground or on the rover) where it could be recovered by a possible future sample return mission. Sending a future mission to recover the cache would be a critically important program option.
- The scientific value of the MAX-C mission would be significantly improved with various "upgrades," if they could fit within the mass, cost, and other mission caps. Possibilities include simple atmospheric monitoring, an atmospheric-surface interactions instrument package, subsurface sounding, a magnetometer, and capability to evaluate heteroatomic constituents of organic materials (such as N, S, and O) to interpret the potential for preservation of chemical biosignatures distinct from prebiotic organic materials. Once the mission constraints are better known, these potential upgrades need to be evaluated by a Science Definition Team.

PROPOSED SUMMARY OBJECTIVE STATEMENT: At a site with high preservation potential for physical and chemical biosignatures, evaluate paleo-environmental conditions, characterize the potential for preservation of biosignatures, and access multiple sequences of geological units in a search for evidence of past life and/or prebiotic chemistry. Samples necessary to achieve the scientific objectives of the proposed future sample return mission would be collected, documented, and packaged in a manner suitable for potential return to Earth.

Landing Site Considerations

This mission concept would require access to outcrops, which in turn are commonly associated with significant topography. We can envision two possible strategies to achieve such access: 1). Choose a flat landing ellipse adjacent to outcrops of interest and provide sufficient mobility to access them ("go-to" capability), or 2). Choose a landing site with outcrops/topography internal to the landing ellipse, and provide for late-stage landing hazard avoidance. These alternatives need to be worked out with several other major system tradeoffs.

Mars has many different types of sites that were (or are) potentially habitable, might preserve evidence of life, and therefore might be appropriate for the pursuit of the proposed mission scientific objective. Many of these kinds of sites are in the Noachian Highlands, a relatively high-altitude region of Mars that has never been explored by a rover. It is scientifically very attractive to retain the capability to explore an ancient Noachian terrane in search of crucial clues to the early history of life on Earth and the possible parallel origin and evolution of life on Mars. Retaining this capability means that the landing system would need to be capable of landing at sites as high as +1 km relative to the MOLA reference.

Finally, by the time this mission would fly, there likely will be additional information on the spatial and temporal distribution of methane on Mars (Mumma et al. 2009). Low-orbit spectral instruments observing solar occultation could provide critical data on temperature and water content of atmospheric regions enriched in methane as a next step toward localizing sources (Smith et al. 2009). Orbiting instruments such as CRISM and HiRISE might be used immediately to map mineralogical, geomorphological, and structural features. Minerals enriched in carbon or sulfur could provide insightful evidence of reactions between methane and surface minerals or fluids.

As with all landed missions to Mars, the best way to evaluate and prioritize multiple candidate sites for sample return is through an open, competitive landing site selection process. In order to take full advantage of the currently orbiting high-resolution instruments, the landing site selection process for a potential future sample return should start as soon as possible.

Summary of Preliminary Implementation Analysis

The proposed MAX-C mission implementation has been studied in concert with the SAG since approximately May 2009. The strategy has been to develop the most cost-effective concept to meet the *in situ* science and caching objectives. The resulting proposed rover would be in a mass class much smaller than MSL, but larger than MER. This makes a clone of the MSL Cruise/EDL system the prudent choice to deliver the proposed MAX-C rover to the surface of Mars. Recent high level discussions between NASA and ESA have precipitated the idea of delivering the ESA ExoMars rover and the proposed NASA MAX-C rover to Mars together in 2018 on a single launch vehicle and with the MSL EDL system. This combined mission concept has been explored only briefly thus far. The implementation discussion herein reflects a proposed NASA-only MAX-C mission, but the general capabilities are not expected to change significantly under a joint mission architecture.

The proposed MAX-C mission would be launched in May of 2018 and arrive at Mars in January of 2019 at Ls=325 (late northern winter). Given the favorable atmospheric pressure at this season, performance of the MSL delivery system might allow altitudes up to +1 km, but altitude trades off against the landed mass. There are also unfavorable effects on the atmosphere from dust storms, but the combined effects of these factors have not yet been fully evaluated. Access for a solar powered rover with one Earth year primary mission lifetime is restricted to between 25 North and 15 South latitude.

The mission concept would require technology development in four key areas:

- Coring, encapsulation, and caching: Lightweight tools/mechanisms for obtaining and handling cored samples.
- Instruments: Additional technology focus to mature instruments that could address the measurement needs posed herein, particularly the micro-scale mineralogy, organics, and elemental composition mapping.
- Planetary protection/contamination control: Bio-cleaning, cataloguing of bio-contaminants, and transport modeling to ensure cached samples would be returnable.
- Rover navigation: On-board image processing and navigation to increase traverse rate.
- Precision landing: A major scientific priority is to improve access to complex terrain, which requires significantly narrowing the landing ellipse.

Based on a draft project schedule and a full JPL Team X study, total project cost in real year dollars, Phase A through D, not including launch vehicle is estimated to be between $1.5-2.0B.

REFERENCES

The references cited in this white paper are compiled in a separate document at the following web site: http://mepag.jpl.nasa.gov/decadal/index.html.