On NASAâ€™s Mars Sample Return Mission Options: Letter Report

Committee on Planetary and Lunar Exploration, National Research Council

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On NASA Mars Sample-Return Mission Options

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On December 3, 1996, Dr. Ronald Greeley, chair of the Committee on Planetary and Lunar Exploration, and Dr. Claude R. Canizares, chair of the Space Studies Board, sent the following letter report to Dr. Jurgen Rahe, NASA's science program director for solar system exploration.

In your letter of September 17, 1996, you requested that the Committee on Planetary and Lunar Exploration (COMPLEX) assess NASA's plans for Mars sample-return missions. COMPLEX understands that you need its remarks in early December to aid in policy decisions by the agency.

As you requested, the assessment was conducted at COMPLEX's October 16-18, 1996, meeting held at the National Research Council's Georgetown offices. The assessment was based on "The Search for Evidence of Life on Mars," a working paper drafted by NASA's Mars Expeditions Strategy Group, guest lectures on the scientific goals for martian samples analyzed in laboratories on Earth, and presentations on NASA's four possible mission options.

NASA's presentations emphasized that the exact sequence and details (e.g., payload mass and instrument complement of orbiters, and ranges and on-board analytical capabilities of rovers) of missions in all of the options are currently under development. Consequently, COMPLEX must defer a specific assessment of mission plans at this time. COMPLEX has, however, provided a general assessment based on recommendations made in previous National Research Council reports. As such, both COMPLEX and the Space Studies Board (SSB) regard this current document as one step in an iterative process that will continue with the evolution of NASA's planning for the implementation of Mars sample-return missions.

As you know, COMPLEX and the SSB have consistently emphasized the importance of an intensive study of Mars by spacecraft. An important element of such a program is the return of martian samples to Earth. COMPLEX continues to

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support this viewpoint. The primary objectives for sample-return missions have been clearly defined and prioritized by both COMPLEX and other groups (see attached "Scientific Assessment of NASA's Mars Sample-Return Mission Options"). These include, among other high-priority objectives, the search for evidence of possible martian life. With regard to the general level of alternate mission option plans (i.e., baseline, paced, accelerated, or aggressive), COMPLEX believes that a vigorous, carefully planned, and well-executed program of martian exploration and sample return is warranted. However, the missions should address substantial scientific goals and not be overly focused on a single objective.

In addition to comments on the principal objectives of martian exploration, COMPLEX's assessment also offers observations and suggestions on implementation strategy, site selection, and sampling strategy, as well as technology requirements and related programmatic issues that the committee believes are essential for the success of any Mars sample-return program.

The Space Studies Board and COMPLEX look forward to following the future development and implementation of NASA's plans for Mars exploration and, in particular, sample-return missions. COMPLEX would look forward to hearing an updated presentation on NASA's Mars planning activities and to receiving feedback on the comments contained in the attached assessment. Perhaps this could be done at the next COMPLEX meeting, scheduled for February 3-5, 1997, at the Jet Propulsion Laboratory.

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On NASA Mars Sample-Return Mission Options

Report

At its October 16-18, 1996, meeting, the Space Studies Board's Committee on Planetary and Lunar Exploration (COMPLEX), chaired by Prof. Ronald Greeley (Arizona State University), conducted an assessment of the plans developed within NASA's Mars Surveyor program office to meet the long-standing scientific goal of returning martian samples to Earth for study in terrestrial laboratories. This assessment was made at the request of Dr. Jurgen Rahe, NASA's Science Program Director for Solar System Exploration, with a requested response date of early December, 1996. This assessment is based on material sent to committee members for review prior to the meeting, [1] presentations by invited experts at the October meeting, and subsequent discussions in executive sessions.

The goals of Mars sample-return missions and the types of scientific investigations that could be conducted on martian specimens in terrestrial laboratories were described by Drs. Bruce Jakosky (University of Colorado), Michael Drake (University of Arizona), Alan Treiman (Lunar and Planetary Institute), and Kenneth Nealson (University of Wisconsin, Milwaukee). The various mission scenarios currently being considered by NASA were described by Dr. Jeffrey Plescia (Jet Propulsion Laboratory). According to Dr. Plescia, NASA has outlined four sample return options, characterized as baseline, paced, accelerated, and aggressive (see appendix for details). The baseline option was described to COMPLEX at its June 1996 meeting by Dr. Daniel McCleese (Jet Propulsion Laboratory) of NASA's Mars Surveyor program office.

Because of the lack of details provided about the four proposed mission options (see appendix), COMPLEX must defer a specific assessment of mission plans. The committee can, however, make the following comments at this time regarding return of samples from Mars:

- It seems imprudent to land a 700-kg inert payload to simulate a sample-return vehicle, as planned in the baseline option. If appropriate instruments were identified, this opportunity could provide for the collection of scientific data.

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- The paced and accelerated options both return what would appear to be scientifically valid samples, with earlier sample retrieval in the accelerated option.
- The aggressive option's scientific potential is rich, but its scope seems unrealistically ambitious.

Although COMPLEX is unable to make detailed comments on particular mission options at this time, it is able to provide observations and suggestions on implementation strategy, site selection and sampling strategy, technology requirements, and related programmatic issues. COMPLEX believes that close attention to these issues, highlighted in past National Research Council (NRC) reports, is essential for the success of Mars sample-return missions.

OVERALL OBSERVATIONS

In its 1996 report, *Review of NASA's Planned Mars Program,* 2 COMPLEX stated that "the goal of returning samples of martian soil, atmosphere, and, most importantly, rocks [should remain] a central element of NASA's planning." The scientific priorities for the study of Mars, as defined in past reports by COMPLEX, can be summarized as follows: 3, 4, 5

- Understanding the evolution of the planet's surface and interior via studies of its chemistry, lithology, and morphology on a range of scales from local to global;
- Characterizing the dynamics and chemistry of the planet's atmosphere and the degree to which climatic conditions have evolved over time;
- Searching the planet for extinct or extant life, including evidence of the accumulation of a reservoir of prebiotic organic compounds and the extent of any subsequent prebiotic chemical evolution; and
- Determining the nature of the planet's interaction with the solar wind and the extent to which these interactions affect the state and evolution of the planet's upper atmosphere and ionosphere.

Sample-return missions are relevant, if not essential, to addressing many of these goals. Therefore, the committee is pleased that NASA has taken the opportunity provided by the increased attention to Mars exploration resulting from the McKay et al. paper 6 on the ALH84001 meteorite to accelerate planning of a program of Mars sample-return missions. Yet although findings by McKay et al. have captured the public's interest, much as they have the attention of scientists, they are only suggestive. The existence of microfossils and other indicators of life in martian meteorites is far from proven and is currently the subject of intense study. Therefore, COMPLEX believes that it is inappropriate to predicate an important aspect of future martian studies on the unconfirmed results described in a single scientific paper. Rather, the appropriate scientific context within which NASA should frame its study of the possibility that life arose on Mars at some time in the past has several elements: the suggestive results from ALH84001, new findings on microbial life in extreme terrestrial environments (e.g., deep beneath Earth's crust

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and oceans), new perspectives on the origin of terrestrial life, current understanding of the evolution of the martian and other planetary environments, and recent findings about the existence of planets around other stars.

COMPLEX agrees with many of the elements in the working paper drafted by NASA's Mars Expeditions Strategy Group, [7] as noted below. However, given the framework for martian studies outlined above, COMPLEX urges that other considerations be incorporated into the program as discussed and summarized in the following sections.

Prime among COMPLEX's concerns is the inadvisability of NASA's seeking only a simple answer to the question of life on Mars, because unequivocal evidence may be hard to find. The full implications of such a question can be realized only in the context of life's origin in a planetary environment and of its subsequent evolution in conjunction with the evolution of the planet. COMPLEX, [8,9,10] the Space Studies Board's (SSB's) former Committee on Planetary Biology and Chemical Evolution, [11] and a recent NASA report [12] have each outlined a consistent strategy for the exobiologic exploration of Mars. The results from ALH84001 do not, in COMPLEX's opinion, invalidate the measured approach embodied in this strategy. On the contrary, while a suite of missions that exclusively address exobiology questions could advance the overall goals for the exploration of Mars, they could just as easily compromise future studies of Mars if the missions and their objectives are misconstrued. For example, if the single objective of sample-return missions is to resolve the question of life on Mars, then highly successful missions could be characterized as failures if they do not return microfossils or living organisms. Therefore, justification of missions in terms of their bearing on the question of martian life alone would be a disservice to the scientific community and to the public, and would have a detrimental impact on the potential scientific results for exobiology and the other planetary science disciplines. Consequently, NASA should focus its Mars program, and sample-return missions in particular, on the more comprehensive goal of understanding Mars as a possible abode of life, a goal that is fully compatible with previous recommendations.

STRATEGY ISSUES

1. The search for life on Mars is only a part of the exobiologic study of the planet and of the scientific rationale for sample-return missions. [13,14,15,16] Even if there is neither extant nor extinct life on Mars, the planet's "prebiotic" chemical evolution is an important part of the history of life in the solar system. [17,18] Study of the "prebiotic Mars" will provide a context for the possible occurrence of martian life and should be a fundamental part of the Mars sample-return program. With respect to life, Mars may provide access to a paleochemical record unavailable on Earth.

2. COMPLEX recognizes that the overall structure of the Mars sample-return and exploration program should be outlined early. However, as noted previously, [19] adaptability and flexibility of the program are of paramount importance. There should be sufficient flexibility in the program to allow later missions to take

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advantage of the results of earlier missions.

3. Global reconnaissance of Mars should be a high priority early in the Mars sample-return program in order to allow intelligent selection of sample collection sites and to provide a global context for analysis of sample data. [20,21] Such reconnaissance is planned from the Mars Global Surveyor (MGS); if that or subsequent orbital missions are not successful, however, pertinent measurements (such as high-resolution imaging and infrared spectroscopy from MGS) need to be obtained at the earliest opportunity.

4. The Mars sample-return program neither begins with sample collection nor ends with the return of martian samples to Earth. The Mars Surveyor program must, for example, maintain a vigorous science analysis program during and following mission activity. Sufficient resources need to be allocated within the program for timely analysis of the data returned from the spacecraft already at Mars and/or related programs such as the development of appropriate instrumentation, and for study of samples in terrestrial laboratories.

5. Planetary protection requirements should be defined as early in the program as is feasible. These requirements will ultimately determine the time scale regarding the availability of samples for analysis in terrestrial laboratories. The SSB's Task Group on Issues in Sample Return is currently investigating these topics and related issues, such as the role of regulatory agencies and public perception of the risk associated with sample-return missions. [22]

ISSUES REGARDING SELECTION OF SAMPLE-RETURN SITES

1. Selection of samples to be returned to Earth must be optimized in order to provide the best opportunities for learning as much as possible about Mars. For example, the sampling mechanism could have the ability to discard a previously selected specimen should a more interesting one be found. Randomly selected rocks or sediments, even from interesting sites, are unlikely to be adequate samples for exobiologic analysis. [23,24,25] Similarly, landing sites for sample-return missions should be selected on the basis of scientific potential rather than engineering constraints alone. The future flexibility of the program should be provided for by identifying a diversity of sites early.

2. The report of NASA's Mars Expeditions Strategy Group [26] identifies three broad environments as potential sample-return sites. These are sites associated with ancient ground water, ancient surface water, and modern ground water. Recognizing that current knowledge of martian geology and geochemistry derives primarily from Viking data, new information from near-term missions, such as Mars Global Surveyor, should have a significant impact on final site selection if adequate resources are provided for data analysis. The set of sites selected should represent different geologic environments relevant to the several objectives of a balanced program of Mars exploration. [27] In this regard, the ancient ground water site and the ancient aqueous environment appear to be well chosen.

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3. Sites should be selected where the relevant geologic record is best preserved and most easily studied. The physical and chemical conditions necessary for the origin and early development of life are unknown, even on Earth. As noted in past NRC documents, [28,29,30] locating relevant sites is dependent on data collected from prior missions, and a broad-based study of Mars is essential to this process. Sites defined to provide maximum information on the physical and chemical conditions early in martian history are especially important, because early conditions are most likely to be relevant to the origin and early evolution of life. Of the two ancient sites, the ground water (highland) site is probably the better choice for the first sample-return mission because older, possibly more diverse, materials should be present.

TECHNOLOGY DEVELOPMENT

1. The capability should be developed for significant mobility (tens of kilometers) to allow sampling of a diverse suite of rocks from a landing site. [31,32,33] The probability of making significant advances in exobiologic investigations depends critically on the quality of the material returned, and increased mobility provides the capability to examine numerous samples before a final selection is made. This capability would greatly enhance the collection of an optimal suite of returned samples, as well as permit a detailed characterization of the environmental context of a site.

2. A broad suite of capable, miniature instruments for in situ determination of the geomorphology, mineralogy, petrology, and chemistry of a site should be developed. [34,35] These instruments will aid in sample selection and determination of the environmental context of samples. The suite of instruments developed should cover the range of currently feasible, as well as anticipated, measurement techniques to permit flexibility in instrument selection and to respond to new discoveries.

3. Methods should be developed for landing close to surface target sites. The size of the major axis of the landing-error ellipse should be smaller than the range of the rovers. This capability will allow complex geologic sites to be targeted safely and within reach of rovers. Examples of potentially interesting sites include volcanic systems, sedimentary basins, or channel floors, walls, and ejecta deposits. [36,37]

4. Development of high-spatial-resolution (centimeter to meter) instruments and platforms to extend the global characterization of rock and soil materials to scales appropriate for lander and rover operations should be pursued. [38] These data should be available in time for site selection and return of samples.

5. It can be argued that sampling techniques should be developed to optimize the mass of the returned samples, to reach less-weathered material in the interior of rocks, and to sample at depth. [39] Natural processes, such as impacts, may have exposed rocks and material from depth, but innovative technologies may still be

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needed to obtain samples suitable for meeting the scientific objectives of any given mission. The ubiquitous, superoxidizing material covering the martian surface material may, however, obviate such requirements for unweathered samples. Even so, technologies to allow sample manipulation for selection and subsampling of large fragments will be important because of the constraints on sample-return mass.

6. Sample handling and return technologies necessary to satisfy planetary protection requirements and to preserve samples in a pristine state should be developed in a timely manner, according to previous reports. [40,41] These topics are currently under consideration by the SSB's Task Group on Issues in Sample Return (TGISR). COMPLEX defers additional consideration of these topics until after the publication of TGISR's report. [42]

RELATED WORK

1. Criteria need to be developed for the unambiguous identification of biotic signatures. The ALH84001 meteorite illustrates the need to distinguish between biotic and abiotic mechanisms at the nanometer scale. [43] Terrestrial laboratory studies and field work are required to understand the chemical signatures in soils and rocks affected by living organisms as well as those caused by purely chemical means. In the former case, there is a need to understand better the diversity of organisms and environments, and their interaction at the microbiological scale. In the latter case, there is a need to know more about the redox chemistry, isotope fractionation, mineralogy, and physiochemical processes that mimic or preceded life. The goal is to be able to distinguish in a definitive manner between biotic and abiotic processes in ancient environments, in particular by analysis of meteorite samples found on Earth as well as samples returned directly from Mars. Previous studies [44,45] have discussed in detail some of these experimental procedures. However, ALH84001 provides an important example of current procedures and limitations to address exobiologic questions. In order to arrive at definitive results regarding life and its origins using small samples, specialized equipment and laboratories will be required.

2. Research on related antarctic meteorites should be improved. The collection of additional martian meteorites will be useful for putting the ALH84001 results into a broader context and for additional studies of evidence of past life or prebiotic materials from Mars. The rate of collection could, according several past participants in the Antarctic Search for Meteorites (ANSMET) program, be increased if, for example, field-collection procedures in Antarctica are made more efficient by eliminating excessive requirements for documenting sample locations. Tests have demonstrated that equipping ANSMET teams with Global Positioning System receivers would allow precise determination of locations, without taking much time away from sample collection.

SUMMARY RECOMMENDATIONS

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In summary, COMPLEX believes that whether or not the results of McKay et al. are confirmed, the measured approach to the exploration of Mars advocated by COMPLEX and other groups is the optimum strategy for advancing our understanding of Mars on all fronts. Moreover, the committee is guardedly optimistic that NASA's current planning for Mars sample-return missions will be consistent with the priorities outlined in past NRC reports, provided that NASA takes into account the issues discussed above, as summarized here:

1. Formulate a program of Mars sample-return missions in the context of recent developments in the planetary, life, and astronomical sciences and directed toward the comprehensive goal of understanding Mars as a possible abode of life.

2. Incorporate previously developed strategies for determining "prebiotic" chemical evolution into the Mars sample-return program.

3. Maintain adaptability and flexibility in the Mars sample-return program to take into account possible new discoveries from ongoing Mars missions.

4. Ensure that the global reconnaissance of Mars is implemented as early as possible.

5. Ensure that sites and samples are selected that are consistent with established strategies for exobiology and martian exploration.

6. To understand the results from each mission and to provide input for the planning of ongoing missions during the entire Mars exploration program, there must be an adequate, ongoing data-analysis program.

7. Ensure that sample handling, including planetary protection issues, are judiciously formulated and implemented.

8. Develop the capability for achieving long-range (tens of kilometers) mobility and high-precision landing.

9. Develop a broad suite of capable, miniature instruments for in situ measurements of surface properties relevant to exobiology and general martian exploration.

10. Develop the criteria to enable the unambiguous identification of biotic signatures.

11. Increase the rate of collection of antarctic meteorites relevant to Mars by, for example, increasing the efficiency of field collection procedures.

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On NASA Mars Sample-Return Mission Options

Appendix

SAMPLE-RETURN OPTIONS PRESENTED TO COMPLEX

The mission options presented to COMPLEX by NASA were primarily calendars of spacecraft launches and sample-recovery dates. The payloads, capabilities, and specific scientific objectives were mostly undefined. Similarly, terms such as "long-range rover," "sophisticated rover," and "robotic field geologist" were used as placeholders by NASA to represent various mobility systems under consideration.

Baseline Option

The baseline option is consistent with NASA's current scientific goals (studies of past life, climate change, and "resources") and budgetary constraints (approximately $150 million per year, including launch vehicles and operations) of the Mars Surveyor program. In this option, Mars Surveyor proceeds as currently defined, with two launches per opportunity, through 1999. Launches at subsequent opportunities include the following:

- 2001. An orbiter with a copy of Mars Observer's Gamma Ray Spectrometer (GRS) to complete the global remote-sensing program scheduled to be initiated by Mars Global Surveyor in 1997. An additional instrument, currently undefined, will gather data to assist in landing-site selection.
- 2003. A lander, with an inert payload of approximately 700 kg to simulate the mass of a sample-return vehicle. No rover or scientific instruments will be carried unless resources from outside the Mars Surveyor program are identified.
- 2004. Sample-return vehicle No. 1 will return approximately 0.1 kg of martian material to Earth in 2008. The samples (including rocks, soil, and atmosphere) will be collected in the immediate vicinity of the landing site by a short-range rover. A contingency "grab" sample (atmosphere and soil) is an option.
- 2006. Long-range rover No. 1 to gather and cache samples for later

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return.
- 2009. Sample-return vehicle No. 2 (return date unspecified).
- 2011. Long-range rover No. 2 to gather and cache samples for later return.
- 2015. Sample-return vehicle No. 3 (return date unspecified).

Paced Option

The paced option assumes a small augmentation of Mars Surveyor's budget and a reorientation of scientific goals to emphasize the search for evidence of possible biotic signatures. The post-1999 launch sequence envisaged is as follows:

- 2001. Science orbiter.
- 2003. Long-range rover No. 1.
- 2004. Sample-return vehicle No. 1 (returns samples to Earth in 2008).
- 2005. Communications orbiter.
- 2006. Long-range rover No. 2.
- 2009. Communications orbiter, plus a sample-return vehicle No. 2 (returns samples to Earth in 2012).
- 2011. Science orbiter.
- 2014. Long-range rover No. 3, plus sample-return vehicle No. 3 (returns samples to Earth in 2016).

Accelerated Option

The accelerated option assumes that the Mars Surveyor's budget is significantly enhanced. Its post-1999 launch sequence is as follows:

- 2001. Science orbiter.
- 2002. Long-range rovers Nos. 1 and 2 to different sites.
- 2003. Sample-return vehicle No. 1 (returns samples to Earth in 2006).
- 2005. Science orbiter, plus long-range rovers Nos. 3 and 4 to different sites.
- 2007. Sample-return vehicle No. 2 (returns samples to Earth in 2010).
- 2009. Communications orbiter, plus long-range rovers Nos. 5 and 6 to different sites.
- 2011. Sample-return vehicle No. 3 (returns samples to Earth in 2014).

Aggressive Option

The aggressive option envisages that a "national commitment" is made to search for evidence of life on Mars.

- 2001. Science orbiter, plus undefined "suborbital reconnaissance" system No. 1 (possibly a balloon-borne science package).
- 2002. "Sophisticated rover" No. 1 and undefined "robotic field geologist" No. 1 to two different sites.

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On NASAâ€™s Mars Sample Return Mission Options: Letter Report
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- 2003. Sample-return vehicle No. 1 (returns samples to Earth in 2006).
- 2005. Communications orbiter, plus suborbital reconnaissance system No. 2, plus sophisticated rover No. 2 and robotic field geologist No. 2 to two different sites.
- 2007. Communications orbiter, plus suborbital reconnaissance system No. 3, plus sample-return vehicle No. 2 (returns samples to Earth in 2010).
- 2009. Sophisticated rover No. 3 and robotic field geologist No. 3 to two different sites.
- 2011. Sample-return vehicle No. 3 (returns samples to Earth in 2014).