Summary of the Mars Science Goals, Objectives, Investigations, and Priorities

Mars Exploration Program Analysis Group (MEPAG) Goals Committee:

Jeffrey R. Johnson
United States Geological Survey 928-556-7157, jrjohnson@usgs.gov

Tori Hoehler
Ames Research Center

Frances Westall
Centre de Biophysique Moléculaire, CNRS

Scot Rafkin
Southwest Research Institute

Paul Withers
Boston University

Jeffrey Plescia
Applied Physics Laboratory

Victoria Hamilton
Southwest Research Institute

Abhi Tripathi
Johnson Space Center

Darlene Lim
Ames Research Center/SETI

Full Document is available on:
http://mepag.jpl.nasa.gov/reports/MEPAG_Goals_Document_1E73AB.pdf

This document was prepared in coordination with the MEPAG Executive Committee and with assistance of many in the MEPAG community. The content reflects the synthesis of recent Goals Committee activities, MEPAG Science Analysis Groups (SAGS), workshops and feedback and discussion of these topics at recent MEPAG meetings.

INTRODUCTION

In 2000, the Mars Exploration Program Analysis Group (MEPAG) was asked by NASA to work with the science community to establish consensus priorities for the future scientific exploration of Mars. Those discussions and analyses resulted in a report entitled *Scientific Goals, Objectives, Investigations, and Priorities*, which is informally referred to as the "Goals Document" (MEPAG 2001). MEPAG periodically revises the Goals Document (MEPAG, 2004; MEPAG, 2005; MEPAG, 2006; MEPAG, 2008,). As was the case with previous versions, the Goals Document is presented as a statement of community consensus positions.

The MEPAG Goals Document is organized into a four-tiered hierarchy: goals, objectives, investigations, and measurements. The goals have a very long-range character and are organized around major areas of scientific knowledge and highlight the overarching objectives of the Mars Exploration Program (Arvidson *et al*., 2006). Expanded statements of the four goals are found in the report, but they are commonly referred to as Life, Climate, Geology, and Preparation for Human Exploration. Developing a comprehensive understanding of Mars as a system requires making progress across all three science goals, while the goal of preparing for human exploration is different in nature. Thus, MEPAG has not attempted to prioritize among the four goals. A general theme of understanding whether or not habitable zones and life have existed, or do exist, on Mars has emerged within the framework of understanding Mars and all its elements--interior, surface, and atmosphere--as a highly interactive and complex system. However, some of the fundamental science questions included in each goal may address the evolution of Mars as a planet more directly than they address habitability. Nonetheless, answers to those fundamental questions ultimately improve the effectiveness of the Mars Exploration Program.

Each Goal includes two or three objectives that embody the strategies and milestones needed to achieve the Goal. Objectives are presented in priority order, because there is often an order within which the scientific questions can most logically be answered, and/or some objectives are perceived to be more important than others. A series of investigations that collectively would achieve each objective is also identified and prioritized for each objective. While some investigations can be achieved with a single measurement, others will require a suite of measurement types conducted across multiple missions.

Completion of all the cited investigations will require decades and it is possible that many investigations are so complex that they may never be truly completed. Thus, evaluations of prospective missions and instruments should be based on how well the investigations are addressed and how much progress might be achieved in that context. While priorities should influence which investigations are conducted first, they should not necessarily be done serially, except where it is noted that one investigation should be completed first. In such cases, the investigation that should be done first was given a higher priority, even where it is believed that a subsequent investigation will be more important.

The goals, objectives, and investigations all indicate that several crucial technical capabilities require additional development. The most important of these are: (1) *Global access* to high and low latitudes, rough and smooth surfaces, low and high elevations, in addition to precision landing. (2) *Access to the subsurface*, from a meter to hundreds of meters, directly (e.g., drilling) and indirectly (e.g., geophysical sounding). (3) *Access to time varying phenomena* that requires the capability to make measurements over long periods (e.g., climate studies covering from one to several Martian years). (4) *Access to microscopic scales* with instruments capable of measuring chemical and isotopic compositions and determining mineralogy *as well the ephemeral or continuous presence of liquid water on microscopic scales*. (5) *Planetary* *protection and sample handling* for both in situ and cached samples that involve implementation of cleaning methods, contamination control, sample acquisition and processing methods, and sample packaging/sealing. (6) *Advanced instrumentation*, especially *in situ* life detection and age dating.

Orbital and landed packages could make many of the high priority measurements, but others may require that samples be returned from Mars. As noted in other MEPAG and National Academy of Science reports, study of samples collected from known locations on Mars and from sites whose geological context has been determined from remote sensing measurements have the potential to significantly expand our understanding of Mars. A full discussion of these issues is beyond the scope of this document and will be addressed by MEPAG science analysis groups in the near future, as well as by the Planetary Sciences Decadal Survey (PSDS).

An inherent consequence of the scientific process is that when one question is answered, others are raised. Because the exploration/discovery process is one of continual feedback and adjustments, it is necessary that the MEPAG Goals Document continually evolve. The investigations and strategies have been carefully revised and reprioritized every 1-2 years (the history of revision is documented on the MEPAG web site) as our knowledge of Mars has progressively increased. This prioritization process involves open discussion among the community of scientists involved in Mars exploration and the development of multi-disciplinary consensus positions. The revision process is such that it incorporates a full spectrum of inputs, including results from the flight missions (on an international basis), Research and Analysis results, and conclusions and advice from the National Research Council.

For example, Goal IV (Preparation for Human Exploration) was revised in 2005 with the assistance of a MEPAG-chartered Mars Human Precursor Science Steering Group (SSG) in order to update the 2001 and 2004 versions of the Goals Document regarding the schedule and engineering implementation options for human missions to Mars. As briefly described in the Appendix below, additional revisions of Goals I and IV will be implemented in the subsequent releases of the Goals Document in 2010.

I. GOAL: DETERMINE IF LIFE EVER AROSE ON MARS

The prime focus of this goal is to determine if life is or was present on Mars. If life exists or existed, we must understand the systems that support or supported it. If life never existed yet conditions appear to have been suitable for formation and/or maintenance of life, a focus would then be to understand why evidence of life was not found. A comprehensive conclusion about the question of life on Mars will necessitate understanding the planetary evolution of Mars and whether Mars is or could have been habitable, and will need to be based in multi-disciplinary scientific exploration at scales ranging from planetary to microscopic. The strategy we have adopted to pursue this goal has two sequential components: assess the habitability of Mars (which needs to be undertaken environment by environment); and test for prebiotic processes, past life, or present life in environments that can be shown to have high habitability potential. These constitute two scientific objectives: "assess habitability" (Objective A) and "test for life" (Objective C). A critical means to achieve both objectives is to characterize Martian carbon chemistry and carbon cycling. Consequently, the science associated with carbon chemistry is so fundamental to the overall life goal that we have established it as a third primary science objective, "follow the carbon" (Objective B). To some degree, these scientific objectives can be addressed simultaneously, as each requires basic knowledge of the distributions of water and carbon on Mars and an understanding of the processes that govern their interactions. Clearly, these objectives overlap, but are considered separately.

A. Objective: Assess the past and present habitability of Mars

1. Investigation: Establish the current distribution of water in all its forms on Mars.

2. Investigation: Determine the geological history of water on Mars and model the processes that have caused water to move from one reservoir to another.

3. Investigation: Identify and characterize phases containing C, H, O, N, P and S, including minerals, ices, and gases, and the fluxes of these elements between phases.

4. Investigation: Determine the array of potential energy sources available on Mars to sustain biological processes.

B. Objective: Characterize Carbon Cycling in its Geochemical Context

1. Investigation: Determine the distribution and composition of organic carbon on Mars.

2. Investigation: Characterize the distribution and composition of inorganic carbon reservoirs on Mars through time.

3. Investigation: Characterize links between C and H, O, N, P, and S.

4. Investigation: Characterize the preservation of reduced compounds on the near-surface through time.

C. Objective: Assess whether life is or was present on Mars

1. Investigation: Characterize complex organics.

2. Investigation: Characterize the spatial distribution of chemical, isotopic signatures.

3. Investigation: Characterize the morphology or morphological distribution of mineralogical signatures.

4. Investigation: Identify temporal chemical variations requiring life.

II. GOAL: UNDERSTANDING THE PROCESSES AND HISTORY OF CLIMATE

The fundamental scientific questions that underlie this goal are how the climate of Mars has evolved over time to reach its current state, and what processes have operated to produce this evolution. Mars climate can be defined as the mean state and variability of its atmosphere and exchangeable volatile reservoirs (near the surface) evaluated from diurnal to geologic time scales. The climate history of Mars can be divided into three distinct epochs: (i) Present, operating under the current obliquity; (ii) Recent past, operating under similar pressures and temperatures but over a range of orbital variations (primarily obliquity); and (iii) Ancient, when the pressure and temperature may have been substantially higher than at present and liquid water may have been stable on the surface. An understanding of Mars climatic evolution rests upon gaining a full understanding of the fundamental processes governing its climate system, and thus upon obtaining detailed observations of the current (observable) system. Each Objective below corresponds to a different climate epoch and is given in priority order.

A. Objective: Characterize Mars' Atmosphere, Present Climate, and Climate Processes Under Current Orbital Configuration

1. Investigation: Determine the processes controlling the present distributions of water, carbon dioxide, and dust by determining the short- and long-term trends (daily, seasonal and solar cycle) in the present climate. Determine the present state of the upper *atmosphere (neutral/plasma) structure and dynamics; quantify the processes that link the Mars lower and upper atmospheres.*

2. Investigation: *Determine the production/loss, reaction rates, and global 3-dimensional distributions of key photochemical species (e.g., O_3, H_2O, CO, OH, CH_4, SO_2), the electric field and key electrochemical species (e.g., H_2O_2), and the interaction of these chemical species with surface materials.*

3. Investigation: *Understand how volatiles and dust exchange between surface and atmospheric reservoirs, including the mass and energy balance. Determine how this exchange has affected the present distribution of surface and subsurface ice as well as the Polar Layered Deposits (PLD).*

4. Investigation: *Search for microclimates.*

B. Objective: Characterize Mars' Recent Climate History and Climate Processes Under Different Orbital Configurations

1. Investigation: *Determine how the stable isotopic, noble gas, and trace gas composition of the Martian atmosphere has evolved over obliquity cycles to its present state.*

2. Investigation: *Determine the chronology, including absolute ages, of compositional variability, and determine the record of recent climatic change that are expressed in the stratigraphy of the PLD.*

3. Investigation: *Relate low latitude terrain softening and periglacial features to past climate eras.*

C. Objective: Characterize Mars' Ancient Climate and Climate Processes

1. Investigation: *Determine the rates of escape of key species from the Martian atmosphere, their correlation with seasonal and solar variability, the influence of remnant crustal magnetic fields, and their connection with lower atmosphere phenomenon (e.g., dust storms). From these observations, quantify the relative importance of processes that control the solar wind interaction with the Mars upper atmosphere in order to establish the magnitude of associated volatile escape rates.*

2. Investigation: *Find physical and chemical records of past climates.*

3. Investigation: *Determine how the stable isotopic, noble gas, and trace gas composition of the Martian atmosphere has evolved through time from the ancient climate state.*

III. GOAL: DETERMINE THE EVOLUTION OF THE SURFACE AND INTERIOR

Insight into the composition, structure, and history of Mars is fundamental to understanding the solar system as a whole, as well as providing insight into the history and processes of our own planet. The geology of Mars sheds light on virtually every aspect of the study of conditions potentially conducive to the origin and persistence of life on that planet, and the study of the interior provides important clues about a wide range of topics, such as geothermal energy, the early environment, and sources of volatiles.

A. Objective: Determine the nature and evolution of the geologic processes that have created and modified the Martian crust

1. Investigation: *Determine the formation and modification processes of the major geologic units and surface regolith as reflected in their primary and alteration mineralogies.*

<u>2. Investigation:</u> *Evaluate volcanic, fluvial/laucustrine, hydrothermal, and polar erosion and sedimentation processes that modified the Martian landscape over time.*
<u>3. Investigation:</u> *Constrain the absolute ages of major Martian crustal geologic processes, including sedimentation, diagenesis, volcanism/plutonism, regolith formation, hydrothermal alteration, weathering, and the cratering rate.*
<u>4. Investigation:</u> *Explore potential hydrothermal environments.*
<u>5. Investigation:</u> *Evaluate igneous processes and their evolution through time.*
<u>6. Investigation:</u> *Characterize surface-atmosphere interactions on Mars, as recorded by aeolian, glacial/periglacial, fluvial, chemical and mechanical erosion, cratering and other processes.*
<u>7. Investigation:</u> *Determine the tectonic history and large-scale vertical and horizontal structure of the crust, including present activity. This includes, for example, the structure and origin of hemispheric dichotomy.*
<u>8. Investigation:</u> *Determine the present state, 3-dimensional distribution, and cycling of water on Mars including the cryosphere and possible deep aquifers.*
<u>9. Investigation</u>: *Determine the nature of crustal magnetization and its origin.*
<u>10. Investigation:</u> *Evaluate the effect of large-scale impacts on the evolution of the Martian crust.*

B. Objective: Characterize the structure, composition, dynamics, and evolution of Mars' interior.

<u>1. Investigation:</u> *Characterize the structure and dynamics of the interior.*
<u>2. Investigation:</u> *Determine the origin and history of the magnetic field.*
<u>3. Investigation</u>: *Determine the chemical and thermal evolution of the planet.*

C. Objective: Understand the origin, evolution, composition and structure of Phobos and Deimos.

<u>1. Investigation:</u> *Determine the origin of Phobos and Deimos.*
<u>2. Investigation:</u> *Determine the composition of Phobos and Deimos.*
<u>3. Investigation:</u> *Understand the internal structure of Phobos and Deimos.*

IV. GOAL: PREPARE FOR HUMAN EXPLORATION

Robotic missions serve as logical precursors to eventual human exploration of space. In the same way that the Lunar Orbiters, Ranger and Surveyor landers paved the way for the Apollo Moon landings, a series of robotic Mars Exploration Program missions is charting the course for future human and robotic exploration of Mars. Goal IV differs from the previous Goals in that it addresses science and engineering questions specific to increasing the safety, decreasing the cost, and increasing the productivity of human crews on Mars. To address these issues, this section describes both the data sets that are to be collected and analyzed (Objective A), and the demonstrations of critical technologies that must be validated in the Martian environment (Objective B). Objective C highlights mission critical atmospheric measurements that would reduce mission risk and enhance overall science return, benefiting all future missions to the planet (both robotic and human). No attempt has been made to prioritize these risk-mitigation and engineering-related measurements, because all are important.

A. Objective. Obtain knowledge of Mars sufficient to design and implement a human mission with acceptable cost, risk and performance.

1A. Investigation. *Characterize the particulates that could be transported to hardware and infrastructure through the air (including both natural aeolian dust and other materials that could be raised from the Martian regolith by ground operations), and that could affect engineering performance and in situ lifetime.*

1B. Investigation. *Determine the atmospheric fluid variations from ground to >90 km that affect Entry, Descent, and Landing and Takeoff/Ascent to Orbit including both ambient conditions and dust storms.*

1C. Investigation. *Determine if each Martian site to be visited by humans is free, to within acceptable risk standards, of biohazards that may have adverse effects on humans and other terrestrial species. Sampling into the subsurface for this investigation must extend to the maximum depth to which the human mission might come into contact with Martian material.*

1D. Investigation. *Characterize potential sources of water to support In Situ Resource Utilization (ISRU) for eventual human missions.*

2. Investigation. *Determine the possible toxic effects of Martian dust on humans.*

3. Investigation. *Assess atmospheric electricity conditions that may affect TAO (Takeoff/Ascent to Orbit) and human occupation.*

4. Investigation. *Determine the processes by which terrestrial microbial life, or its remains, is dispersed and/or destroyed on Mars (including within ISRU-related water deposits), the rates and scale of these processes, and the potential impact on future scientific investigations.*

5. Investigation. *Characterize in detail the ionizing radiation environment at the Martian surface, distinguishing contributions from the energetic charged particles that penetrate the atmosphere, secondary neutrons produced in the atmosphere, and secondary charged particles and neutrons produced in the regolith.*

6. Investigation. *Determine traction/cohesion in Martian regolith (with emphasis on trafficability hazards, such as dust pockets and dunes) throughout planned landing sites; where possible, feed findings into surface asset design requirements.*

7. Investigation. *Determine the meteorological properties of dust storms at ground level that affect human occupation and EVA.*

B. Objective. Conduct risk and/or cost reduction technology and infrastructure (T/I) demonstrations in transit to, at, or on the surface of Mars.

1A. Demonstration. *Conduct a series of three aerocapture flight demonstrations:*

1B. Demonstration. *Conduct a series of three in-situ resource utilization technology demonstrations:*

1C. Demonstration. *Demonstrate an end-to-end system for soft, pinpoint Mars landing with 10 m to 100 m accuracy using systems characteristics that are representative of Mars human exploration systems. (Mid)*

2A. Demonstration. *Demonstrate continuous and redundant in situ communications/navigation infrastructure (Early). Deploy in full-up Precursor Test Mission (Late).*

2B. Demonstration. *Investigate long-term material degradation over times comparable to human mission operations. (Mid)*

3. Demonstration. Develop and demonstrate accurate, robust and autonomous Mars approach navigation. (Mid)

C. Objective. Characterize the state and processes of the Martian atmosphere of critical importance for the safe operation of both robotic and human spacecraft

1. *Investigation: Understand the thermal and dynamical behavior of the planetary boundary layer.*
2. *Investigation: Understand and monitor the behavior of the lower atmosphere (0-80km) on synoptic scales.*
3. *Investigation: Determine the atmospheric mass density and its variation over the 80 to 200 km altitude range.*
4. *Investigation: Determine the atmospheric mass density and its variations at altitudes above 200 km.*

APPENDIX

As described in the Introduction, the MEPAG Goals Document evolves as new discoveries are made in the Mars Exploration Program. Goals I and IV are currently undergoing revisions to reflect updated consensus positions of the respective communities. For example, Goal I ongoing discussions may result in the consolidation of Objective B (carbon cycling) into the other objectives related to habitability and life. The intent would be to eliminate some redundancies in the current document and more clearly demonstrate the connection between specific carbon investigations and broader scientific objectives. Further discussion of these changes will involve community input to determine the appropriate weighting between investigations that emphasize habitability as a means of prioritizing sites for life detection efforts, and those that emphasize the search for traces of past and extant life in terms of biomarkers. For Goal IV, a working group will be assembled to revise the structure and content of Goal IV to align it with the results of the Design Reference Architecture 5.0 and the upcoming results from the U.S. Human Space Flight Plans panel (Augustine Commission). This group's report will be presented to the March, 2010 MEPAG meeting for community input and consensus.

References

MEPAG (2001), Scientific Goals, Objectives, Investigations, and Priorities, in Science Planning for Exploring Mars, JPL Publication 01-7, p. 9-38. Available on the web at http://mepag.jpl.nasa.gov/reports/index.html.

MEPAG (2004), Scientific Goals, Objectives, Investigations, and Priorities: 2003, G. J. Taylor, ed., 23 p. white paper posted 07-16-04 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

MEPAG (2005), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2005, 31 p. white paper posted August, 2005 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

MEPAG (2006), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2006, 31 p. white paper posted February, 2006 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

MEPAG (2008), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2008, 37 p. white paper posted September, 2008 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

Arvidson, R.E., Allen, C.C., DesMarais, D.J., Grotzinger, J., Hinners, N., Jakosky, B., Mustard, J.F., Phillips, R., and Webster, C.R., (2006). Science Analysis of the November 3, 2005 Version of the Draft Mars Exploration Program Plan.