CAPTEM

Curation and Analysis Planning Team for Extraterrestrial Materials

"Dedicated to Maximizing Planetary Sample Science While Protecting the Integrity of NASA Collected Extraterrestrial Materials"

CAPTEM ANALYSIS DOCUMENT

Pathways to the Return of Samples from Mars

October 10, 2008
CAPTEM Document
2008-01

This report was prepared by the Mars Sample Return Roundtable organized by CAPTEM.

- Charles Shearer, University of New Mexico, Chair CAPTEM
- Dave Bish, Indiana University
- James Farquhar, University of Maryland (CAPTEM)
- Virgil Luth, New Mexico Tech
- Chris McKay, NASA Ames Research Lab
- Glenn MacPherson, Smithsonian Institution
- Doug Ming, Johnson Space Center
- Clive Neal, University of Notre Dame (CAPTEM)
- James Papike, University of New Mexico
- Dimitri Papanastassiou, JPL (CAPTEM)
- Allan Trieman, Lunar and Planetary Institute (CAPTEM)
- Dave Vaniman, Los Alamos National Lab

Table of Contents

1. Executive Summary

Since the mid-1970s, the return of samples from Mars has been an elusive goal in NASA's program to explore the Solar System. An assortment of National Research Council surveys and investigations have consistently ranked Mars sample return missions as a high priority goal for the exploration of the Solar System. Highly successful missions as part of the NASA Mars exploration program has documented the complexity of Mars and identified fundamental questions that could be answered through Mars sample return. Still, the realization of a Mars sample return mission has consistently be derailed due to its expected costs and complexity. The Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) was requested by the Director of Planetary Science, NASA Science Mission Directorate to organize a workshop on Mars Sample Return and to evaluate some of the cost, risks and infrastructure needs associated with Mars sample return. To this end, the CAPTEM and the Mars Sample Return Roundtable has identified the following findings:

Finding 1. Sample return from Mars is the logical next step in the Mars Exploration Program theme of "follow the water".

Finding 2. Martian meteorites illustrate the scientific power of the analysis of samples in terrestrial labs. Orbital and surface missions have demonstrated the wide variety of surface environments unrepresented by the meteorite collection. "Science Priorities for Mars Sample Return" produced by the Next Decade Science Analysis Group (http://mepag.jpl.nasa.gov /reports/index.html) has demonstrated the richness of Martian science that can be achieved with samples returned from the Martian surface.

Finding 3. For the first Mars sample return mission, a simple approach as advocated by the MSR SSG II and ND-SAG (at least the less complex missions) provides the potential for successful science. Further, such a mission provides an engineering demonstration of technologies for more complex sample return missions and eventual human missions.

Finding 4. A careful analysis of the relationship between the duration of a MSR mission on the Martian surface and risk and cost to the mission should be used in planning the sampling strategy for the first mission to reduce cost and risk.

Finding 5. The MSR Roundtable concluded that it would be important in the planning stages to resist the costly temptation to add many on-board instruments to MSR. However, several key instruments could be considered advantageous to a successful mission: (1) an instrument capable of distinguishing among samples so that a diverse set of sample are collected and (2) instruments capable of reducing time on the Martian surface because it reduces roving time.

Finding 6. Placing samples within the context of local and regional geology makes the samples more scientifically valuable. This can be accomplished in a shorter time on the Martian surface and using a small instrument package if a previously documented site is sampled.

Finding 7. A sample collection strategy that will reduce overall time on the Martian surface will reduce cost and risk to a sample return mission. Elements of such a strategy could be examined during the Mars Science Lab mission.

Finding 8. For some targets, the goals of reducing time on the Martian surface and collecting a variety of well-documented samples from a significant area may be accomplished with sample caching. The most appropriate samples for caching are those that will not be significantly affected by conditions on the Martian surface or interact during transport to Earth.

Finding 9. There is a plethora of important science that can be accomplished with a simple MSR mission (with mobility ≥ 1km) to a previously visited site.

Finding 10. The mitigation of cost and risk for a Mars sample return mission puts an even higher priority on early technology development for sample return missions than for more conventional mission types.

Finding 11. Several priority technology investments are identified that enable Mars Sample Return. Early priority technology investments such include: (1) Mars Ascent Vehicle to place samples in orbit around Mars, (2) Autonomous rendezvous and docking capability in Mars orbit, (3) Mars sample collection and storage, and (4) Mars sample return vehicle that can provide a high probability of samples being returned to Earth.

Finding 12. Lower priority technology investments that would reduce cost and risk to MSR should be identified and prioritized.

Finding 13. Sample return technologies feed forward to more complex missions on Mars, missions to other planetary bodies, and human exploration.

Finding 14. Advanced planning is necessary to establish the appropriate sample handling protocols and design-build-test containment facility for samples returned from Mars.

Finding 15. The LSAPT/CAPTEM experience demonstrates the need for an integrated, international advisory committee. It is important to devise a unified advisory committee to oversee activities from the start and into the distant future, as indicated by LSAPT/CAPTEM experience.

Finding 16. Preliminary examination of samples returned from Mars must occur prior to and concurrently with hazard assessment during planetary protection. Knowing rock type and chemistry resulting from preliminary examination is beneficial for science, but critical for hazard assessment.

Finding 17. It is important that the United States planetary science community is technologically mature to lead the science resulting from Mars sample return. Therefore, it is important to upgrade analytical instrumentation and approaches in planetary science laboratories at both NASA centers and P.I. facilities.

Finding 18. It is important that the United States planetary science community is intellectually mature to lead the science resulting from Mars sample return. This may be accomplished by further supporting sample science in existing NASA research and analysis programs.

2. Introduction

The return of samples from Mars has been advocated as a priority science-driven mission by numerous assessments prepared by the National Research Council (NRC). The most recent NRC Decadal Survey (2003) "New Frontiers in the Solar System: An Integrated Exploration Strategy" concluded:

"that NASA begin its planning for Mars sample return missions so that their implementation can occur early in the decade 2013-2023."

The NRC report "Grading NASA's solar system exploration program: A Midterm Review" (2008) recommended:

"Devise a strategy to implement the Mars Sample Return mission and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission."

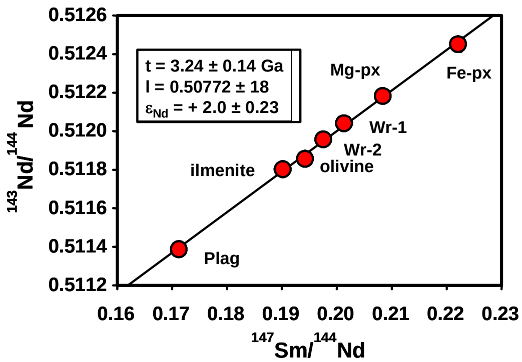
Why is Mars sample return viewed as a critical component in our exploration of Mars and the solar system?

The return of samples from Mars will provide a unique perspective not offered by either orbital or surface missions – the opportunity to study the returned material in well equipped Earth laboratories. Compared to most analyses done on a planetary surface, this unique perspective is based on scale (down to angstroms), precision, offer a high degree of sample manipulation, facilitate multiple analytical approaches, allow repeat non-destructive analyses, and the ability to modify analytical experiments as logic and technology evolves. Mars sample return provides fundamental chronological and geochemical ground truth that enhances the value of both orbital and surface observations far beyond their stand-alone importance. The science return on samples from the Martian surface is extremely extensive and will provide fundamental insights into Mars as a potential habitat for life and the evolution and current state of a planetary body. The MEPAG document on "Science Priorities for Mars Sample Return" produced by the Next Decade Science Analysis Group (http://mepag.jpl.nasa.gov /reports/index.html) has identified the richness of Martian science that can be achieved with samples. Further, sample return is a vital necessity for the human exploration program (Moon to Mars and beyond) for resource identification as well as human health and safety issues. The price paid for this unique and valuable information is increased cost and risk relative to other types of planetary exploration missions.

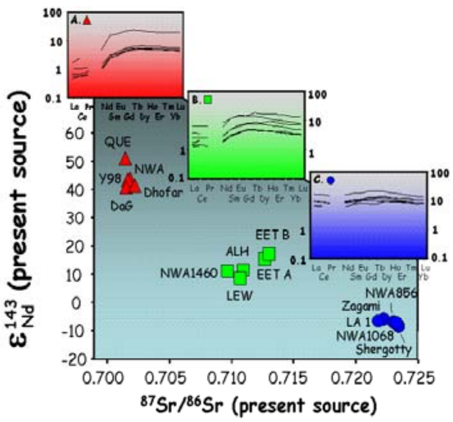
To facilitate a MSR mission this "white paper" addresses: (1) Potential components of a MSR strategy that should be investigated to reduce cost and risk to the first sample return mission. (2) Investments in Enabling Technologies for Mars Sample Return Technology investments that need to be made to reduce cost and risk to MSR. (3) Receiving Laboratory and sample curation issues that will address planetary protection concerns, protect the integrity of samples and maximize the science extracted from them and (4) Analytical and Human Infrastructure Needed to Support Mars Sample Return Science.

This analysis and the associated workshop were funded by the NASA Director of Planetary Science, SMD. "The mandate of this action committee is to define technological linkages between simple missions and complex sample return missions and to identify those critical technological capability investments that would best reduce cost and risk for increasingly complex sample return missions over the next 20 years.

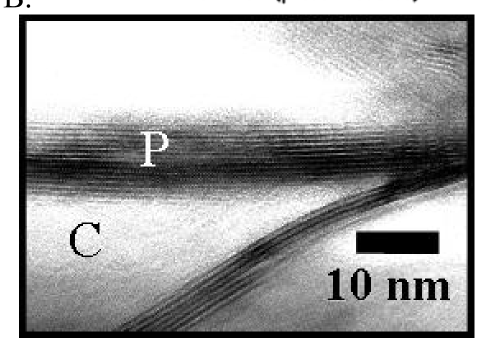
The Mars Sample Return Roundtable is a temporary CAPTEM (Curation and Analysis Planning Team for Extraterrestrial Materials) committee that focuses upon promoting Mars Sample Return and investigating issues tied to Mars Sample Return. CAPTEM



A.



B.



C.

Figure 1. Three examples that illustrate the multifaceted value of da derived from samples for understanding the origin and evolution of planetary body. (A). Sm-Nd isotopic data derived from an Apollo 1 mare basalt. In addition to illustrating the high precision required to produce a crystallization age for the basalt, it also illustrated that a high degree of sample manipulation is required to produce mineral separates and that the isotopic systematics also provide insights into the nature of the lunar interior (ε_{Nd}) and the impact history of the inner solar system as recorded on the Moon. (from L. Borg). (B) Sm-Nd, Rb-Sr, and Rare Earth Element data derived from martian basalts. This illustrates the precision required for the analysis and th usefulness of both multiple analytical approaches and the ability to modify experiments as logic and technology dictate over an extende period of time (from L. Borg). (C) TEM image illustrating H_2O-bearing sheet silicates within carbonates from martian meteorite ALH84001 (from A. Brearley).

reports to the director of solar system science. The Mars Sample Return Roundtable committee is presided over by the CAPTEM chair. The committee consists of several permanent members of CAPTEM and outside members that bring expertise required to carry out the mandate of this endeavor. The membership of this committee includes Charles Shearer, University of New Mexico, Chair CAPTEM, Dave Bish, Indiana University, James Farquhar, University of Maryland, Virgil Luth, New Mexico Tech, Chris McKay, NASA Ames Research Lab, Glenn MacPherson, Smithsonian Institution, Doug Ming, Johnson Space Center, James Papike, University of New Mexico, Dimitri Papanastassiou, JPL (CAPTEM), Allan Trieman, Lunar and Planetary Institute (CAPTEM), and Dave Vaniman, Los Alamos National Lab. Many of these members have extensive experience planning and participating in NASA sample return missions and have been intimately involved in sample curation and allocation.

3. Importance of Sample Return to the Exploration of Mars

3.1 Mars Sample Return, A matter of scale and precision. The unique planetary perspectives based on returned samples have a strong symbiotic relationship to orbital and surface observations/measurements. This unique perspective is closely tied to the use of terrestrial laboratories, which have capabilities exceeding those of instrumentation currently associated with spacecraft surface (i.e., in situ) measurements. The terrestrial labs provide higher analytical accuracy and precision, afford a higher degree of spatial resolution (to angstroms), offer a high degree of sample manipulation, and facilitate multiple analytical approaches. Examples of these analytical attributes and the essential information that they yield are shown in Figure 1. These analytical attributes result in copious contrasts between sample return missions and other types of missions: (1) The best instruments can be used to analyze returned samples, not the best available at the end of mission design reviews.

(2) Instrumentation is not limited by mass, power, reliability, data rate, the requirement to work autonomously, etc. This results in much lower cost to do an analysis**.** (3) Analyses are iterative and not limited by preconceived ideas at the time of the mission, (4) Unexpected or ambiguous result can be tested with additional measurements or modified experiments. A new mission is not required to retest results. However, new insightful orbital, surface or sample return missions may be launched based on these new observations. (5) The diagnosis of analytical instrument technical problems and instrument repair can be better facilitated in a terrestrial lab, (6) The ability to modify experiments as logic and technology dictate over an extended period of time. (7) "Samples are the gift that keep giving" to future generations of planetary scientists. (8) Large numbers of scientists can usefully participate. This includes not only scientists involved in sample measurements, but also scientists who will place these data into a planetary context using orbital and surface measurements, and conversely the sample data will add value to the orbital and surface in situ measurements by providing a greater measure of groundtruth. The end result of all of these positive attributes of sample analysis and sample return missions is in a large science return and the establishment of a firm foundation to base other sample return and non-sample return missions upon. For example, the Moon is the best understood extra-terrestrial object because of the samples returned by the Apollo program and the planetary-scale context in which these samples could be placed through both orbital and surface observations**.** Numerous examples of the usefulness of samples in studying a planetary body and the importance of placing the samples with a planetary context are contained in "New Views of the Moon" [1].

The symbiotic relationships between sample return, orbital, surface, and exploration science enriches the data collected by any single approach and affirms that the integration of these approaches provides a logical and balanced scientific attack to exploring Mars (Figure 2). Examples illustrating the symbiosis between sample science-orbital science, sample science-surface science, and sample science-exploration science are shown in Figure 2. Samples from Mars will provide ground truth for orbital data (See Appendix I and II), while orbital data allow samples from a local area on Mars to be placed into a regional and even planetary context. Surface material derived from the Martian interior (through volcanism or impact processes) can be inverted to interpret surface geophysical measurements, whereas surface measurements made by geophysical networks place the sample data within a context of planetary structure and dynamics. Finally, samples provide an initial foundation for understanding the in situ resource utilization potential and health hazards for human exploration on Mars, while in situ measurements of mechanical properties of materials in a planet's environment will provide insights into their behavior during exploration and utilization.

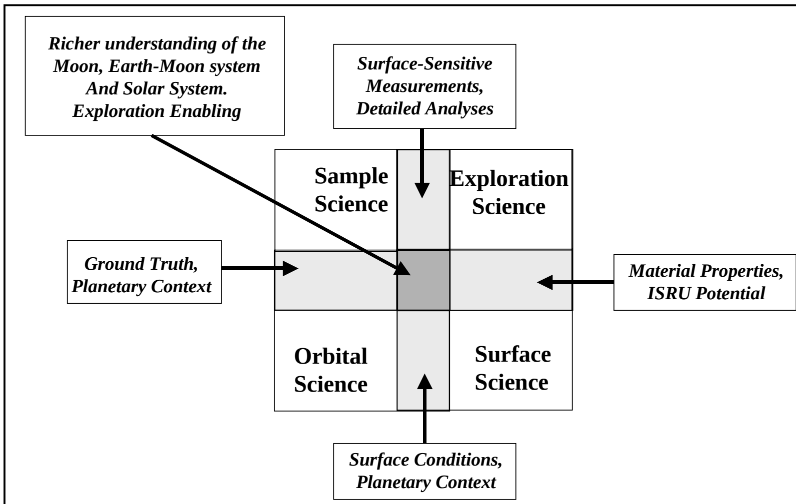


Figure 2. Overlapping relationships among sample return science, exploration science, orbital science, and surface science to gain a better understanding of Mars.

3.2 The importance of Martian meteorites and the value of Mars Sample Return.

3.2.1 Introduction Approximately 51 meteorites are acknowledged as samples derived from Mars. The total mass of these samples exceeds 84 kg. All of them have an igneous origin and formed by the crystallization of basaltic magmas on or near the Martian surface. With such a large sample mass in hand, why is it critical to return an additional 0.5 to 1.0 kg of material from Mars?

3.2.2 What has been learned from Martian meteorites?

Mars is active: The relatively young ages of many Martian meteorites indicate that Mars was a dynamic planet in the recent past, capable of igneous processes, specifically melting of the Martian mantle. The young ages further indicate that igneous processes are probably active on Mars today [2-5].

Mars differentiated early: Radiogenic isotope studies of Martian meteorites show that Mars differentiated rather quickly (within ~25 Ma of solar system formation) and that the products of this early differentiation did not remix for most of its history. This early differentiation is consistent with the presence of a magma ocean, comparable to that inferred for the Moon [2-5].

Mars is complex: Some chemical features of the martian basalts (e.g., K/La, Fe/Mn, O isotopes) link them to a common parent body. The array of Martian basalt compositions implies that they were derived by mixing of two distinct sources produced during the early stages of Martian differentiation. The super-chondritic Ca/Al of many of the Martian basalts suggests that they may have been derived from (magma ocean) cumulates that experienced the removal of garnet prior to their formation. Estimates of the crystallization conditions of Martian basalts imply that the Martian mantle may be under a range of f_{O2} conditions from IW+1 to more oxidizing conditions [2-5].

Mars has "groundwater": Most of the Martian meteorites contain complex assemblages of water-deposited minerals, and many of these clearly formed on Mars. The water-deposited minerals include: smectite; Fe-O-H phases; Fe-Mg-Ca carbonates; Ca, Mg, and K-Fe sulfates; Na & K chlorides; Ca & Mg-Fe phosphates; and amorphous material. Ages of these assemblages range from ~ 3.9 – 0.1 Ga, proving that Mars had "groundwater" through most of its history. S isotope data ($\delta^{34}S$ and ^{33}S depletions) and large ^{17}O excesses imply that this water came from (or interacted strongly with) the Mars' atmosphere. Alteration phases in the Martian meteorites provided a first glimpse of phases that could be stable at or near the Martian surface.

Composition & evolution of the martian atmosphere and hydrosphere: Noble gases, N_2, and CO_2 trapped in impact-produced glass not only confirmed that these meteorites were from Mars, but provided constraints on the composition and dynamics of the martian atmosphere. The $\delta^{13}C$ data from Martian meteorites provide insights into the Martian carbon cycle. The D/H in apatite relative to atmospheric D/H has been used to suggest early H_2O escape from a wetter Mars.

3.2.3 The value of Mars Sample Return

The Martian meteorites present a biased view of Mars: Orbital and surface missions have revealed that Mars' surface is far more diverse than was imagined only a decade ago. This indicates that Mars has a plethora of distinct environments, each of which is characterized by different samples types, with different potential scientific returns. For example, the meteorite collection does not contain samples representative of clays identified from orbit or Br- or Si-rich samples identified by rovers. Most of the lithologies encountered by orbital and surface missions on the martian surface are not in the meteorite collection because they are extremely fragile and do not survive the impact process that would launch them into space. These fragile samples record processes on the surface or in the shallow Martian crust that reflect the activity of water.

Geologic context: Although the data derived from Martian meteorites paints a general picture of Martian planetary evolution and development, it would be significantly more valuable if the data could be placed within a geologic context. Although dates reflecting crystallization or alteration can be tied to a specific sample or groups of samples, they cannot be related to the evolution and alteration of a particular Martian terrain or placed within the context of planetary scale events. For example, geologic context is required in order to determine cratering rates and develop accurate crater density chronology. Thus, returned samples that are placed within a geologic context (local-, regional-, and planetary-scale) will provide a means of dating events on the Martian surface and constraining the regional extent of mineralogical and geochemical features, thereby more precisely establishing the overall history of Mars.

Ground truth: Sample return should not be viewed as a terminal mission in the exploration of Mars. Ground truth offered by sample return provides insights into the reinterpretation of data gathered by previous orbital and surface missions. Orbital and surface observations allow sample data to be placed in a planetary-scale context. "New Views of the Moon" illustrates the scientific dynamics among orbital, surface, and sample observations in better understanding a planetary body. Further, ground truth enables the implementation of much more complex orbital and surface missions in the future.

Follow the Waters: Both orbital and surface missions have demonstrated that water has a central role in shaping the Martian surface and perhaps the evolution of the Martian crust. However, the history of water on Mars and its evolving role in shaping the Martian crust have not been extracted from these observations. These previous missions have identified numerous lithologies that upon sampling will provide insights into fluid characteristics, sources of fluids, interactions with environments of biologic activity, and history-duration of fluid activity. Samples returned from Mars will potentially preserve more of the fragile secondary alteration phases used to track aqueous processes. Importantly, returned samples may be analyzed with a greater variety of analytical techniques than possible on the surface of Mars by rovers or remotely with orbiters.

Search for life: The initial sample return mission will probably not return samples that directly answer the question of whether or not life flourished on Mars. Because life and the history of life is inextricably connected with the physical factors of its environment, the study of Mars as a possible home for life is more likely the prudent scientific investigation for an initial sample return mission. Such a mission combined with orbital and surface derived data will likely provide information needed to design a mission that accomplishes this task.

Finding 1. Sample return from Mars is the logical next step in the Mars Exploration Program theme of "follow the water". The National Research Council (NRC) in numerous assessments has endorsed Mars Sample Return (MSR) as an important component in NASA's solar system exploration program. MSR is a valuable exploration tool, as it increases the value of both orbital and surface observations.

Finding 2. Martian meteorites provide one valuable perspective of Mars. Further, they illustrate the scientific power of the analysis of samples. However, orbital and surface missions have demonstrated the wide variety of surface environments unrepresented by the meteorite collection. "Science Priorities for Mars Sample Return" produced by the Next Decade Science Analysis Group (http://mepag.jpl.nasa.gov /reports/index.html) has demonstrated the richness of Martian science that can be achieved with samples.

4. Approach to the Analysis

The first meeting of the Mars Sample Return Roundtable was held on November 22 and 23, 2007. This meeting was to organize a workshop on Mars sample return and identify important issues tied to the first Mars sample return mission, Mars Receiving lab, technology investments needed to enable MSR and infrastructure needed to study the returned samples. Members of the committee submitted contributions to this white paper as abstracts. Additional information was extracted from the MEPAG document "Science Priorities for Mars Sample Return" produced by the Next Decade Science Analysis Group (http://mepag.jpl.nasa.gov /reports/index.html, CAPTEM analysis document "Analysis of Investments in Sample Return Capability to Reduce Risks and Costs of Sample Return Missions", and a MEPAG draft document "2004 MSR SSR II". The first draft of the white paper was reviewed by the roundtable prior to and during the MSR workshop held on April 20-23, 2008.

5. Reducing Risk and Cost to the First Mars Sample Return

5.1 Introduction

Returning samples from Mars is a complex endeavor with a higher cost and risk compared to orbital and surface missions. Yet, as demonstrated above, the scientific returns are significantly higher by providing a large scientific payoff to orbital, surface, and sample communities. Here, we identify some of the factors that could increase risk and cost to the first MSR mission, identify potential solutions to reduce risk and cost that must be explored within mission trade space, and the impact of these solutions on science that can be achieved with sample return.

5.2 First Mars Sample Return Mission, Keep it Simple.

5.2.1 A First Mars Sample Return Mission. Mars sample return is a complex mission requiring the use of both proven technologies from previous surface missions (i.e. lander, rover,) combined with new technologies (Mars ascent vehicle, autonomous rendezvous and docking system, Mars sample return vehicle, sample collection and storage). Just as the exploration of the Mars surface has successfully evolved in complexity from Pathfinder to Mars Exploration Rovers to Mars Science Lab, one should envision Mars sample return in the same manner: a simple mission evolving into more complex missions. Eventually, sample return missions must connect in a direct technological and programmatic way with human missions to Mars. The first sample return mission should not be expected to fulfill all of the science goals in the MEPAG Goals Document. However, it is important to consider how we can maximize the science return from such an initial mission.

Various MEPAG analysis groups have explored different Mars sample return mission styles ranging from the first grab and launch "Groundbreaker" (MSR SSG I, 2002) to the "Groundbreaker with mobility" (MSR SSG II, 2004). Although the charter of the ND-SAG 2008 was to identify the richness of science that could be accomplished by MSR, they did identify mission philosophy-mission components that could be used to attain mission success. These desired components envisioned missions that were only slightly more complex than the "mobile Groundbreaker" to significantly more complex (ND-SAG 2008). A general summary of these sample return mission styles are shown below:

MSR SSG Groundbreaker:

<u>Non-Mobile Lander</u>: Acceptable if it goes to a site shown by prior missions to contain information about present and past Mars climate and habitability.
<u>Landing Precision</u>: comparable to that of MSL, ~ 10 km, targeting <u>wide-scale</u> geologic units
<u>Sampling System</u>: extendable robotic arm with arm-camera and scoop + sieve, and a gas-tight sample canister

On-board Instruments: Simple context imager, plus a camera on the extendable robotic arm.
The enabling assumption: Going to a characterized site.
Baseline requirements: Return ≥ 500g (total) of regolith, rock chips (~ 1 cm), pristine atmosphere.

MSR SSG II Groundbreaker with mobility:
Lander and Rover: Mobility essential and must have a capability of ≥ 1 km, assuming pinpoint landing.
Sampling System: Sample corer and scoop. Sample isolation is highly desirable. Sample temperature control (<20ºC or better) and organic / inorganic contamination control are critical.
Sample Cache: Does not require MSR to retrieve cache collected from prior mission although this option is kept open.
On-board Instruments: Resist the costly temptation to add many on-board instruments because analyses will be done in Earth labs. Imposing too many requirements /desirements will result in a mission that is too costly to afford.
Baseline requirements: Return ≥ 500g (total) of cores, regolith, rock chips (~ 1 cm).

ND-SAG.
Lander and Rover: Mobility essential and must have a capability of > 1 km. More complex missions require more mobility.
Sampling System: Sample corer. Sample isolation is highly desirable. Sample temperature control (<20ºC or better) and organic / inorganic contamination control are critical
Sample Cache: The MSL cache was viewed as providing inferior samples. Other sample caches may be more desirable and therefore retrieving a sample cache should be kept as an option.
On-board Instruments: Many options considered for on-board instruments from a simple context imager, plus a camera on the extendable robotic arm to extensive instrument packages (mineralogy, geochemistry, organic analyzer) to document the terrain prior to sampling and to continue exploration after the primary goals of the mission have been met.

The least complex style of Mars sample return mission identified by the ND-SAG and the mobile Groundbreaker mission envisioned by MSR SSG II are very similar in complexity and capability. The less complex architectures envisioned by MSR SSG II and ND-SAG require very small instrument packages and a relatively small mass delivered to the Martian surface.

All of these analyses of MSR (MSR SSG, MSR SSG II, ND-SAG, and CAPTEM MSR Roundtable) illustrate the diversity of potential science, mission complexity, and mission cost. However, they also demonstrate both the diversity of opinions concerning MSR within the various factions making up the Mars science community and the difficulty in coming to an overall consensus. The opinions for the first MSR mission range from a simple "grab and go" style mission similar to "Groundbreaker" to a "mobile geologist" mission designed to explore the Martian surface with a array of tools over the duration of a year to excluding MSR from the exploration of Mars. Perhaps, an independent NRC analysis group should evaluate the architecture of the first MSR mission within the context of solar system exploration.

Finding 3. For the first Mars sample return mission a simple approach as advocated by the MSR SSG II and the ND-SAG provides the potential for successful science. Further, such a mission provides an engineering demonstration of technologies for more complex sample return missions and eventual human missions.

Reducing the complexity of the first sample return mission will reduce cost and risk. However, it is important to design a sample acquisition strategy that will limit the time on the Martian surface, collect a diversity of samples, and place samples within a geologic context. There are a number of approaches that could be used to accomplish these goals. These include sampling a previously documented terrain on the Martian surface, return a sample cache as part of the samples returned, and utilize an analytical instrument that can accomplish analyses from a distance and thereby identify sampling targets and decreasing roving time.

Finding 4. A careful analysis of the relationship between the duration of a MSR mission on the Martian surface and risk and cost to the mission should be used in planning the sampling strategy for the first mission to reduce cost and risk.

Finding 5. The MSR Roundtable concluded that it would be important in the planning stages to resist the costly temptation to add many on-board instruments; however, several key instruments could be considered advantageous to a successful mission: (1) instrument capable of distinguishing among samples so that a diverse set of sample are collected and (2) instruments capable of reducing time on the Martian surface because it reduces roving time.

Finding 6. Placing samples within the context of local and regional geology makes the samples more scientifically valuable. This can be accomplished in a shorter time on the Martian surface, and using a smaller instrument package if a previously documented site is sampled. This would include two MER sites, the MSL site, and the ExoMars site.

Finding 7. A sample collection strategy that will reduce overall time on the Martian surface will reduce cost and risk to a sample return mission. Elements of such a strategy could be examined during the Mars Science Lab mission.

These approaches in sampling the Martian surface may reduce cost and risk. Engineers must rationally evaluate this reduction in cost and risk. How do these approaches to MSR impact the science that can be accomplished on the first Mars sample return?

5.2.2 Keeping it Simple, the Effect on the Astrobiology Component of MSR. As noted above, a simple Mars sample return mission may not directly answer the question of whether or not life flourished on Mars. However, even the most simple sample return mission can provide important advances for Astrobiology.

Astrobiology goals for soil sample: A first soil sample contributes to Astrobiology goals on Mars in the following ways: (1) Light element geochemistry: Of the biogenic elements (C, H, N, O, P, S) and their compounds we have direct measurements only of elemental S in the soil. The important compounds such as nitrates, carbonates, and phosphates are not determined. (2) Weathering history: The Martian soil is a product of chemical weathering. It is not just mechanically ground rock. Various hypotheses have been suggested: acid fog (of Cl and S), occasional liquid water even as films, UV and oxidants, extensive liquid water but long ago. The resolution of this question has important implications for the search for organics and understanding the environmental and geological history of Mars. (3) Residual organics: Direct measurements of organics with high sensitivity remains of interest. The Viking GCMS did not detect organics in the soil with an instrumental sensitivity of a few ppb. The appropriate upper limit in the soil may have been much higher. A few ppb of organics, if present purely as microorganisms places a lower limit of cell count only at about 1,000,000 per gram soil. In addition, it is possible that Mars may have refractory organics that would not have been detected at the temperature reached by the Viking ovens (500ºC). These refractory organics may be the results of oxidative reactions. Thus laboratory measurements of organics on a returned sample could be of considerable interest even of the sample was heat sterilized. (4) Iron redox state: Iron may he the key redox element in the Martian soil and understanding its mineralogical state will help understand the weathering and oxidative history of the soil. (5) Magnetic fraction: The most interesting aspect of the ALH84001 remains the indication of magnetite of the same shape as biogenic magnetite. The soil of Mars has a large, unexplained, magnetic fraction. Is it of biogenic origin? Studies of the shape and size of the magnetic particles and searches for chains of identical particles could be conducted in laboratories on Earth. (7) Oxidant: The nature of the oxidant(s) may require in situ investigations but analysis of a returned sample may help rule out some proposed hypotheses (such as high peroxynitrate levels). (8) Toxicity of the soil: A soil sample will allow for easy direct determination of any exotic or toxic soil components. This would be directly relevant to future human exploration.

5.2.3 Keeping it Simple, the Role of a Sample Cache. Sample caching by a capable rover prior to the first sample return has been discussed as a way of reducing cost and risk while providing a diverse set of characterized samples. For example, caching samples during a mission with MSL's capabilities contribute to a follow-up MSR mission a broad suite of analytical instruments, traverse endurance of 20 km, and intended lifetime of at least one Martian year. These attributes potentially reduce the cost of the MSR by reducing rover size, duration of time on the Martian surface, and the number of instruments required to categorize the samples. NASA should further assess the reduction of cost and risk provided by the cache with cost and risk associated with pinpoint landing required to retrieve the cache. There are deficiencies in using the sample cache. These deficiencies include modification of fragile samples in the cache prior to retrieval by the MSR mission and interactions between samples that are not isolated from one another. The MEPAG ND-SAG examined the scientific usefulness of cached samples. The scientific value of the cache is closely tied to the capability of the cache to represent the variability in regional geology, the relationship of cached samples to adjacent outcrops, and the ability to document the collected samples. Also, collection of a diverse set of samples such as basalts and impact melts would be ideal for the sample cache. They would provide a diversity of samples for chronology and geochemistry while reacting very little with the Martian environment. Therefore, it seems that the scientific value of the sample cache is very useful if the proper lithologies are targeted.

Finding 8. For some targets, the goals of reducing time on the Martian surface and collecting a variety of well-documented samples from a significant area may be accomplished with sample caching. The most appropriate samples for caching are those that will not be significantly affected by conditions on the Martian surface or interact during transport to Earth. This includes igneous rocks and impact melts. The scientific value of the sample cache can only be evaluated following its collection. Sample collection during MSL or follow-on missions would provide insights into future sampling strategies. The reduction of cost and risk provided by a sample caching must be balanced against the cost and risk associated with pinpoint landing required to retrieve the cache.

5.3 Keep it Simple, Return to a Previously Explored Site.

The NASA Mars Exploration Program has four main goals: (1) determine if life ever arose there, (2) understand the processes and history of its climate, (3) determine the evolution of its surface and interior, and (4) prepare for human exploration of Mars [6]. These goals are embodied in the NASA Mars exploration strategy "Follow the Water." Current Mars exploration tactics for lander-rover missions build on knowledge gained by prior orbital investigations; the science rationale for choosing landing sites is based on the current best interpretation of the geology. A future Mars sample return mission will greatly exceed in cost typical rover missions because of the need to design for return to Earth and the infrastructure needed on Earth to curate and process the samples safely and cleanly. Because of this added cost burden, expectations for science return are higher. There must be some prospect that the returned samples will allow for testing higher-level hypotheses relevant to NASA's goals. Site selection must be based on knowledge gained from prior *in situ* measurements to enhance the prospects for successfully meeting these goals.

5.3.1 Science that could be achieved at a previously explored site. An example from Meridiani Planum. The following is taken directly from Mittlefehldt [7] from his assessment of the potential science that could be achieved with a MSR mission to Meridiani Planum. Meridiani Planum is a low-relief terrain with few craters in the central portion of Sinus Meridiani [8]. Orbital thermal emission spectrometry showed that the plains have a significant cover of hematite, postulated to have formed from aqueous solutions [9,10]. The rocks of Meridiani Planum form a nearly horizontally layered sequence perhaps 800 meters thick, of which the hematite-rich units are only a portion [8,11]. Although prior to *in situ* investigation the rocks were thought to be volcanoclastic [11], the Mars Exploration Rover Opportunity has shown that the outcrops in its immediate vicinity are sedimentary [12]. This is inferred to hold for the entire section in Meridiani Planum [8]. The rocks investigated by Opportunity represent only about 1% of the section and are near its top [8,11]. They are among the youngest sediments in the section, and are interpreted to be Late Noachian or Early Hesperian in age [8,11].

The ~7 meter sedimentary section investigated by Opportunity is interpreted to be a sequence of wind and water transported clastic materials [12-14]. Within this section, the lower unit consists of cross-bedded sandstones interpreted to be fossil eolian dunes. Above this lies an eolian sand sheet composed of fine-scale planar-laminated to low-angle-stratified sandstones. The boundary between the lower and middle units is an eolian deflation surface indicating a period of erosion. A zone of diagenetic recrystallization defines the top of the middle unit. The upper unit consists in part of eolian sand sheet sediments and in part of interdune playa lake sediments showing sedimentary structures indicative of water transport.

The mineralogy of the sediments has been constrained by Mössbauer spectrometry and miniature thermal emission spectrometry (Mini-TES). The iron mineralogy is dominated by hematite, jarosite, an unidentified ferric phase (Fe3D3) and pyroxene, with a very small amount of olivine [15,16]. Mini-TES spectra for light-toned outcrops also demonstrate the presence of jarosite and hematite, and identify Mg- and Ca-bearing sulfates, Al-rich opaline silica, plagioclase feldspar, and possibly nontronite [15,16]. (Mini-TES spectra are on natural rock surfaces, while Mössbauer spectra are from rock interiors exposed by grinding – the two data sets are not on equivalent materials.)

The sediments in Meridiani Planum are interpreted to have been derived from muds from an evaporating playa lake [17]. The muds were composed of primary igneous minerals, siliciclastic alteration materials and evaporite minerals. Desiccation of the playa lake exposed the surface to wind erosion allowing sand-sized dried mud particles to be transported by wind to the site of deposition. These grains form the framework of the Meridiani rocks that were subsequently affected by diagenesis.

There are numerous investigations that could be accomplished with this geologic environment that directly respond to the scientific objectives associated with the Mars exploration program.

Determine if life ever arose on Mars. Orbital [12,13] and *in situ* [15,16,18] investigation of Meridiani Planum provide a compelling case for aqueous processes having occurred at this site, including the likelihood that standing pools of water once existed on the surface. Thus, rocks returned from Meridiani Planum hold a strong potential for harboring signs of past life, if it ever existed. Examination of samples by electron microbeam techniques to search for microfossils and biogenic mineralization, and by geochemical analysis to search for organic chemical and isotopic fractionations diagnostic of biological activity can test for past (or extant) life. These analyses might best be done on cores intercepting playa lake sediments below the current erosion surface as this would minimize the chance that Mars' current environment has degraded the evidence.

Understand the processes and history of climate on Mars. Clear signs of aqueous activity by ground water and standing water at Meridiani Planum require that the climate was different at the time of deposition and diagenesis. Although some constraints can be placed on the nature of the diagenetic solutions from the mineralogy and chemistry determined *in situ* [17,18], these data lack the precision and completeness that can be achieved by laboratory study. Examination of returned rocks will allow for complete characterization of mineralogy, mineral compositions and compositional zoning, textural context (requiring that the samples remain intact during the journey back to Earth), and bulk chemical and stable isotopic composition that will allow for much more detailed and precise modeling of fluid evolution. This would certainly be true for the post-depositional diagenesis process. If later diagenesis did not completely overprint the evidence, it may be possible to elucidate the chemistry of the standing waters in which the sediments of the upper unit were deposited. These waters were in contact with the atmosphere, and the compositions of minerals derived from them may thus yield more direct information on the ancient Mars atmosphere and climate. Returned samples will thus allow for greater fidelity of models with nature. A major advance, however, would be to determine absolute ages for this climatic period. This can be accomplished by radiometric age dating of key minerals. Jarosite, formed by aqueous alteration, is amenable to K-Ar (and possibly Ar-Ar) dating to yield its formation age, and dating by other radiometric techniques may also be feasible [19].

Determine the evolution of the surface and interior of Mars. In addition to addressing climatic issues, Meridiani sediments would yield important new insights into the evolution of the surface and interior of Mars. Pyroxene and plagioclase are significant components of the outcrops, and they and olivine are components of the younger eolian bedforms [15,16,20]. These phases likely are remnants of primary crustal igneous rocks. Their preservation demonstrates that chemical weathering was not 100% effective, opening the door for investigations of the evolution of the surface and interior. One outcome would be determination of the chronology of the development of the crust. Some accessory phases concentrate the parent nuclides of radiometric chronometers. Zircon and baddeleyite concentrate U and individual grains can be dated using microbeam techniques [21,22]. By using laser extraction techniques, Ar-Ar dating of individual major mineral grains can be done [23]. These techniques would yield information on the chronology of formation of the crust that was altered and eroded to provide the Meridiani sediments. The assemblage and mineral compositions of remnant igneous grains can be used to infer the nature of the crust supplying the detritus [24]. Terrestrial experience [21,25] shows that by using the full panoply of modern microbeam analytical instrumentation, details of the formation of Mars' ancient crust may be discovered, even if that crust no longer exists.

Finding 9. There is a plethora of important science that can be accomplished with a simple MSR mission (with mobility ≥ 1 km) to a previously visited site. This science includes observations that are fundamental to our understanding of the potential of life on Mars.

5.4 Enabling Technologies for Mars Sample Return.

A Mars sample return mission is generally more complex than other robotic Mars exploration missions because it needs to return safely to its body of origin (Earth) with a "payload" of collected planetary materials. Relative to other robotic missions, MSR is the closest approximation to human flight in overall goals. Further, MSR has to perform a series of interrelated, complex tasks. Each stage of a sample return mission must accomplish its task and be integrated with follow-on stages of the mission to be successful. The mitigation of cost and risk with a mission puts an even higher priority on early technology development for sample return missions than for more conventional mission types.

Finding 10. The mitigation of cost and risk for a Mars sample return mission puts an even higher priority on early technology development for sample return missions than for more conventional mission types.

Some of the critical technology investments that need to be made for MSR to occur are a Mars Ascent Vehicle, autonomous rendezvous and docking capability, a Mars sample return vehicle, and a sample collection and containment system. A summary of potential sample return technology investments and their commonality to Mars sample return is presented in CAPTEM analysis document: "Analysis of Investments in Sample Return Capability to Reduce Risks and Costs of Sample Return Mission".

Mars Ascent Vehicle: Technology requirements for ascent from a planetary surface are unique to each planetary body. Many technologies are in place to fulfill the goals of launching from the surfaces of airless bodies the size of the Moon and smaller. The problem lies with bodies that have atmospheres (i.e., Venus, Mars) and are larger than the Moon. In the case of Mars, investment in a Mars Ascent Vehicle is critical.

The engineering challenges for Mars are neither simple nor insurmountable --- this is the conclusion of NASA in-house studies as well as private and government-funded studies by at least three major industrial firms. Mars surface gravity is 38% of Earth, and its escape velocity is 5027 m/s. Various studies have considered liquid, solid, gel, and hybrid propellant systems. NASA-funded and directed consortium studies considered all options. This funding was terminated in 2001. Although no new technological breakthroughs are required to develop a Mars Ascent Vehicle (MAV), there are many uncertainties surrounding its actual implementation. These uncertainties are critical to development of the entire MSR scenario because the size, configuration, and thermal capabilities of the landed system for MSR are totally dependent upon the design details of the MAV. Thus, the MAV is the critical link in the chain of a MSR mission scenario, which takes advantage of staging the sample into Mars orbit. This architectural approach is desirable for two independent but very important reasons: (1) it minimizes the mass of the system and hence lowers the cost of the Earth launch vehicle, and (2) it "breaks the chain of contact" between Mars and Earth to relieve planetary protection concerns. In this scenario, the Martian samples would be packaged in a container, sometimes called an Orbiting Sphere (OS), which would be left in Mars orbit for pickup by an independent Mars orbiter / Earth transit vehicle.

From a cost and implementation risk standpoint, the MAV is currently the most critical link in the chain for a successful MSR mission. If NASA would sponsor the development of the MAV now, significant risk to the program and a far more competitive, lower risk MSR program could be constructed. In contrast to the previous approach, however, when budgetary support was greater than now realistic, it is recommended that a fully independent competitive development be sponsored, rather than a large consortium approach. The basic requirements for a MAV should be developed in sufficient detail to enable an effective competition. Previous specifications were for multiple samples with an aggregate mass of 0.5 kg to be segregated and containerized into an OS of nominal 19-cm diameter and a total mass of 5 kg. The OS would constitute the payload of the MAV, and the MAV would have various performance requirements such as launch platform instability limits, final orbit parameters and their uncertainties, capability to operate in a cold Martian environment, etc. NASA should develop the MAV to include at least one demonstration test flight, notionally from a highly altitude balloon in Earth's atmosphere to simulate the Martian atmospheric drag conditions. Once a MAV development is finalized, the MSR program can be placed on a much firmer footing with respect to cost, risk, development time, and reliability.

Orbital Rendezvous: Given the major fuel requirements to lift mass from the surface of Mars, the additional requirements of lifting active cooling systems, hardware associated with planetary protection needs, and heat-shielding for Earth reentry will have a significant impact on mission cost. Alterative models would involve fully autonomous rendezvous with a return spacecraft in orbit around the planetary body being sampled or in Earth orbit. The savings in mission cost through reduction in landed mass and vehicle size must be traded against mission risk associated with autonomous rendezvous and sample capsule transfer above a distant planet and/or, perhaps, human assisted or autonomous rendezvous in Earth orbit. Such risk has been partially mitigated through the recent DART mission. However, additional testing of capsule transfer, capsule security, and connection to required cooling or security systems for reentry may require additional testing. Transfer of containment systems between spacecraft systems in Earth orbit may provide additional capability for sterilization of return component exteriors in order to "break the chain" of potential forward contamination before reentry. Return of humans from the Martian surface would also involve a similar, although much more scaled-up approach.

Mars sample collection and storage: Robotic collection of samples from a planet's surface has not been accomplished since the Luna missions carried out by the Soviet Union. Even in this case, the collection was somewhat easier as lunar regolith was the targeted sample. To accomplish sample collection investments must be made in a variety of sample collection tools (corer, drill, rake) and a robotic arm capable of involvement in sample collection functions (i.e. robotic manipulation of sample for collection, transfer to container, and final selection or discard). Samples from Mars may be highly reactive in a single storage container. This is a result of both low temperature of stability (Figure 3A) and volatile content of phases that have been documented to make up both the regolith and rocks. Reactivity among mineral phases could lead could lead to the destruction of either subsamples or the entire sample cache. An example of the reactivity between sulfates and clays is illustrated in Figure 3B. This is an extreme case (Figure 3), but as preserving textural context is important for science goals of MSR it is critical that the samples remain intact during the journey back to Earth. Therefore, it is critical to investigate and invest in both sample containment technologies and sample collection-storage strategies.

Mars sample return vehicle: Genesis and Stardust missions demonstrated two methodologies for re-entry and landing of sample return vehicles: "soft landing" landing via parachute and survivable "hard landing", although the latter was inadvertent and the sample return container was breached. For the return of Mars samples, planetary protection concerns will probably dictate that such a mission must be able to survive a "hard landing". Based on the conclusion that most sample returns will involve "survivable hard landing", what are important technologies that will preserve sample integrity?

To insure sample integrity during re-entry and landing, it seems that investments should be made in (1) defining overall philosophy of sample loading/isolation on a planetary surface prior to launch, (2)

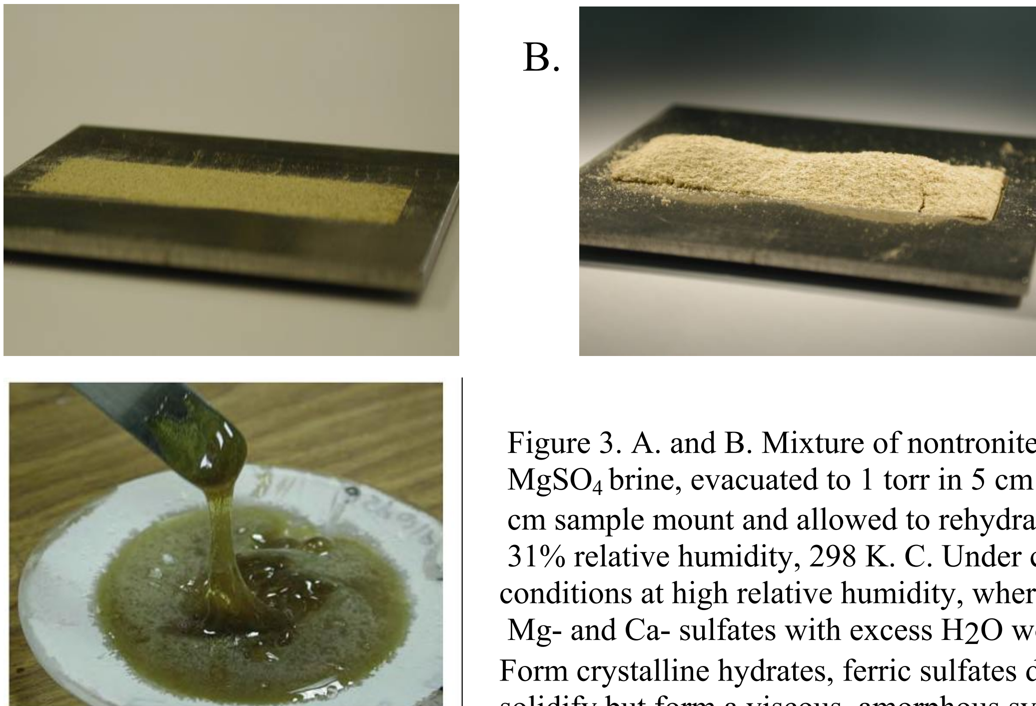


Figure 3. A. and B. Mixture of nontronite and $MgSO_4$ brine, evacuated to 1 torr in 5 cm x 5 cm sample mount and allowed to rehydrate at 31% relative humidity, 298 K. C. Under cold conditions at high relative humidity, where Mg- and Ca- sulfates with excess H_2O would Form crystalline hydrates, ferric sulfates do not solidify but form a viscous, amorphous syrup (images provided by David Vaniman).

designing sample containment that insures sample integrity during transport and landing, and (3) testing of sample containment designs using geological materials that have mechanical and chemical properties that mimic expected returned samples.

Finding 11. Several priority technology investments are identified that enable Mars Sample Return. Early priority technology investments such include:

(1) Mars Ascent Vehicle to place samples in orbit around Mars
(2) Autonomous rendezvous and docking capability in Mars orbit.
(3) Mars sample collection and storage.
(4) Mars sample return vehicle that can provide a high probability of samples being returned to Earth.

Depending on the architecture of the first MSR mission, precision landing, hazard avoidance, and autonomous robotic capabilities may not be necessarily critical. However, because of previous investments made in these technologies for non-sample return missions, it may be both desirable and cost-effective to continue their development for application for MSR. Further, they will feed forward to more complex sample return missions to a number of planetary, more complex non-sample return missions to Mars, and human exploration.

Finding 12. Lower priority technology investments that would reduce cost and risk to MSR should be identified and prioritized. These technologies could include: precision landing, hazard avoidance, and autonomous robotic capabilities.

Finding 13. Sample return technologies feed forward to more complex missions on Mars, missions to other planetary bodies, and human exploration.

6. Receiving Laboratory and Sample Curation

Several planetary bodies of interest for sample return missions are classified "Restricted Earth Return" and must meet strict planetary protection requirements that necessitate the development of capabilities for evaluating and containing possible biological hazards in the returned samples. In particular this has direct application to Mars and icy moons of outer planets (Titan, Europa). Initial operations associated with receiving "Restricted Earth Return" samples will need to be carried out under biocontainment for hazard assessment and life detection. Research on the worst known biohazards is currently done in laboratories that satisfy requirements for BioSafety Level 4 (BSL-4), issued by the Centers for Disease Control and Prevention and the National Institutes of Health ("Biosafety in Microbiological and Biomedical Laboratories", U.S. Dept. of Health & Human Services. 4th edition, 1999) and/or similar standards from the World Health Organization. BSL-4 requirements are sufficient to define the biocontainment requirements for any "Restricted Earth Return" samples. There are several such labs worldwide, and they have excellent safety records: no cases of worker illness or environmental contamination have been reported. Existing biocontainment technology is mature and works. Although these biocontainment facilities are extremely successful at protecting the environment from biohazards associated with samples they do not begin to satisfy the stringent requirements necessary for protecting the integrity of samples from the environment.

Technology for extremely clean conditions is also mature and has been led by advances in the semiconductor industry. Very efficient systems to filter particles out of the air has been followed by substantial progress in limiting Airborne Molecular Contamination (AMC), which is primarily composed of semi-volatile organic compounds. There are no requirements for sterility or biocontainment in the semiconductor industry. The Food and Drug Administration (FDA) has stringent sterilization requirements for avoiding contamination of products, and also requires strict containment of highly potent pharmaceuticals. This is a highly competitive, strictly regulated business, with industry focusing on satisfying FDA requirements so that they may proceed with the production of their varied products. However, the pharmaceutical industry does not need to address the extremely low levels of contamination from trace-levels of inorganic contaminants, life-like organic compounds, and dead organisms that are of concern in preserving the scientific integrity of returned samples.

The technologies and techniques to meet requirements for biological containment while maintaining the scientific integrity of the returned samples does not currently exist. The present requirements to maintain biocontainment in an environment that is non-contaminating in order to protect the samples are unique to NASA. Fortunately, certain aspects can be borrowed from existing biomedical and industrial technology and practices but integrating these aspects into the necessary functions will take considerable effort.

Building a biologically clean sample receiving/handling facility and developing safe and secure sample handling protocols may be costly, based on previous studies. Investments in studies of unique "out of the box" concepts for implementing a biologically clean sample handling facility will be important in not only determining viable approaches to meeting planetary protection requirements but also in focusing and prioritizing future investments. Specifically, early work refining the necessary planetary protection requirements will reduce the cost associated with over-design. In addition, a thorough review of existing BSL-4 facilities, their capabilities, and the suitability and availability of using an existing (or modified) facility will provide important information.

Increasingly, use is made of isolated mini-environments when clean containment is required. Technology advancement needed of existing containment / isolation cabinets is necessary but doable to provide the necessary double wall construction to prevent leakage either from the cabinet contents into the environment (escape of sample biohazard) or the environment into the sample containing cabinet (sample contamination). Transfer ports and transfer containers for moving samples between isolation cabinets are mature but assessing changes necessary for material restrictions required for maintaining sample integrity will involve technology development. Current curation sample handling and processing techniques rely on handling samples using Teflon covered gloves and simple tools. Gloves applicable to double-walled systems do not exist with adequate reliability, performance, and low-offgassing self-healing properties. Remote manipulation and simple robotic systems integrated into isolation cabinets may be able to replace the current human-gloved handling of samples. There remain issues of material compatibility with sample contamination requirements and the variety of sample handling and processing motions that must be accommodated. These systems must be low-offgassing, provide no or easily identifiable wear and abrasion products, no contaminating lubricants, and either external or sealed motors. Technology development is also needed to modify existing capabilities to address the different sample processing tasks at both macro- and micro-scale (such as sample splitting, rock drilling, subdividing, etc.) for the different sample types but has promise for providing the means for clean and precise sample processing.

Potentially important for the handling of Martian samples in the receiving and curation facilities is the capability to accomplish tasks under particular temperature and relative humidity conditions. These needs must be identified prior to the MSR missions and incorporated into planning and testing.

There are numerous analyses of the nature of the Mars Receiving Laboratory that have been produced over the last decade [26-30]. These analyses should be reevaluated in the light of current technologies, legal requirements, public sensitivities, and funding scenarios. The COMPLEX Report on the Mars Receiving laboratory –(John Wood, chair) which discusses containment for Preliminary Examination; expand facility if evidence for life or pathogenicity is detected; protocol for biological studies if clear evidence of life present should be updated by COMPLEX.

At this time, it is important to devise a unified advisory committee to oversee activities from the start and into the distant future, as indicated by LSAPT/CAPTEM experience. There are numerous talent pools of experience that could be tapped. Extensive experience is available for extraterrestrial samples and must be sought and applied. Apollo experience and structures offer a key perspective to emulate. Extensive experience is available in studies of pathogenicity and life detection and must be sought and applied as required by law and as scientifically necessary. This advisory committee can handle a variety of tasks tied to planning, construction, sample handling and examination, hazard assessment protocols and planetary protection-science conflicts that will be present and need to be resolved. During this process Public Health professional and legally binding decisions must be adhered to and the public must be kept informed and engaged

Finding 14. Advanced planning is necessary to establish the appropriate sample handling protocols and design-build-test containment facility for samples returned from Mars. This planning should involve updating existing documents, and obtaining specific planning advice to prepare for Mars sample return. Assuming a MSR mission that launches in 2020-2022, a

planning budget in the period 2012-2016 is needed to support Mars Sample Receiving Facility scoping activity, NEPA, a competed site selection processes, and associated public communications activity. Further, the site of the Mars Sample Receiving Facility should be identified no later than 2016.

Finding 15. LSAPT/CAPTEM demonstrates the need for an integrated, international advisory committee. It is important to devise a unified advisory committee to oversee activities from the start and into the distant future, as indicated by LSAPT/CAPTEM experience.

Finding 16. Preliminary examination of samples returned from Mars must occur prior to and concurrently with hazard assessment during planetary protection. Knowing rock type and chemistry resulting from preliminary examination is beneficial for science, but critical for hazard assessment.

7. Analytical and Human Infrastructure Needed to Support Mars Sample Return Science

Central to the scientific success of Mars sample return is the ability to analyze small sample masses in state-of-the-art laboratories upon their successful return to Earth. This does not only include traditional Mars related science but also "Life-detection" of non-terrestrial. Currently there is a widening gap between the United States and the rest of the world with regards to analytical infrastructure available to the planetary science community. Many new instruments for analyzing planetary materials are no longer made in the United States, but are produced in Japan and Europe. Analysis of the scientific literature on geological and planetary materials indicates a substantial growth in papers produced in state-of-the-art labs outside the United States. Building this analytical infrastructure in the United States is important not only to our competitiveness in the analysis of martian samples, but to restore our scientific and technological prowess.

Finding 17. It is important the United States planetary science community is technologically mature to lead the science resulting from Mars sample return. Therefore, it is important to upgrade analytical instrumentation and approaches in planetary science laboratories at both NASA centers and P.I. facilities.

NASA has been very successful at building an infrastructure of young scientists around many of their missions that involve orbital or surface activities. The Mars exploration program is an extraordinary example of growing and maintaining a vibrant and demographically youthful science community. However, sample return missions have been rare since the Apollo program (Stardust, Genesis) and therefore the sample science community does not have an infrastructure consisting of a large number of young sample scientists. Prior to MSR this new generation of planetary sample scientists must be trained. There are several means of training and growing such a community: (1) Grow sample science community through NASA science programs such as Cosmochemistry and Mars Fundamental Research. Evaluate the extent these programs are funding sample based research applicable to MSR. Also, initiate sample science training under the Astrobiology Institute and Lunar Science Institute.

Finding 18. It is important the United States planetary science community is intellectually mature to lead the science resulting from Mars sample return. This may be accomplished by further supporting sample science in existing NASA research and analysis programs.

8. Summary of Findings

Finding 1. Sample return from Mars is the logical next step in the Mars Exploration Program theme of "follow the water". The National Research Council (NRC) has endorsed Mars Sample Return (MSR) as an important component NASA solar system exploration program in numerous assessments. MSR is a valuable exploration tool, as it increases the value of both orbital and surface observations.

Finding 2. Martian meteorites provide one valuable perspective of Mars. They illustrate the scientific power of the analysis of samples. However, orbital and surface missions have demonstrated the wide variety of surface environments unrepresented by the meteorite collection. "Science Priorities for Mars Sample Return" produced by the Next Decade Science Analysis Group (http://mepag.jpl.nasa.gov /reports/index.html) has demonstrated the richness of Martian science that can be achieved with samples.

Finding 3. For the first Mars sample return mission a simple approach as advocated by the MSR SSG II and the ND-SAG provides the potential for successful science and an engineering demonstration of technologies for more complex sample return missions and eventual human missions.

Finding 4. A careful analysis of the relationship between the duration of a MSR mission on the Martian surface and risk and cost to the mission should be used in planning the sampling strategy for the first mission to reduce cost and risk.

Finding 5. The MSR Roundtable concluded that it would be important in the planning stages to resist the costly temptation to add many on-board instruments; however, several key instruments could be considered advantageous to a successful mission: (1) instrument capable of distinguishing among samples so that a diverse set of sample are collected and (2) instruments capable of reducing time on the Martian surface because it reduces roving time.

Finding 6. Placing samples within the context of local and regional geology makes the samples more scientifically valuable. This can be accomplished in a shorter time on the Martian surface, and using a smaller instrument package if a previously documented site is sampled. This would include two MER sites, an MSL site, and an ExoMars site.

Finding 7. A sample collection strategy that will reduce overall time on the Martian surface will reduce cost and risk to a sample return mission. Elements of such a strategy could be examined during the Mars Science Lab mission.

Finding 8. For some targets, the goals of reducing time on the Martian surface and collecting a variety of well-documented samples from a significant area may be accomplished with sample caching. The most appropriate samples for caching are those that will not be significantly affected by conditions on the Martian surface or interact during transport to Earth. This includes igneous rocks and impact melts. The scientific value of the sample cache can only be evaluated following its collection. Sample collection activities during MSL or ExoMars would provide insights into future sampling strategies. The reduction of cost and risk provided by sample caching must be balanced against the cost and risk associated with pinpoint landing required to retrieve the cache.

Finding 9. There is a plethora of important science that can be accomplished with a simple MSR mission (with mobility ≥ 1km) to a previously visited site. This science includes observations that are fundamental to our understanding of the potential of life on Mars.

Finding 10. The mitigation of cost and risk for a Mars sample return mission puts an even higher priority on early technology development for sample return missions than for more conventional mission types.

Finding 11. Several priority technology investments are identified that enable Mars Sample Return. Early priority technology investments such include:

(1) Mars Ascent Vehicle to place samples in orbit around Mars
(2) Autonomous rendezvous and docking capability in Mars orbit.
(3) Mars sample collection and storage.
(4) Mars sample return vehicle that can provide a high probability of samples being returned to Earth.

Finding 12. Lower priority technology investments that would reduce cost and risk to MSR should be identified and prioritized. These technologies could include: precision landing, hazard avoidance, and autonomous robotic capabilities.

Finding 13. Sample return technologies feed forward to more complex missions on Mars, missions to other planetary bodies, and human exploration.

Finding 14. Advanced planning is necessary to establish the appropriate sample handling protocols and design-build-test containment facility for samples returned from Mars. This planning should involve updating existing documents, and obtaining specific planning advice to prepare for Mars sample return. Assuming a MSR mission that launches in 2018-2020, a planning budget in the period 2010-2014 is needed to support Mars Sample Receiving Facility scoping activity, NEPA, a competed site selection processes, and associated public communications activity. Further, the site of the Mars Sample Receiving Facility should be identified no later than 2014.

Finding 15. LSAPT/CAPTEM demonstrates the need for an integrated, international advisory committee. It is important to devise a unified advisory committee to oversee activities from the start and into the distant future, as indicated by LSAPT/CAPTEM experience.

Finding 16. Preliminary examination of samples returned from Mars must occur prior to and concurrently with hazard assessment during planetary protection. Knowing rock type and chemistry resulting from preliminary examination is beneficial for science, but critical for hazard assessment.

Finding 17. It is important the United States planetary science community is technologically mature to lead the science resulting from Mars sample return. Therefore it is important to upgrade analytical instrumentation and approaches in planetary science laboratories at both NASA centers and P.I. facilities.

Finding 18. It is important the United States planetary science community is intellectually mature to lead the science resulting from Mars sample return. This may be accomplished by further supporting sample science in existing NASA research and analysis programs.

9. References

[1] Jolliff, B.L. et al. (2006) New Views of the Moon. Reviews in Mineralogy and Geochemistry v. 60, 720pp.

[2] Borg L. E. et al (2003) Geochim. Cosmochim. Acta **67,** 3519-3536.

[3] Brandon, A.D. et al (2000) LPSC XXXI, abstract # 1676.

[4] Shearer, C.K. et al. (2008) MAPS, in press.

[5] Wadhwa, M. (2001) Science, 292, 1527-1530.

[6] Johnson J. R. et al. (2008) Mars Science Goals, Objectives, Investigations, and Priorities, http://mepag.jpl.nasa.gov/reports/index.html.

[7] Mittlefehldt D. W. (2008) Ground truth from Mars: Science Payoff from a sample return mission, abstrac #4031.

[8] Edgett K. S. (2005) Mars 1, 5.

[9]Christensen P. R. et al. (2000) JGR-Planets 105, 9623.

[10]Christensen P. R. et al. (2001) JGR-Planets 106, 23873.

[11] Hynek B. M. et al. (2002) JGR-Planets 107, 5088.

[12] Squyres S. W. et al. (2004) Science 306, 1709.

[13] Squyres S. W. et al. (2006) Science 313, 1403.

[14] Grotzinger J. P. et al. (2005) EPSL 240, 11.

[15] Morris R. V. et al. (2006) JGR-Planets 111, E12S15.

[16] Glotch T. D. et al. (2006) JGR-Planets 111, E12S03.

[17] McLennan S. M. et al. (2005) EPSL 240, 73.

[18] Clark B. C. et al. (2005) EPSL 240, 95.

[19] Papike J. J. et al. (2006) GCA 70, 1309.

[20] Glotch T. D. & Bandfield J. L. (2006) JGR-Planets 111, E12S06.

[21] Pidgeon R. T. & Nemchin A. A. (2006) Precam. Res. 150, 201.

[22] Herd C. D. K. et al. (2007) LPS XXXVIII, abstract #1664.

[23] Walton E. L. et al. (2007) M&PS 42, A159.

[24] Piper D. J. W. et al. (2007) Can. J. Earth Sci. 44, 665.

[25] Valley J. W. et al. (2005) Contrib. Min. Pet. 150, 561.

[26] Allen and 18 co-authors (1999) J. Geophys. Res. **104**, 27,043-27,0666

[27] Carr, M.H.(1999) NASA Tech. Memo., TM-1999-209145 pp.

[28] Gooding, J. L. (1990) NASA Tech. Memo, 4184.

[29] Landis, G. A. et al. (2007) 7th International Mars Conference, abstract #3369.

[30] Neal C.R. (2000) J. Geophys. Res. 105, 22,487-22,506

10. APPENDIX

10.1 APPENDIX I. WORKSHOP REPORT
GROUND TRUTH FROM MARS:
SCIENCE PAYOFF FROM A SAMPLE RETURN MISSION

April 20 – 23, 2008
Albuquerque, New Mexico
Prepared by Charles Shearer, David Beaty, and Carl Agee, June 4, 2008

Mars Sample Return is again on the horizon and endorsed as a logical continuation of the "Follow the Water" strategy of NASA's Mars Exploration Program. This strategy has tied together the search for life and potential habitats for life, evolution of the martian atmosphere, nature of martian surface processes, and the thermal-magmatic evolution of the martian mantle and crust. Orbital and surface missions have revealed that Mars' surface is far more diverse than was imagined only a decade ago, with a plethora of distinct environments– each of which presents different sorts of samples, with different potential scientific returns. Returning samples from these martian environments and analyzing them in the best terrestrial labs available will provide an unparalleled perspective of Mars not yet achieved. Data derived from sample returned from the martian surface will provide both ground truth for interpreting observations made during past orbital and surface missions and insightfulness in planning for future missions. There will be few sample return missions, and so the few targets must be chosen to maximize the likelihood of answering fundamental questions about Mars. There is a delicate balance between science return and mission complexity. To address these issues, this workshop was designed to explore the science and science value that could be extracted from a Mars samples return, illustrate the important science linkages between previous-ongoing missions and sample return missions, and discuss the requirements needed to ensure the record preserved in the samples are undisturbed during sampling, return, and curation.

This workshop was convened by Charles (Chip) Shearer (*University of New Mexico),* Carl Agee (*University of New Mexico)* and David Beaty (*Jet Propulsion Laboratory).* Sponsors included the National Aeronautics and Space Administration (NASA), the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM), Lunar and Planetary Institute, Mars Exploration Program Analysis Group (MEPAG), and the Institute of Meteoritics. The scientific organizing committee consisted of David Bish (*University of Indiana),* James Farquhar *(University of Maryland),* John Grotzinger *(California Institute of Technology),*Virgil Lueth, *(New Mexico School of Technology),* Chris McKay *(NASA Ames),*Glenn MacPherson (*Smithsonian),*Doug Ming *(Johnson Space Center),*Dimitri Papanastassiou *(Jet Propulsion Laboratory)***,** James J. Papike, *(University of New Mexico)*, Dawn Y. Sumner (*University of California Davis)*, Allan Treiman (*Lunar and Planetary Institute)*, and David Vaniman, *(Los Alamos National Laboratory).* The scientific organizing committee was responsible for identifying session themes, inviting speakers, and chairing sessions.

The two and a half day workshop was held April 20 – 23, 2008 at the Hotel Albuquerque at Old Town in Albuquerque, New Mexico. The workshop was attended by 105 participants with interests in Mars related science and potential Mars sample return missions. The workshop consisted of 6 sessions: ENABLING SAMPLE RETURN: PRIORITIES, MISSIONS, AND STRATEGIES (Chairs: D. W. Ming and A. H. Treiman), SAMPLE REQUIREMENTS FROM THE ASTROBIOLOGY POINT OF VIEW (Chairs: C. P. McKay and G. J. MacPherson), SULFATES AS RECORDERS OF MARS NEAR SURFACE PROCESSES AND THE MER SITES AS FIRST SAMPLE RETURN LOCALITIES (Chairs: V. W. Lueth and J. J. Papike), UNDERSTANDING THE EVOLUTION OF MARS' CORE, MANTLE, CRUST, SURFACE, ATMOSPHERE (Chairs: J. Farquhar and D. A. Papanastassiou), HYDROUS MINERALS AS RECORDERS OF FLUID-ATMOSPHERIC EVOLUTION AND SECONDARY ALTERATION (Chairs: D. L. Bish and D. T. Vaniman) and a POSTER SESSION (Chairs: C. Agee and C.K. Shearer). The recommended bibliographic citation for this report is presented at the end of this document. Sixty-two presentations were made during these sessions. The outline of each session is presented in the Appendix. Abstracts for each presentation can be accessed at http://www.lpi.usra.edu/ meetings/msr2008/ and selected presentations can be viewed at http://www.lpi.usra.edu/captem/. A brief summary of each session follows.

ENABLING SAMPLE RETURN: PRIORITIES, MISSIONS, AND STRATEGIES: This first session emphasized the fundamental importance of sample return for understanding Mars, the rich array of important questions that could be answered with a sample return mission, the science linkages between orbital and surface missions and sample return in terms of potential sample targets and establishing ground truth, and the relationship between mission scale and science return. Dave Des Marais (#4037) and Charles Shearer (#4004) illustrated the scientific richness linked to a Mars sample return mission that provided a perspective to understanding Mars that was different from the viewpoint reached from previous missions or scientific studies of martian meteorites. Presentations by Murchie (#4035), Bibring (#4061), Ming (#4016), and Crisp (#4047) illustrated the complexity of Mars revealed by previous orbital and surface missions, the approaches being used by future missions to further explore surface environments of Mars, and the impact these observations could have in defining Mars sample return. Des Marais (#4037) emphasized that sample return with mobility would result in the collection of a diversity of samples required to answer a very large number of scientific questions. Hausrath (#4039) suggested diversity across interfaces between weathered and unweathered lithologies would provide insights into the history of Mars surface processes. On the other hand, Jones (#4002), Jones et al. (#4020; poster) and Clark (#4051; print only) emphasized much simpler missions that would address a smaller number of scientific questions and test technologies required for sample return from the martian surface. Significant discussion focused on the importance of placing samples within a geological context and the approaches that should be used to accomplish this goal. Most attendees considered geologic context important, but there was no clear consensus of the extent or methodology (return to a previous site, documentation during MSR mission with a variety of tools). Finally, Clive Neal (#4026) introduced the workshop to the sample collection and storage steps that must be taken to insure samples preservation upon return to Earth.

SAMPLE REQUIREMENTS FROM THE ASTROBIOLOGY POINT OF VIEW: Kraft (#4049) and Allen (4011) identified potential sampling sites on Mars (northern plains, possible ancient hydrothermal springs) that would be important in testing the possibility of life on Mars. Andy Steele (invited, no abstract) presented a very broad view on the procedures and protocols for the collection of martian samples with the purpose of protecting and preserving the biological record. Chris McKay (#4033) proposed that a non-mobile Mars sample return mission could provide insights into the habitability of Mars both in the past and for humans in the future. Conley (#4060) presented planetary protection considerations for any Mars sample return mission. This led to a long discussion on the protection of the scientific value of samples, the fulfillment of planetary protection constraints, and the establishment of curation-allocation procedures for martian samples. Penny Boston (#4053) and Mike Spilde (#4045) presented terrestrial studies that illustrated the potential mineral-rock environments that could be targets during a sample return mission. Boston showed microorganism communities closely associated with sulfates. Spilde showed that coatings on rocks and mineral surfaces might contain fingerprints of biological activity. Monica Grady (#4062) presented terrestrial lab methodology and measurements to illustrate the presents and distribution of carbon in martian meteorites, whereas Kotler (4054) illustrated the usefulness of using laser desorption fourier transform mass spectrometry to search for astrobiology relevant materials on the martian surface.

SULFATES AS RECORDERS OF MARS NEAR SURFACE PROCESSES AND THE MER SITES AS FIRST SAMPLE RETURN LOCALITIES: Numerous presentations in this session emphasized the geologic record preserved in sulfates (Lueth, #4027,#4040; Burger, #4010; King, #4017; Hyde, #4042). Many of these presentations focused upon the environment of precipitation and history of water revealed by sulfates (conditions of precipitation, history and geochemistry of water, groundwater-atmosphere interactions). Mittlefehldt (#4031) and Morris (#4048) illustrated the wealth of science that could be extracted from the MER sites with a sample return mission to these previously visited sites. This is an overall approach that would address the problem of placing samples within a geologic context defined by both orbital and surface exploration. Dave Vaniman (#4025) provide detailed insights into the stability of sulfates, sulfate-clay interactions and the caution needed in collecting and storing samples to minimize science loss. Finally, Mike Zolensky (#4007) demonstrated the range of science that could be accomplished using microbeam analytical approaches for the study of martian dust. These techniques can been used to look for microfossils in the martian dust.

UNDERSTANDING THE EVOLUTION OF MARS' CORE, MANTLE, CRUST, SURFACE, ATMOSPHERE: This afternoon session focused on much broader themes than the previous sessions. One of the invited speakers, John Valley illustrated the usefulness of microbeam stable and radiogenic isotopic analysis to analyze the geological record preserved in individual mineral grains. He illustrated the usefulness in two examples: analysis of carbonates in ALH 84001 and analysis of some of the oldest terrestrial zircons. A follow on presentation by Jim Greenwood further illustrated the use of microbeam analyses to look for the record of reservoirs of water in phosphates in martian meteorites. In addition to microbeam approaches for analyzing stable isotopes, James Farquhar (#4057) illustrated the broad array of information about the martian atmosphere, reaction pathways for the precipitation of sulfates, temperatures of weathering processes, and fingerprints for life that can be extracted from returned samples using a battery of stable isotope systems. Don Bogard (#4003) and Larry Nyquist (#4014) illustrated the importance of sample return in establishing the martian chronology. Further, they illustrated the undesirable approach of in situ dating on the martian surface. Draper (#4021) gave examples of how experimental studies on returned samples could be used to understand the early differentiation of Mars. This is particularly powerful approach when used in conjunction with isotopic and geochemical measurements. Measurement of cosmogenic nuclides can only be done in terrestrial labs and these measurements could potentially answer questions such as crater ages, erosion rates, and rates of deposition (Nishiizumi. #4028). Ballentine (#4044) illustrated that noble gas measurements on returned samples are critical to understanding the nature and evolution of different reservoirs on Mars and critical for establishing a martian chronology. Samples returned from Mars can also be utilized to measure geophysical properties and to than be used to reconstruct the history of the martian magnetic field and the martian core (Weiss, #4024). Collection of a diverse sample suite may be obtained through the sampling terrain excavated by recent impacts (Swindle, #4029). Dimitri Papanastassiou (#4009) concluded from his comparison between past sample return from the Moon and a potential future Mars sample return that we are missing the complexity of that exists in martian samples by in situ analysis on the surface of Mars. Substantially more insight into these complexities will be reached in terrestrial labs.

HYDROUS MINERALS AS RECORDERS OF FLUID-ATMOSPHERIC EVOLUTION AND SECONDARY ALTERATION: This session focused on hydrous minerals from the point of view of their geological occurrence on Mars and the geological record preserved in clays based on terrestrial and experimental studies. Mustard (#4038), Milliken (#4013), and Michalski (4018) reviewed the planetary distribution of hydrated silicates on Mars, their composition, and potential environments of formation. Bish (#4022) illustrated that clay composition and mineral assemblage could be used to reconstruct the environment under which it formed and to date the clay-forming event. Further, he illustrated that science lost from a clay response to changing in its environment during sampling and storage was incremental and that careful scrutiny must be used to evaluate the balance between science loss and the cost of preservation. Velbel (#4019) further illustrated the importance of clay mineral composition and textures during alteration in terrestrial environments, the protection required to protect delicate textures, and application to understanding alteration conditions on Mars. Muttik (#4013) demonstrated the nature of clay mineralogy associated with impact induced hydrothermal systems. Results of experimental studies presented by Rietmeijer (#4008) illustrated potential processes not considered above that could lead to the formation of ferric iron-rich sheet silicates.

POSTER SESSION: The poster session contained an exceedingly wide range of sample return relevant topics from sample return strategies to instruments on sample return missions to examples of fundamental science extracted from martian meteorites. Presentations by Zacny (#4001), Karcz (#4059), Jones (#4020), and Wiens (#4032) demonstrated new analytical or sampling technologies that would enable sample return. These include sample caching on MSL, LIBS instrumentation to select sample stations from a distance and thereby reduce roving time, sampling from orbit, and sampling-handling technologies. Newsom (#4041) discussed the attributes of sampling a previously visited site for MSR, while Rampe (#4034) suggested the northern plains are an important target for sample return. Ashley (#4046) and Thomson (#4043) explored the rationale for the collection of meteorites on the martian surface. Kashiv (#4055), Walker (#4015) and Spivak-Birndorf (#4050) illustrated the usefulness of cosmogenic radioisotopes, siderophile elements, and boron isotopes for interpretating of interior and surface processes on Mars.

Observations of the conference discussions by the conveners
There were several overarching points reached from presentations and discussions during this workshop:

- The presentations at the workshop showed that a wonderful variety of compelling scientific objectives is possible via Mars sample return.

- In many cases, the different possible sample-related scientific objectives discussed at the conference require different kinds of samples, and/or samples from different geologic setting. Difficult choices will need to be made regarding which questions we choose to answer with the first MSR, and which to defer. Thus, for the first MSR mission it will be imperative to consider carefully 1). The choice of the landing site, and 2). The nature of the sample selection and the surface operations (especially mobility and stay time) capabilities.
- There is a large untapped reservoir of sample scientists with a wide range in background (i.e. terrestrial) that are poised to participate in and contribute to MSR.
- Within the sample analysis community, the use of analytical technology to extract more information from samples continues to improve. Part of the power of MSR is that it will take advantage of this tidal wave of development that is happening in many associated fields. Therefore, the best instruments will be used to analyze returned samples, not the best available at the end of mission design reviews and the measurements can be modified as logic and technology dictate over extend periods of time following the mission.
- There was an increased realization that important samples from the surface of Mars may be both fragile and reactive. The strategy for sample collection, storage, preservation, curation, and allocation must be deliberated in exacting detail.
- Conference participants discussed a spectrum of possible MSR missions ranging from options that are relatively simple (with a focused and limited set of science goals) to relatively complex (with a much broader set of science goals).
- There were no presentations at the conference relating to mission cost or potential budget availability. However, there was quite a bit of unconstrained discussion about how to strike the right balance between relatively simple and relatively complex versions of MSR.

10.2 APPENDIX II

Outline of Sessions

Monday, April 21, 2008
ENABLING SAMPLE RETURN: PRIORITIES, MISSIONS, AND STRATEGIES
8:00 a.m. Alvarado ABC

Chairs: D. W. Ming
A. H. Treiman

Welcome and Introduction

MEPAG ND-SAG Team *
Possible Science Priorities for Mars Sample Return **[#4037]**

Murchie S. * McEwen A. Christensen P. Mustard J. Bibring J.-P. [INVITED]
Discovery of Diverse Martian Aqueous Deposits from Orbital Remote Sensing **[#4035]**

Bibring J.-P. * [INVITED]
OMEGA/Mars Express Feed Forward to MSR **[#4061]**

Ming D. W. * [INVITED]
2003 Mars Exploration Rover Mission: Robotic Field Geologists for a Mars Sample Return Mission **[#4047]**

Crisp J. A. * Grotzinger J. P. Vasavada A. R. Karcz J. S. MSL Science Team [INVITED]
Mars Science Laboratory: Science Overview **[#4016]**

Karcz J. S. * Beaty D. W. Conley C. A. Crisp J. A. Des Marais D. J. Grotzinger J. P. Lemke L. G. McKay C. P. Squyres S. W. Stoker C. R. Treiman A. H.
Science Definition of the Mars Science Laboratory Sample Cache **[#4058]**

Shearer C. K. * Borg L. E. Treiman A. King P.
If We Already have Samples from Mars, Why Do We Need Sample Return Missions? The importance of Martian Meteorites and the Value of Mars Sample Return **[#4004]**

Neal C. R. *
Mars Sample Return: Which Samples and Why **[#4026]**

Jones J. H. *
Mars Sample Seturn: 20+ Years After the First Mars Sample Return Workshop **[#4002]**

Hausrath E. M. * Navarre-Sitchler A. K. Moore J. Sak P. B. Brantley S. L. Golden D. C. Sutter B. Schröder C. Socki R. Morris R. V. Ming D. W.
Mars Sample Return: The Value of Depth Profiles **[#4039]**

Monday, April 21, 2008
OVERALL THEME: SAMPLE REQUIREMENTS FROM THE ASTROBIOLOGY POINT OF VIEW
1:30 p.m. Alvarado ABC

Chairs: C. P. McKay
G. J. MacPherson

Steele A. * [INVITED]
Talk Development of Procedures and Protocols for the Collection and Characterization of Martian Samples. Experience from the Field and Lab

McKay C. P. * [INVITED]
Astrobiology with a Groundbreaker Sample Return Mission **[#4033]**

Kraft M. D. * Rampe E. B. Sharp T. G.
The Biological Potential of the Northern Plains for Mars Sample Return **[#4049]**

Boston P. J. * Spilde M. N. Northup D. E. Todd P.
Extremophile Microorganism Communities in Sulfates and Other Sulfur Minerals a Sample Return Target Materials **[#4053]**

Allen C. C. * Oehler D. Z.
Sample Return from Ancient Hydrothermal Springs **[#4011]**

Kotler J. M. * Hinman N. W. Richardson C. D. McJunkin T. Scott J. R.
Geochemistry and Astrobiology Science Payoff Using Laser Desorption Fourier Transform Mass Spectrometry (LD-FTMS) Techniques for Mars Sample Return **[#4054]**

Spilde M. N. * Boston P. J. Northup D. E. Odenbach K. J.
Rock Coatings: Potential Biogenic Indicators **[#4045]**

Grady M. M. * Pearson V. K. Gilmour I. Gilmour M. A. Verchovsky A. B. Watson J. Wright I. P.
Identification (or Otherwise) of Martian Carbon in Martian Meteorites **[#4062]**

Conley C. A. * [INVITED]
Planetary Protection Considerations for Mars Sample Return **[#4060]**

Monday, April 21, 2008
POSTER SESSION
6:00 – 8:00 p.m. Alvarado D

Chairs: C. K. Shearer
C. B. Agee

MEPAG ND-SAG Team
Possible Science Priorities for Mars Sample Return **[#4037]**

Karcz J. S. Cappuccio M. Demo A. G. Eisen H. J. Feldman J. Gheno K. Kruger C. E. Liu M. Reimer J. H. Santos O. Serviss O. E. Tong P. K.
The Implementation of the Mars Science Laboratory Sample Cache **[#4059]**

Jones S. M. Jurewicz A. J. G. Wiens R. Yen A. Leshin L. A.
Mars Sample Return at 6 Kilometers per Second: Practical, Low Cost, Low Risk, and Ready **[#4020]**

Thomson B. J. Bridges N. T. McCanta M. C.
Meteorites on Mars: Implications for Sample-Return Strategy **[#4043]**

Wiens R. C. Clegg S. Maurice S. ChemCam Team
ChemCam as the Instrument to Select Samples and Enable Mars Sample Return **[#4032]**

Zacny K. Paulsen G. Davis K. Mumm E. Gorevan S.
Honeybee Robotics Sample Acquisition, Transfer and Processing Technologies Enabling Sample Return Missions **[#4001]**

Kashiv Y. Paul M. Collon P.
Determining Production Rates of Cosmogenic Radioisotopes on Mars **[#4055]**

Rampe E. B. Kraft M. D. Sharp T. G.
The Importance of an Investigation of the Northern Plains **[#4034]**

Walker R. J. Puchtel I. S. Brandon A. D. Irving A. J.
Highly Siderophile Elements Abundances in SNC Meteorites: An Update **[#4015]**

Spivak-Birndorf L. J. Wadhwa M. Williams L. B.
Boron Isotopic Composition of Igneous Minerals and Secondary Alteration Products in Nakhla **[#4050]**

Ashley J. W.
Scientific Rationale for Consideration of Chemically Altered Meteorites in a Mars Sample Return Mission **[#4046]**

Newsom H. E. Lanza N. L. Ollila A. M.
Landing Site Selection for the Mars Science Laboratory and Implications for Mars Sample Return **[#4041]**

Tuesday, April 22, 2008
SULFATES AS RECORDERS OF MARS NEAR SURFACE PROCESSES AND THE MER SITES AS FIRST SAMPLE RETURN LOCALITIES
8:00 a.m. Alvarado ABC

Chairs: V. W. Lueth
J. J. Papike

Lueth V. W. * [INVITED]
Encoding of Water-Rock-Atmosphere Interactions in Jarosite: Implications for Mars **[#4040]**

Burger P. V. * Papike J. J. Shearer C. K. Karner J. M.
Interpreting Mars Surface Fluid History Using Minor and Trace Elements in Jarosite: An Example from Post Pit, Nevada **[#4010]**

King P. L. * Lane M. D. Hyde B. C. Dyar M. D. Bishop J. L.
Fe-Sulfates on Mars: Considerations for Martian Environmental Conditions, Mars Sample Return and Hazards **[#4017]**

Hyde B. C. * King P. L. Spilde M. N. Ali A.-M. S.
Characterization of Fe-Sulfate Minerals: Preparation for Mars Sample Return **[#4042]**

Lueth V. W. Campbell A. R. Papike J. J.
Stable Isotope Characterization of a Terrestrial Kieserite with Comparisons to Other Sulfate Minerals **[#4027]**

Zolensky M. E. * Nakamura-Messenger K.
What Can You Do with a Returned Sample of Martian Dust? **[#4007]**

Vaniman D. T. * Bish D. L. Chipera S. J.
Salt-Hydrate Stabilities and Mars Sample Return Missions **[#4025]**

Mittlefehldt D. W. * [INVITED]
Mars Sample Return from Meridiani Planum **[#4031]**

Morris R. V. * [INVITED]
What We Might Know About Gusev Crater if the Mars Exploration Rover Spirit Mission were Coupled with a Mars Sample Return Mission **[#4048]**

Tuesday, April 22, 2008
OVERALL THEME: UNDERSTANDING THE EVOLUTION OF MARS' CORE, MANTLE, CRUST, SURFACE, ATMOSPHERE
1:30 p.m. Alvarado ABC

Chairs: J. Farquhar
D. A. Papanastassiou

Valley J. W. * Ushikubo T. Kita N. T. [INVITED]
Two Generations of Carbonate in ALH 84001: Three Oxygen Isotopes and OH **[#4023]**

Greenwood J. P. *
Evolution of Water on Mars: Mars Sample Return Considerations for Hydrogen Isotope Measurements **[#4030]**

Farquhar J. *
Mars Sample Return: Stable Isotope Targets with Return Samples **[#4057]**

Bogard D. D. * [INVITED]
Martian Chronology and Atmospheric Composition: In Situ Measurements Versus Sample Return **[#4003]**

Nyquist L. E. * Shih C.-Y. Reese Y. D. [INVITED]
Prospects for Chronological Studies of Martian Rocks and Soils **[#4014]**

Swindle T. D. * Tornabene L. L. McEwen A. S. Plescia J. B.
Using Recent Impact Craters as a Sampling Mechanism for a Mars Sample Return Mission **[#4029]**

Papanastassiou D. A. *
Why an "Early" Mars Sample Return: Lessons from Apollo **[#4009]**

Draper D. S. * Agee C. B.
Fundamental Importance of Returned Samples to Understanding the Martian Interior **[#4021]**

Nishiizumi K. * Caffee M. W. Herzog G. F. Reedy R. C.
Measurements of Cosmogenic Nuclides In and Their Significance for Samples Returned from Mars **[#4028]**

Ballentine C. J. Burgess R. Edwards S. Gilmour J. D. *
Science Payoff from Noble Gas and Associated Halogen Analysis: Towards a Sample Wish List **[#4044]**

Weiss B. P. * Garrick-Bethell I. Kirschvink J. L.
Magnetic Studies of Returned Samples from Mars **[#4024]**

Wednesday, April 23, 2008
OVERALL THEME: HYDROUS MINERALS AS RECORDERS OF FLUID-ATMOSPHERIC EVOLUTION AND SECONDARY ALTERATION
8:00 a.m. Alvarado ABC

Chairs: D. L. Bish
D. T. Vaniman

Bish D. L. * Vaniman D. T.
Clay Mineralogy as a Guide to Alteration Environments on Mars **[#4022]**

Mustard J. F. * Murchie S. L. Ehlmann B. Milliken R. E. Bibring J.-P. Poulet F. Bishop J. Noe Dobrea E. Roach L. Seelos F. McKeown N. K.
Hydrated Silicate Minerals and Their Geologic Environments from Oribt **[#4038]**

Milliken R. E. * Mustard J. F. Ehlmann B. Bishop J. L. Murchie S. CRISM Science Team [INVITED]
Interpreting and Constraining the Composition and Depositional Environments of Phyllosilicates on Mars **[#4036]**

Michalski J. R. * Bibring J.-P. Poulet F. Fergason R. Mangold N. Loizeau D. Noe Dobrea E. Bishop J. L. [INVITED]
Clay-bearing Rocks in the Mawrth Vallis Region, Mars **[#4018]**

Muttik N. * Kirsimäe K. Somelar P.
Clay Minerals Formation in Impact Induced Hydrothermal Systems: Source of Hydrous Phases on Mars **[#4013]**

Noe Dobrea E. Z. * Bishop J. L. McKeown N. K. Swayze G. Michalski J. R. Poulet F. Bibring J.-P. Mustard J. F. Ehlmann B. L. Arvidson R. Morris R. V. Murchie S. Malaret E. Hash C. CRISM Team
Transition Between Altered and Non-Altered Minerals in Mawrth Vallis and Arabia Terra **[#4052]**

Rietmeijer F. J. M. * Thiel K.
An Experimental Study of Phyllosilicate Modification in Comets During Perihelion Could be Relevant to Ferric Iron-rich Layer Silicate Formation at the Martian Surface **[#4008]**

Velbel M. A. *
Clay Minerals in Returned Samples and Alteration Conditions on Mars **[#4019]**

PRINT ONLY

Papike J. J. Spilde M. N. Karner J. M. Shearer C. K.
Fumaroles on Mars: Lessons Learned from the Valley of Ten Thousand Smokes, Alaska **[#4005]**

Papike J. J. Burger P. V. Karner J. M. Shearer C. K.
Martian Sulfates: Gypsum Crystal Chemistry and Characterization of Two Terrestrial Analogs **[#4006]**

Clark B. C.
Affordable MSR: Constraining Requirements on Sampling and Sample Preservation **[#4051]**

Recommended bibliographic citation:

Shearer, C., Beaty, D. and Agee, C. (2008) **WORKSHOP REPORT GROUND TRUTH FROM MARS: SCIENCE PAYOFF FROM A SAMPLE RETURN MISSION.** Unpublished workshop report, 11 p, posted June 2008 by the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) at http://www.lpi.usra.edu/captem/.