WORKSHOP ON

MARS 2001: INTEGRATED SCIENCE IN PREPARATION FOR SAMPLE RETURN AND HUMAN EXPLORATION

October 2–4, 1999
Lunar and Planetary Institute, Houston, Texas

Edited by
John Marshall and Cathy Weitz

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PREFACE

The Workshop on Mars 2001: Integrated Science in Preparation for Sample Return and Human Exploration was held on October 2–4, 1999, at the Lunar and Planetary Institute in Houston, Texas. The workshop was sponsored by the Lunar and Planetary Institute, the Mars Program Office of the Jet Propulsion Laboratory, and the National Aeronautics and Space Administration. Scientific conveners for the workshop were John Marshall (*SETI Institute/NASA Ames Research Center*), Cathy Weitz (*Jet Propulsion Laboratory*), and Stephen Saunders (*Jet Propulsion Laboratory*). The three-day meeting was attended by 133 scientists whose purpose was to share results from recent missions, to share plans for the 2001 mission, and to come to an agreement on a landing site for this mission.

Logistical, administrative, and publications support were provided by the Publications and Program Services Department of the Lunar and Planetary Institute.

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WORKSHOP SUMMARY

J. Marshall, C. Weitz, S. Saunders, and T. Thompson

MISSION OVERVIEW

The Mars Surveyor Program 2001 mission consists of a Lander, a lander-deployed Rover (Marie Curie), and an Orbiter. It is the first Mars mission to carry a payload integrating planetary/astrobiology science with investigations for the Human Exploration and Development of Space (HEDS) Enterprise. The mission will be a precursor to the sample collection and return missions in 2003 and 2005, while simultaneously spearheading investigations of environmental hazards in preparation for human exploration early in the twenty-first century.

Launch of the Orbiter is scheduled for March 30, 2001; the Orbiter will arrive at Mars on October 20, 2001. After a propulsive maneuver into a 25-hour capture orbit, aerobraking will be used over the next 76 days to achieve the 2-hour science orbit. The Orbiter will carry three science instruments: a Thermal Emission Imaging System (THEMIS), a Gamma Ray Spectrometer (GRS), and a Mars Radiation Environment Experiment (MARIE). THEMIS and GRS will characterize global geology, while MARIE will investigate radiation hazards for future human explorers. The 2001 Orbiter will also support communications for the Lander.

The 2001 Lander is scheduled to launch on April 10, 2001, and land on Mars on January 22, 2002. The Lander will carry an imager (MARDI) for visualizing the descent of the platform. These pictures will provide the context of the surrounding terrain and will aid planning for operations by the rover. The Lander carries an integrated suite of instruments — APEX (ATHENA precursor experiment) — that will characterize the surrounding geology using IR spectroscopy (MiniTES), panoramic imaging (Pancam), and a Mössbauer instrument for iron mineralogy. The rover will carry cameras and the APXS for elemental analyses. Analyses of rocks and soils will be conducted with these instruments using remote sensing from the Lander, direct sensing from the Rover, and direct sensing from the Lander's Robotic Arm (RA).

The RA is a mission facility instrument that will attempt to dig a trench down to 50 cm. Excavated samples will be imaged by a Robot Arm Camera (RAC) and further scrutinized by the Mars Environmental Compatibility Assessment (MECA) experiment using optical microscopy, atomic force microscopy (AFM), wet chemistry, electrometry, and materials testing with internal and external arrays of engineering samples. Samples will be assessed for potential hazards to human exploration; samples analyzed by MECA will also be analyzed by the APEX instrument suite.

HEDS payloads Mars Radiation Environment Experiment (MARIE), which will assess surface radiation hazards, and the Mars In Situ Propellant-Production Precursor (MIP) are also carried by the Lander. The latter is actually five distinct experiments that test propellant production, collect data on the thermal and radiation characteristics of the environment, and investigate solar cell materials, including dust repulsion from cell surfaces.

MSP 2001 is conducted under the auspices of Code S (Michael Meyer, Program Scientist) and Code U (Peter Ahlf) at NASA Headquarters, and is managed by the Jet Propulsion Laboratory in Pasadena (Steve Saunders, Project Scientist). Science oversight is conducted on a regular basis by the Project Science Group (PSG) led by Steve Squyres, while operational plans for science, logistics, and data archiving are guided by the Science Operations Working Group (SOWG) led by Ray Arvidson.

WORKSHOP GOALS

The purpose of the MSP 2001 Workshop was primarily to introduce the mission to the science community. This would be the first "end-to-end" exposition for the mission, and its timeliness was made possible by four factors. First, by the fall of 1999, all the scientific payloads were fully defined, and were materializing in the form of deliverable flight hardware. Second, planning activities conducted by the Science Operations Working Group (SOWG) had reached significant maturity in defining the first critical 21 sols of scientific activities, with science "campaigns" and strategies loosely defined for the full 90 sol plan. Third, the Landing Site Selection Committee had downsized the number of site options to a manageable number, and a final thrust of activity could bring closure to the selection process. Last, at the time planned for the workshop, NASA Headquarters would be in a position to release information about the mission's Participating Scientist Program.

During 1999, the mission underwent significant redefinition, and the workshop would provide an opportunity for those directly involved in the mission to be reintroduced to Surveyor 2001 in its matured format. However, the primary goal of the workshop was to expose the mission's science objectives, investigative approaches, and technical capabilities to the science community residing both inside and outside NASA. In reciprocation, the workshop offered a forum via presentations and posters for the community to present the latest ideas about Mars, and ideas about the best places on Mars to go looking for answers. This input from the science community would be invaluable to the mission science teams who would be exposed to current thinking and discoveries derived from Pathfinder and Mars Global Surveyor (MGS). The two-year cycle for the MSP Program, and the ongoing analysis of Pathfinder and MGS data, have made it inherently difficult to analyze, digest, and disseminate data in a timely fashion so as to provide maximum benefit to the next mission(s) in the queue. Many of the scientists analyzing recent data were generally not involved directly with the 2001 mission, so this would be an excellent opportunity for the payload teams to finely tune their science goals and instrument responses in line with the latest knowledge available.

In addition to the community's input to the mission, the workshop was to provide a forum for the MSP Project at JPL and the MSP Program at NASA Headquarters to frame the scientific goals of the 2001 mission into the broad picture of NASA's Mars Exploration Program. How the mission interfaces with previous and future missions would also be presented. Headquarters would announce the goals of the Participating Scientist Program (PSP), which will enable the science community to become directly involved in 2001. The PSP increases the scope and depth of mission science, and was being positively anticipated by the payload teams as a means of expanding their scientific capabilities. It was intended that the "nonmission" science community would be able to make better-informed decisions about responding to the PSP after hearing about the mission's goals and capabilities.

An important objective of the workshop was to showcase the fact that the mission had greater scientific depth that many realized, and that it had now become a highly integrated mission between planetary and HEDS science. It would be shown how there were synergistic relationships not only between the science disciplines, but also between orbital and surface science, and between facility-scale activities such as rover traversing and trench excavation.

Site-selection activities for 2001 had a catalog of approximately sixty landing site possibilities expressed at the Buffalo meeting in June of 1999. By October, the time of this workshop, the number had been reduced to four (see discussion below). A prime goal of the workshop would be to reduce this number even further. The workshop would also provide a forum for the science community to observe the actual process by which the sites became downselected.

WORKSHOP HIGHLIGHTS

- The workshop brought together under one roof all the diverse groups associated with the mission, namely, the science community, the mission payload teams, program management, organizational groups (PSG and SOWG members), JPL Project members, the Site Selection Committee, and representatives of the highly successful Pathfinder and MGS missions. Many of these groups had not previously interacted within an overall mission framework. Notably, the workshop provided a forum for interactions between planetary and HEDS communities, and in the spirit of the mission, it often became difficult to distinguish between them.

- Fourteen oral presentations described the payloads, with explanations of science objectives, investigative strategies, and technical design and capability of instruments. The range of instruments described indicated that 2001 is indeed a very complex and capable suite of science investigations.

- Ray Arvidson described how the mission was organized scientifically and logistically. The activities of the SOWG are focused on science "campaigns" that cut across boundaries between planetary and human exploration science to produce a truly integrated approach to the mission's objectives. A classic example is the use of the robot arm as a mission facility that will excavate soil samples down to 50 cm; by combining the resources of APEX, RAC, and MECA, some soil samples will be analyzed by no fewer than ten instruments. Very few terrestrial field samples receive as much analytical attention! The workshop also showed how orbital science and surface science were tied together.

- Steve Saunders (JPL Project Scientist), Michael Meyer (HQ Program Scientist), and Alex Pline (representing HQ HEDS interests) provided overviews of planetary and HEDS scientific goals for the mission. Steve Saunders noted that 2001 complements past (Viking, Pathfinder) and future (03/05) missions. Ken Nealson additionally described plans for 2003 and 2005 and highlighted the problems of scientifically controlling the recognition and preservation of microbial guests on either outgoing or return flights. Dave Spencer gave an overview of the mission architecture — the technical details of safely delivering 2001 to the surface of Mars. The overviews noted that 2001 was meeting the broad MSP goals of seeking evidence for water activity on Mars, while simultaneously assessing the compatibility of the environment with human occupation.

• Michael Meyer described the Participating Scientist Program (a preliminary version of the program was released at the workshop). It was generally agreed by workshop participants that the selection of participating scientists should be done at the earliest opportunity, even though the financial resources had not been guaranteed for the program at the time of the workshop. Participating scientists will be selected through an NRA planned for release on November 15, 1999, proposals being due February 15, 2000.

• Twenty oral presentations and seven posters were given on Mars science issues: the types of data that should be sought, the landing sites that should be considered, and methods of optimizing the analysis of returned data. Additionally, four talks were given on the results of the Pathfinder mission and the latest data from MGS. The camera MGS (MOC) data provided a new perspective on the complex geomorphology of Mars, while the IR mapping (TES) provided high definition of the hematite region, which would be a strong candidate for a landing site.

• The number of landing sites was successfully downsized to a prime site and a secondary "backup" site (see following section). In addition to a full day for site selection discussion, two *ad hoc* evening sessions were scheduled. The workshop culminated in a consensus choice of Isidis Rim as the prime site. Part of the selection involved a formalized process in which working groups defined the top success criteria for five major mission science areas and evaluated them with respect to the choices of Isidis Rim and the hematite region, sites that were chosen from the *ad hoc* evening sessions. The selection process will now meet the landing site selection timeline.

All the topics mentioned in this summary can be found in expanded form within the abstracts of this volume, or within the detailed site selection discussion that follows. The workshop was an intensive three days, but highly productive. We thank all attendees for their wisdom and enthusiasm, and not least for devoting their weekend to the cause of MSP 2001. We also thank the Lunar and Planetary Institute for its hospitality and the Institute's staff for creating an efficient and smooth operation.

LANDING SITE DOWNSELECTION SUMMARY

M. Golombek, G. McGill, C. Weitz, S. Saunders, and J. Marshall

PRE-WORKSHOP RESULTS

A Mars Surveyor '01 Landing Site Workshop was held at the State University of New York at Buffalo June 22–23, 1999. This workshop was open to the science community and had sessions on the general project science and constraints, new MGS results, general landing site considerations, and specific proposed candidate landing sites. About 60 candidate landing sites were proposed at the workshop. Most of the sites proposed met the engineering and remote sensing criteria. These sites are located in the highlands (0°–40°W), Valles Marineris, Memnonia, Aeolis, Elysium, Terra Cimmeria, Isidis, and Sinus Sabaeus. Unavailable prior to the workshop for most proposed sites were the new MOC high-resolution images. Because of the importance of these data in interpreting the meter-scale hazards at potential landing sites and the inverse correlation between smoothness in Viking-scale (hundreds of meters per pixel) and MOC-scale (meters per pixel) images, no attempt was made at the workshop to downselect the number of sites under consideration.

Following the Buffalo workshop, there were two other significant meetings. Immediately after the workshop, Steve Squyres met with the APEX team and discussed the community input expressed at the workshop and summarized their preferences based primarily on payload capabilities and science. Subsequently, the Project Scientist sent out a Dear Colleague letter to the community dated July 1, 1999, that outlined a strawman site selection policy. The Mars Surveyor 2001 Project Science Group then endorsed the policy, which is based on the capabilities of the Mars '01 lander, its payload, and on the scientific objectives of the Mars Surveyor Program. In summary: (1) The Mars 2001 Landing Site Workshop demonstrated that many scientifically exciting landing sites can be found that are consistent with the mission's engineering constraints. (2) The Mars '01 lander payload is excellent for studying soils. Soils can be found virtually anywhere on Mars, and provide substantial new science. Given this, safety is therefore the first priority (needless to say, safe landing is required to do any new science). (3) After the discussions at the workshop, and further discussions with the '01 investigator team, it was concluded that the best new science is likely to come from landing within ancient highland crustal materials. (4) With the above scientific constraints (and within the engineering constraints), the final site should be chosen so as to (a) maximize total mission duration; (b) maximize rock abundance; (c) maximize large-scale topography in the visible distance, particularly if it exposes stratigraphy; (d) maximize the chances of finding aqueous minerals; and (e) consider potential for future human/outpost base site. Given the present thermal and power constraints on the MS '01 lander, the desire to maximize total mission duration (4a) places preferred landing sites near the northern end of the latitude band (within a few degrees of the equator). As the lander mission progresses, insolation at the southern end of the latitude band decreases owing to seasonal effects, which shortens the length of daily operations and may end the mission prematurely. In addition, early in the mission, warm conditions at the southern latitudes also have the potential to shorten daily operations. Near the equator longer "sols" (7 hr) of operation are possible, and seasonal effects are minimized.

Within these guidelines the "hematite" site would not be favored; it is rough at fine scales and the science that could be addressed there is narrowly focused. Most "lakebed" and "hydrothermal" sites would not be favored because the '01 vehicle's limited mobility would make it difficult to achieve the most important goals at such sites, which would involve searching for particular sedimentary or hydrothermal materials or deposits. It was also suggested that sites on the floor of the Valles Marineris should be kept under consideration if possible.

A subset of the steering committee and project personnel met at Malin Space Science Systems on July 30 and September 3, 1999, to look at MOC images of potential '01 landing sites. All the sites presented at the Buffalo meeting as well as those proposed afterwards (including those that the APEX team submitted) were reviewed at these times. Roughly three-fourths of the sites proposed had some MOC coverage at the time of our survey. The results of the survey are as follows: (1) Most of Mars within the equatorial band of interest appears rough and unsuitable for landing in MOC images. (2) There are acceptable dissected (by valley networks) highland sites south of the dichotomy boundary in the Amenthes highlands region. (3) A few good sites were identified in highland materials in the Isidis Rim. (4) Safe highland sites appear in Northeast Meridiani, just west of the crater Schiaparelli. (5) There are no safe landing sites within Valles Marineris (except perhaps part of Ganges Chasma). Melas and Coprates Chasma all look very rough at MOC 3-m/pixel resolution. Valles Marineris Outflow sites appear hazardous and rocky from imaging, thermal inertia, and Earth analogs. (6) A former crater lake, "Hesperia Paleolake," was retained as a lake site (2.5S, 249W). (7) Anomaly sites were rejected either because they were too rough (e.g., Hematite) or because the science objectives did not match the capabilities of the science payload (e.g., magnetic anomaly site).

Based on this survey, the top sites were narrowed down to the following:

1. *Isidis Rim*: 3°N–1°S, 270°–280°W. This area is ancient Noachian material uplifted by the Isidis impact. Massifs of ancient uplifted material are a few kilometers above the plains, allowing the opportunity of landing nearby, providing significant topographic relief to be viewed by the lander. This combination of ancient crustal materials, significant topographic relief, safe-looking plains in MOC images, valley networks dissecting the plains materials, and location toward the north of the latitude band make this area the highest priority.

2. *Amenthes Highlands*: 3°N–1°S, 238°–248°W. This area provides ancient heavily cratered terrain dissected by valley networks, but without the topographic relief of the Isidis Rim. It is near the northern edge of the latitude band and smooth areas have been imaged by MOC.

3. *Northeast Meridiani*: 0°–4°S, 349.7°–350.7°W. This area of Noachian highlands with significant albedo contrast appears unusually smooth and safe in MOC images (similar to the Ganges sand shee but not as far south).

4. *Hesperia Paleolake*: 2.2°–3.2°S, 248.5°–249.7°W. A smooth (in Viking images) flat floored crater with a channel draining into and out of it.

WORKSHOP DISCUSSIONS

Two landing site evening splinter meetings occurred during the workshop to discuss the downselection process and the science of the top candidate landing sites. A concern raised at these meetings was whether the 2001 landing site should be selected to help maximize the return from the upcoming 03/05 missions. No consensus was reached on this issue, however. Another concern of most of the participants was the ability to infer slopes and roughnesses from the MOC images. Much work on this problem must be done to verify that surfaces in MOC images that LOOK dangerous really are and, more important, surfaces that LOOK safe really are. Everyone agreed that the more northerly sites should be favored due to the longer mission duration possible for sites centered at the equator.

A description of the five sites that were evaluated during the evening sessions and the pros and cons of each are listed below.

Isidis Rim: This is a large zone with multiple possible landing ellipses (an image of the zone with possible ellipses superposed was prepared by Tim Parker and available during the discussion). Its great advantage is that it has the potential to address a number of important science questions, while at the same time satisfying site constraints for the HEDS instruments. Specific characteristics of scientific relevance include:

1. The zone is located on the rim of a Noachian (probably early Noachian) impact basin (Isidis Basin), and thus there is an excellent chance that Noachian rocks will be sampled.

2. There is clear morphologic evidence for the past presence of water in the form of networks of small channels or valleys. This is a fundamental requirement for exobiology objectives.

3. Because the Isidis impact would have excavated rocks from significant depth, there is a chance that deep crustal or mantle rocks will be present.

4. This site is higher than all putative northern lowland shorelines, whereas both Viking sites and the Pathfinder site are within the lowest shoreline. If the northern ocean(s) existed, it is possible that the chemistry and mineralogy of the soil will be different for sites that were and were not flooded by the ocean(s).

5. This site is in the area where TES data seem to require that feldspar be more common than pyroxene, a result in apparent conflict with liquid descent models based on melts that could produce SNC meteorites and anorogenic andesites (Rutherford). Thus the Isidis Rim may expose ancient rocks that either have been altered in some unknown way to mask pyroxene, or else expose ancient rocks derived from the cryptic high-alumina layer predicted by Rutherford's model.

6. The scenery should be spectacular because the landing ellipses are all in plains areas that lie between the massifs that make up the Isidis basin rim. This is of obvious PR value, but the side view of the rocks in these massifs may well provide data of scientific importance as well.

The only significant weakness is that MOC images indicate that many of the landing ellipses selected on the basis of apparent smoothness on Viking images are in areas with rather ominous appearing meter-scale roughness.

Hematite: As pointed out by Steve Squyres, the instrument payload is ideally suited for characterizing this site, in large part because of the Mössbauer spectrometer. The site is of great potential interest because of the expectation that the high content of crystalline hematite implies the presence of water in general, and possibly hydrothermal water in particular. The high hematite values correspond with a mappable geomorphic/geologic unit visible on Viking Orbiter images. This correspondence between geology and mineralogy is uncommon. This, in turn, raised the question of why this correspondence exists here but apparently nowhere else (so far, anyway). In particular, does it imply that the surface is completely stripped of dust (an undesirable characteristic for the HEDS objectives)? In general it was believed that a total absence of dust is highly unlikely. However, it is not clear if the high hematite content is associated with a young layer superposed on surrounding older highland crust, or if the high hematite content is associated with an older layer that has been exposed by localized erosion. Thus possible scientific strengths include:

1. Probable involvement of water in the formation of the hematite.

2. The possibility of preservation of microfossils, by analogy with banded iron formations (BIF) on Earth.

3. Site uniqueness: If we do not go here in 01, we probably will not do so in the foreseeable future (a fundamental rule of field geology is that most collected and returned samples should be representative of the most abundant rocks and soils, not of oddities; thus a sample-return mission is not likely to be targeted to the hematite site).

4. MOC images of the western part of the hematite site show a surface that looks very safe. Thus this site could be considered as a safe backup if one is needed.

Some weaknesses pointed out by participants included:

1. Site uniqueness: Not representative.

2. Other than the hematite itself, we do not yet have a clear set of scientific justifications for picking this site (this could change with time, however). A good story needs to be assembled, comparable to what we have for the Isidis Rim.

3. The smooth, safe surface may mean few rocks, and it almost certainly implies no scenery.

NE Meridiani: The site has surfaces that are generally smooth on MOC images. The bright terrain is interesting and not really understood; it is smooth, whereas in most places on Mars bright terrain is rough. This site provides an opportunity to visit an area with low albedo (past landing sites have been in areas with higher albedo). The rocks may well be different. The general feeling was that this site would satisfy the need for a safe backup if safety becomes the only issue of importance. However, the group felt that the hematite site would be a more interesting safe backup than this one.

Amenthes Highlands: Although in an area likely to contain Noachian rocks, this site does not provide the variety of the Isidis rim. In addition, it is marginally too dusty.

Hesperia Paleolake: This is a very interesting site where it appears as if a lake was once present within an old impact crater. Scientifically interesting characteristics include:

1. Low, presumably erosional, scarps within the crater lake basin that can be reasonably interpreted as eroded lake beds, assuming that the lake hypothesis is valid.

2. At least one post-lake impact crater with fresh-looking ejecta, and thus samples of the underlying putative lake beds could be available.

3. An impact crater just outside the crater rim that has emplaced ejecta from the surrounding Noachian terrain into the crater (not clear, however, if this occurred before or after the lake deposits were emplaced).

4. Interesting scenery (crater walls, ejecta blanket edge, intra-basin scarps).

Problems include:

1. The relatively abundant MOC coverage shows a very rough surface.

2. Because of the presence of low scarps, it is possible to fit only one landing ellipse within the crater, and this is in an area with no MOC coverage.

3. 2001 roving capability will not permit visiting any of the scarps or the apparently fresh crater ejecta because these features cannot be within the landing ellipse. This constraint may well eliminate this site from consideration in 03 and 05 as well unless landing ellipses are shrunk sufficiently to allow roving beyond their limits.

WORKSHOP RESULTS

At the conclusion of these evening discussions, it was mutually agreed to carry two areas forward for further evaluation and study: **Isidis Rim** and **Hematite**. The NE Meridiani site was recommended as a distant third, to be used only if a super-safe site is required and if the Hematite site does not satisfy this need. The coordinates of the Isidis Rim area are 3°N–1°S, 270°–280°W and those for the Hematitie site are 0°–3°S, 2°–7°W.

On Monday morning participants broke up into five subgroups based on the scientific themes of the mission: (1) rocks; (2) dust, soils, and atmosphere dynamics; (3) geology from orbit and the surface;

(4) astrobiology; and (5) HEDS payload objectives. Each subgroup evaluated the two sites in terms of their objectives.

The criteria selected for each of the five subgroups and used to evaluate the two landing sites are listed below.

I. Rocks (C. Weitz)

(1) Diversity of rock types. This was deemed the top priority because each new type of rock lithology is capable of providing new insight into the geology of Mars.

(2) Potential to access Noachian-aged rocks. The previous three landing sites on Mars are all located in the younger northern plains. Hence, the group felt that a landing site in the ancient highlands was very important. Analyses of the oldest rocks could tell us about what the composition of the earliest melts were and how they may differ from the younger rocks studied at the Pathfinder and Viking sites.

(3) High abundance of rocks. The more rocks located around the landing site, the better the opportunity to analyze different rock lithologies and ages, satisfying the first two criteria. Obviously, the group recognizes that the landing site is limited by safety considerations to a site with few rocks but the group favors a site that has the maximum rock abundance within the engineering guidelines.

(4) Bedrock exposures. Rocks that are scattered about at the landing site are difficult to interpret because we don't know if they are the result of impact, sedimentary, or volcanic processes. Hence, bedrock exposures would provide an opportunity to analyze rocks in-situ either by the rover or lander and thereby reveal the geologic context of the rocks.

(5) Vertical exposures. Vertical exposures in the distance would be a criteria because the images and spectra obtained by Pancam, RAC, and mini-TES could all be used to reveal the stratigraphy and infer the geologic history of the landing site region.

II. Dust, Soils, and Atmosphere Dynamics (R. Arvidson)

(1) Maximize soil diversity. Diversity in the soils is needed to allow studies of different soil layers, determine the geologic history and context of the site, and determine the provenance of soil particles, particularly local materials that have paleoclimatic and exobiological importance.

(2) Mission duration. The longer the mission duration, the more soil experiments that could be performed and the better the opportunity to observe atmospheric dynamics.

(3) Access to soils by the Robotic Arm. The RA should be able to dig a hole at least 50 cm deep to determine the soil properties as a function of depth.

(4) Post-depositional processes. Determining the provenance of soil particles, particularly local materials that have paleoclimatic and exobiological importance, and determining the extent to which the soils have been modified since deposition by chemical and physical processes, particularly aqueous processes.

(5) Characterizing the atmosphere and its dynamics. Characterizing the mass (water, carbon dioxide, and dust) and energy fluxes between the surface and the atmosphere over diurnal cycles as the atmospheric boundary layer shifts from stable to unstable as the night changes into day. Changes in atmospheric conditions and dust accumulation and removal associated with local (e.g., dust devils) and regional-scale processes (e.g., dust storms).

III. Geology from Orbit and the Surface (K. Herkenhoff)

(1) Unique surface features are needed to locate the lander in orbital images, to permit stereogrammetric analysis of orbital images, and to allow comparison of observations of features visible from the lander acquired from orbit and from the lander.

(2) Steep slopes will produce shadows in orbital images, allowing atmospheric scattering to be measured and modeled over the landing site. Such observations will facilitate comparisons of spectral and photometric data acquired from orbit and the lander, and will constrain atmospheric dynamics and opacity near the landing site.

(3) Geologic contrasts in the region surrounding the landing site will simplify the interpretation of the geologic history of the landing region. Contrasts in spectral, thermal, geomorphic, or color/albedo properties will help the geologic context of the landing site to be inferred.

(4) Compositional uniformity over 300-km scales may simplify the interpretation of GRS data from the 2001 Orbiter. However, no one with expertise in the analysis of GRS data was present in our working group.

IV. Astrobiology (J. Farmer)

(1) Indicators of water are central to the whole theme of the MSP missions since they form the direct bases for assessing life's potential, the ability of a planet to evolve prebiotic chemistry, and the history of the atmosphere, hydrosphere, and geothermal

aqueous emissions that are all key to the question of life on Mars.

(2) Hydrothermal sites are high priority because they are archetypal niches for life on Earth, and provide excellent preservation of chemical and biological processes.

(3) Diversity of lithologies are indicators of the maturity of crustal evolution — in general, the greater the diversity, the greater the chances of processes occurring that could assist the evolution of life.

(4) Potential for biomarker preservation is very much a function of the type of "encapsulating" lithology. Not all biologically active sites will be preserved. Hence, it is important to select areas (lithologies) that preserve the evidence.

(5) Age of deposits is desired information, in order to develop correlations between other sources of evidence regarding the hydrological and atmospheric history of the planet. Access to ancient crustal materials and sediments is preferred.

V. HEDS (J. Marshall)

(1) Ability to dig is a critical component for the whole 2001 mission. The hole itself, as well as the excavated material, will provide data on local pedological history and on the origin of sedimentary, volcanic, or impact deposits at the site. Soil physical properties are assessed by the soil behavior (mechanical and tribological), and soil compositional and component grain properties are assessed by microscopy, wet chemistry, electrometry, hardness testing, adhesion potential, spectroscopic properties (IR), elemental abundances, and iron mineralogy. Through these analytical techniques, HEDS will evaluate soil hazards as a function of depth and soil type, and planetary/astrobiology investigations will seek evidence of hydrological activity.

(2) Access to dust is important because the generally ubiquitous dust mantle on Mars is the most common source of material hazards for human (or robotic) exploration.

(3) Long duration mission is needed to enable completion of digging activity (slow, power intensive process), since this and many other activities, are delayed until rover deployment.

(4) Active dust is potentially a mission hazard, but in moderation, the movement of dust (entrained or settling) provides a means of assessing dust lofting mechanisms, entrainment thresholds, and provides the raw material for both the DART (dust removal) experiment, and the MECA (dust analysis) experiment.

(5) Representative radiation is required to assess cosmic and solar radiation hazards likely to be encountered by human explorers.

Following the working group presentations, there was a general discussion and evaluation of the landing sites. The consensus among the workshop participants was that Isidis Rim is the preferred landing site and the Hematite site should be considered as a backup site. However, the Astrobiology Group noted that while the Isidis Rim region provides a much clearer opportunity to sample a broad range of ancient (Noachian-aged) crustal materials, the potential for biomarker preservation in the ancient fluvial sediments at that site, as well as the access to aqueously deposited materials, was far less certain owing to rigid safety constraints and the possibility of heavy aeolian mantling at the most landable sites. On the other hand, a safe landing area on the margin of the "hematite" site appears to provide direct access to aqueously deposited minerals, with the specular hematite signature (observed in TES data) potentially acting as a proxy for other important accessory aqueous minerals present in low (below TES resolution) abundances. The evidence for a focused mineralization in a lacustrine depositional setting suggests favorable conditions for biomarker preservation, while the instrument payload (which includes Mössbauer spectrometer) seems particularly well suited to the hematite problem.

The next step is to continue to evaluate the MOC, TES, and MOLA images for the Isidis and Hematite landing zones. By January 23, 2000, selection of a 10° longitude by 7° latitude region box is required for the engineers. The preliminary L/V target specifics are due to Boeing by February 9, 2000, and the final L/V target specifics are due to Boeing by June 23, 2000.

ABSTRACTS

MARS SURVEYOR 2001 21-SOL PLAN, R.C. Anderson, Jet Propulsion Laboratory, Pasadena, CA 91011, randerson@jpl.nasa.gov.

Introduction: The Mars Surveyor 2001 21-sol plan defines the baseline surface science mission. This success-oriented plan is designed to be conservative and demonstrates that the primary mission success for each instrument can be attained during the first 21 sols on the surface of Mars. The 21-sol plan is designed to meet all of the power and data volume constraints placed upon the payload by the lander and is developed by the Science Operations Working Group (SOWG). It is the intent of the mission that SOWG will form a Core Operations Team (COT) that will be responsible for taking this plan and producing conflict free sequences of science activities.

Highlights

Below is a list of highlights for each instrument:

Health checks for all instruments will be obtained on Sol 0.

Robotic Arm (RA): will be unstowed on Sol 0.

Robotic Arm Camera (RAC): Predeploy rover panorama acquired on Sol 1.

Rover: Rover will be deployed by Sol 7.

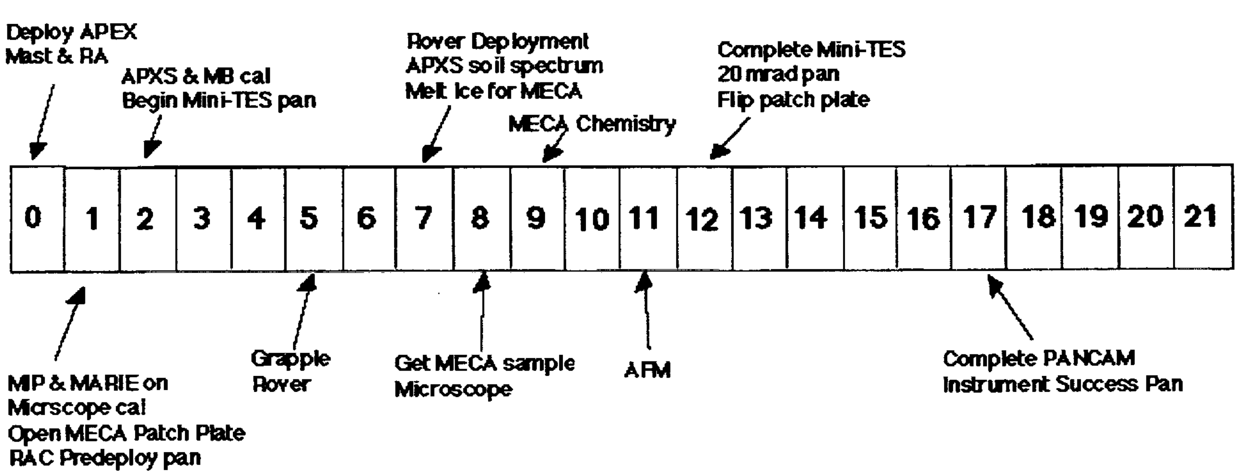
Mardi: All MARDI images will be downlink by the end of Sol 5. It is crucial for this data to be transmitted early in the mission since we can not regain this data if lost.

MIP & Marie: Both are turn on during Sol 1 and remain on as long as there is sufficient power. For MIP, oxygen is scheduled to be produced on Sol 4.

MECA: Microscope calibration and opening of the Patch Plate will occur on Sol 1; microscopy of surface and subsurface soil will be obtained on Sol 8 and 17; full wet chemistry experiments on the above soils will be completed on Sol 9 and 18; AFM images of soil will be acquired on Sol 11, and electrometer readings will be acquired during all robotic arm (RA) movements.

APEX: APEX Mast will be deployed on Sol 0; PANCAM Surveyor Pan will be obtained on Sol 0; instrument calibrations will be completed on Sols 1 and 2; PANCAM 0.28 mrad 3-color stereo panorama (16 parts) will be completed by Sol 20; Mini-TES 20 mrad panorama (6 parts) will be completed on Sol 12; Mossbauer measurements of surface soil and magnet arrays will be gathered on Sols 3, 10, and 11; APXS calibration measurement will be on Sol 2, with rock and soil measurements scheduled on Sols 7, 9, 12, 15, and 19; PANCAM optical depth will be acquired on Sol 0, with sky brightness being imaged on Sol 11.

Key Highlights
21-Sol Plan



MARS 2001 LANDER MISSION: MEASUREMENT SYNERGY THROUGH COORDINATED OPERATIONS PLANNING AND IMPLEMENTATION. R. Arvidson, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO, arvidson@wunder.wustl.edu.

The 2001 Mars Surveyor Program Mission includes an orbiter with a gamma ray spectrometer and a multispectral thermal imager, and a lander with an extensive set of instrumentation, a robotic arm, and the Marie Curie Rover [1]. The Mars 2001 Science Operations Working Group, a subgroup of the Project Science Group, has been formed to provide coordinated planning and implementation of scientific observations, particularly for the landed portion of the mission. The SOWG will be responsible for delivery of a science plan and, during operations, generation and delivery of conflict-free sequences. This group will also develop an archive plan that is compliant with Planetary Data System (PDS) standards, and will oversee generation, validation, and delivery of integrated archives to the PDS. In this abstract we cover one element of the SOWG planning activities, the development of a set of six science campaign themes that maximize the scientific return from lander-based observations by treating the instrument packages as an integrated payload.

Scientific objectives for the lander mission have been defined in [2]. They include observations focused on determining the bedrock geology of the site through analyses of rocks and also local materials found in the soils, and the surficial geology of the site, including windblown deposits and the nature and history of formation of indurated sediments such as duricrust. Of particular interest is the identification and quantification of processes related to early warm, wet conditions and the presence of hydrologic or hydrothermal cycles. Determining the nature and origin of duricrust and associated salts is very important in this regard. Specifically, did these deposits form in the vadose zone as pore water evaporated from soils or did they form by other processes, such as deposition of volcanic aerosols? Basic information needed to address these questions includes the morphology, topography, and geologic context of landforms and materials exposed at the site, together with quantitative information on material mineralogy, chemistry, and physical properties (rock textures; soil grain size and shape distributions; degree and nature of soil induration; soil magnetic properties). Observations from the APEX [3], MECA [4], and MIP [5] Experiments, including use of the robotic arm, robotic arm camera (RAC), and the Marie Curie rover, will be used to address these parameters in a synergistic way. Further, calibration targets on APEX will provide radiometric and mineralogical control surfaces, and magnet targets will allow observations of magnetic phases. Patch plates on MECA will be imaged to determine adhesive and abrasive properties of soils.

Coordinated mission planning is crucial for optimizing the measurement synergy among the packages included on the lander. This planning has already begun through generation of multi-sol detailed operations activities.

Site Characterization Campaign. An important initial activity is to survey the scene in the vicinity of the lander with Pancam, Mini-TES, RAC, and MARDI data in ways that take advantage of the unique capabilities of each instrument. These observations provide the context with which to interpret more detailed data, including the determination of the geographic location of the landing site, verification of site properties predicted from remote sensing observations, and comparison of the overall geologic properties of the site to the Viking and Pathfinder landing sites. Site characterization begins with a three-color view of a small portion of the site and a single band (red) highly compressed Pancam mosaic of nearly the entire site, followed by a RAC-based view of part of the site in stereo. The Pancam then begins to acquire the "Instrument Success" mosaic, which consists of full area stereo coverage of the scene in three colors using only modest compression. This mosaic is accompanied by acquisition of 20 milliradian/pixel Mini-TES data for most of the scene. These data sets are to be acquired as early as possible within the first 21 sols of operations. RAC will also acquire images, perhaps in stereo, of the area surrounding the lander that cannot be viewed by the Pancam, including areas that might be sites for digging and areas beneath the lander that may have had dust blown free by engine exhaust during landing.

Another aspect of the site characterization campaign (conducted as early as feasible, but not necessarily within the first 21 sols) will be to acquire Pancam data over several times of day along a plane that includes the sun-surface vector, both looking toward the sun and away from the sun. Data should also be acquired perpendicular to this plane. These photometric data, when combined with Pancam-based observations of atmospheric optical depth and sky brightness, will allow characterization of the scattering properties of rocks and soils. This part of the surface characterization campaign will also include acquisition of Mini-TES data for the same areas at different times of day to extract thermal inertia. These thermal observations provide additional constraints on the textural properties of surface materials. Further constraints could be provided from RAC observations: (a) acquired close to the ground, of soils and rocks acquired at very small and large scattering angles, and (b) at night using its blue, green, and red lamps.

It is expected that the data to be acquired as part of the surface characterization campaign will be used as fundamental inputs to the other campaigns that are focused on specific topics.

Surface Soils Campaign. Experience from Viking and Pathfinder suggests that soils are likely to be ubiquitous at the landing site, with varying physical, compositional, and spectroscopic properties that depend on the regional geology and topography of the site as well as its ancient and recent aeolian and perhaps fluvial history. The physical properties and mineralogy of surface soils will provide important constraints on weathering and provenance, in addition to hazard assessment. The primary goals of this campaign are to assess the past and present history of surface-atmosphere interactions (such as weathering, aeolian transport) and surface compositional variability at the landing site, particularly to determine how and whether the soils are compositionally and mineralogically related to or derived from the local rocks at the site (see Rock campaign). Additional goals include characterization of the geomorphology and texture of soils at the landing site (see also Site Characterization campaign), assessment of the chemistry and origin of hardpan or duricrusted soils, determination of soil physical properties like adhesion potential and particle size, and determination of soil electrostatic and magnetic properties. Unlike the Deep Hole campaign, the Soil campaign is focused on constraining the properties and spatial relationships of exposed materials over a large area.

The Soil Campaign will include use of the data acquired in the Site Characterization Campaign to target sites for acquisition of Pancam spectral cubes, 8 milliradian/pixel Mini-TES data, regions for APXS measurements and detailed imaging by the rover cameras, and targets for Mössbauer measurements. Complementary data will also be provided from the Aerosol and Soil Magnetic Properties Campaign (saturation magnetization) and the Atmosphere-Surface Dynamics Campaign (dust particle sizes, shapes, opacity). Physical properties experiments will also be conducted, including digging and scraping with the Rover wheels and digging with the RA. This campaign will also include acquisition of the first soil sample for microscopy and wet chemistry for MECA. Additional MECA experiments related to this campaign will include electrometer measurements and RAC imaging of: (a) soil deposited on the MECA Patch Plates, (b) scoop abrasion plates after surface contact, and (c) close up imaging of soil in the scoop. RAC-based UV imaging will also be attempted to search for fluorescence. It will be important that some measurements in this campaign be acquired on a single soil unit using Pancam, Mini-TES, RAC, APXS, Mössbauer, and MECA. In this way, the full scientific complementarity of the MSP'01 lander instrument set can be brought to bear.

Deep Hole Campaign. Perhaps below the surficial deposits, and in reach of the robot arm's digging capabilities, are ancient weathered materials ("soils"), or even aqueously-emplaced sedimentary layers. Study of a subsurface region that is protected from intense surface UV irradiation and that may have a higher moisture content has important implications for a number of 2001 Lander mission objectives. The Deep Hole campaign is complementary to the Soil campaign and explores the properties of soil, sediment, and small rocks as a function of depth, using the RA to dig to a depth of perhaps 50 cm over the course of the 90 sol mission. The location where the trench will be dug will be selected using Pancam image cubes and high-resolution Mini-TES data. RAC will play a key role in imaging details of the trench as a function of time. Soil samples from various depths will be placed on the surface as piles and examined with Pancam, Mini-TES, APXS and Mössbauer. Subsurface soil samples, at depths of 25 and 50 cm will be acquired for MECA-based microscopy and wet chemistry. These same two samples should also be examined using the Mössbauer Spectrometer and and APXS. An issue of particular importance for Mössbauer will be determination of Fe^{2+}/Fe^{3+} as a function of depth, as an indicator of oxidation gradient in the martian soil. Also, the MECA electrometer mounted on the RA will determine triboelectrification of the RA as it scrapes against the floor of the trench. This assessment is important for HEDS in terms of understanding charging and grounding states of near-surface materials. At the same time, the RAC will assess abrasion wear on patches mounted on the underside of the scoop in order to determine the hardness of soil constituents. The RA itself will perform physical properties experiments such as evaluating soil strength (induration and cohesion).

Aerosol and Soil Magnetic Properties Campaign. Determination of soil magnetic properties is a fundamental objective and one that places constraints on both the mineralogy and textural characteristics of soil deposits. Identification of the magnetic mineral(s) in martian soils and aerosols will help reveal the environment of formation of these materials. Both the APEX and MECA Payloads will measure magnetic properties. APEX includes strong and week magnets on the lander deck and a weak magnet on a lander footpad. These magnets will be imaged a number of times by Pancam and/or RAC to determine the build up rate of magnetic aerosols. Further, the Mössbauer Spectrometer will be placed against the deck magnets to determine the mineralogy of the magnetic phase or phases. The APXS will be used to examine the footpad magnet to determine the elemental chemistry of the same material. Pancam multispectral imaging of the footpad magnet will also help reveal mineralogy. The MECA patch plate located on the MECA experiment box will contain magnetic materials and will be imaged with the RAC. The MECA microscopy experiment will include magnetic material within one or more of the sample holders. Finally, if MEEC is include on Marie Curie, magnetic portions of the wheel strips will be monitored for adhering materials after traverses through particular soil types.

Rock Campaign. The rock campaign is focused primarily within the APEX Payload. Pancam multispectral cubes and high spatial resolution Mini-TES data will be acquired for rocks first observed in the Pancam mission success pan and the 20 mrad/pixel Mini -TES data. If analyses showed that these rocks were good candidates for testing ideas related to the geology of the landing site, they will then be visited by Marie Curie for detailed imaging and acquisition of APXS data. Within the working envelop of the RA, Mössbauer data will also be acquired for relevant rocks. Data analyses will focus on evaluating the extent to which the observations allow testing of models for the bedrock geology of the site, particularly models related to paleoclimatic conditions and the possibility of preservation of pre-biological or biological materials.

Atmosphere-Surface Dynamics Campaign. The lander payloads will contribute in substantial ways to quantifying the dynamics of atmosphere-surface interactions, focusing on the dust cycle. Pancam will be able to determine atmospheric optical depth, primarily a measure of the total abundance of aerosols, by direct imaging of the sun through its solar filters. This instrument will also acquire sky brightness measurements as a function of angular distance from the sun to constrain aerosol size and shape distributions. Pancam will also be used to search for clouds and dust devils. RAC will image a convex mirror on the MECA Patch Plates to constrain sky brightness and to search for clouds and dust devils. Mini-TES will use the 15-mm band of CO_2 to perform upward-looking vertical sounding of the temperature structures of the martian atmospheric boundary layer. The combination of upward-looking Pancam and Mini-TES data should provide substantially improved understanding of the physics of aerosol loading as a function of time.

Pancam/Mini-TES data for the sky will be combined with MIP-derived observations of the solar spectrum and sky brightness. MIP-based microscopy of aerosols will provide additional constraints on these materials, as will MIP-generated estimates of dust loading onto DART surfaces. Further, Pancam will independently monitor the DART surfaces for dust accumulation. This monitoring will also extend to imaging of the lander solar panels, the panels on Marie Curie, MECA Patch Plates, and both disturbed and undisturbed sites in the vicinity of the lander. These observations will quantify the nature of the aerosols, their rate of transport within the atmosphere, and the rate of accumulation and removal onto surfaces. These inferences will have both scientific and practical implications. On the science side, the dust cycle has clearly been important in shaping the surface of the planet and needs to be better understood. On the practical side, dust accumulation on solar panels reduces power and mission lifetimes. Understanding accumulation and erosion rates is therefore of great importance.

References. [1] Saunders et al. (1999) *LPS XXX*, 1769. [2] Saunders et al. (1999) *LPS XXX*, 1734. [3] Squyres et al. (1999) *LPS XXX*, 1672. [4] Marshall et al., *LPS XXX*, 1163. [5] Kaplan et al. (1999) *LPS XXX*, 1797.

MARTIAN RADIATION ENVIRONMENT EXPERIMENT (MARIE). Gautam D. Badhwar, NASA Johnson Space Center, Houston, Texas 77058-3696, USA (gbadhwar@jsc.nasa.gov).

Introduction: Space radiation presents a very serious hazard to crews of interplanetary human missions. The two sources of this radiation are the galactic cosmic rays (GCR) and solar energetic particle (SEP) events. The GCR provides a steady source of low dose rate radiation that is primarily responsible for stochastic effects, such as cancer, and can effect the response of the central nervous system. Nuclear interactions of these components with the Martian atmosphere produces substantial flux of neutrons with high Radio Biological Effectiveness. The uncertainty in the knowledge of many fragmentation cross sections and their energy dependence required by radiation transport codes, uncertainties in the ambient radiation environment, and knowledge of the Martian atmosphere, lead to large enough uncertainties in the knowledge of calculated radiation dose in both free space (cruise phase), in Martian orbit, and on Martian surface. Direct measurements of radiation levels, the relative contributions of protons, neutrons, and heavy ions, and Martian atmospheric characteristics is thus a pre-requisite for any human mission. An integrated suite of two spectrometers to provide these data will be described. The Orbiter spectrometer will measure the energy spectrum of SEP events from 15 to 500 MeV/n, and when combined with data from other space based instruments, such as the Advanced Composition Explorer (ACE), would provide accurate GCR spectra also. The Lander spectrometer would measure the absorbed dose rate, dose equivalent dose rate, and the linear energy transfer (LET) spectra and is capable of separating the relative contribution of these quantities from protons, neutrons, and high Z particles.

There are two separate flight instruments, one for the Orbiter and one for the Lander, based on a common design of the backplane, the central processing unit (CPU), power supply, and onboard data storage. The Orbiter instrument consists of an energetic particle spectrometer that can measure the elemental energy spectra of charged particles over energy range of 15-500 MeV/n. The spectrometer will be mounted on the science deck and has an angular acceptance of 50°. As the spacecraft orbits Mars, the axis of this field of view sweeps a cone of directions on the sky. During each orbit, the angle between the axis of the spectrometer's field of view and the mean interplanetary field direction varies from 90° to 180°.

The Lander instrument is designed: (1) to measure the accumulated absorbed dose and dose rate in tissue as a function of time, (2) to determine the radiation quality factor, (3) to determine the energy deposition spectrum from 0.1 keV/μm to 1500 keV/μm, and (4) to separate the contribution of protons, neutrons, and HZE particles to these quantities.

COMPOSITION AND ORIGIN OF MARTIAN SURFACE MATERIAL, REMOTE DETECTION OF MINERALS, AND APPLICATIONS TO ASTROBIOLOGY. J. L. Bishop[1], M. D. Lane[2], E. Murad[3], and R. L. Mancinelli[1], [1]SETI Institute/NASA-ARC, MS-239-4, Moffett Field, CA 94035 (jbishop@mail.arc.nasa.gov), [2]NASA-JSC, SN3, Houston, TX 77058, [3]Bavarian Geol. Survey, Concordiastraße 28, D-96029 Bamberg, Germany.

Introduction: Martian surface composition and processes are under study through analysis of spectral, magnetic and chemical data from Mars and analysis of laboratory analog materials. The focus of this study is on potential lander/rover measurements of weathered volcanic tephra and hydrothermal rocks because these samples resulted from processes that may have occurred on Mars. Fine-grained particles from these sources may be responsible for origination of the dust/soil on Mars that is shaping the planet's surface character. Alteration on the surface of Mars likely includes both chemical and physical interactions of soil particles and rock surfaces.

Many of the minerals present in hydrothermal samples may be associated with organisms and may be useful as indicators of life or environments supportive of life on Mars. Characterization of the spectroscopic properties in the visible/near-infrared (VIS/NIR) and mid-infrared (IR) regions using reflectance, emittance and Raman, as well as the thermal properties of minerals thought to be present on Mars are being performed in order to identify them remotely. Particular interest is directed toward locating minerals, and hence landing sites, important to Astrobiology.

Composition of Martian Surface Rocks and Soils: The chemical and spectral data from rocks near the Pathfinder Lander indicate that they are andesitic-basaltic and covered with alteration rinds [1]. Global composition measured by TES varies from basaltic to andesitic-basaltic and includes one larger hematite basin [2,3]. Initial analysis of the Pathfinder soil units showed that they are chemically and mineralogically distinct from the rocks, and that they may contain some iron oxyhydroxides, but do not show the expected evidence for crystalline hematite [4]. Magnetic experiments indicate the presence of maghemite and/or magnetite in the Martian dust/soil suggesting that this magnetic phase must be intimately mixed with the other components [5]. Recent analyses of Pathfinder spectra following revised calibration procedures show stronger evidence for crystalline iron oxide/oxyhydroxide minerals in the soil [6].

Palagonitic alteration of volcanic ash is common on Earth, resulting in nanophase or poorly crystalline Fe oxides, clays or protoclays, and tiny feldspar, pyroxene and glass particles. This process is likely occurring on Mars as well. Hydrothermal alteration near volcanic steam vents often produces material containing substantial hematite, maghemite/magnetite, jarosite/alunite and/or layer silicates [7,8]. This process may be responsible for the production of crystalline iron oxides, silicates and sulfates on Mars. Spectra of palagonitic and hydrothermal alteration products are given in [7,8].

Another source of crystalline silicates, sulfates and carbonates at an early period on Mars could have been hydrothermal activity similar to what is observed in Yellowstone National Park, WY. An analysis of the potential relevancy to Mars of hydrothermal fluids from geothermal hot springs was presented recently by Newsom et al. [9].

Possible Alteration Scenarios on Mars: The idea of "acid-fog" weathering on Mars was suggested recently based on a non-thermal, acid-weathering laboratory study [10]. This model suggests that aerosol particles in the atmosphere slowly penetrate the surface layers of the rocks. This process would form rock coatings comprised of nanophase or poorly crystalline, ferric oxide and silicate protominerals out of the primary rock minerals.

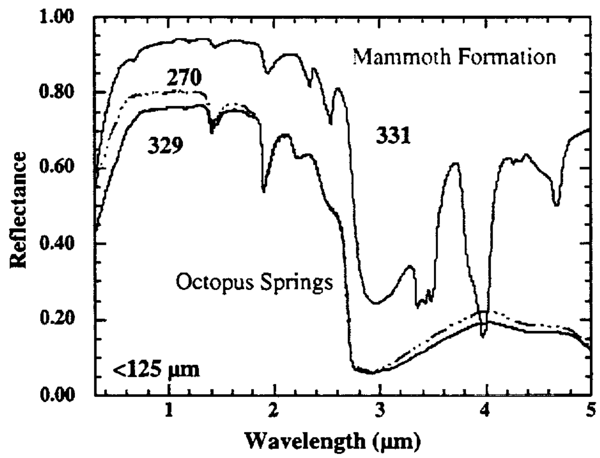
Another alteration model involves generation of rock coatings and duricrust via interaction of dust/soil particles with each other and rock surfaces [8]. This model requires dust/soil particles having a different origin from the rocks, where both palagonitic and hydrothermal alteration products contribute to the composition of the dust/soil particles. Aeolian mixing of these two kinds of alteration materials produces a non-homogenous but regionally similar, fine-grained material. The physical rock coatings and soil units in this model are merely larger aggregates of dust particles, held together by electrostatic or physical forces. The dust/soil particles in this model contain corrosive sulfate and ferric species that both "chew" up the rock surfaces to form chemical rock coatings and bind together to form duricrust units [8].

Applications to Astrobiology: Important issues for Astrobiology on Mars include site selection for sample return missions as well as design and implementation of *in situ* analyses. Spectral remote sensing during current and upcoming missions will provide significant information about the mineralogy and composition of the surface of Mars that will contribute to these decisions. Specifying which minerals are indicative of life is an integral aspect of this. Microorganisms are known to utilize and produce a variety of carbonate, silicate and iron oxide minerals. Potential Mars analog samples relevant to Astrobiology should be studied by interdisciplinary teams of scientists now in order to determine the optimal methods of remote sensing for *in situ* Astrobiology studies. Hydrothermal springs are one such potential analog site.

Spectral Comparison: Analyses of two hydrothermal rocks from Yellowstone using VIS/NIR, mid-IR (reflectance and emittance), and Raman spectroscopy as well as differential thermal analysis (DTA) are presented here in order to facilitate an understanding of the relative usefulness of these techniques on detection of different minerals and the power of combining them. The hydrothermal rock collected at the Mammoth Formation is primarily carbonate with some gypsum especially on the surface of the rock, while the sample collected near Octopus Springs primarily contains quartz, phyllosilicates and sulfate minerals.

Visible/NIR reflectance spectra are shown in Figure 1 for ground rock samples (<125 μm) from two locations at Yellowstone. These were measured at Brown Univ. using bidirectional spectra for the extended visible region and FTIR spectra measured in a dry environment at longer wavelengths (>1.3 μm) as in previous studies [e.g. 7]. Broad hydration bands are observed in spectra of both the Mammoth and Octopus Springs samples near 1.45, 1.95 and 2.9-3.1 μm in Figure 1. Weak, broad features near 1.0 and 1.2 μm are also attributed to hydration bands in minerals. The Mammoth Formation sample exhibits carbonate bands near 2.3, 2.5, 3.4-3.5, 4.0 and 4.7 μm. The bands in this spectral region are consistent with both calcite and aragonite [11]. The spectrum of the Octopus Springs sample has a broad band from 2.2-2.3 μm which is characteristic of sulfates and sharper asymmetric edges on the hydration features near 1.41, 1.91 and 2.75 μm which are characteristic of 2:1 layer silicates [12]. These clay minerals also exhibit a band near 2.2-2.3 μm (although sharper than observed here). The spectrum of anhydrite is more consistent than that of gypsum with the sulfate component in the VIS/NIR Octopus Springs spectrum [12].

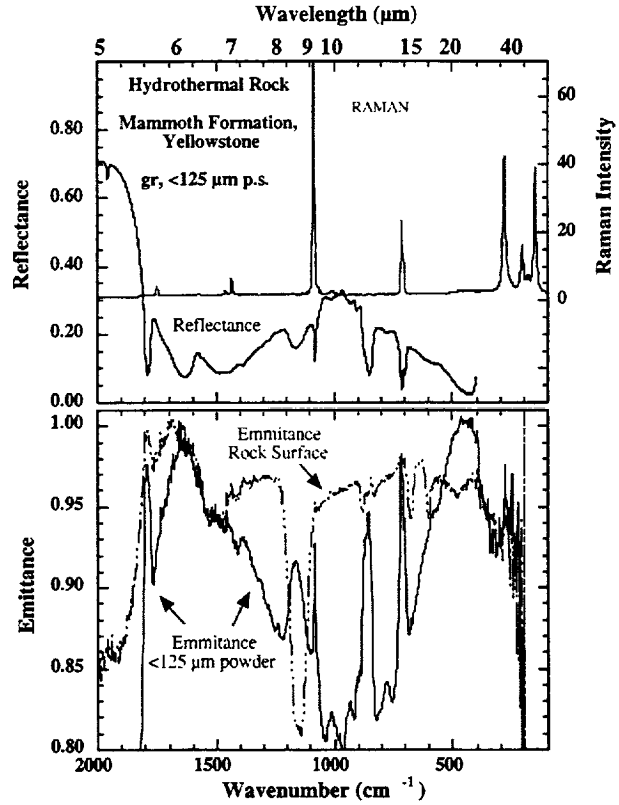
<u>Figure 1</u> VIS/NIR Reflectance Spectra of Hydrothermal Rock Samples from Yellowstone.



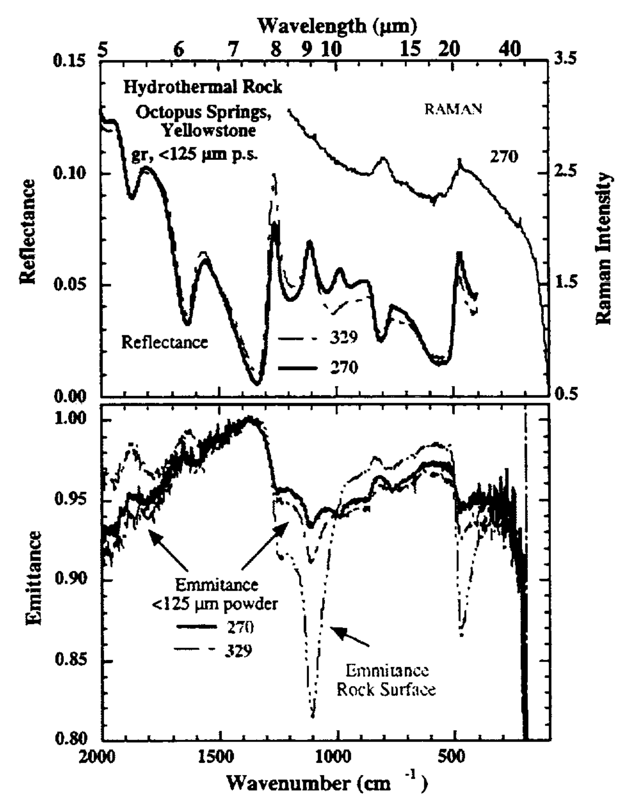
Shown in Figures 2 and 3 are mid-IR region Raman, reflectance and emissivity spectra for the same particulate samples, plus emissivity spectra of a rock surface as well. Raman spectra were measured at the Bavarian Geological Survey as in previous studies [e.g. 13]. Reflectance spectra were measured using an FTIR as in [e.g. 7]. Emittance spectra were measured at Arizona State Univ. using a system similar to the TES on MGS [14] and previous lab studies [e.g. 15].

A strong carbonate band is observed at ~1090 cm^{-1} (9 μm) in the Raman spectrum of the Mammoth sample in Figure 2, with weaker bands at 710 (shoulder at 700), 282, 207 and 155 cm^{-1}. These are attributed to a combination of calcite and aragonite. Both carbonates have strong Raman bands near 1090 cm^{-1}. The weaker bands near 712, 282, and 155 cm^{-1} are assigned to calcite and at 700, 207 and 155 cm^{-1} are assigned to aragonite [16,17]. Features near 1800, 1600-1650, 1400-1500, 1100-1200, 850, 700 cm^{-1}

<u>Figure 2</u> Mid-IR Raman, Reflectance and Emittance Spectra of the Mammoth Sample.



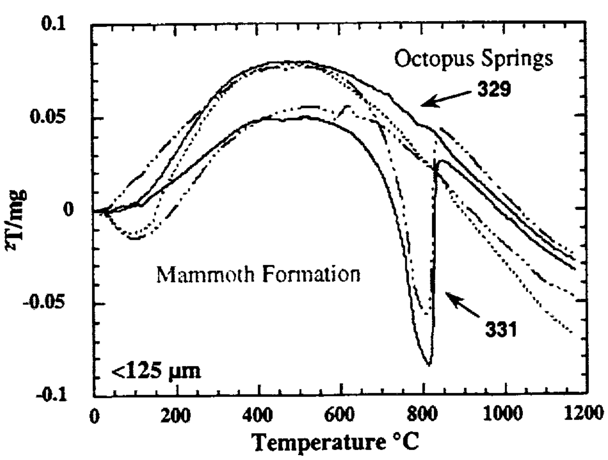
<u>Figure 3</u> Mid-IR Raman, Reflectance and Emittance Spectra of Octopus Springs Rock



are characteristic of particulate calcite and aragonite; however, the sharp band near 1080-1090 cm^{-1} is due only to aragonite-structure carbonates [16,17]. The emissivity spectrum of the particulate Mammoth sample is very similar to the emissivity of particulate calcite [15], with the exception of the sharp upward feature at 1083 cm^{-1}, which is attributed to aragonite. The emissivity spectrum of the rock surface contains bands due to both carbonate and gypsum. The gypsum features in this spectrum include the strong band near 1160 cm^{-1} and sharp, weaker bands near 680 and 600 cm^{-1} [15]. As seen in Figure 3 the Octopus Springs sample exhibits quartz features in the reflectance and emmitance spectra near 1850, 1600, 1100, 800 and 500 cm^{-1} (or 5-5.5, ~6, ~9, ~12.5 ~20 μm) and Raman features near 800 and 500 cm^{-1} (12.5 & 20 μm). Anhydrite and montmorillonite are thought to be responsible for mid-IR features near 1250 cm^{-1} (8 μm) and 1100 cm^{-1} (9 μm), respectively.

Figure 4 shows differential thermal plots of the Mammoth and Octopus samples from room temperature to 1200°C. Samples were measured at NASA-ARC as in [7]. A strong endotherm is observed near 800 °C due to calcite decomposition in the Mammoth Formation sample shown in Figure 4. DTA measurements of surface samples from a Mammoth rock contain additional features near 150°C due to gypsum and near 450-500°C due to aragonite.

Figure 4 Differential Thermal Analysis of Yellowstone Samples



Identification of Minerals on Mars: A lander/rover on Mars would gain the most information about the dominant and minor mineralogies by combining several instruments. VIS/NIR and mid-IR spectroscopy are frequently used for mineral identification in geologic materials in the laboratory and in the field. Raman spectroscopy and DTA have also been applied successfully to mineral identification in laboratory studies and have been proposed and/or are planned for upcoming missions to Mars. There are numerous secondary minerals that can be readily identified through spectroscopic features and whose presence on Mars would provide important information about the geochemical environment including factors such as the presence and abundance of water and salts, and the range of pH and temperatures. These secondary minerals could be iron oxides/oxyhydroxides, sulfates, carbonates and phyllosilicates.

Raman spectroscopy can be successfully combined with VIS/NIR and mid-IR studies because Raman is largely insensitive to water. Raman is also different from reflectance and emittance spectroscopy in that solar or planetary radiation cannot be utilized; for Raman a laser is needed for excitation, then Raman scattering is measured corresponding to the vibrational frequencies which are linked to the mineral structure. For this reason a Raman spectrometer would be a logical component of a lander/rover mission, but could not be used for an orbiter on Mars. The nature of DTA measurements would also require a rover or lander. Spectrometers on Mars missions have contributed greatly to our understanding of the surface mineralogy using both the VIS/NIR region (ISM) [e.g. 18] and the mid-IR region (TES) [e.g. 2,3].

Summary and Applications to Mars: The success of mineral detection in natural, multi-component samples is variable depending on the grain size of the mineral and the technique used. For the hydrothermal rocks described here calcite, aragonite, gypsum, anhydrite, quartz and phyllosilicates were identified using a combination of VIS/NIR, mid-IR and Raman spectra and DTA. Remote detection of these minerals on Mars would identify sites for *in situ* measurements pertinent to Astrobiology. If organisms were ever present on Mars, perhaps one of their last homes might have been within evaporite deposits containing these minerals. Finally, it should be possible to distinguish between calcite and aragonite (if either is present on Mars) using a combination of mini-TES and Raman measurements from the upcoming landers and rovers. This may be important to Astrobiology on Mars because aragonite is frequently associated with organisms.

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GEOLOGIC MEASUREMENTS USING ROVER IMAGES: LESSONS FROM PATHFINDER WITH APPLICATION TO MARS '01. N.T. Bridges[1], A.F.C. Haldemann[1], and K.E. Herkenhoff[2]. [1]Jet Propulsion Laboratory, California Institute of Technology (MS-183-501, 4800 Oak Grove Drive, Pasadena, CA 91109; nathan.bridges@jpl.nasa.gov), [2]U.S. Geological Survey, Flagstaff, Arizona.

Introduction: The Pathfinder Sojourner rover successfully acquired images that provided important and exciting information on the geology of Mars. This included the documentation of rock textures, barchan dunes, soil crusts, wind tails, and ventifacts (1-5) (Figure 1). It is expected that the Marie Curie rover cameras will also successfully return important information on landing site geology. Critical to a proper analysis of these images will be a rigorous determination of rover location and orientation. Here, the methods that were used to compute rover position for Sojourner image analysis are reviewed. Based on this experience, specific recommendations are made that should improve this process on the '01 mission.

Determining Rover Position and Orientation: Before effective quantitative analysis of rover images can be made, it is necessary to determine both rover position (x-y-z) and orientation (pitch-roll-yaw). For the Pathfinder mission, this was done using several methods. During a traverse, Sojourner estimated and recorded its own position and orientation by dead reckoning. However, these estimates often deviated from the true values due to uneven topography that affected the number of wheel turns per distance traveled, gyroscopic drift, and other factors. This frequently led to erroneous positions and orientations in the header information of rover images taken during mid-traverse. Without correcting this information, the computed locations of geologic features of interest (e.g., rocks, dunes) and their orientations (e.g., aeolian flutes, wind tails) were in error.

To reset Sojourner's knowledge of its own position and orientation, IMP (Imager for Mars Pathfinder) images taken at the end of each sol were analyzed. The images, compressed 6:1, generally consisted of 2 to 4 frame mosaics and as such occupied minimal downlink volume. This information was then used to update the rover on its proper location and attitude. However, this only proved effective for application to rover images that were taken at the beginning or end of a sol, when Sojourner was in the same position as that seen in the "end of day" IMP images.

To determine rover position in mid-traverse, when many of the best rover images were taken, three methods employing both IMP and rover images were used [3]: 1) Mid-traverse IMP stereo or monoscopic images of Sojourner at the time of rover imaging were used to compute the true rover position and orientation ("stereo" and "monoscopic" methods). These generally consisted of 24:1 compressed rover "movie" frames or images from panorama sequences that happened to image the rover. 2) Dead reckoning data in the rover image headers, dead reckoning data at the end of a traverse, and the IMP-derived true rover position at the beginning and end of a traverse were used to compute rover positions in mid traverse by estimating the drift in dead reckoning as a function of rover moves ("interpolation" method). 3) Where features visible in both rover and IMP images were known relative to IMP, the rover position was computed by tying the location of these image features together ("triangulation" method). Once the position of the rover was determined using these techniques, positions and orientations in the Mars surface fixed frame were computed (i.e., the frame used on Mars maps).

Error Analysis: When trying to determine the orientation of features in three-dimensional space using stereo rover images, the two main sources of error are the determination of orientation in the rover images themselves and the estimation of rover orientation. Knowledge of the latter is necessary to convert from the rover coordinate frame to the Mars surface fixed frame. Errors measuring positions in rover images affect both trend and plunge values, whereas uncertainties in the rover orientation mostly affect trends. In rover images, a line connecting endpoints of a given linear feature is made of N pixels and has N-1 pixel-pixel boundaries. The number of pixels depends upon both the length and the distance between the rover cameras and the feature. The number of orientations over which the pixels can be arrayed over a 180° range is $4(N\text{-}1)$. This gives a potential degree error within the image plane of $\pm$ $180°/(8[N\text{-}1])$. For the study of ventifacts described in [3]. values for this uncertainty varied from 0.4° to 4.4°. In cases for which IMP stereo images documented rover position, rover orientation uncertainty was assumed to be a function of the pixel size of the rover in the images and was computed using the method described above (except in this case the number of pixels making up the rover length is substituted for the number of pixels making up the flute length). Where only monoscopic images were available, the error was judged to be twice as poor (i.e., $\pm$ $180°/(4[N\text{-}1])$). It was difficult to estimate the error using the interpolation method because the drift was in most cases probably not a linear function of the number of rover moves. Being conservative, the uncertainty was taken as the difference between the IMP-derived and dead reckoning position at the end of the traverse. The uncertainty using the triangulation method is also difficult to estimate but is probably of the order of 10°. Using all these methods, the error associated with rover position varied from 0.1° to 54° for the Pathfinder ventifact study [3]. The total uncertainty for this study, computed by summing the errors associated with positions in rover images and those associated with rover orientation, varied from 1 to 55°, but in most cases was less than 15°.

Recommendations for Mars '01: For the '01 mission, it will be critical that the position of Marie Curie be known as accurately as possible when images are acquired. The following recommendations are offered to help achieve this:

1) PANCAM images must be acquired at the end of each day during which a rover traverse takes place. These can be

single filter, 6:1 compressed frames. When possible, similar PANCAM images should also be acquired in mid-traverse.

2) Pancam rover "movies" with 24:1 compression should be made when Marie Curie is traversing and imaging rough terrain.

3) Close-up stereo rover images should be nested within larger rover image mosaics such that surface features recognizable to both the rover and Pancam can be tied together. This will facilitate the computation of position in three-dimensional space

With these considerations in mind and taking into account the "lessons learned" from Pathfinder, the use of Marie Curie on Mars '01 should be very successful and teach us much about geologic processes on the Martian surface.

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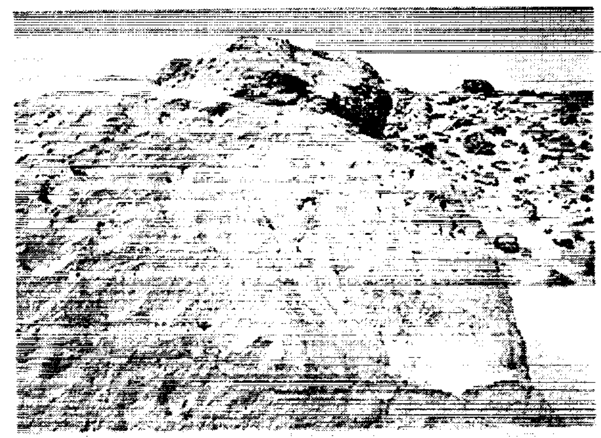

Figure 1: Examples of Pathfinder rover images that show geologic features for which deriving accurate position and orientation data is important. In the top frame, the rock Moe exhibits aeolian flutes. The bottom frame shows barchan dunes. Both features reveal important information about the present and past wind regimes that have operated at the Pathfinder landing site.

THE CRITICAL IMPORTANCE OF AN INTEGRATED APPROACH BETWEEN THE MARS SURVEYOR PROGRAM AND THE FUTURE HUMAN EXPLORATION LANDING SITE SELECTION.

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Rationale: The priority science objectives of the Mars Surveyor Program are to document the evolution of water, life, and climate, and to assess the existing resources on Mars. The same areas of investigations are planned by the Human Exploration and Development of Space (HEDS) for the human exploration of Mars [the Reference Mission, NASA SP 6107, 1997]. The objectives of automated and human exploration are thus very close, although we can assume that the emphasis could vary (e.g. seeking for resources might be a more developed activity for the human exploration that for the current automated exploration). Therefore, the current automated missions of the Surveyor Program are an important source of information that will influence the way we will explore Mars with EVA-Rover crews in the future. It also makes sense that the Surveyor Program sites are likely to be high-priority candidate-sites for landing human mission for the simple reason that we will know the environment associated to these sites better than the rest of Mars. Thus, there is a critical need to include an important HEDS component in the Mars Surveyor Program site selection. The implications are not only science, but also technology and engineering, mission safety and cost effectiveness.

A Necessary Connection: The new vision of Mars provided by the current Mars Global Surveyor mission and the recent first Silver Lake field experiment between an EVA astronaut and a rover (ASRO project), see Fig. 1, [Cabrol, 1999a,b; Cabrol et al., 1999a,b] demonstrate the necessity of a synergism between the Surveyor Program and the HEDS landing site requirements.

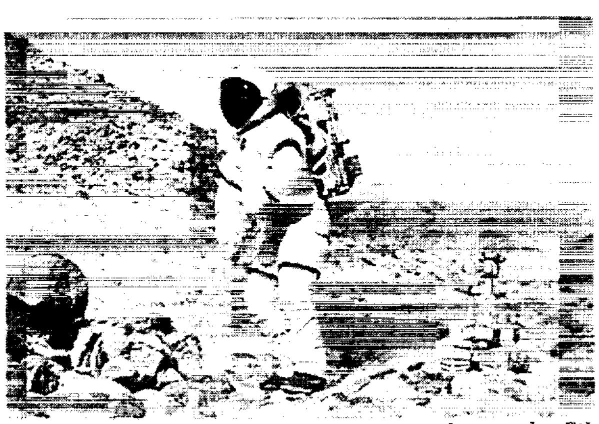

Fig. 1 EVA astronaut and rover exploring the Silver Lake (Mojave Desert, CA) test site during the ASRO field experiment in February 1999.

Preliminary studies must be made before sending a human crew to Mars. These studies must encompass the assessment of the environment, which include, for instance, its level of hostility in terms of radiation This is the role of the MSP 2001 that will be conducting environmental assessment for the HEDS program during the Athena Precursor (01'APEX) mission, while the MECA experiment will test the level of chemical toxicity of the soil, the presence of abrasive soil dust component as a potential threat for the astronaut spacesuit, and the geoelectrical-triboelectrical character of the surface environment [Marshall, 1999 this Workshop].

This assessment only is of vital importance for the success and the safety of a human mission to Mars. Another example can be taken from the weather assessment of the landing site region. It is clear that the regional and local weather (e.g. recurrence and magnitude of dust storms, cycle, directions and importance of daily dust devils) will strongly influence the daily activity of the astronauts at the surface of Mars. However, although the site for the 2001 program seems to be selected according to its potential to document the Surveyor Program science objectives -- and the availability of the MOC image coverage as provided by the MOC team -- it is not clear that a particular emphasis has been put on how this site was going to respond to the demand of these environmental assessments and the instruments and experiments that have been designed for. These criteria were never really hardly discussed as main parameters during the 2001 landing site selection previous workshops, when it is a matter of vital importance.

There are many other reasons to inject more HEDS discussions in the Surveyor landing sites selection and use the HEDS arguments as important criteria of site selection more than they currently are. The recent ASRO field experiment, which for the first time combined a rover and an EVA suited test subject in the field to simulate an EVA-Rover exploration of a planetary surface, showed that it would be a misconception to believe that we will be able to design a safe and productive mission to Mars by just assembling the technology and instruments we currently have, the exploration strategies that were used for the Moon, and hope to be successful on Mars [Cabrol, 1999b]. The exploration of Mars will come with a series of specific technical and physical challenges. New suits, new instruments and experiments need to be designed and tested. They will be better designed and ready for the Martian field if we know in which geological environments we are sending the human crew, and what could be their tasks. Also, the perspective of building a base on Mars should be always present in the selection of sites. Such site might provide the necessary elements to allow natural protection for a crew, and resources (access to water – liquid or ice --). Surveyor can provide this crucial knowledge and become a powerful precursor to human missions.

Using the Surveyor Fleet as a Precursor for Human Exploration: All the above assessment studies will have to be done imperiously anyway before any human mission can be sent on Mars. It would be wise and much cost effective to use the Surveyor Program as a Precursor Fleet for the human missions, and inject a strong and effective synergism between HEDS and MSP in term of landing site selection. If this synergism is not achieved, we will end up with the necessity of sending other automated missions with a special HEDS focus prior to manned spacecrafts in order to achieve the environmental survey, while this aspect could be an ongoing effectively coupled with the Surveyor missions.

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EVOLUTION OF LACUSTRINE ENVIRONMENTS ON MARS AND THEIR SIGNIFICANCE: THE CASE FOR THE BRAZOS LAKES AND EAST TERRA MERIDIANI BASINS AS LANDING SITES FOR SURVEYOR 2001.

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Introduction: Ancient Martian lacustrine environments must be considered as primary targets to explore on Mars. Terrestrial studies show that lakes are exceptional sites to keep the record of the evolution of climate, geology, water and life. Finding this record is also the principal objective of the *Mars Surveyor Program*. This record encompasses changes at local, regional and global scales. Lacustrine sediments provide critical information about all events occurring in the lake catchment area. They are also a locus of complex chemical processes, concentration for life and favorable sites for fossilization processes to take place [Farmer *et al.*,1999]. We proposed two candidate-sites in the Schiaparelli Crater region responding to this high-priority scientific objective at the June 1999 meeting in Buffalo, NY [Cabrol *et al.,* 1999]. The two sites are located in the Sinus Sabeus quadrangle, are well documented by MOC images, and are among the best evidence yet of a Martian past lacustrine activity. We develop their case as high-priority sites for the 01' mission.

I. Formation and Identification of Martian Lakes and Lacustrine Environments from Orbit and from the Ground: To form, lakes require: water, gravity, topography, atmosphere, and more water input than output. All these conditions were met in the past history of Mars as suggested by abundant geologic evidence of hydrologic activity as observed by Viking, and more recently even more dramatically by the Mars Global Surveyor mission [Malin and Carr, 1999]. Thus, lakes might have been generated on Mars as they have been on Earth. The major differences between the two planets are the partial loss of the Martian atmosphere through time, and the lower mean average temperature. It is likely that conditions were more favorable to form and sustain lakes during the Noachian period. However, episodical lacustrine activity occurred later through the Hesperian and Amazonian [Grin and Cabrol, 1997; Cabrol et al., 1999; Cabrol and Grin 1999, in press].

Thinning atmosphere and lowering temperatures may have affected the formation, duration, and evolution of Martian lakes over time. These conditions are likely to have generated changing environments from possible perennial, relatively mild temperature water bodies during the Noachian, to episodical ice-covered lakes later on during the Martian geologic. These conditions not only had consequences on the water body itself but also on the water supply system that generated them, and potentially on any living organisms associated to these changing environments. Thus, lacustrine environments on Mars are expected to show a certain degree of complexity and variation in their stratigraphy and surface expressions. This complexity needs to be recognized both from orbit (surface expression) in order to select appropriate landing sites, and from the ground (exposed stratigraphy in outcrops), once the lander and the rover have landed and start investigate the site.

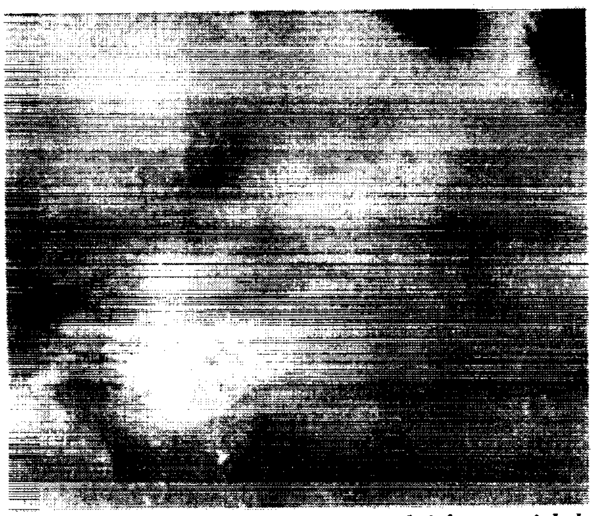
On Earth, a lake can be defined and recognized by its physical, hydrological, chemical, and biological processes. As today, the definition of a Martian lake is reduced to the physical processes that we are able to deduce from observation of orbital data and models we infer from them, the chemical processes are poorly known and the biological processes still a hypothesis. The hydrological processes, although also reconstructed from orbital and lander imagery, provide the best evidence to base a classification upon [Cabrol, 1998, Cabrol and Grin 1999], and help predict the potential environments [Forsythe and Zimbelman, 1995, Forsythe and Blackwelder 1998, Cabrol and Grin 1999].

Past limitations for the identification and survey of Martian lakes from orbit have been the lack of spatial resolution of the imagery, and the lack of satisfactory topographic and mineralogical data. Valley networks and channels inflowing toward a topographic low were the best indicators that ponding might have taken place, and that the sediment observed were actually aqueous sedimentary deposits and not subsequent resurfacing material. The dramatic improvement in resolution, altimetry, and the mineralogical data returned by the Mars Global Surveyor mission allow to go a step forward in the positive identification of lakes from orbit. *(see – Fig.A-)*

The first information that can be collected from orbit with the MOC resolution relates to morphology and climate. Fluvio-lacustrine morphologies reveal the conditions under which a lake was formed. For instance, a lake developed under warm and wet conditions is likely to show a high drainage density of converging valley networks (model of surface water supply), and regular lacustrine terraces and shorelines.

If the conditions are cold and wet, the lake might show ice-push marks on terraces and shorelines, a less dense supply system associated to the melt of snow packs, and possibly scour marks related to the presence of a large body of ice in the lake region.

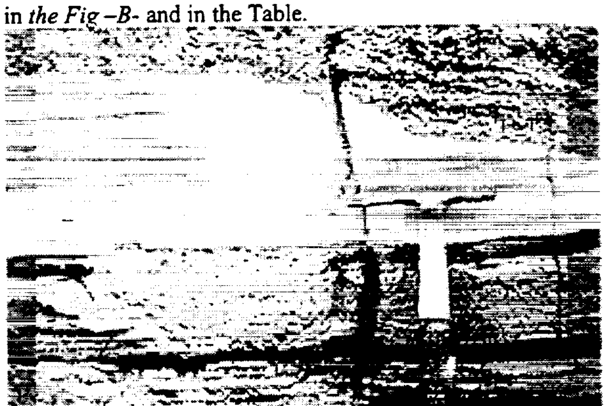
Under cold and dry conditions, the water supply is reduced to potential local or regional emergence of groundwater associated with low drainage density, possibly ice-push marks on benches associated to the freezing of water, less terracing, and in general weaker lacustrine surface expression.



-A- The MOC image No.2306 shows a bright material deposits 50km south of Schiaparelli in the Brazos Valles. This is up to now one the best candidates of evaporite basins ever observed on Mars.

Shorelines, carbonates mounds, tufa towers and benches are also accessible to the resolution of MOC and TES. Therefore, from the features we select from orbital data, we should already have a good insight on what to expect to observe from the ground with the lander and the rover, these features being all associated with specific stratigraphic sequences.

From the ground, the morphology, stratigraphy and mineralogy should allow to document the hypotheses on climate (e.g. nature of salts present, temperature of the water, capacity of transportation and sedimentation deduced from sediment grain-size, grain- shape), hydrogeological and possibly biological processes. We summarized important evidence that should be looked for by the lander and the rover in *the Fig -B-* and in the Table.



-B- Lens of gypsum exposed by a channel near a dry lakebed in the Nevada Desert. This lens shows the existence of isolated and abandoned ponds once the lake water receded. Lamination, varving and sediment chemistry provide information about climate and sedimentation rate.

Morphological and Mineralogical Evidence of Various Types of Lacustrine Environments

Lake System	**Surface and Stratigraphic Expression**
1. *Open: Water-fresh/river dominated clastic sediment*	
Oligotroph	Annual varve or poor lamination. Little organic matter
Lake chain	Increasing salinity. Fractioning of evaporite (carbonate to chloride)
2. *Closed: Shifting facies belt repeated. Reworking and dissolution of salts*	
Eutotroph	Bottom life sparse or absent. Distinct lamination rich in organic matter
Fluctuating levels	Bedded carbonates and/or thick evaporite alternating with fine-grained clastics or black shales
Ephemeral (Playa, Inland Sabkha)	Evaporite pumping through high water table. Central thin salt deposit alternating with clastics.
Water Table Below Lake Floor	Deflation and leaching of salt; Clay dunes.
3. Sea-Lagoon	Different carbonates (changing in water chemistry)

After Einsele, 1992

II. Candidate Landing Sites in Sinus Sabeus: The two following sites hold the potential of providing critical response to the Surveyor Program science objectives.

2.1 Site 1: Brazos Lakes During Orbit 023, image No. 2306 showed a portion of the Brazos Valles centered at 5.5S/347.7W. The image reveals two important informations: (a) a field of exceptionally bright dunes that covers the bottom of the valley. Bright dunes were first observed in this region by the Viking Orbiter 1 in 1978 with 15m/pxl resolution images. They were located in valleys that debouched northwest in a basin for which Rice [1994] proposed a lacustrine origin. The field of dunes observed by MOC is located in one of the Brazos Valles south of Schiaparelli and might have been active recently [Thomas et al., 1999]. These dunes seem to move away from the crater basin into the valley (northwest to southeast), plausibly suggesting that the bright material composing these dunes originates from the crater basin; (b) Similarly bright material is observed on small depressions just south of Schiaparelli. The MGS Imaging team [MOC Release 16-A, B, C, Image No.2036, 1998] proposes that the morphology of the depressions and deposits is similar to dry lake beds with salts or other materials deposited as the lake evaporated (see *Fig. -A-*). The hypothesis of bright salt deposits could be supported by Viking IRTM measurements [Christensen 1988] showing that a derived albedo of this bright material composing both the dunes and the deposits is 0.21, when most Martian dunes usually show lower albedo around 0.15 [Edgett and Parker 1998]. Thomas et. al., [1999] also propose that the dunes are formed of relatively soft minerals, possibly sulphates which are common components of evaporites. To explain faint dark lines that cross the lighter deposits, an alternate hypothesis involving freezing and thawing of water saturated soil was proposed [MOC Release 16-A, B, C, Image No.2036, 1998, *unpublished*]. These observations need to be documented as potential evidence of water ponding on Mars because if verified, this is the type of material that can help achieve some of the most important science objectives of the Surveyor Program (*e.g.* water evolution and favorable environments for life).

• Science Interests: Noachian, Hesperian and Amazonian Materials; Evidence for fluvial activity: convergence of fluvial valleys; plausible presence of evaporites as suggested by the presence of high albedo material in the topographic lows. Strong morphological indicators of ancient lakes; Trafficability TBD.

2.2 Site 2: East Terra Meridiani Basin: The same bright albedo materials are observed west of Schiaparelli and East Terra Meridiani over a surface area covering about 30,000 km^2. At Viking resolution, old valley networks are observed and cover the entire area. They converge towards the bright albedo material. One of the MOC image (#2306) showed a spectacular seepage valley located east to this potential site. The valley is probably similar to the valleys converging towards the basin. Therefore, there is a high probability for this area to be an ancient paleolake bed with exposed evaporites deposits.

• Science Interests: Noachian and Hesperian Materials. Amazonian TBD; Evidence for fluvial activity: convergence of fluvial valleys in topographic low, thus plausible presence of evaporites as suggested by the presence of high albedo material in the basin. Morphological indicators of ancient lakes; Trafficability TBD.

III. Engineering Constraints: The high science interest of the region where the two targets are is combined with a favorable configuration for landing that designates this region as a high-priority candidate area. The recent MOLA altimeter topographic profile No. 23 allows to adjust the regional topography, and shows that the Schiaparelli crater and the surrounding region lie significantly lower than previously thought. The floor of Schiaparelli is now located at -500+/-30m (with reference to the Mars datum) and the Plateau West of the crater and immediately South in the region of the Brazos Basin lies between 1000 and 1500 m [Smith et al., 1998].

Considering the 3-sigma landing footprint ellipse required [Golombek et al., 1999], the revised data show that the elevation requirement made both by the APEX 2001 mission and the Mars Pre-Projects definition for the Mars Sample Return [Spencer et al.,1998] would be met in the Sinus Sabeus region, wherever a landing site being selected in most of the regions directly South, West and Southwest of the crater in Terra Meridiani, which are the regions of interest.

The low elevation will also benefit the mission by allowing savings in mass and propellant margin, the amount of propellant used during the terminal descent being a function of the landing site elevation -the higher the elevation, the higher the amount of propellant expended- [Spencer et al., 1998]. The almost equatorial position of the survey area is also a favorable parameter for landing precision. For instance, for the 01' APEX mission, at 5S, the landing footprint would be around 25 km (compared to 44 km at 15N, the best being 18 km at 15S, Golombek et al., 1998, 1999).

The existence of several sites in the same area with similarly high scientific interest provides safety back-ups in case of deviation in ellipse trajectory. In addition, the location of the region is also favorable for solar energy power and potential mission duration. We show its distribution over time in the plot that we established for the Lander energy profiles for the Sites 1 and 2 region (see Fig. -C-). We compare it against the plots proposed by Spencer et al., (1998) for the 01' APEX mission.

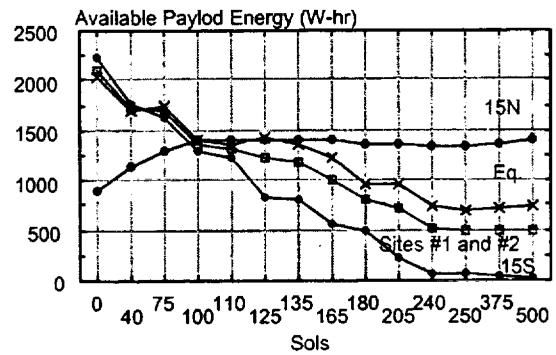


Fig. -C- shows the Lander energy profiles for various latitudes (*after Spencer et al., 1998*). Equatorial and South landing sites provide the highest energy during the beginning of the mission when it is the most critical to secure the science objectives. North sites provide a more regular level but lower at the beginning of the mission that could be of prejudice for the mission. With time, mechanical failure may prevent to complete the mission objectives. Higher levels of energy during the primary mission might be preferable.

Acknowledgments: This work is supported by the NASA Ames Research Center/SETI Institute Cooperative Agreement No. NCC2-1064.

THE THERMAL EMISSION IMAGING SYSTEM (THEMIS) INSTRUMENT FOR THE MARS 2001 ORBITER. P.R. Christensen[1], B. M. Jakosky[2], H.H. Kieffer[3], M.C. Malin[4], H.Y. McSween, Jr.[5], K. Nealson[6], G. Mehall[1], S. Silverman[7], S. Ferry[7]. [1] Arizona State University, Tempe, AZ 85287, [2] LASP, University of Colorado, Boulder, CO. [3] U.S. Geological Survey, Flagstaff, AZ, [4] Malin Space Science Systems, San Diego, CA. [5] University of Tennessee, Knoxville, TN. [6] Jet Propulsion Lab, Pasadena, CA. [7] Santa Barbara Remote Sensing, Goleta, CA.

The primary objective of the Thermal Emission Imaging System (THEMIS) on the Mar Surveyor ;01 Orbiter is to study the composition of the Martian surface at high spatial resolution. THEMIS will map the surface mineralogy using multi-spectral thermal-infrared images in 8 spectral bands from 6.5 to 14.5 µm. In addition, a band centered at 15 µm will be used to map atmospheric temperatures and provide an important aid in separating the surface and atmospheric components. The entire planet will be mapped at 100 m resolution within the available data volume using a multi-spectral, rather than hyperspectral, imaging approach. THEMIS will also acquire 20 m resolution visible images in up to 5 spectral bands using a replica of the Mars 98 Orbiter (MARCI) and Lander (MARDI) cameras. Over 15,000 panchromatic (3,000 5-color), 20 x 20 km images will be acquired for morphology studies and landing site selection.

The thermal-infrared spectral region contains the fundamental vibrational absorption bands of most minerals which provide diagnostic information on mineral composition. All geologic materials, including carbonates, hydrothermal silica, sulfates, phosphates, hydroxides, silicates, and oxides have strong absorptions in the 6.5-14.5 µm region. Silica and carbonates, which are key diagnostic minerals in thermal spring deposits, are readily identified using thermal-IR spectra. In addition, the ability to identify all minerals allows the presence of aqueous minerals to be interpreted in the proper geologic context.

An extensive suite of studies over the past 35 years has demonstrated the utility of vibrational spectroscopy for the quantitative determination of mineralogy and petrology [*Lyon*, 1962; *Lazerev*, 1972; *Farmer*, 1974; *Hunt*, 1976; *Salisbury et al.*, 1987; *Salisbury and Walter*, 1989; *Salisbury et al.*, 1991; *Salisbury*, 1993; *Lane and Christensen*, 1997; *Hamilton et al.*, 1997]. The fundamental vibrations within different anion groups, such as CO_3, SO_4, PO_4, and SiO_4, produce unique, well separated spectral bands that allow carbonates, sulfates, phosphates, silicates, oxides, and hydroxides to be readily identified. Additional stretching and bending modes involving major cations, such as Mg, Fe, Ca, and Na, allow further mineral identification, such as the excellent discriminability of minerals within the silicate and carbonate groups. Significant progress has also been made in the development of quantitative models to predict and interpret the vibrational spectra produced by emission of energy from complex, natural surfaces [*Conel*, 1969; *Henderson et al.*, 1992; *Hapke*, 1993; *Moersch and Christensen*, 1995; *Wald and Salisbury*, 1995; *Mustard and Hays*, 1997].

A key characteristic of mid-infrared spectroscopy for quantitative mineral mapping lies in the fact that mid-infrared spectra of mixtures are linear combinations of the individual components [*Ramsey*, 1996; *Thomson and Salisbury*, 1993]. The mid-IR fundamental vibration bands have very high absorption coefficients and therefore much of the emitted energy only interacts with a single grain. When absorption coefficients are low, as is the case for overtone/combination bands, the energy is transmitted through numerous grains and the spectra become complex, non-linear combinations of the spectral properties of the mixture.

THEMIS is designed as a follow-on to the Mars Global Surveyor Thermal Emission Spectrometer (TES), which is currently mapping the surface and atmosphere of Mars in 143 spectral bands. The TES investigation has mapped the existence of coarse-grained, crystalline hematite [*Christensen et al.*, this issue-b], determined that basalt is the major constituent of the southern-hemisphere dark regions [*Christensen et al.*, this issue-a], and mapped the spatial and temporal properties of atmospheric dust and clouds [*Smith et al.*, this issue-a; *Pearl et al.*, this issue]. In addition, the TES investigation has demonstrated that the atmospheric components can be accurately separated from the surface components in thermal-IR spectra [*Bandfield et al.*, this issue; *Smith et al.*, this issue-b; *Christensen et al.*, this issue-a]. The techniques developed for the TES investigation will be applied directly to the THEMIS data. THEMIS covers the same wavelength region as the TES, and the THEMIS filters were selected utilizing knowledge of martian minerals determined from TES data. TES global maps will also allow efficient targeting of areas with known concentrations of key minerals.

Remote sensing studies of natural surfaces, together with laboratory measurements, have demonstrated that 9 IR spectral bands are sufficient to identify mineral classes at abundances of ~10%

[*Feely and Christensen*, in press]. The long-wavelength IR can also provide some penetration through atmospheric dust and surface coatings.

The specific science objectives of the THEMIS experiment are:

(1) to determine the mineralogy and petrology of localized deposits associated with hydrothermal or sub-aqueous environments, and to identify sample return sites likely to represent these environments.

(2) to provide a direct link to the global hyperspectral mineral mapping from the MGS TES by utilizing the same infrared spectral region at high (100 m) spatial resolution.

(3) to study small-scale geologic processes and landing site characteristics using morphologic and thermophysical properties.

(4) to search for pre-dawn thermal anomalies associated with active sub-surface hydrothermal systems

The quantitative mineral mapping objective will be met with a noise-equivalent delta emissivity (NE) of 0.006-0.03, corresponding to a signal-to-noise ratio of 33-150. The instrument design will achieve this performance at the surface temperatures typical for the 4:30 PM orbit (235-265 K) using an uncooled microbolometer detector array. In addition, the '01 orbit is ideally suited to the search for pre-dawn temperature anomalies associated with active hydrothermal systems, whose discovery would radically alter our view of the current Mars. The instrument performance will detect temperature differences of only 1 K at 180K.

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MELAS CHASMA : POTENTIAL LANDING SITE FOR THE MARS 2001 MISSION. F. Costard[1], N. Mangold[1], Ph. Masson[1], D. Mege[2] and J.P. Peulvast[1]. [1]UMR 8616 CNRS, Laboratoire de Géologie Dynamique de la Terre et des Planètes, Univ. Paris-Sud, 91405 Orsay Cedex, France, peulvast@geol.u-psud.fr. [2] Département de Géotectonique, ESA CNRS 7072, case 129, Univ. Pierre et Marie Curie, 75005 Paris, France.

Introduction : The French Working Group on landing site retained Melas Chasma, Valles Marineris (figure 1) among its highest priorities for in situ exploration of Mars. Therefore this region is proposed by the authors as one of the most interesting site for the 2001 mission. Its characteristics fit all the engineering constraints including landing ellipse and slopes [1]. Since Valles Marineris seems to be unlikely to be selected as a landing site for the Mars Sample Return missions, the Mars Surveyor mission in 2001 will be the last opportunity in the next decade to improve what we know about Valles Marineris.

Geomorphological context : The central Valles Marineris is the widest part of the equatorial trough. It is 260 km wide and 380 km long. The walls and plateau edges are dissected by large amphitheaters and displays wide regional collapses which were possibly formed along and around multiple parallel weakness zones (figure 2) initiated by tectonics [2, 3]. Removal of material may be the result of sapping processes, ice-lubricated creep, sublimation, subsurface drainage [4] or karst collapse [5]. The removed material may have been partly incorporated into the canyon interior stratified deposits, possibly due to the drainage of a postulated lake.

Figure 1: Candor Chasma. Controlled photomosaic M500K-10/72CM showing the layered rocks bench. Scale : 150 x 125 km.

The nature of these stratified deposits (figure 1) is uncertain and has been discussed by many authors. Several hypotheses were proposed including eolian, alluvial, evaporitic, lacustrine, or volcanic origins [6]. These deposits would be volcanic ash interbedded with layers of relatively resistant welded tuffs or mafic lava flows erupted within the chasmata [2, 3, 4]. Alternatively, these layers could be lacustrine deposits, or both volcanic and lacustrine materials - i.e. volcanism in paleo-lake [4, 7].

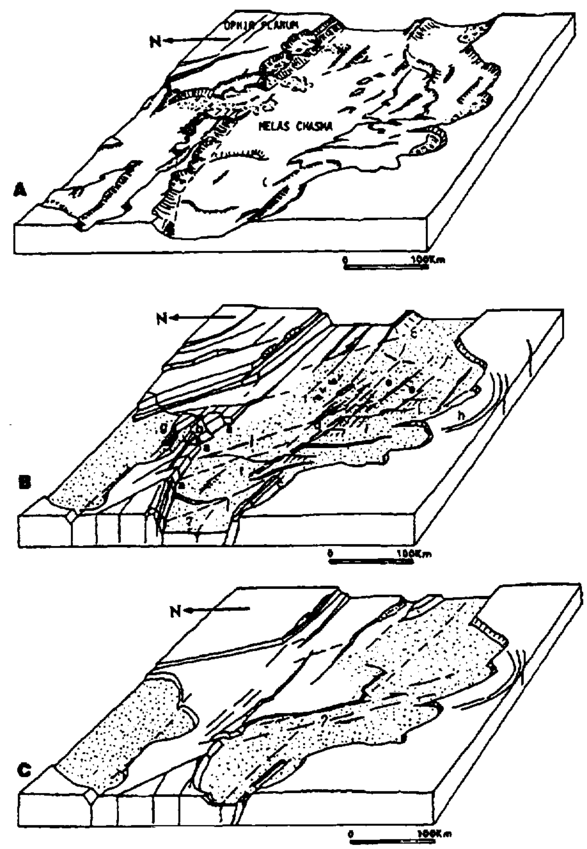

Figure 2 : Block diagrams of Central Valles Marineris. (A) Present morphology. (B) Present structural pattern, (C) Previous structural pattern (first stage of subsidence and deposition of layered deposits). From [2, 3].

Volatile characterization of the Melas Chasma: The presence of rampart craters in the surroundings of the troughs provides clues about the volatile distribution around Valles Marineris. Ejecta mobility can be expressed by the EM ratio, of the maximum diameter of ejecta deposits divided by the diameter of the parent crater. This ratio, termed the ejecta mobility (EM ratio) is assumed to correlate with the quantity of volatiles involved during emplacement [8, 9, 10, 11]. The relationship between the distribution of relatively high mobile ejecta around rampart craters and the occurrence of erosional landforms related to important wall retreat or dissection (figures 3 and 4) strongly suggests that volatiles may have contributed to the widening of Central Valles Marineris troughs [8, 12]. Another hypothesis is the presence of ground water below the permafrost [13]. According to the latter author, water that fully saturates the pore space of the rock may have produced regolith mass movements, at the base of some high walls, e.g. in western Ophir Chasma, though the porosity is reduced at depth by the effect of lithostatic stresses, [14]. It may have induced sapping along discontinuities in more coherent rocks (Louros Valles).

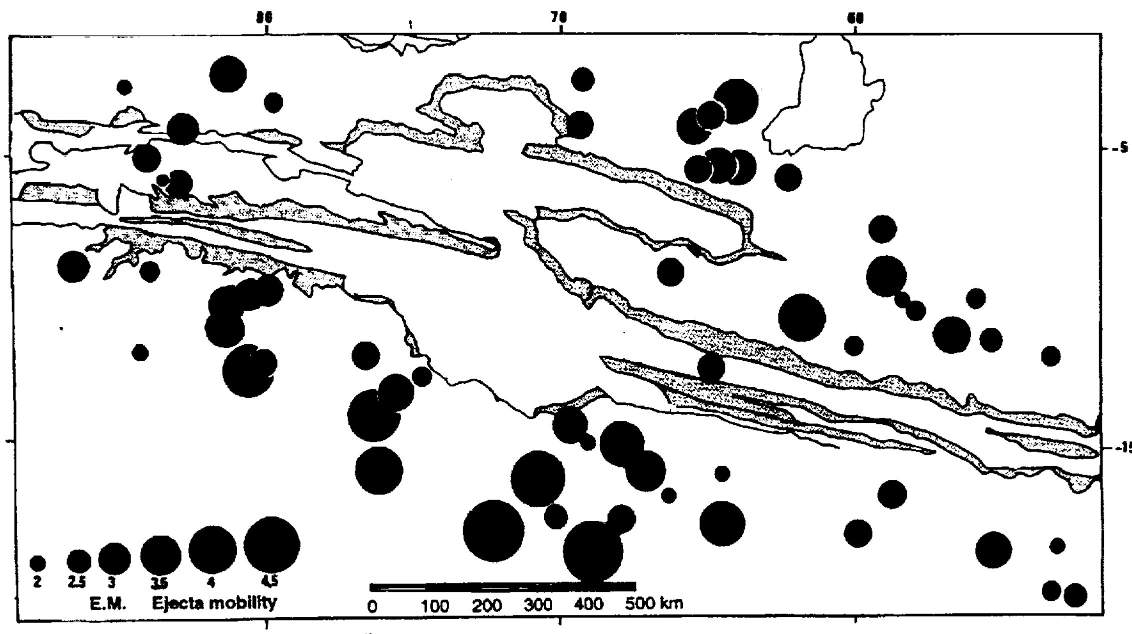

Figure 3 : Distribution of rampart craters within ± 5° of the Valles Marineris. High EM ratio generally appears near the Chasma unit. From [8, 12].

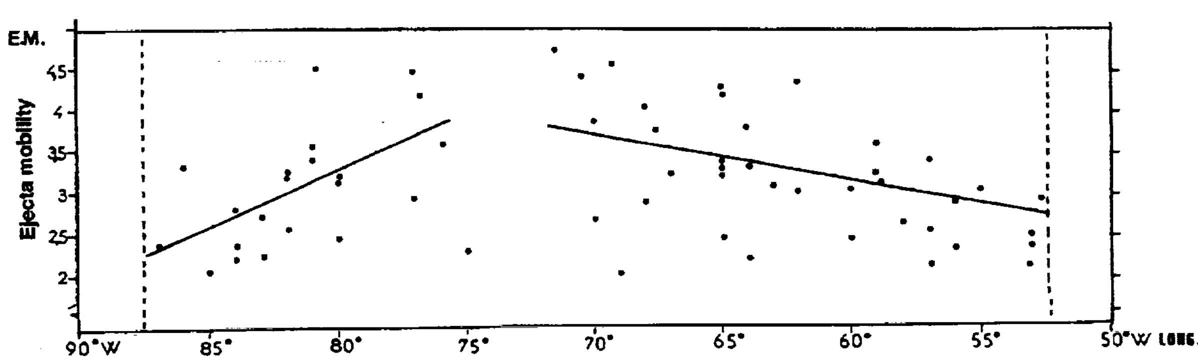

Figure 4 : Variations of the EM ratio (Y axis) for 62 rampart craters according to their location on the canyon (X axis). Both regression lines exhibits a clear general rise in the EM ratio (ejecta mobility) towards the central part of the canyon. Note the enrichment in volatile materials from the margins to the Central Valles Marineris. This concentration of volatile may have contributed to the widening of the Chasma. From [8, 12].

In all cases, it is suggested that the EM ratio may be closely related to the porosity of the wall rock. If this is the case, it is assumed that the upper crust in the central chasmata area is relatively more porous than in peripheral areas. The regional concentration of volatiles may result from accumulation of underground water from neighbouring areas. The widening of the chasmata by sapping may have involved release of water from confined aquifer [15, 16, 17]. This interpretation might be genetically consistent with a lacustrine origin for the layered deposits that were emplaced in Central Valles Marineris.

Melas Chasma : A safe landing site with lots of scientific interests. Melas Chasma represents an interesting site because all instruments would be able to be used in optimal way. Thanks to the new small landing ellipse (less than 10 km), the resolution of the IR spectrometer (Mini-TES) and of the camera (PanCam) will be enough to analyze the geology and mineralogy of the geologic units of nearby scarps.

The proposed sites are located on the floor of central-south Melas Chasma in the vicinity of the edge of the layered deposits. Two landing ellipses centered on –9.8° ; 74.1°W and –10.3° ; 73.4°W are presented (figure 1). Their topography appears to be very flat on Viking pictures but they are overlooked by nearby erosional escarpments where the layered deposits are not concealed by talus. Should the final landing site be 10 km far away from the scarp, the resolution would be 2.8 m/pix for the PanCam and 80 m/step for the Mini-TES. Taking a 2 km high scarp, this last resolution will be enough to distinguish between two tens of stratigraphical units from the top to the bottom of the scarps. If the material is volcanic, as it is usually argued, the result would improve the understanding of the geochemical evolution of the crustal material in the Tharsis region. The geological study of the scarp would also be improved with the Descent Imager that would take high-resolution pictures of the region near the site before landing.

In-situ analyzes related to water processes and past environment with APEX are also possible because of the context of Melas Chasma. The topographic map given by MOLA [18] shows that Melas Chasma is a closed depression. So if water flowed into this canyon it may have formed lacustrine deposits interesting for climatic and exobiological perspectives. These analyses would also improve the knowledge of the geological evolution of Valles Marineris [19]. The MECA experiment would also be interesting in this place because this region would be a popular and scientifically interesting place to land for a manned mission. For all these reasons we think that Melas Chasma is a first choice landing site for 2001.

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NANNOBACTERIA ON EARTH ARE TRULY LIVING ORGANISMS. R. L. Folk[1] and F. L. Lynch[2], [1]Dept. of Geosciences, Univ. of Texas, Austin, TX, USA, [2]Dept. of Geology, Mississippi State College, Starkville, Mail Stop, USA.

The crux of the argument about so-called Martian "nannobacteria" discovered by NASA in meteorite ALH84001, is that they are "too small to be bacteria". When in 1990 mineralized nannobacteria were first discovered in hot spring travertines of Viterbo, Italy, their size was typically 50 - 200 nm (Folk, 1992, 1993). This is about 1/10 the diameter, or 1/1000 the volume of most bacteria; nannobacteria are larger than most viruses (typically 10-30nm). The Martian features (McKay et al., 1996) were balls, worms and filaments around 50nm in diameter, exactly in the size range of the earthly analogues.

Biologists' arguments against the concept of nannobacteria were good in theory; a cell smaller than 200 nm in diameter should not have sufficient room inside to contain genetic coding, ribosomes and other organelles required for metabolism and "life"—life as we "know" it in the 1990's. However, new facts are continually bursting old dogmatic wineskins and such has been the case in the last few years. The lower limit of "life" has descended to at least 50 nm or perhaps even smaller. Now, in 1999, the Martian nannnobacteria are clearly within the range of known culturable organisms on earth, no matter whether one wants to call them nannobacteria, viruses, nannobionts or anything in between and no matter where one wishes to place the fuzzy lower boundary of "life". Before Leeuwenhoek or Pasteur, no one thought that anything invisible to the naked eye could be "alive". But the optical microscope lowered this limit to 0.2 μm and later the scanning electron microscope's higher resolution revealed a whole hidden nano-universe awaiting investigation.

The poster will show examples of nano-organisms in the 50-150 nm size range from various laboratories. Most of these are culturable, some stain positively for DNA, some are composed of C, N, O (the elements in living tissue) and some even show cell walls.

Foremost among the laboratories working on nano-organisms is a group of medical researchers at the University of Kuopio, Finland under Olavi Kajander. They found "nanobacteria" in mammal blood in the early 1990's, but nobody believed them and they could not get their findings published; "...too small to be bacteria....", said the rejection notices. Finally in 1993 they published in *Scanning*, an SEM journal where they could evade bio-critics. Their work was little noticed until 1996: after the NASA announcement about Martian life, an Austin-American Statesman reporter, Dick Stanley, looked up the word "nan(n)obacteria" in his search engine and found two laboratories independently working on the same creatures, the University of Texas and the Kajander Group. So the Finnish work finally swam into the ken of geologists and astronomers (eg. Kajander and Ciftcioglu, 1998 Proc. National Acad. Sciences).

Professor Allen Hamilton, microbiologist at the University of Aberdeen, Scotland, has successfully cultured nannobacteria on samples of feldspar, using lactate and temperatures up to 90°C. His samples of 100 x 300 nm "worms" look exactly like the SEM of Martian "swimming hordes", and his other cultured colonies are made of 100 nm balls. These nannobacteria are not associated with larger bacterial cells (ie. they are not infecting anything) so they must be able to reproduce and metabolize independently, unlike viruses.

Professor Robert J. C. McLean and his student Sabitha Prabhakaran at Southwest Texas State University, San Marcos, have been working on nannobacteria in calf blood and kidney stones, duplicating the Finnish work. They have cultured the organisms and gotten excellent TEM sections showing cell walls and dark internal particles (similar in appearance to ribosomes) in bodies ranging from 200 nm to as small as 40 nm.

Professor Phillippa Uwins (University of Queensland, Australia) has cultured organisms she calls "nanobes" in sandstone from a deep well (1998 Am. Min.). Most of these are bean sprout-shaped, but there are also many spheroids as small as 40 nm. From these organisms she has obtained chemical analyses diagnostic of life, stained successfully for DNA, and observed probable cell walls in TEM.

At the University of Texas we have collected 30 – 150 nm spherical and worm-like shapes from hot and cold spring waters by filtration or centrifugation. It appears that many natural waters are rich in organisms that are able to pass through the standard 0.2 micron filters used by microbiologists to declare waters officially clean and bacteria-free.

The medical literature is replete with images of such objects as Cell-Wall-Deficient Bacteria, Mycoplasmas, etc., consisting of small spheres and rods as small as 50 nm with cell walls – again, right in the size range of the Martian objects. We have found nannobacteria-like objects in human cataracts and arterial plaque. Dwarfed, filter-passing forms of bacteria have been known for a century (Hadley, 1931; Oppenheimer, 1952; Morita, 1988) but were believed to be rare and unimportant. It now appears, however, that they may form most of the earth's biomass. Similarly, Martian life probably started with – and may have ended with – nannobacteria.

THE MARS PATHFINDER MISSION AND SCIENCE RESULTS. M. P. Golombek. Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109.

Mars Pathfinder, the first low-cost, quick Discovery class mission to be completed, successfully landed on the surface of Mars on July 4, 1997, deployed and navigated a small rover, and collected data from 3 science instruments and 10 technology experiments. The mission operated on Mars for 3 months and returned 2.3 Gbits of new data, including over 16,500 lander and 550 rover images, 16 chemical analyses of rocks and soil, and 8.5 million individual temperature, pressure and wind measurements. The rover traversed 100 m clockwise around the lander, exploring about 200 square meters of the surface. The mission captured the imagination of the public, and garnered front page headlines during the first week. A total of about 566 million internet "hits" were registered during the first month of the mission, with 47 million "hits" on July 8th alone, making the Pathfinder landing by far the largest internet event in history at the time.

Pathfinder was the first mission to deploy a rover on Mars. It carried a chemical analysis instrument, to characterize the rocks and soils in a landing area over hundreds of square meters on Mars, which provided a calibration point or "ground truth" for orbital remote sensing observations [1, 2]. The combination of spectral imaging of the landing area by the lander camera, chemical analyses aboard the rover, and close-up imaging of colors, textures and fabrics with the rover cameras offered the potential of identifying rocks (petrology and mineralogy). With this payload, a landing site in Ares Vallis was selected because it appeared acceptably safe and offered the prospect of analyzing a variety of rock types expected to be deposited by catastrophic floods, which enabled addressing first-order scientific questions such as differentiation of the crust, the development of weathering products, and the nature of the early Martian environment and its subsequent evolution [2]. The 3 instruments and rover allowed seven areas of scientific investigation: the geology and geomorphology of the surface, mineralogy and geochemistry of rocks and soils, physical properties of surface materials, magnetic properties of airborne dust, atmospheric science including aerosols, and rotational and orbital dynamics of Mars. Scientists were assembled into 7 Science Operations Groups that were responsible for requesting measurements by the 3 instruments, rover and engineering subsystems for carrying out their scientific investigations and for analyzing the data and reporting on their findings.

The spacecraft was launched on December 4, 1996 and had a 7 month cruise to Mars, with four trajectory correction maneuvers. The vehicle entered the atmosphere directly following cruise stage separation. Parachute deployment, heatshield and lander separation, radar ground acquisition, airbag inflation and rocket ignition all occurred before landing at 2:58 AM true local solar time (9:56:55 AM PDT). The lander bounced at least 15 times up to 12 m high without airbag rupture, demonstrating the robustness of this landing system. Reconstruction of the final landing sequence indicates that the parachute/backshell/lander was tilted due to a northwest directed wind and wind shear, which resulted in the lander bouncing about 1 km to the northwest and initially downhill about 20 m from where the solid rockets fired. Two anomalously bright spots located in the lander scene are likely the heatshield, which continued in a ballistic trajectory about 2 km downrange (west southwest), and the backshell/parachute, which stayed nearer to where the rockets fired. Unconnected disturbed soil patches in the scene indicate that the final few bounces of the lander were from the east-southeast and were followed by a gentle roll to the west before coming to rest on the base petal. The location of the lander away from where the solid rockets fired and considerations of the exhaust products used to inflate the airbags and their fate, indicate that the Pathfinder landing system is one of the cleanest designed leaving the local area essentially contaminant free. The radio signal from the low-gain antenna was received at 11:34 AM PDT indicating successful landing.

Because the lander and rover were solar powered, most real time operations occurred during the Martian day, which shifted 37 min a day relative to time on the Earth, and involved 24 hr staffing during the nominal mission. Scientists and engineers had 3 hours from the end of the last downlink of a sol to analyze the data that had been returned, assess what had been learned, determine the actual location of the rover, and revise plans for the subsequent sol. The next 12 hours involved creating the specific lander, rover and instrument sequences, fitting them in a workable timeline, testing and validating them on a testbed, and uplinking them to the spacecraft at the start of the next sol.

Five prominent horizon features, including 3 knobs, one large crater on the horizon and two small craters have been identified in lander images and in the high-resolution Viking orbiter images, which allows the lander to be located with respect to other surface features [3]. Based on azimuths to the features, the location of the lander in the Viking images can be determined to within a few pixels (about 100 m). Within the USGS cartographic network the lander is located at 19.13°N, 33.22°W, but a revised cartographic network [4] for the local area and the two-way ranging and Doppler tracking [5] results in inertial space suggest that the USGS network is displaced about 18 km to the north and 9 km to the west.

Many characteristics of the landing site are consistent with its being shaped and deposited by the Ares and Tiu catastrophic floods [6]. The rocky surface is consistent with its being a depositional plain (16% of the area is covered by rocks) with subrounded pebbles, cobbles and boulders that appear similar to depositional plains in terrestrial catastrophic floods. The Twin Peaks appear to be streamlined islands in lander images, which is consistent with interpretations of Viking orbiter images of the region that suggest the lander is on the flank of a broad, gentle ridge trending northeast from Twin Peaks [3]. This ridge, which is the rise to the north of the lander, is aligned in the downstream direction from the Ares and Tiu Valles floods, and may be a debris tail deposited in the wake of the Twin Peaks. Rocks in the Rock Garden may be imbricated or inclined blocks generally tilted in the direction of flow. Channels visible throughout the scene may be a result of late stage drainage. Large rocks (>0.5 m) appear tabular, subrounded, and many appear perched, consistent with deposition by a flood. Smaller (<0.3 m) angular darker rocks and blocks may be ejecta from a nearby crater [6]. Evidence for eolian activity at the site includes wind tails behind rocks and wind streaks of what appears to be very fine grained bright red drift material, similar in color to dust in the atmosphere. Dirt covering the lower 5-7 cm of several rocks suggest that they have been exhumed [6]. Some rocks appear to be fluted and grooved by saltating sand size particles in the wind and light colored sand dunes have been imaged in the trough behind the Rock Garden by the rover.

In general, rocks are dark gray with discontinuous coatings of bright red dust and/or weathered surfaces [6]. Undisturbed dark soil, which appears dark (black) in surface images, and dark red soil, which appears in areas disrupted by the rover and airbags, have colors between the bright red and dark gray. A very bright red material (e.g., Scooby Doo) may be an indurated soil, because its composition is similar to soils elsewhere at the site [7]. Soil compositions are generally similar to those measured at the Viking sites, which are on opposite hemispheres. Thus this soil may be a globally deposited unit on Mars [7]. The similarity in compositions among the soils implies that the differences in color may be due to either slight differences in iron mineralogy or differences in particle size and shape.

The rock chemistry is similar to basalts, basaltic andesites, and andesites on the Earth. [7]. These rocks have compositions that are distinct from those of the Martian meteorites. Analyses of lower silica rocks appear rich in sulfur implying that they are covered with dust or weathered. The chemistry and normative mineralogy of the dust free rocks are similar to those of common terrestrial anorogenic andesites, such as icelandites, which formed by fractional crystallization of mantle derived parent materials. Rover images show some rocks appear vesiculated and may be volcanic. Rover close-up and lander super resolution images show rocks with a variety of morphologies, textures and fabrics such as pitted, smooth, bumpy, layered and lineated, suggesting that a variety of rock types are present at the site. Soils are chemically distinct from the rocks measured at the landing site [7].

Airborne magnetic dust has been progressively deposited with time on most of the magnetic targets on the lander [8]. The dust is bright red and has a magnetization consistent with composite particles with a small amount of maghemite as stain or cement. An interpretation of these results suggests that the iron was dissolved out of crustal materials in water, suggesting an active hydrologic cycle on Mars, and the maghemite is a freeze-dried precipitate.

Observations of wheel tracks and soil mechanics experiments suggests that compressible, drift, cloddy and indurated surface materials are present [9]. Bright red drift material and others may be very fine grained dust; most are composed of poorly sorted dust, sand-sized particles, lumps of soil, and small rocks. Angles of repose and internal friction are like those on Earth and imply bulk densities of surface materials between 1.2 and 2 g/cm^3. Rover images show a large number of loose spherically rounded pebbles and cobbles on the surface. Some rocks show reflective hemispheric pockets or indentations and rounded pebbles, implying that the rock is a conglomerate [9]. Conglomerates require running water to smooth and round the clasts and to deposit the materials and argues for a warmer and wetter past in which liquid water was stable and the atmosphere was thicker.

The atmospheric opacity has been about 0.5 since landing on Mars [6] in late northern summer (Ls of 143°). Slightly higher opacity at night and early in the morning may be due to clouds, which have been imaged, and fog. The sky has been a pale-pink color and particle size (roughly a micron) and shape and water vapor (about 10 precipitable microns) in the atmosphere are all consistent with measurements made by Viking [10]. The upper atmosphere (above 60 km altitude) was relatively cold, although this may be consistent with seasonal variations and entry at 3 AM local solar time (compared with the warmer upper atmosphere measured by Viking at 4 PM local solar time [11, 12]). The multiple peaks in the landed pressure measurements and the entry and descent data are indicative of dust uniformly mixed in a warm lower atmosphere, again similar to that measured by Viking [13].

The meteorology measurements show repeatable diurnal and higher order pressure and temperature fluctuations [12]. The barometric minimum was reached at the site on sol 20 indicating the maximum extent of the winter south polar cap. Temperatures fluctuated abruptly with time and between 0.25 and 1 m height in the morning. These observations suggest that cold morning air was warmed by the surface and convected upward in small eddies. Afternoon temperatures, after the atmosphere has been warmed do not show these variations. Winds have been light (<10 m/s) and variable, peaking at night and during daytime. Dust devils have been detected repeatably in the early afternoon [12] and have been found in lander images.

Daily Doppler tracking and less frequent two-way ranging during communication sessions between the spacecraft and Deep Space Network antennas have resulted in a solution for the location of the lander in inertial space and the direction of the Mars rotation axis [5]. Combined with earlier results from the Viking landers, this gives a factor of three improvement in the Mars precession constant. The estimated precession rate is consistent with the hypothesis that the non-hydrostatic component of the polar moment of inertia (0.3662±0.0017) is due to the Tharsis bulge [5]. The estimated precession constant rules out warm interior models with mantle compositions similar to Earth and cold, highly iron enriched models. If the (iron-enriched)

Shergottite meteorites are typical of the mantle composition, then the mantle must be warmer than Earth's (for the same pressure level) and the core radius must be larger than ~1300 km (but no larger than ~2000 km for other mantle compositions). The annual variation in rotation agrees with the expected seasonal mass exchange of carbon dioxide between the ice caps and atmosphere.

Taking all the results together supports an early Mars that may be Earth-like. Some crustal materials on Mars may be similar in silica content to continental crust on Earth. The rounded pebbles, cobbles and the possible conglomerate and the abundant sand- and dust-size particles and models for their origin, support a water rich planet in which the early environment was warmer and wetter and liquid water was in equilibrium, perhaps similar to the early Earth. In contrast, Mars, since the Hesperian (1.5-3.5 Ga), appears to be a very un-Earth like place, with very low erosion rates producing minor changes to the surface at the Pathfinder landing site. [3].

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CONSTRAINTS, APPROACH AND PRESENT STATUS FOR SELECTING THE MARS SURVEYOR '01 LANDING SITE. M. Golombek[1], F. Anderson[1], N. Bridges[1], G. Briggs[2], M. Gilmore[1], V. Gulick[2], A. Haldemann[1], T. Parker[1], R. Saunders[1], D. Spencer[1], J. Smith[1], L. Soderblom[3], and C. Weitz[1], [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, [2]Ames Research Center, Moffett Field, CA 94035, [3]U. S. Geological Survey, Flagstaff, AZ 86001.

Introduction: There are many similarities between the Mars Surveyor '01 (MS '01) landing site selection process and that of Mars Pathfinder. The selection process includes two parallel activities in which engineers define and refine the capabilities of the spacecraft through design, testing and modeling and scientists define a set of landing site constraints based on the spacecraft design and landing scenario. As for Pathfinder, the safety of the site is without question the single most important factor, for the simple reason that failure to land safely yields no science and exposes the mission and program to considerable risk. The selection process must be thorough, defensible and capable of surviving multiple withering reviews similar to the Pathfinder decision. On Pathfinder, this was accomplished by attempting to understand the surface properties of sites using available remote sensing data sets and models based on them (see [1] for a description of the approach and [2] and [3] for the results). Science objectives are factored into the selection process only after the safety of the site is validated. Finally, as for Pathfinder, the selection process is being done in an open environment with multiple opportunities for community involvement including open workshops, with education and outreach opportunities.

Engineering Constraints: The engineering constraints are derived from the spacecraft design and landing scenario as defined by the MS '01 engineering team. Present targeting capabilities using aeromanuevering result in a 26 km diameter landing circle at the equator that varies linearly to about 20 km diameter at 12°S. All elevations within the landing ellipse must be below 2.5 km with respect to the 6.1 mbar geoid to allow the parachute sufficient time to bring the spacecraft to terminal velocity before the retro-rockets fire. The actual requirement derives from the density profile of the atmosphere above the surface, which is translated into an elevation requirement via atmospheric models relative to the geoid, season, location, and time of entry. The surface pressure must also be less than 10.6 mbar to allow proper opening of the solar panels, which requires that elevations be above -3 km. The latitude of the landing site is presently limited by lifetime requirements of the mission (90 days), which translates into temperature and solar power considerations to be near equatorial and between 3°N and 12°S, which has been significantly narrowed from the original 15°N to 15°S.

Severe surface slopes negatively impact the lander and rover in a number of ways. During terminal descent a radar altimeter measures the closing velocity and triggers the firing of the retro-rockets for safe landing. For example, the rockets might begin firing on top of a mesa, only to be carried by residual horizontal velocity to the edge of the mesa with a precipitous drop off resulting in insufficient propellant to land safely. Alternatively, the rockets might fire too late if its horizontal velocity carried it towards a steep rise during landing. The three-legged lander is stable on surfaces with slopes up to 16°. Allowing for a 6° tilt due to maximum leg crush during lander impact, limits the acceptable surface slope to about 10°. Finally, any tilt of the lander could adversely affect power generation on the surface. Steep slopes are also a concern for rover power generation and trafficability.

Rocks are also a major concern. Depending upon the amount of leg crush that occurs during landing, the underside of the lander thermal enclosure could be as low as 33 cm above the surface, which limits the height of rocks that can be safely spanned. In addition, each leg has two stabilizers that extend from the lander feet to the base of the lander that could be damaged by impact during landing. The preliminary engineering constraint is that the probability of landing on a rock >33 cm high should be less than about 1%. Extremely rocky areas also slow or impede rover trafficability. The Sojourner rover on Pathfinder (a nearly identical rover will be flown on MS '01) traversed and maneuvered slowly and carefully in local areas with >20% rock coverage, but maneuvered easily and took long traverses without stopping in areas with <15% rock coverage.

Finally, extremely dusty environments can negatively impact the mission. The surface must be radar reflective for the lander to measure the closing velocity. Surfaces covered with extreme thicknesses of dust may not be reflective and may not provide a load bearing surface needed for safe landing and roving. Very dusty surfaces also could raise a plume of dust that could coat instruments and rocks. Dust also could be deposited on solar cells thereby reducing power and/or mission lifetime.

Landing Site Safety Criteria: To determine if the surface characteristics of a site meet the above engineering constraints, the evaluation, interpretation and modeling of remote sensing data are required. Because 20 year old Viking data are used to evaluate the sites, the initial means of inferring the surface characteristics are very similar to those used by Pathfinder [e.g., 1 and references therein].

Higher resolution Viking Orbiter images allow more detailed evaluation of potential hazards at prospective locations than lower resolution images because smaller landforms can be identified. Landforms about 250-500 m across can be identified in Viking images of about 50-100 m/pixel, which are preferable to areas covered by lower resolution images. Slopes over tens of meters scale can be investigated in areas covered with high-quality and -resolution images using photoclinometry or photogrammetry. Potential landing sites should be covered by <100 m/pixel images and appear hazard free with relatively few large scarps, slopes, mesas, hills, and craters.

Infrared thermal mapper (IRTM) data can be used to identify rocky areas and those dominated by dust [4]. Areas with very rocky surfaces (like the two Viking and Pathfinder landing sites) are also potentially hazardous. Model rock size-frequency distributions derived from those measured at the Viking and Earth analog sites [5] (and that accurately predicted those at the Pathfinder site) were used to show that areas with total IRTM rock abundance [6] of <10% (roughly similar to the Viking Lander 1 site without the outcrops) meet the preliminary engineering constraint of <1% chance of landing on a rock higher than 33 cm. Areas with <5% total rock abundance are likely to have surfaces dominated by dust [4] that may not be radar reflective or load bearing. As a result, areas with rock abundance between 5% and 10% likely meet the safety criteria. In addition, areas with fine component thermal inertias of $<4 \times 10^{-3}$ cgs units (or 10^{-3} calories cm^{-2} $s^{-0.5}$ K^{-1}) may be very dusty and may not provide a load bearing surface suitable for landing and roving [1].

Radar data provides information on the elevation, roughness, distribution of slopes, and bulk density of the surface. A radar reflective surface is obviously required for safe landing. Areas with normal radar reflectivity greater than 0.05 will provide a reflective surface for the descent altimeter and will provide a load bearing surface with acceptable bulk density [e.g., 1]. One relation suggests that areas with radar derived root-mean-square slopes of <4° will have surface slopes exceeding 10° for about 4% of its surface [1]. Finally, albedo and Viking Orbiter color can be used to infer the coverage of dusty or weathered surfaces versus rocky or less weathered or dusty surfaces because dust has a high albedo and is bright in the red and less weathered surfaces have lower albedo and are less red [1].

Areas that have: (1) elevation below 2.5 km and above -3 km in the USGS DTM (Digital Terrain Model); (2) locations between 3°N and 12°S; (3) rock abundance between 3% and 13% (which must be later verified to be within 5%-10%); (4) fine component thermal inertia above 4×10^{-3} cgs units; and (5) contiguous 50 and 100 m/pixel or better Viking Orbiter images are shown on our web site at http://mars.jpl.nasa.gov/2001/landingsite/index.html. Approximately 30 locations meet these remote sensing safety requirements. An additional 10 locations meet the requirements with lower resolution (<100 m/pixel) Viking Orbiter images. These 40 locations are in Melas Chasma, Eos Chama and others at the eastern end of Vallis Marineris, Maja Valles, Terra Meridiani, and north of Hesperia Planum. Most locations are in Noachian heavily cratered terrain, although some are in Hesperian channel materials.

Future Data: A major difference between the MS '01 landing site selection process and that of Pathfinder is the availability of new information from the completed Pathfinder mission and the ongoing Mars Global Surveyor (MGS) mission. Although the timeline for site selection requires the activity to begin with existing Viking data, these data sets will be improved and augmented substantially with MGS data acquired in 1999 (note that data acquired by the Mars Climate Orbiter will be too late to affect the selection, which must be finalized by 1/00). High resolution (1.5 m/pixel) Mars Orbiter Camera (MOC) images and roughly 6 m/pixel image swaths are being acquired and will be required in any approved landing site or in nearby similar terrain to identify potential hazards at the meter scale. Thermal Emission Spectrometer data will be needed to update, refine and improve both the spatial and spectral data from the Viking IRTM and to assure that the rock abundance is between 5% and 10%. Mars Orbiter Laser Altimeter (MOLA) data (and gravity data) will be needed to improve the shape, geoid and elevation of prospective sites as well as to examine the slopes between measurements and relief at lander scale from the returned pulse spread. Agreements with all MGS investigators have been made to collect and make available relevant data in a timely manner. Initial comparison of Viking era topographic data with new MOLA data suggest little difference in areas available for landing.

A final difference between the MS '01 landing site selection process and that of Pathfinder is the reliance on delay-Doppler radar data, which Pathfinder required to constrain the elevation and roughness. For MS '01, the elevation will be provided by MOLA and other radar data sets such as Continuous Wave, Arecibo, and Goldstone-Very Large Array will be used to show areas with anomalous properties, such as low reflectivity (e.g., stealth) or extreme roughness. MOLA data will also be used to assess slopes and local relief.

Data sets, announcements and a schedule for the selection of the MS '01 landing site is being maintained on our web site (URL above). After the June 1999 landing site workshop, the number of sites being studied in detail will be limited to order 10.

Landing Site Workshop: A Mars Surveyor '01 Landing Site Workshop was held at the State University of New York at Buffalo June 22-23, 1999. This workshop was open to the science community and had sessions on the general project science and constraints, new MGS results, general landing site considerations, and specific proposed candidate landing sites. About 60 candidate landing sites were proposed at the workshop [7]. Most of the sites proposed met the engineering and remote sensing criteria discussed earlier. These sites are located in Highland Sites (0-40°W), Valles Marineris, Memnonia, Aeolis, Elysium and Terra Cimmeria, Isidis, and Sinus Sabaeus. Unavailable for most proposed sites were the new MOC high-resolution images. Because of the importance of these data in interpreting the meter-scale hazards at potential landing sites and the inverse correlation between smoothness in Viking-scale (hundreds of meters per pixel) and MOC-scale (meters per pixel) images, no attempt was made at the workshop to downselect the number of sites under consideration.

The Mars Surveyor '01 project has also evaluated and ranked different general types of sites in terms of the science objectives of the mission. The Mars '01 lander payload is well suited to studying soils and given that soils can be found virtually anywhere on Mars, the mission will do new science anywhere it safely lands. Considering the capabilities of the vehicle and the payload (particularly limits on landing accuracy and limited mobility), the best new science is likely to come from landing somewhere within ancient highland crustal materials. Sites on the floor of Valles Marineris should also remain under consideration. Within the above scientific constraints (and within the engineering constraints), the final site will be chosen to: maximize total mission duration, maximize rock abundance, maximize large-scale topography in the visible distance, particularly if it exposes stratigraphy, and maximize the chances of finding aqueous minerals. These constraints argue against some sites such as the "hematite" site, because it is rough at fine scales and because the science that could be addressed there is narrowly focused. Many "lakebed" and "hydrothermal" sites are not favored because the '01 vehicle's limited mobility would make it difficult to achieve the most important goals at such a site (although such sites will be considered for future missions).

Many of the candidate landing sites proposed at the workshop now have high-resolution MOC images available and these images are expected to provide the basis, along with the scientific preferences described above, to downselect the number of candidate sites to a relatively small number (<10). These sites will be studied and further evaluated in terms of specific instrument measurements and mission capabilities at a Mars Surveyor '01 workshop in October 1999. This evaluation will allow further prioritization of the candidate sites. Targeted MGS data will be evaluated throughout the process and site selection will take place by 1/00, with some flexibility for changes until launch in 4/01.

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THE MARS ENVIRONMENTAL COMPATIBILITY ASSESSMENT (MECA) WET CHEMISTRY EXPERIMENT ON THE MARS '01 LANDER

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Introduction. The Mars Environmental Compatibility Assessment (MECA) is an instrument suite that will fly on the Mars Surveyor 2001 Lander Spacecraft. MECA is sponsored by the Human Exploration and Development of Space (HEDS) program and will evaluate potential hazards that the dust and soil of Mars might present to astronauts and their equipment on a future human mission to Mars. Four elements constitute the integrated MECA payload: a microscopy station, patch plates, an electrometer, and the wet chemistry laboratory (WCL).

The WCL consists of four identical cells, each of which will evaluate a sample of Martian soil in water to determine conductivity, pH, redox potential, dissolved CO_2 and O_2 levels, and concentrations of many soluble ions including sodium, potassium, magnesium, calcium, and the halides. In addition, cyclic voltammetry will be used to evaluate reversible and irreversible oxidants present in the water/soil solution. Anodic stripping voltammetry will be used to measure concentrations of trace metals including lead, copper, and cadmium at ppb levels. Voltammetry is a general electrochemical technique that involves controlling the potential of an electrode while simultaneously measuring the current flowing at that electrode.

The WCL experiments will provide information on the corrosivity and reactivity of the Martian soil, as well as on soluble components of the soil which might be toxic to human explorers. They will also guide HEDS scientists in the development of high fidelity Martian soil simulants. In the process of acquiring information relevant to HEDS, the WCL will assess the chemical composition and properties of the salts present in the Martian soil.

Salts in the Martian soil. Based on results from the two Viking landers and Mars Pathfinder, the Mars surface soil appears to consist of ~10% salts (dominated by sulfur- and chlorine-containing salts, presumed to be sulfates and chlorides). Salts are formed by the following processes:

- the water-based weathering of rocks;
- the action of volcanic gases; and
- biological activity.

Salts will therefore accumulate wherever the drainage water evaporates, wherever volcanic gases act upon the soil, and potentially in areas where microbial activity is found. Characteristic salts will be formed by each of the above processes. An analysis of the salts present at a given location can potentially provide information on the geochemical history of Mars, and in particular the history of liquid water on the planetary surface.

A single wet chemistry cell has a total mass of ~600 g including an upper Actuator Assembly built by Starsys Research and a lower Soil Analysis Beaker built by Orion Research, and will consume approximately 2-5 W of power during operation with a peak power requirement of 15 W. Each cell will evaluate a 1 cc soil sample combined with 30 cc of water using 25 sensors arrayed around the perimeter of the cell. The primary analytical tool of the wet chemistry laboratory is the ion-selective electrode (ISE). In addition, microelectrodes will be used to perform voltammetric analyses of the solution composition. All of the sensors are compact and rugged and are not subject to radiation damage.

Actuator Assembly. The actuator assembly shown in Figure 1 is used to deliver (1) soil, (2) solution, and (3) a calibration pellet to the soil analysis beaker as well as to (4) mix the soil/water solution.

(1) A paraffin actuator with a 25% volumetric expansion at T ~ 72 C is used to extend the sample drawer over a distance of 0.75" so that the robot arm can deposit a 1 cc soil sample into the drawer. This actuator requires 13 -15 W for approximately 3

minutes. When the power to the actuator is turned off, a spring is used to retract the drawer and create a vacuum seal between the inside of the unit and the Martian ambient. A brush is used to remove soil particles from the edges of the drawer.

(2) A second paraffin actuator is used to drive a puncture needle through a burst disk at the base of the water tank. The over-pressure in the tank relative to the pressure in the base of the unit drives 30 cc of water into the analysis chamber. This actuator requires 13-15 W for ~ 2 minutes.

(3) A third paraffin actuator is used to puncture a kapton disk and drop a calibrant pellet with a mass of 0.2 g into the soil/water solution.

(4) A MicroMo 8 mm motor is used to drive a mixing paddle at 2 Hz in order to stir the soil/water solution.

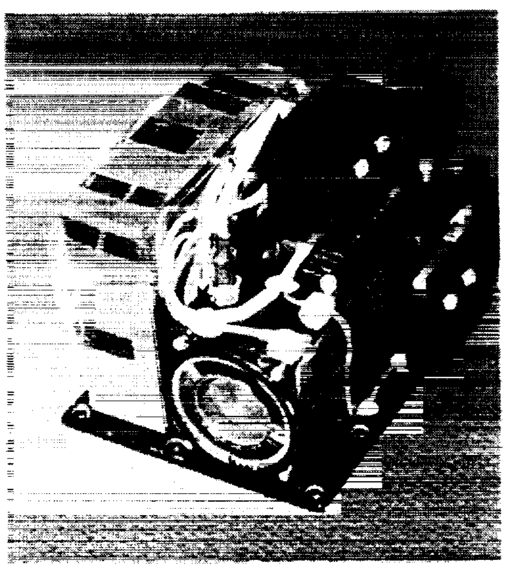

Figure 1. *Actuator Assembly built by Starsys Research for the Wet Chemistry Experiment.*

Soil Analysis Beakers. Complementary to the Viking experiments, the WCL analysis beakers will characterize the properties of the water/soil solution rather than evolved gases, using a suite of potentiometric, voltammetric, and conductimetric sensors. These sensors will provide information on the toxicity and reactivity of soluble components of the Martian soil in preparation for an eventual manned mission to Mars. Table 1 summarizes the sensors contained in each MECA Wet Chemistry Experiment analysis beaker.

Sensor *(Qty)*	**Type**	**Measurement Technique**
Conductivity Cell	4-electrode, planar chip	Conductimetric for measuring total ionic content
pH *(2)*	Polymer membrane	Ion Selective Electrode (ISE) (Potentiometric)
pH	Iridium dioxide	ISE (Potentiometric)
Membrane-Covered CV Electrode	3-Electrode, 0.25-mm gold cathode	Cyclic Voltammetry (CV) for measuring O_2 and other volatile oxidants
Platinum Macro-electrode	1.0-mm disc	ISE (Potentiometric) for measuring redox potential
Gold Macro-electrode	0.25-mm disc	Cyclic Voltammetry (CV) for evaluating oxidants and reductants
Gold Micro-electrode Array (MEA)	Planar chip, 512 10-μm elements	Anodic Stripping Voltammetry (ASV) for trace metal detection
Silver/ Sulfide	Solid-state pellet	ISE (Potentiometric)
Cadmium	"	ISE
Chloride *(2)*	"	ISE
Bromide	"	ISE
Iodide	"	ISE
Lithium *(3)*	Polymer membrane	ISE, used as reference
Sodium	"	ISE
Potassium	"	ISE
Magnesium	"	ISE
Calcium	"	ISE
Ammonium	"	ISE
Nitrate/ perchlorate	"	ISE
Perchlorate or bicarbonate	"	ISE
Carbon Dioxide	Membrane-covered gas sensor	ISE

Table 1. *Wet Chemistry Experiment sensors.*

THE HYPOTHESIS OF CAVES ON MARS REVISITED THROUGH MGS DATA; THEIR POTENTIAL AS TARGETS FOR THE SURVEYOR PROGRAM. E. A. Grin and N. A.Cabrol, and C. P. McKay, NASA Ames Research Center, Space Science Division, MS 245-3, Moffett Field, CA 94035-1000. Email: egrin@mail.arc.nasa.gov; ncabrol@mail.arc.nasa.gov.

Rationale: In a previous publication (Grin et al., 1998), we proposed the formation of caves at mega and microscale on Mars and emphasized their potential for the exobiology exploration. The recent MOC images have shown promising indicators that caves are actually existing on Mars. In the first section, we develop the theoretical potential formation of martian caves. Then, we show how MOC is supporting this hypothesis of their formation and the new types of environments it suggests.

The existence of caves on Mars from microscale to microscale structures can be predicted according to the Mars geological and climatic history. A first global approach is to consider caves as a result of underground water activity combined with tectonic movement. They can be formed by: (1) diversion of channel courses in underground conduits; (2) fractures of surface drainage patterns; chaotic terrain and collapsed areas in general; (4) seepage face in valley walls and/or headwaters; (5) inactive hydrothermal vents and lava tubes.

Classification of Martian Caves: Based on potential terrestrial analogs, we describe in Table I the types of caves that could be formed on Mars, by the joined action of tectonic, thermal, chemical, aeolian, and hydrological activities.

-Table 1a-

Type	Process	Morphology	Host Environment
A. *Mechanical Formation Independent of Host Environment Chemical Composition*			
Tectonic	Mass mov. Of regolith	Fossae	Cohesive with low water content
Sinking	Soil piping	Chamber	Fine-grained non-cohesive
Subsurf. erosion	Water drainage	Underground conduits	Water-rich porous
Valley and rampart talus	Piling of slope material	Interconnected holes	Coarse-grained
Channel Bank	Flow scouring	Longitudinal Excavation	Cohesive
Lake Shoreline	Wave-scouring ice-push	Leveled-shore excavation	
Aeolian	Wind Scouring	Holes	Loosely cohesive

-Table 1b-

Type	Process	Morphology	Host Environment
B. *Chemical/Thermal Formation Dependent of Host Environment Composition*			
Dissolution	Chemical	Holes, Chambers	Soluble
Lava blister	Pushed away gas	Small empty pocket	Basalt
Fracture	Mechanical pressure	Ridges	
Lava Tubes	Roof Cooling	Shallow depth conduit	Pahoehoe lava
Ice cave I	Steam from volcanic origin	Opening in dynamical equilibrium	Ice material
Ice cave II	Tension Wind Abl.	Ice cracks Grooves	Ice Ice
Glacial Potholes	Ice melt block	Isolated cavities	Ancient segregated ice environment
Pseudo-karsts	thermo-karsts	Collapsed structures	Poorly consolidated sediment

Caves. Like other depressions are favorable environment for the deposition of sediments. The process of sediment deposition can be classified (1) according to : (a) the way of transportation, and (b) the chemical deposition/erosion by the weathering of the cave structure. Entrapped sediment may keep unaltered records of their sedimentation sequence, and provide favorable environments for exobiology exploration. In Table II, we describe the most likely sediments that could be observed in Martian caves.

-Table 2-

Type	Sediment	Surface Equivalent
Clastic		
Autochtonous	Weathering detrit.	Eluvium soil
Allochtonous	Infiltrated	Colluvium
Transported	Fluvial/glacial/ aeolian	Alluvium
Chemical	Evaporites	Evaporites
Hydrothermal	Tufas Travertines	Evaporites
Ice	Ice	Ice

Martian Hydrology as a Main Trigger for the Generation of Caves. The above classification tables that water activity on Mars has to be considered as a predominant factor in cave formation. The variety of hydrothermal processes observed and/or predicted on Mars may have led to diverse cave environments that have specific relationship with the aquifer. By analogy with Earth, we propose in Table III a description of plausible cave setting on Mars. It is also predictible that the location of such environment may have been modified through time, following the subsurface aquifer through time.

-Table 3. Setting of Caves in the Aquifer-

Surface Features	Subsurface Location	Aquifer Zone	Expected Morphology
Hole	Vadose	Above perma-frost	Chamber
Collapsed Ground	Unconf. Aquifer	Above Water Table	Sink, Con-duit
Channel Bank Piling	Confined Aquifer	Below Water Table	Seepage Face Hole
Depression	Vadose	Above perma-frost	Fractured Evaporites
Lake	Vadose	Above perma-frost	Shoreline Scouring

Table III point out that the channel bank piling leading to seepage face hole formation is the only case where the cave will be potentially located below the water table. In all other configuration, the caves will be between the water table and the surface. Valley walls, crater ramparts will provide exposed surface, where seepage caves may be identified at the foot of debris slopes and on terraces. Along the course of channels, the seepage caves are closely related to drainage pattern such as headwaters. The seepage face is located at the base of the drained aquifer. It is the result of the underpressure expelled water that has extracted the fine-grained material, leaving the coarser and larger blocks of the regoliths at the seepage face.

Exploration of Caves. The Mars Surveyor Spacecraft provides hight resolution images that reveal new details about the past water activity and climate of Mars. The high-resolution imagery shows indicators of subsurface water activity such as: (a) patterns of rimless pits produced by the removal of surface material on undissected watersheds of valley networks (MOC 8205), [see 1]; (b) interior of valleys wall talus slope that exibit headwater sapping morphologies, where water springed beneath the surface; (c) the interior of old impact crater ramparts, such as on the Bakhuysen Crater (MOC 10605) also displays probable sources of water confined within the crater; (d) the abrupt headwater termination of rimless valley walls show protusions of lava flow margins that resisted the retreat of the valley wall during the sapping process. These water emergences are potential candidates for the generation of caverns and alcoves protected beneath a resistant layer of volcanic rock as shown on recent MOC images.

We consider that these subsurface water constructs are promising targets for the exploration of Mars because they could provide access: (a) to the geology and stratigraphy of the subsurface down to the deepest drainage flow system; (b) to the aqueous underground activity and history of water; (c) to potential micro ecosytem for biological investigation and sample return; (d) to be investigate as potential base for future human settlement.(;e) to be investigated as deep drilling plateform as reducing the length of the boring to reach deep aquifere.

ROCK STATISTICS AT THE MARS PATHFINDER LANDING SITE, ROUGHNESS AND ROVING ON MARS. A. F. C. Haldemann, N. T. Bridges, R. C. Anderson and M. P. Golombek, Jet Propulsion Laboratory, California Institute of Technology (JPL 238-420, 4800 Oak Grove Dr., Pasadena, CA 91109-8099, albert@shannon.-jpl.nasa.gov).

Introduction: Several rock counts have been carried out at the Mars Pathfinder landing site [1,2,3,4,5] producing consistent statistics of rock coverage and size-frequency distributions. These rock statistics provide a primary element of "ground truth" for anchoring remote sensing information used to pick the Pathfinder, and future, landing sites [1,6,7]. The observed rock population statistics should also be consistent with the emplacement and alteration processes postulated to govern the landing site landscape [8,9,10]. The rock population databases can however be used in ways that go beyond the calculation of cumulative number and cumulative area distributions versus rock diameter and height. Since the spatial parameters measured to characterize each rock are determined with stereo image pairs, the rock database serves as a subset of the full landing site digital terrain model (DTM) [11]. Insofar as a rock count can be carried out in a speedier, albeit coarser, manner than the full DTM analysis [11], rock counting offers several operational and scientific products in the near term. Quantitative rock mapping (see Figure 1) adds further information to the geomorphic study of the landing site, and can also be used for rover traverse planning. Statistical analysis of the surface roughness using the rock count proxy DTM is sufficiently accurate when compared to the full DTM to compare with radar remote sensing roughness measures, and with rover traverse profiles.

Rock Counts: *MarsMap rock count.* A first rock count was produced using the MarsMap virtual reality software [12] during Pathfinder operations. The analysis was carried out on the Monster pan set of IMP images. One person measured some 2000 rocks in about 1 month. For each rock the position at the left tangent point of the rock's touching the soil, the rock apparent width, and the rock maximum z extent were measured. The map of MarsMap rock positions is shown in Figure 1. A 3 m to 6 m annulus, considered to have been thoroughly surveyed for rock sizes above 3 cm was used to assemble rock statistics. The cumulative area covered within the annulus is 16%, with variation ranging from 11% coverage in the eastern half of the annulus, to 25% coverage within the rock garden (southwest quadrant).

Showstereo Rock Count. This second more detailed rock count consisted of measuring 9 (x,y,z) points on each of some 4400 rocks to define position, apparent width, long axis, short axis, and maximum height. Additionally rock shape (roundness and angularity), texture, and burial were assessed for all sufficiently large rocks. This work was carried out using showstereo display software on stereo image pairs, one pair at a time. The work required the cumulative effort of 6 summer students working for 10 weeks each, or about one person-year. A summary of the rock statistics of this database will be presented at the meeting. Fits of the Golombek and Rapp [8] rock distribution relationships for some 3200 of the rocks within the dataset (from 2.5 to 10 m) yield reasonable results for a cumulative fractional coverage of 12.9% (assuming simple elliptic rock shape) and exponential factor of 2.5. Analyses of whether distinct rock populations can be identified using the rock characterization parameters will also be discussed.

Far field rock count. Rocks in the far field were examined using the vertical IMP stereo pairs produced by pre- and post-mast-deploy panoramas. Rock positions were estimated both by comparison with the horizon position and by triangulation. The horizon method appears sufficiently accurate to produce rock statistics that are in agreement with the size-frequency distributions of smaller rocks closer to the lander.

Surface Roughness: Surface roughness can be estimated using the rms deviation of the proxy DTM corresponding to the cloud of (x,y,z) points of rock positions. An initial conclusion from the MarsMap rock count data is that the surface roughness at the Pathfinder landing site is self-similar at scales from 0.5 to 5.0 m, with a fractal dimension D=2.47+/-0.04. The rock garden is rougher with D=2.2+/-0.7, while the eastern sector is smoother with D=2.55+/-0.05. These observations are also consistent with the rover traverse profiles for which D=2.47+/-0.01 for all the traverse data. The connection to the remotely sensed radar Hagfors rms slope of 4.8 degrees is that this corresponds to a length scale of around 3.5 m at the Pathfinder landing site. This value is some 100 times the radar wavelength used (3.5 cm), and is thus entirely consistent with the assumptions of the Hagfors scattering model used to analyze the radar data.

Outlook: Rock population analysis offers operational opportunities, first for selection of a landing site, then for analysis of the geomorphic information at the landing site. Initial, "by-hand", rock counts can probably be effected in a manner that would support rover traverse planning, especially if some degree of automation can be developed [5]. These data also offer an opportunity to test sampling scenarios, and automation scenarios for future missions; what sort of sample-return target rock would be chosen at the Pathfinder site using the algorithms being developed for Mars '03? Can quantitative rock mapping provide useful information for rover targeting decisions? This may aid Marie Curie on '01. Does our Pathfinder experience with surface roughness lend itself to an improved analysis for '01 and later landing site selection?

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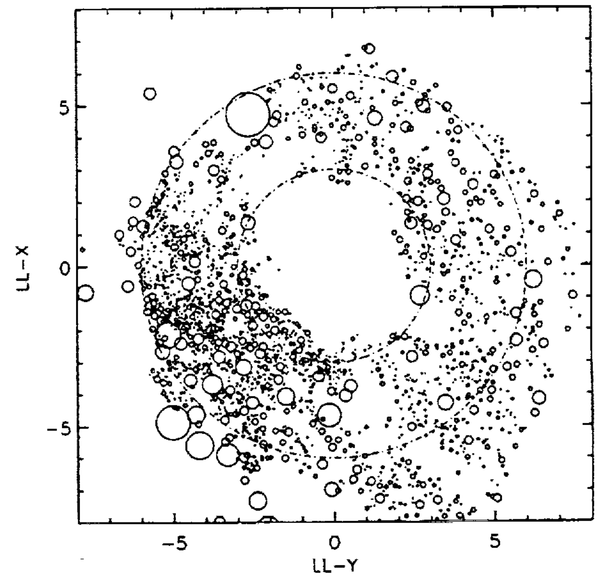

Figure 1. Map of rock positions measured with Marsmap virtual reality software [12]. Coordinates are local lander frame in units of meters. North is at the top, and the rock Yogi is the largest circle centered at approximately LL-Y –2.7 m, LL-X 4.8 m.

OCEANS ON MARS. J. W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912 USA (James_Head_III@brown.edu).

Introduction: Understanding water, and its state, distribution and history on Mars, is one of the most fundamental goals of the Mars exploration program. Linked to this goal are the questions of the formation and evolution of the atmosphere, the nature of crustal accretion and destruction, the history of the cryosphere and the polar regions, the origin and evolution of valley networks and outflow channels, the nature of the water cycle, links to SNC meteorites, and issues associated with water and the possible presence of life in the history of Mars. One of the most interesting aspects of recent discussions about water on Mars is the question of the possible presence of large standing bodies of water on Mars in its past history. Here we outline information on recent investigatios into this question, and address the ways in which various types of present and future Mars missions can contribute to the debate, and gather data to test hypotheses.

Background: Abundant evidence exists for the presence of water on the surface and in the subsurface in the past history of Mars [1]. Among the most distinctive pieces of evidence are the outflow channels that begin full-size at discrete sources and flow hundreds to thousands of km downslope into the northern lowlands displaying a wide variety of bedforms on their floors. An unusual characteristic of outflow channels is that channel cutting does not continue far into the northern lowlands even though downslope topographic gradients appear to continue. Where did the water go? Did it spread out over the broad smooth lowlands and sink into the substrate, or could it have ponded, creating lakes, seas or oceans? Some investigators have hypothesized that outflow channels had enough volume and occurred with sufficient simultaneity and repetitiveness to produce large standing bodies of water in the northern lowlands (Oceanus Borealis) at several times in the history of Mars [2]. Specifically, Parker et al. [3-4] mapped two contacts near and generally parallel to the highland boundary of the northern lowlands and interpreted these contacts to be shorelines, representing two separate highstands of a north polar ocean. Contact 1 is older and corresponds approximately to the highland-lowland dichotomy boundary. Contact 2 is younger, lies northward of Contact 1, and is more well-expressed by a sharply defined smooth, lobate, or arcuate contact and associated features interpreted to be related to shorelines and basinward deposition and evoution.

Results: The new MOLA data permit us to test theses hypotheses in several ways. First, if the mapped contacts are ancient shorelines, then they should also represent the margins of an equipotential surface, and if no vertical movement has occurred subsequent to their formation, the elevation of each contact should plot as straight lines. Preliminary analysis of the first 18 orbits showed that neither Contact plotted as a straight line, but that Contact 2 was a closer approximation than Contact 1 [5]. We have now plotted data from Hiatus phase; SPO1, and SPO2, and later orbits, and produced a topographic map of the northern hemisphere. Contact 1 as presently observed is not a good approximation of an equipotential surface; variation in elevation ranges over several km, an amount exceeding plausible values of post-formation vertical movement. Contact 2 is a much closer approximation to a straight line, and the most significant variations occur in areas where post-formation vertical movement is anticipated (e.g., Tharsis, Elysium, and Isidis). Derivation of the topographic map permits us to test for volumes of water that might be contained in topographic basins of various scales. Assuming that the present topography is a reasonable approximation of the topography in Hesperian and Amazonian time, we have measured the volume of the topography below Contact 2 and find that it is about 1.4 x 10^7 km^3, a value lying between the minimum for all outflow channels (~0.6-0.8 x 10^7 km^3, [1,2]) and the maximum value for water-containing megaregolith pore space (~5-20 x 10^7 km^3) [6]. This volume of the area below Contact 2 is equivalent to a global layer about 100 m deep, and is within the range of estimates for available water [1].

The northern hemisphere topographic map also permits us to assess what would happen if the lowlands were flooded concurrently or if individual channels emptied into the lowlands at different times. We sequentially flooded the northern lowlands in 500 m increments and observed where the water would pond and how candidate seas and oceans might evolve with increased depth. The sequence of maps show that there are two distinctive basins in the northern lowlands, the Utopia Basin and the North Polar Basin. Individual channel-forming events may have flooded only one of these basins, and volumes of the order of 1-3 x 10^6 km^3 are required to fill one of the basins to spill over into the adjacent one. Detailed simulations of flooding events from individual channels are underway [7].

Several other geologic features are thought to have been associated with the presence of bodies of water or residual ground ice remaining from them, and the new topographic data can be used to assess their locations. Lucchitta et al. [8] examined the locations of a variety of features in the northern lowlands using Viking image data in an attempt to identify the location and characteristics of sedimentary deposits that might have resulted from the debouchment of the large outflow channels into the adjacent plains. They brought strong support to the sedimentary layer hypothesis by pointing out that the polygonal ground occurred in close proximity to major channel systems, that the outflow channels and the fractured plains deposits have similar ages, that Antarctic analogs revealed many similarties to this process, and that polygonal ground occurred elsewhere on Mars in similar situations. We digitized the global map of the polygonally fractured terrain on Mars of Lucchitta et al. and superposed it on our MOLA topography map; we found that there is a strong correlation between the location of the polygonal ground and the position of the Utopia and North Polar basins.

Martian impact craters in the 2-50 km diameter range commonly have ejecta deposits with distinctive lobe and rampart morphology, interpreted [9] to be due to the presence of ground water or ground ice in the target area which mobilizes the ejecta material. It is also observed that craters on Mars smaller than a few km do not have ramparts, and thus the onset diameter of ramparts may be an indication of the depth where ground water or ground ice is encountered. On the basis of this concept, Kuzmin et al. [10] assessed the onset diameter globally and found that in equatorial regions the diameter was 4-6 km but toward the pole it was 1-4 km. We have digitized the Kuzmin et al. global onset-diameter map and superposed it on our MOLA topographic map; we find that there is a strong correlation between the smallest onset diameters and the position of the two large basins.

If there was a standing body of water earlier in the history of Mars, it is not there now. In order to examine the fate of a possible ocean as it regressed, we produced slope maps for the interior of the northern lowlands. We find narrow linear slope anomalies that are parallel to each other, parallel to topographic contours, and parallel to Contact 2 in the Utopia basin and on the northern slopes of Alba Patera. One interpretation of these linear slope anomalies is the production of subtle topographic terraces during variations in the rate of regression of a candidate ocean.

Summary: MOLA data show that the topographic position of Contact 2 [3,4] is consistent with a boundary interpreted as a shoreline: the contact altitude is close to an equipotential surface, topography is smoother at all scales below the contact than above it [5], and the implied ocean volume is within the range of estimates of available water on Mars. In addition, detailed topographic maps of the northern lowlands reveal two major basins (Utopia and North Polar); features thought to be related to the evolution of standing bodies of water (polygons, lobate impact craters) show a high degree of correlation with basin topography. New slope maps reveal evidence for subtle terraces that may be related to regression of such a standing body of water. These new data are consistent with, but do not prove, the hypothesis that the northern lowlands of Mars was occupied by standing bodies of water ranging in scale from seas to perhaps as large as oceans in earlier Mars history.

In addition to the possible presence of large standing bodies of water in the northern lowlands in the past history of Mars, other workers have identified numerous regions elsewhere on Mars where evidence exists for former standing bodies of water at the lake and sea scale [e.g., 11-16, and see discussion in 1]. Furthermore, consideration of the hydrosphere and cryosphere [17] in the past history of Mars has led to the proposal that large standing bodies of water in the Noachian were an inevitable consequence of the presence of outflow channels later in history [18]. All of these observations and hypotheses show that exploration plans should be testing various aspects of these questions at all scales and should be complementary in their approach [e.g., 19, 20].

General exploration goals and objectives: On the basis of the observations and proposed hypothesis, what are the types of questions that might be addressed and measurements that can be made?

1) What is the origin of smooth plains deposits in craters and intercrater areas? How can one distinguish among volcanic, eolian, fluvial and aqueous deposits? What are the criteria for orbital remote sensing and lander/rover exploration?

2) What types of evaporites are predicted for Mars and in what configurations might they be found?: What are the starting conditions, how do such deposits evolve, can they be recognized after eolian modification?

3) What is the relationship between aqueous sedimentation and hydrothermal alteration?: Can we identify environments in which hydrothermal alteration alone is occurring and can we find places where hydrothermal alteration occurred in standing bodies of water?

4) What is the scale of evaporite deposition?: Should we anticipate only the grain-size-scale, the sebkha-scale, the crater-and-basin-scale, or some combination of these? How do we link these?

5) What can the SNC meteorites tell us about evaporites and their possible mode of occurrence in Mars surface and subsurface rocks?: Recent theories for the evolution of samples from Mars call on the presence of ancient bodies of water in their evolution

[21, 22]. How can we translate this information into a sampling and measurement strategy?

6) What can the results from the previous landing sites tell us about sampling strategy for standing bodies of water?: The Viking 1 and 2, and Pathfinder spacecraft [23-25] all landed below Contact 2, and some of the anomalous chemistry (e.g., unusual abundance of S and Cl and their possible presence as sulfate minerals and chloride salts [26-27]) could conceivably be related to the presence of former standing bodies of water.

Linking ocean-related questions and exploration strategy: Questions related to the presence of large standing bodies of water, like those in other areas [e.g., 19], are multi-faceted and multi-scaled. Listed below are several steps that need to be accomplished to address effectively many of the questions outlined above:

1) *Learning how to bridge the gap between orbiter perspectives and questions, and lander capabilities:* We tend to pick landing sites on the basis of Viking and MOC-scale geological features (many tens of meters to kilometers), but surface exploration is accomplished with much more detailed goals and scales (centimeters to several meters) [e.g., 20]. Successful exploration requires understanding what we are seeing in the MOC images and linking that to objectives largely determined at the Viking scale.

2) *Establishing ground truth for ocean-related units and processes in several different places on Mars:* As the gap in 1) is bridged, then the information learned from the surface can more effectively be linked from site to site, and with the results from previous sites.

3) *Extrapolating lander and rover results to global units and questions on Mars:* Armed with the detailed results from several sites, and links to orbital instruments, results can be applied to regional and global problems. At this point, more sophisticated tests involving the global indentification of potential deposits can be made.

4) *Linking local and global results to the SNC meteorites:* Laboratory characterization of SNCs, mineralogical assessment of surface rocks and soils, and comparison with orbital remote sensing data [e.g., 21-22], can begin the process of more sophisticated global interpretations, and selection of sample return landing sites.

5) *Linking the Mars geological record to Solar System chronology:* Returned sample missions must provide information for absolute calibration of Mars surface geologic units and geological history. This must be one of the most fundamental contributions of the Mars exploration program.

6) *Studying specific important questions with distributed surface exploration:* This background information can pave the way for focused goals and objectives that might be addressed by micro-missions. Questions about the mineralogy or chemistry of various geological units might be addressed by deployment of multiple instrumented penetrators. For example, large parts of the northern lowlands may be outside the area of accessibility for long-duration landers and rovers, but could be easily explored with abundent penetrators and related micro-mission payloads testing for subsurface composition and how it might vary as a function of position in an evolving sedimentary basin.

7) *Studying specific important questions with in-depth surface exploration:* Armed with these background data, some goals and objectives related to oceans are uniquely suited to human exploration capabilities (e.g., in depth context, drilling and areal exploration related to changing facies, other aspects of three dimensional exploration).

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SITE SELECTION FOR MARS SURVEYOR LANDING SITES: SOME KEY FACTORS FOR 2001 AND RELATION TO LONG-TERM EXPLORATION OF MARS.

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The Site Selection Process: Site selection as a process can be subdivided into several main elements and these can be represented as the corners of a tetrahedron (Figure 1). Successful site selection outcome requires the interactions between these elements or corners, and should also take into account several other external factors or considerations. In principle, elements should be defined in approximately the following order: (1) *major scientific and programmatic goals and objectives*: What are the major questions that are being asked, goals that should be achieved, and objectives that must be accomplished [e.g., 1-5]. Do programmatic goals (e.g., sample return) differ from mission goals (e.g., precursor to sample return)? It is most helpful if these questions can be placed in the context of site characterization and hypothesis testing (e.g., Was Mars warm and wet in the Noachian? Land at a Noachian-aged site that shows evidence of surface water and characterize it specifically to address this question). Goals and objectives, then, help define important engineering factors such as type of payload, landing regions of interest (highlands, lowlands, smooth, rough, etc.), mobility, mission duration, etc. Goals and objectives then lead to: (2) *spacecraft design and engineering landing site constraints*: the spacecraft is designed to optimize the areas that will meet the goals and objectives, but this in turn introduces constraints that must be met in the selection of a landing site [7]. Scientific and programmatic goals and objectives also help to define (3), *the specific lander scientific payload requirements and capabilities* [6]. For example, what observations and experiments are required to address the major questions? How do we characterize the site in reference to the specific questions? Is mobility required and if so, how much? Which experiments are on the spacecraft, which on the rover? The results of these deliberations should lead to a surface exploration strategy, in which the goals and objectives can in principle be achieved through the exploration of a site meeting the basic engineering constraints. Armed with all of this important background information, one can then proceed to (4) *the selection of optimum sites to address major scientific and programmatic objectives* [8-9]. Following the successful completion of this process and the selection of a site or region, there is a further step of mission optimization, in which a detailed mission profile and surface exploration plan is developed.

In practice, the process never works in a linear fashion. Scientific goals are influenced by ongoing discoveries and developments and simple crystallization of thinking. Programmatic goals are influenced by evolving fiscal constraints, perspectives on program duration, and roles of specific missions in the context of the larger program. Engineering constraints are influenced by evolving fiscal constraints, decisions on hardware design that may have little to do with scientific goals (e.g., lander clearance; size of landing ellipse), and evolving understanding (e.g., assessment of engineering constraint space reveals further the degree to which mission duration is severely influenced by available solar enengy and thus latitude). Lander scientific payload is influenced by fiscal constraints, total mass, evolving complexity, technological developments, and a payload selection process that may involve very long-term goals (e.g., human exploration) as well as shorter term scientific and programmatic goals. Site selection activities commonly involve scientists who are actively trying to decipher the complex geology of the crust of Mars and to unravel its geologic history through geological mapping. By the nature of the process, they are thinking in terms of broad morphostratigraphic units which may have multiple possible origins, defined using images with resolutions of many tens to hundreds of meters, and whose surfaces at the scale of the lander and rover are virtually unknown; this approach and effort is crucially important but does not necessarily readily lend itself to integration with the other elements.

Although the process does not operate in a linear fashion, it is critically important that all of these elements are kept in mind because each of these factors must be addressed for mission and program optimization, and if they are lost sight of, crucial opportunities will be missed. But these elements must not be looked upon as individual bastions. The key guiding principle, learned from very hard work in the Apollo Program, is synergistic flow leading to mission optimization. The scientists are not in charge, the engineers are not in charge, and so on. All the elements should be equal partners, and those participating in each element should have a common broader goal, which is striving toward mission optimization. In this way, the process will be synergistic and the whole (mission optimization) will always be greater than the simple sum of the parts. This process requires mutual respect and education, but the rewards are so great, as demonstrated in the later Apollo missions, that any lesser approach is indefensible.

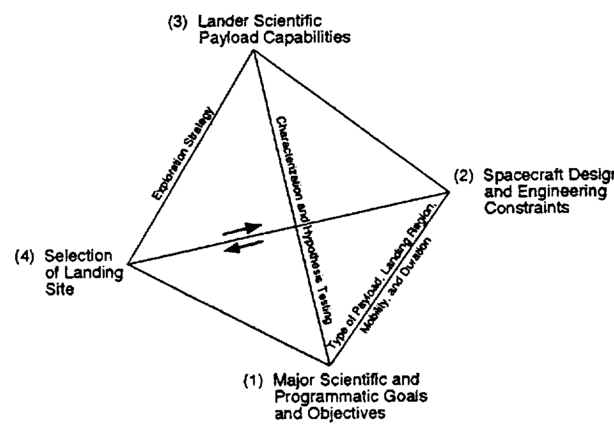

Figure 1. Tetrahedron illustrating site selection process elements and their relationships.

Where are we in the process?: Prior to the first workshop (January 26-27, 1998), broad scientific goals and objectives had been elaborated, general spacecraft and engineering constraints had been defined, the payload was taking shape, which at that time included a rover capable of ~10 km traverse length. The landing sites described [8] focused on defining broad goals and objectives, but did not relate to payload specifics, often did not meet evolving engineering constraints, and were relatively unrealistic in terms of surface mobility. Following this workshop, engineering constraints became better defined and made available to the community, the lander payload became much more well defined, and the nature of the mobility was decided (Marie Curie, essentially equivalent to Pathfinder). In the second workshop (June 22-23, 1999) [9], most of the activity focused on interactions between points (2) and (4) on the tetrahedron (Figure 1) [10-11]: broad landing site regions (4) were discussed in terms of meeting the key engineering constraints (2) for elevation, latitude, roughness, etc. There was also discussion between points (4) and (1), but it was very bimodal; each site was described as meeting very broad objectives, but the detailed relationships were usually not described. 2001 lander and rover scientific payload capabilities (3) were well described at the meeting [12], but there was commonly no linkage between points (3) and (4); very few discussions occurred concerning how the lander payload would be used to achieve the major objectives at the site [13]. Implicit, but not spelled out in detail or discussed in relation to individual landing sites, was the link between points (1) and (3). In summary, these observations do not constitute a criticism, but rather help to define the links that need to be developed in the future as we move toward final site selection decisions.

The Use of MOC Images: Another factor discussed intensely at the meeting was the use of MOC images for high-resolution 'site verification'. One of the engineering constraints that emerged prior to the meeting was that sites had to have image coverage at resolutions near that of MOC images (a few m/pixel) for the terrain that they were investigating. At the meeting Malin et al. [14] provided general guidelines for the characterization of terrain in the Mars Surveyor 2001 landing site latitude and elevation region using mapping phase MOC images. As pointed out by Mike Carr, surface features seen at MOC resolution often bear little resemblance to broad geological units defined at Viking resolution; processes operating at MOC resolution scale (e.g., eolian, mass wasting, small-scale cratering) are usually different from those operationg at Viking resolution (e.g., volcanic, channels, sedimentary, ejecta blankets). Furthermore, landing site vistas may seem unfamiliar relative to features seen at MOC resolution, and not at all relatable to features seen at Viking resolution, where broad objectives are being defined. The potential danger here is clear: MOC images could be used to select the 'smoothest' site without considering the implications for elements (1), (3) and (4) (Figure 1), and significant sites without MOC images could be ruled out prematurely. Although MOC images are essential to the further evolution of site selection processes, care must be taken in developing procedures for their use. In an ideal world, MOC images will help us to land safely and to translate broad objectives into exploration strategies that will let us achieve our major goals and objectives. For this to become a reality, site advocates need to study these images and understand what they are telling us. An excellent start on this is provided by Malin et al. [14].

Where do we go from here?: More discussion needs to take place between *major scientific and programmatic goals and objectives* and *lander scientific payload capabilities* [points (1) and (3)] so that the crucial link between *lander scientific payload capabilities* and *selection of landing sites* [points (3) and (4)] can be developed. If it is more clear how the major goals can be met with the payload, than it will be easier to see how the capability of the payload can be linked to the geology of candidate landing sites. This, in turn, will decrease the bimodality of discussion between (4), *selection of individual sites*, and (1) the *major scientific objectives*. This, together with other considerations and the steps described below, can lead to site selection optimization.

Other Considerations: In addition to the elements described in Figure 1, there are several other considerations that must be kept in mind throughout the process, as they may literally move the whole tetrahedron around in location from one place to another.

1) Relation of 2001 to the Mars Surveyor Program (2003, 2005 and beyond): What role does 2001 play in the overall Mars Exploration program [5]? Should it be planned to undertake preliminary exploration of a site that is likely to be a candidate for '03 and '05 (e.g., Noachian-aged highlands, layered deposits on the floor of Valles Marineris)? Should it be planned to address a specific scientific goal that would optimize use of the payload but be different than that for a sample return mission (e.g., explore the nature of the 'hematite anomaly')? Should it be planned to learn how to optimize the scientific return for surface operations and the Athena payload? Should it focus on learning how to use MOC images to select landing sites that bridge the gap between Viking resolution and lander resolution? Or should it be doing some combination of the above?

2) Relation to long-term human exploration goals: An important case can be made to consider the needs of longer-term human exploration in the process [4, 15], in that Surveyor exploration sets the stage for a better understanding of the scientific capabilities of human exploration, its relation to robotic exploration, and helps to identify many of the constraints and hazards that must be planned for in human exploration.

3) Public interest factors: As amply demonstrated by Pathfinder, missions can result in public interest and in the public understanding of how tax dollars are spent, and this can lead directly into fiscal support and program duration. Such considerations might include homogeneous versus heterogeneous site geology, focused versus diffuse scientific objectives, or vistas of distant terrain, such as canyon walls, visible in the background. Such considerations might be implicitly part of the process (e.g., a scientifically interesting site might happen to be diverse, with a good view) but it could also serve as a 'tie-breaker' among sites with similar scientific characteristics.

Summary: Each of the elements (Figure 1) has been defined in more detail in the recent past: (1) Major scientific and programmatic goals and objectives are outlined in several documents [1-6]. (2) Spacecraft design and engineering landing site constraints can be found at web sites [7,16,-17]. (3) Specific lander scientific payload capabilities are known and available [12, 18]. (4) A range of sites is being investigated to address the major scientific and programmatic objectives [8-9].

What is the nature of the 2001 mission?: It could be described as "A scientifically more capable Pathfinder, landing at a smoother site, with fewer rocks." A convincing argument could be made that the mission experience should teach us: 1) how to select a site of interest using Viking images and how to land safely and traverse effectively using MOC images as a basis; 2) how to plan and execute an exploration strategy that optimizes the scientific return of the APEX/Athena payload; 3) how to identify the major steps in sample selection and storage for future sample return missions; and 4) how to accomplish fundamental scientific objectives using the Mars Surveyor landing system. A convincing case could also be made that, in terms of scientific objectives, the site does not need to be linked to a specific site of interest to future sample return missions. For example, it could focus on such important but collimated questions as "What is the nature and significance of the 'hematite' anomaly identified in the TES data?" "Is there evidence for water in the units of Noachian age, and in what form?" "What is the compositon of Noachian-aged upland units?" This might then lead the way for 2003/2005 and beyond to go to more diverse and complex sites (channels, crater floor 'paleolakes', crater ejecta, etc.) where extended mobility would be more likely to achieve multiple objectives. It is, however, abundantly clear that whatever the subset of these objectives that ultimately make up the mission, the 2001 mission is essential to overall program success. Any of these mission experiences that are not achieved in 2001 must be achieved in 2003, and on down the line.

Critical Steps and Timeline: The following steps need to be accomplished; see also http://mars.jpl.nasa.gov/2001/landingsite/schedule.html:

1) Any additional candidate sites need to be identified in the nearest future.

2) Site advocates need to explore the rest of the tetrahedron [particularly (1) to (4) and (3) to (4)], other data sets such as TES [19], MOC [14] and MOLA [20], and provide further completed studies to post on the web site.

3) MOC images need to be obtained of candidate sites for which they are not available.

4) Sites need to be classified into broad types with similar scientific themes. Some examples might be: a. Noachian highlands with evidence for water activity; b. Hydrothermal sites; c. Valles Marineris: Interior layered deposits with a wall view; d. Hematite deposits; e. Paleolake beds; f. Channel deposits.

5) Further guidelines (scientific and engineering) need to be developed for the interpretation and use of MOC images.

6) Regions (perhaps about 10 degrees square) need to be identified which contain sites in which high priority goals and objectives can be accomplished.

7) Broad regions and sites need to be downselected and studied further (Site Selection Steering Group?; late summer of 1999?).

8) Downselected broad regions and sites reviewed with the landing site analysis community (October 2-4 meeting?) and criteria for further downselection discussed.

9) Detailed analysis of downselected site regions to review in winter and spring review meetings.

10) Final downselected sites/regions decided.

11) Site selection recommendations and decision.

12) Mission optimization for selected site.

13) Launch, landing and mission operations.

14) 2001 landing site selection processes need to be integrated and merged with those for 2003 and 2005.

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HAND-HELD LENS FOR MARS. P. Jakeš, Department of Geochemistry, Faculty of Sciences, Albertov 6, Praha 2, 128 43 Czech Republic.

The studies of the Earth, Moon, and meteorites show that deciphering the planetary history, its evolution and interaction of atmosphere with solid surface (e.g., fluvial, aeolian, glacial) relies on the visual observations that determine phase composition (i.e., mineralogy), phase relationships (petrology), and together with geochemical and geophysical data provide data for the constructions of meaningful planetary models.
Terrestrial, lunar and meteorite experience shows that the size of phases that crystallized during the igneous process or later through metamorphic, impact induced or sedimentary processes (regolith) is usually less than 10 milimeters, often less than 1,0 millimeter. Petrologists, mineralogists and experimentalists have developed criteria that help to establish or define processes such as magmatic crystallization, sedimentary features, impact processes, weathering through the studies of particle morphologies. Number of such criteria relies on the observation of the rocks (soils, regoliths) through the eye powered by magnifying lenses, i.e., through hand held lens and microscope.

In early planetary missions (e.g.,Viking, Venera or Surveyor) the preference has been given to determination of chemical composition rather than to optical images (close-ups). Images were thought (probably based on Apollo sample imaging experience) to be of little value and the transmission of optical images byte-costly. The interpretation of chemical data without the images of analyzed area appears to be difficult, if not impossible. Thus for example excellent chemical data that were collected at Viking or Pathfinder landing sites apear to be interpreted in several manners. Except for the above mentioned samples studied in the laboratory, "in situ" microscopic studies were not carried out since available images of the surfaces (Moon, Venus, Mars) had resolutions worse than grain size of rock or regolith particles. The images of large i.e., planetary features (in range of 10 meters to 1000 meters) have been widely used to interpret the processes that acted upon the planet.

The presented poster argues for the presence of imaging lens and microscope like systems that examines the surfaces of the Mars. The imager is connected to analytical tools (XRF, APX, and/or Moessbauer) allowing the area that is analyzed to be imaged at low magnifications (Rieder et al., 1995). The detail in an analyzed area could be obtained through different optic and CCD geometries. The independent illumination allows to use light of known spectral characteristics and sufficient intensity and the camera could be used in the unfavourable light conditions. With the "white light" and color filters multispectral images could be obtained, though the use of moveable filters seems awkard in such small and compact device. The multispectral images could also be obtained using monochromatic sources (such as LEDs). Computer combination of images taken at different defined wavelenghts can provide a color images. UV illumination providing the "visible light" effects could be added to detect "fluorecent phases" (e.g., quartz, zirkon, etc). The use of NIR or IR illumination enlarges the analytical capabilites. The use of the discrete light wavelengths computer grabbing of the images and the processing the images makes such lens into an identification tool.

An another application of microscope imager is in soft penetrator tool that is slowly driven to loose surface, imaging the "walls" of the profile. This provides the record of stratigraphic column, and may indicate the resurfacing through the volcanism, impacts or erosion. These changes could be studied in undisturbed samples that are difficult to obtain through "robotic" sampling. The stratigraphy (sequence of layers) in the regolith that covers planetary surface provides a direct record of planetary evolution. History of last few milions or thousands years is recorded. The studies of lunar regolith for example, done with relatively stratigraphically undisturbed samples, have shown the importance of such studies. Therefore the use of an microscope hand held lens imaging system in the drilling (softly pushed tool) will enable to study„maturity“ of regolith, stratification, and stratigraphy.

The use of lens and microscope systems should become part of geology-petrology-geochemistry oriented robotic missions. The chemical data, rock textures, particle sizes and shapes (optical image analysis) should be one of the decision making (site selection) criteria.

THE MARS IN-SITU-PROPELLANT-PRODUCTION PRECURSOR (MIP) FLIGHT DEMONSTRATION. D. I. Kaplan[1], J. E. Ratliff[1], R. S. Baird[1], G. B. Sanders[1], K. R. Johnson[2], P. B. Karlmann[2], C. R. Baraona[3], G. A. Landis[3], P. P. Jenkins[3], and D. A. Scheiman[3], [1]NASA Johnson Space Center, Houston, Texas, 77058; [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109; [3]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135.

Introduction: Strategic planning for human missions of exploration to Mars has conclusively identified in-situ propellant production (ISPP) as an enabling technology. A team of scientists and engineers from NASA's Johnson Space Center, Jet Propulsion Laboratory, and Glenn Research Center is preparing the MARS ISPP PRECURSOR (MIP) Flight Demonstration. The objectives of MIP are to characterize the performance of processes and hardware that are important to ISPP concepts and to demonstrate how these processes and hardware interact with the Mars environment. Operating this hardware in the actual Mars environment is extremely important due to (1) uncertainties in our knowledge of the Mars environment, and (2) conditions that cannot be adequately simulated on Earth.

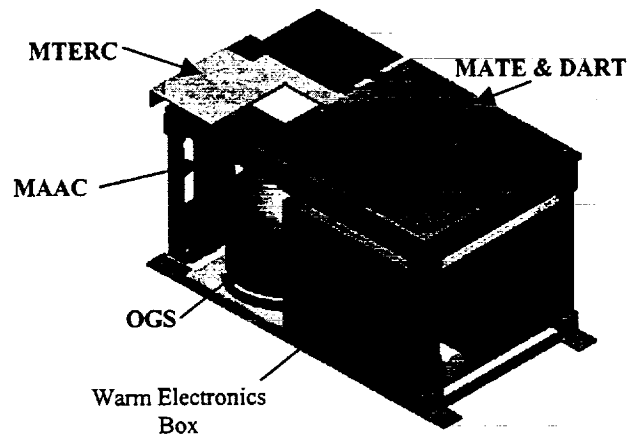
The MIP Flight Demonstration is a payload onboard the MARS SURVEYOR Lander and will be launched in April 2001. MIP will be the first hardware to utilize the indigenous resources of a planet or moon. Its successful operation will pave the way for future robotic and human missions to rely on propellants produced using Martian resources as feedstock.

MIP Overview and Objectives: MIP is comprised of five distinct experiments; their names and key objectives are:

- Mars Atmospheric Acquisition and Compression (MAAC): to selectively absorb and compress carbon dioxide from the Martian atmosphere;
- Oxygen Generator Subsystem (OGS): to produce propellant-grade, pure oxygen;
- Mars Array Technology Experiment (MATE): to measure the spectrum at the Mars surface and to test several advanced photovoltaic solar cells;
- Dust Accumulation and Repulsion Test (DART): to investigate the properties of dust and to test techniques to mitigate the settling of airborne dust onto solar arrays; and
- Mars Thermal Environment & Radiator Characterization (MTERC): to measure the night sky temperature and to demonstrate the performance of radiators.

The MIP package will be small and lightweight. Its overall external envelope is approximately 40 x 24 x 25 cm (15.7 x 9.4 x 9.8 inches), and its mass is 8.5 kg (18.7 lbm).

The long-term effects of operating in the Martian environment are key information being sought by MIP.



Therefore, MIP would like to operate for a lifetime of 90 sols or more on Mars.

Mars ISPP Precursor (MIP) Flight Demonstration

Mars Atmospheric Acquisition and Compression (MAAC): The most readily available resource on Mars is the atmosphere. Hence, carbon dioxide (CO_2), which makes up more than 95% of the atmosphere, is the primary resource being considered for early Mars missions. However, the Mars atmospheric pressure is only 6 to 10 torr (0.1 to .15 psi), while most ISPP processes operate at approximately 760 to 3800 torr (1 to 5 atm.). Therefore, a CO_2 collection and compression device is required that is relatively small, lightweight, power efficient, tolerant to dust contamination, rugged and reliable enough to operate for long periods under the severe daily and seasonal temperature variations.

The primary objective of the MAAC experiment is to demonstrate and characterize the performance of a sorption compressor. A sorption compressor contains virtually no moving parts and achieves its compression by alternately cooling and heating a sorbent bed comprised of materials that absorb low pressure gas at low temperatures and desorb high pressure gas at higher temperatures. The characteristics of the material in the sorption pump define how much gas can be absorbed and which species are more readily absorbed over others. Due to the lack of rotating/moving parts, it has significant potential for high lifetime, reliability, and robustness.

MAAC acquires CO_2 during the cold Mars night when temperatures are typically 200°K. To facilitate absorption, MAAC inlet valves will be opened to the Martian atmosphere for 1 to 3 diurnal cycles. Once an adequate amount of CO_2 has been absorbed (~4 g), the sorbent bed is heated and pressure in the sorption pump rises until 815 torr of pressure is reached. At this point, CO_2 can now be feed to the OGS experiment.

Oxygen Generator Subsystem (OGS): The ultimate objective of any ISPP demonstration is the production of oxygen and/or fuel from in-situ resources. The primary objectives of the OGS experiment are to demonstrate the production of oxygen from Martian atmospheric carbon dioxide (CO_2) as well as to investigate the basic performance of zirconia solid-oxide oxygen generator hardware in the Mars environment. The zirconia solid-oxide oxygen generator produces oxygen by electrolyzing CO_2 at elevated temperatures (750°C) to strip off an oxygen ion from the molecule. Once the oxygen ion has been removed from the CO_2 molecule, the zirconia material acts as an oxygen pump and separator by allowing only the oxygen to pass through it's crystal lattice when a voltage is applied across the zirconia material. The OGS is sized to produce 0.5 standard cubic centimeters of O_2 per minute (sccm) while operating. We desire to run the OGS about ten times on the Martian surface.

Mars Array Technology Experiment (MATE): Until Mars PATHFINDER landed in July 1997, no solar array had ever been used on the surface of Mars. PATHFINDER was designed for a relatively short duration mission compared to a 500 sol surface stay for a Mars sample return mission that would incorporate ISPP. Since making propellants and storing them cryogenically requires significant power, power generation over a long period of time is critical for mission success.

MATE will incorporate five different individual solar cell types, two different solar cell strings, and temperature sensors to characterize promising solar cell materials and designs. MATE will also incorporate two radiometers and a dual spectrometer. The dual spectrometer will measure the global solar spectrum from 300 to 1700 nm by incorporating two separate photodiode arrays each with its own fiber optic feed and grating. Besides measuring the solar spectra on Mars, the dual spectrometer will also identify dust absorption and reflection bands, quantify daily variations in spectra and intensity, and improve atmospheric modeling.

Dust Accumulation and Repulsion Test (DART): Measurements from the PATHFINDER mission showed a dust deposition rate of 0.3% per day during a relatively clear (no dust storms) season. This accumulation could be catastrophic for a 500 sol lifetime mission.

DART will utilize a microscope, a dust accumulation monitor, and a sun position sensor package. The microscope will measure the amount and the properties of settled dust, and determine the rate of dust deposition, the particle size distribution, the particle opacity, the particle shapes, and possibly information about the particle composition through measurements of the optical properties.

DART will also incorporate tilted solar cells and an electrostatic dust repulsion device. Instead of attempting to remove settled dust, the DART experiment will use high-voltage to attempt to repel the dust before it settles.

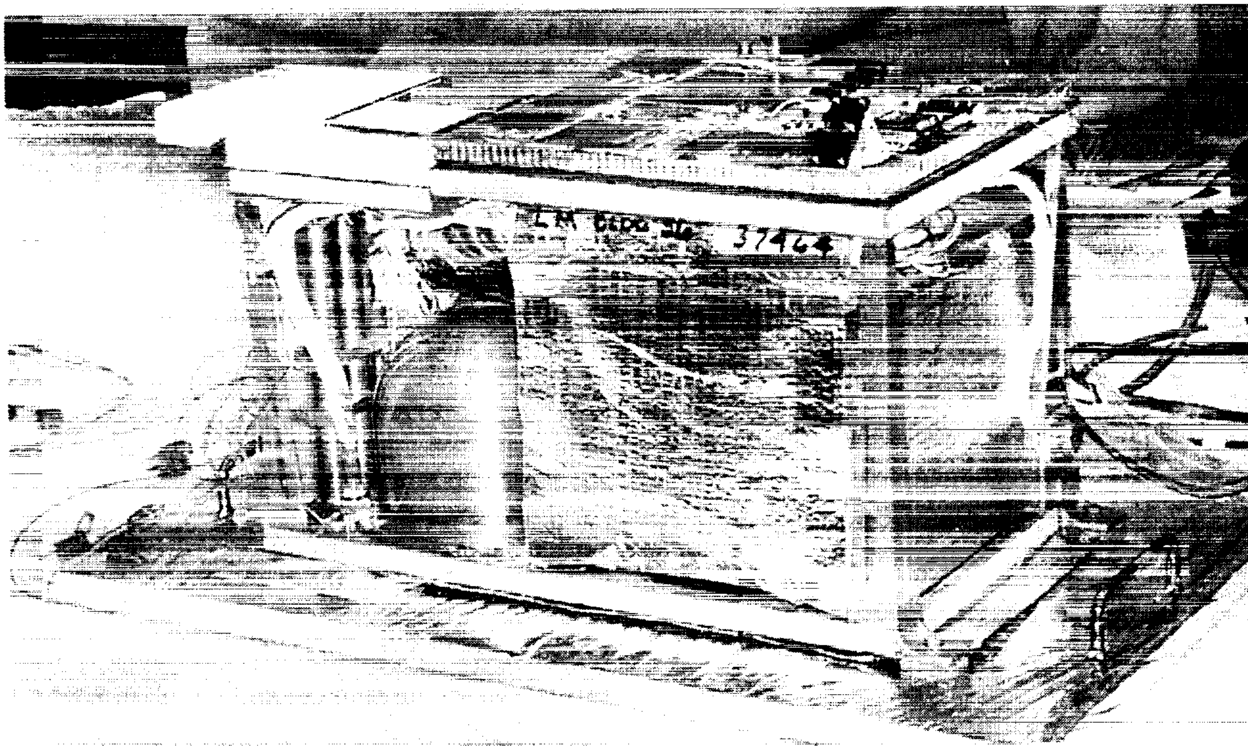
Mars Thermal Environment & Radiator Characterization (MTERC): Thermal management is critical for efficient operation of an ISPP plant. Heat removal radiators will be required for such operations as cooling down a sorption pump sorbent bed, and cooling oxygen and fuel before liquefaction and storage.

The MTERC experiment will include four radiator plates: two with high emissivity and two with low emissivity. One high and one low emissivity plate will be protected by a movable cover and will serve as the experiment control radiators. These control radiators will experience the least degraded measurement of the effective Mars night sky temperature and will serve as comparisons for the two continuously exposed radiators in order to examine the impact of dust accumulation, wind abrasion, etc., on long-term radiator performance.

Conclusion: The successful performance of the five individual demonstrations of MIP will provide both knowledge of and confidence in the reliability of this technology. At the completion of this flight demonstration, the MIP Team will be able to:

- recommend preferred hardware configurations for the intake and adsorption of carbon dioxide from the Martian atmosphere;
- understand the performance characteristics of zirconia cells to generate propellant-grade oxygen;

- understand long-term performance degradation characteristics of advanced solar array and radiator concepts operated in the actual Mars environment;
- evaluate the functionality of electrostatically repelling airborne dust from landing on a solar array; and
- recommend preferred hardware designs for innovative thermal management, including the radiation of heat to the outside environment.



MIP Engineering Development Unit

WORKSHOP REPORT: *SPECTROSCOPY OF THE MARTIAN SURFACE: WHAT NEXT?*

L. E. Kirkland[1], [1]Lunar and Planetary Institute, Houston, TX <kirkland@lpi.jsc.nasa.gov>.

Introduction. On June 10 - 11, the workshop *Spectroscopy of the Martian Surface: What Next?*, sponsered by the Lunar and Planetary Institute and the JPL Mars Program Office, was held at LPI. Leaders of the planetary community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist in planned spectral measurements of Mars, and in supporting research programs. It was felt that the community needed to address these issues, given the shift of the NASA Mars program toward a search for regions conducive to the preservation of biomarkers, and the desire for sample return. The two letters here summarize our consensus. The full workshop report, including abstracts, is also available by emailing kirkland@lpi.jsc.nasa.gov. The letters were edited by L. Kirkland, J. Salisbury, J. Mustard, R. Clark, P. Lucey, and S. Murchie, and were circulated by email to all workshop participants for approval.

WORKSHOP RECOMMENDATIONS 1: NEXT SPECTRAL DATA SET

Summary: High resolution spectroscopy will be of great importance for future Mars exploration and is particularly important for assessing present and past environments in the search for evidence of life. After the successful return of planned data sets, the next orbited instrument should emphasize hyperspectral measurements that:

1) are targeted to regions of interest rather than global.
2) have very high information content (high signal to noise ratio, high spectral resolution, and cover both the reflectance and emission spectral regions).
3) have high spatial resolution.

This information will allow the best opportunity to select the most desirable landing sites for missions focused on life detection and biomarkers.

Background. On June 10 - 11, 1999 the workshop "*Spectroscopy of the Martian Surface: What Next?*" was held at the Lunar and Planetary Institute in Houston, TX. At this workshop, leaders of the science community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist after the successful completion of currently planned Mars missions. Participants agreed that the most critical gap that will remain is a spectral data set containing targeted, very high information content measurements to support the selection of landing sites that may preserve biomarkers. This information will enable sample return missions focused on life detection the best opportunity to bring back definitive samples. This letter summarizes the consensus of the participants.

Planned data sets. Should the currently planned instruments complete their objectives, then we feel that the global reconnaissance mapping of Mars will be completed. The Global Surveyor TES will provide global measurements of Mars using emission spectroscopy (6 - 50 μm) at 3 km spatial resolution. This will be complemented in 2001 by multispectral visible and thermal infrared imaging at <100 m/pixel (MARCI and THEMIS). Equally important, the 2003 Mars Express OMEGA will obtain hyperspectral visible and near-infrared imaging (0.4 to 5.0 μm) at 2 km/pixel, filling a critical gap in the type of data available for mineralogical analysis.

Next data set. The next instrument should collect high spatial resolution, high information content spectra of targeted regions. Mineralogy is an essential tool to assess ancient and modern environments on Mars that may have been conducive to the support and preservation of life and biomarkers, and reflectance and emission spectroscopy remain the most capable method for remote mineral identification. It is likely that the global data sets (TES, THEMIS, MARCI, OMEGA) can be used to identify many potential sites for lander science measurements and sample return. Experience gained from spectral data sets of Mars and Earth has shown that an unambiguous interpretation of a complex region requires spectra with both high spatial resolution and very high information content. Such data will be important for selecting the most desirable among the potential landing sites. It will also greatly facilitate traverse planning, and lead to maximal return from landed science and sample return missions.

High information content is obtained by measuring with broad spectral range, high spectral resolution, and most importantly high signal to noise ratio (SNR). Spectral resolution should be coupled with SNR, so that lower spectral resolution requires higher SNR. The data set should not be global, but should focus on the most promising sites identified from the global data sets. The currently proposed Ariane piggyback micromissions will lack the payload for an instrument capable of making these measurements.

Neither reflectance nor emission spectroscopy alone is sufficient to uniquely determine the full range of minerals that may be present, as each method is sensitive to different physical processes. Together they provide the best capability to identify the surface mineralogy. The broader the spectral range, the less ambiguous the interpretations, and the more technical the justification for selecting a particular landing site.

Accurate interpretations of mineralogy require a strong analytical and laboratory foundation. Although much progress has been made, the program would be considerably strengthened by coordinated testing and integration of analytical approaches; identification and mitigation of gaps in community spectral libraries and facilities; and an explicit means to make existing and future laboratory measurements readily available to the entire community.

On the basis of our extensive experience with laboratory, planetary, and terrestrial spectroscopy, the workshop participants identified the following instrument characteristics required to best determine the minerals present and to best select among potential landing sites:

–**Targeted coverage rather than global.**
–**High spectral resolution:** <10nm for 0.4 - 2.5 μm region; $\lambda / \lambda\Delta > 250$ for 2.5 - 50 μm.
–**High SNR:** >500rms for 30% albedo at 2 μm, and >500 to 1000rms for thermal for 270K.
–**High spatial resolution:** <100 m/pixel.
–**As broad a wavelength range as possible.**
–**Continuous spectra,** sampled >1 to 2 measurements per spectral resolution element.
–**High quality calibration.**

Such an instrument would provide an essential tool in the phased approach to Mars exploration that NASA has developed. We strongly encourage NASA and the Mars community to consider these recommendations in planning for future missions.

Sincerely,
Participants of the workshop, "*Spectroscopy of the Martian Surface: What Next?*"

Jim Bell	Diana Blaney	Phil Christensen
Ben Clark	Roger Clark	Stéphane Erard
Jack Farmer	William Farrand	Rudy Hanel
Gary Hansen	Ken Herr	Eric Keim
Laurel Kirkland	Melissa Lane	Paul Lucey
Richard Morris	Scott Murchie	John Mustard
Carlé Pieters	Jack Salisbury	Steve Saunders
Allan Treiman	Steve Young	

WORKSHOP RECOMMENDATIONS 2: SUPPORTING RESEARCH

Summary: Spectroscopic remote sensing of surface composition has been of critical importance to our current understanding of Mars, as well as other planets. Spectroscopy, especially high resolution spectroscopy, will continue to be of great importance for future Mars exploration and is particularly important for assessing present and past environments in the search for evidence of life. There are two areas that need more emphasis by Research and Analysis Programs: 1) Measurement and public archiving of spectra covering the range 0.4 - 50 μm; and 2) Testing of quantitative mineral analysis methods. Participants also felt there should be additional discussion of what materials should be measured, and how the data should be archived.

Background. On June 10 - 11, 1999 the workshop "*Spectroscopy of the Martian Surface: What Next?*" was held at the Lunar and Planetary Institute in Houston, TX. At this workshop, leaders of the planetary community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist in planned measurements of Mars and supporting research programs. This letter summarizes our consensus about the supporting research programs.

Knowledge of surface composition is an essential tool to assess ancient and modern environments on Mars that may have been conducive to the support and preservation of life and biomarkers. Reflectance and emission spectroscopy are the most capable method for remote compositional mapping. Participants concluded that there remain several critical needs in the ability of the community in order to reliably interpret current and planned spectral data sets. One is the unavailability of supporting spectral libraries that contain diverse measurements over the entire wavelength range measured by current and planned spectrometers (0.4 - 50 μm). Another is the need to test and compare currently available analytical methods that are used to quantitatively examine remotely sensed spectra.

Laboratory spectra. Two factors are essential for detection and quantification of surface materials: high information content spectra of Mars, and high quality laboratory spectra. Participants concluded that a lack of access by the entire community to measurements over the full wavelength range measured by current and planned spectrometers (0.4 - 50 μm) seriously impedes interpretations. Measurement of diverse materials relevant to active processes and the environment of Mars over the full wavelength range should be encouraged by current Research and

Analysis Programs. This community effort will be strongly aided by insuring that there is a community measurement facility capable of measuring the entire 0.4 - 50 μm range. It is essential to the success of this integrated approach that spectral data measured under this program are publicly archived, and that the materials measured are well-characterized.

Quantitative methods. Workshop participants concluded that there is a strong need to test and evaluate currently available identification and unmixing algorithms. An important baseline could be established through blind measurements by different algorithm proponents of prepared samples representing increasing degrees of difficulty.

Participants also felt quantitative methods will be advanced by the development of liaisons to similar research programs, such as those developed by Department of Defense and Intelligence agencies. One goal should be to test and incorporate knowledge from these other programs into the NASA community, perhaps by inviting them to participate in the blind measurement program.

Additional discussions. Participants concluded there should be additional public discussion of what materials should be measured, and how the data should be archived. Materials discussed included weathering materials and coatings, and poorly crystalline materials that may be present on Mars. The workshop did not have the goal of addressing these issues, and no consensus was reached, but these issues were felt to be of sufficient importance to warrant further discussion.

Recommendations. Selecting among potential landing sites will be aided by measuring targeted, high information content spectra from orbit, followed by clear, unambiguous interpretations of the spectra. Community access to measurements over the full wavelength range covered by current and planned instruments, and the development and testing of quantitative analysis methods will provide the enabling foundation and data analysis tools that are essential to the phased approach to Mars exploration that NASA has developed. We strongly encourage NASA and the Mars community to consider these recommendations in planning for future research programs.

Sincerely,
Participants of the workshop, "*Spectroscopy of the Martian Surface: What Next?*"

Jim Bell	Phil Christensen	Ben Clark
Roger Clark	Stéphane Erard	Jack Farmer
William Farrand	Rudy Hanel	Gary Hansen
Ken Herr	Eric Keim	Laurel Kirkland
Melissa Lane	Paul Lucey	Scott Murchie
John Mustard	Carlé Pieters	Jack Salisbury
Steve Saunders	Allan Treiman	Steve Young

HISTORICAL NOTE

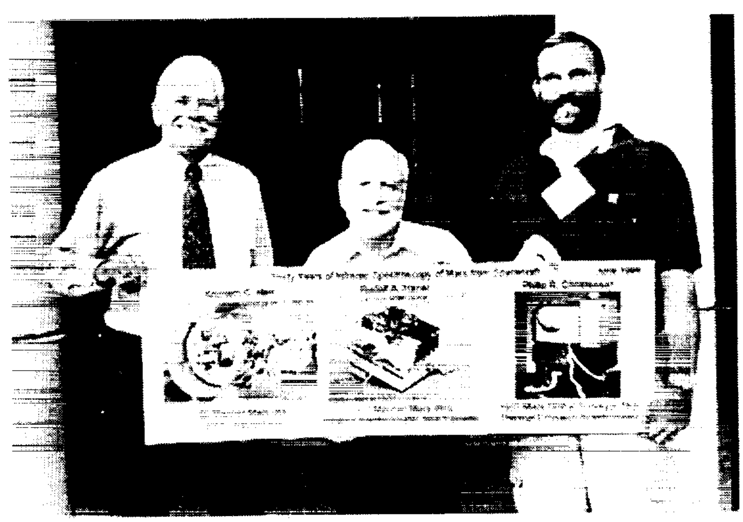
The workshop had an unusual breadth of researchers present, and included expertise in spectroscopy of Mars, Earth, and the moon; from both NASA and the DOD/Intelligence community; and in laboratory spectral research and computational spectral analysis. However, an interesting historical note was the presence of all three builders of the only thermal infrared spectrometers ever sent to Mars. It is the first, and will perhaps be the only time, that all three have met:

Kenneth C. Herr (1969 Mariner Mars 6/7 Infrared Spectrometer, *IRS*), left

Rudolf A. Hanel (1971 Mariner Mars 9 Infrared Interferometer Spectrometer, *IRIS*), center

Philip R. Christensen (1997 Global Surveyor Thermal Emission Spectrometer, *TES*), right

Photo Credit: Debra Rueb, LPI Staff Photographer. Taken during the workshop, at the entry to the LPI



MOD: AN ORGANIC DETECTOR FOR THE FUTURE EXPLORATION OF MARS. G. Kminek[1], J. L. Bada[1], O. Botta[1], F. Grunthaner[2], D. P. Glavin[1], [1]Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA-92093-0208, gkminek@ucsd.edu, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA-91109.

Abstract: The Mars Organic Detector (MOD) is designed to assess whether organic compounds, possibly associated with life, are present in Martian rock and soil samples. MOD has a detection limit that is at least two orders of magnitude more sensitive than the Viking GCMS. MOD is focused on detecting amino acids, amines and PAH (polycyclic aromatic hydrocarbons). Amino acids play an essential role in biochemistry on Earth and PAH are widespread throughout the universe and can provide an indication of the delivery of meteoritic organic material to Mars.

The advantage of MOD is the absence of wet chemistry and its simple and robust design. The sample will be extracted from the mineral matrix (0.1-1g of rock-powder) using sublimation and analyzed with a fluorescence detector. The isolation method is based on the fact that amino acids and PAH are volatile at temperatures greater than 150°C. The fluorescence detection scheme is based on UV excitation with LED's, optical filters, PIN diode photon detector and a sample calibration reservoir. Fluorescamine is used as a fluorescing reagent for amino acids and amines, while PAH are naturally fluorescent. There is no sample preparation required and the turnaround time for a single analysis is on the order of minutes.

One part of the MOD design is a tuneable diode laser spectrometer (TDL). The MOD-TDL spectrometer will quantify the extend of adsorbed and chemically bound water and carbon dioxide. Evaluating the reservoir of near surface water is of crucial importance for in-situ resource utilization concepts. In combination with the MOD heaters, it will be possible to identify carbon bearing minerals using the evolved carbon dioxide signature at specific temperatures.

These characteristics make MOD an ideal instrument for a screening device used by astronauts in a field-work environment on Mars as well as for robotic missions. It is possible to assess the presence or absence of key organic compounds in a reliable, fast and simple manner. In case of a positive result, more detailed and complex investigations can be carried out.

The MOD is being developed under the Planetary Instrument Definition and Development Program (PIDDP) and the Mars Instrument Development Program (MIDP). The lab-version of MOD is used to extract organics from natural samples on a daily routine. The first functional prototype will be ready for field tests in September of 1999.

MEASURING THE CHEMICAL POTENTIAL OF THE MARTIAN REGOLITH TO GENERATE AND SUSTAIN LIFE. S. P. Kounaves[1], M.G. Buehler[2], and K.R. Kuhlman[2], [1]Tufts University, Department of Chemistry, Medford, MA 02155, skounave@tufts.edu, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, martin.g.buehler@jpl.nasa.gov

A critical component for identifying chemical biosignatures is the ability to assess in-situ the potential of an aqueous geochemical environment to generate and sustain life. On Mars or other solar bodies, in-situ chemical characterization could provide evidence as to whether the chemical composition of the regolith or evaporites in suspected ancient water bodies have been biologically influenced or possess the chemical parameters within which life may have existed, or may still exist. [1-3]

A variety of analytical techniques have been proposed for use in detecting and identify signatures of past or present life.[4,5] These techniques fall into two groups; *visual observation* with instruments such as cameras or optical/atomic-force microscopes; *or elemental chemical analysis* with such instruments as X-ray fluorescence (XRF) and diffraction (XRD), α-proton backscatter (APX), γ-ray, Mössbauer, Raman, IR, UV/VIS spectroscopies, gas chromatography (GC), or mass spectrometry (MS). Direct observation of an identifiable lifeform by the first set of instruments in a single sample is highly unlikely, especially for extinct organisms or on the surface. The later instruments can provide vital data as to the elemental mineralogy and geological history of the planet, but are highly inadequate for understanding the chemistry of the planet in terms of indigenous life or interactions with human explorers. Techniques such as XRD, XRF, and APX, provide elemental composition at high limits of detection. Some of this data can be extrapolated or interpolated to provide chemical parameters such as oxidation state or composition. Gas chromatography (GC) without standards and non-specific detectors, has little chance of identifying a mixture of unknown components. Combined with GC or by itself, mass spectrometry (MS) can provide identification of compounds, but in both cases the sample must be appropriately prepared for accurate and reliable analysis.

Life as we know it, and probably identify it as such, requires an aqueous environment. Deciphering the chemical speciation of this aqueous environment is the key to recognizing therein the biosignatures of any extinct or present life forms. Identifying the soluble (ionic and nonionic) components by reacting a currently dormant environment can provide a "picture" of the thermodynamics and chemical components of a possibly bioactive environment. The only devices which can provide such information are electrochemical sensors based on the potentiometric *ion selective electrodes* (ISEs) and on dynamic techniques such as *cyclic voltammetry* (CV) and *stripping voltammetry* (SV). Such an array of devices can provide not only the chemical composition of a water-soluble Martian soil sample, but also several other vital chemical parameters such as pH, conductivity, redox potential, and dissolved gases.

To address these issues we have been investigating the possible use of an electrochemically-based ion sensor array as a new integrated approach to quantitative analytical and chemometric electrochemical measurements. The sensor array will consist of specific and semispecific ion selective and amperometric transducers, which can simultaneously and continuously identify and semi-quantitatively determine over 50 organic and inorganic analytes in water-based environments. Several individual sensors, based on the same principle, have been flight-tested and have been installed as part of the MECA instrumentation on the Mars 2001 Lander for in-situ analyses. However, the microfabrication, integration and multiplexing of such a large number of these sensors on a single substrate have not been previously attempted.

The Chemometric Neural Network Approach. Application of multi-sensor arrays is critically dependent on the ability to process and interpret raw sensor data and to model the sample chemistry. Development of chemometric processing technology to ISE-based sensor arrays in aqueous systems has not been attempted or reported. The combination of an ISE array and neural networks can provide rapid and correct *identification and quantification* of multiple ionic species. Multiple sensors for the same ion as well as multiple ions will allow for accurate dynamic recalibration of the individual sensors as well as for quantification of the ionic species present. Self-diagnosis of performance *in-situ* and dynamic recalibration are highly desirable for treatment of changing operating conditions and shifting baselines in the individual ISE sensors. Such a sensor array can posses both the ability to *recognize* the presence of a chemical species and also provide quantitative information.

References: [1] Nealson K.H. (1997) *JGR, 102*, 23,675-86. [2] Shock E.L. (1997) *JGR, 102*, 23,687-94. [3] Gaidos E.J., Nealson K.H. and Kirschvink J.L. (1999) *Science, 284*, 1631-33. [4] Schwartz D.E., Mancinelli R.L. and White M.R. (1994) *Adv. Space Res., 15*, 193-97. [5] Brack A. et al., (1998) *ESTEC*, Noodwijk, Netherlands.

CHARACTERIZATION OF SETTLED ATMOSPHERIC DUST BY THE DART EXPERIMENT. Geoffrey A. Landis,[1] Phillip P. Jenkins[1], and Cosmo Baraona[2] [1]Ohio Aerospace Institute, NASA Glenn Research Center mailstop 302-1, 21000 Brookpark Road., Cleveland OH 44135, e-mail: geoffrey.landis@alum.mit.edu [2]NASA Glenn Research Center mailstop 302-1, 21000 Brookpark Road., Cleveland OH 44135, e-mail: cosmo.baraona@grc.nasa.gov.

Introduction: The DART ("Dust Accumulation and Removal Test" [1]) package is an experiment which will fly as part of the MIP experiment on the Mars-2001 Surveyor Lander [2].

Dust deposition could be a significant problem for photovoltaic array operation for long duration missions on the surface of Mars. Measurements made by Pathfinder showed 0.3% loss of solar array performance per day due to dust obscuration [3,4]. The DART experiment is designed to quantify dust deposition from the Mars atmosphere, measure the properties of settled dust, measure the effect of dust deposition on the array performance, and test several methods of mitigating the effect of settled dust on a solar array. Although the purpose of DART (along with its sister experiment, MATE [5]) is to gather information critical to the design of future power systems on the surface of Mars, the dust characterization instrumentation on DART will also provide significant scientific data on the properties of settled atmospheric dust.

Components of DART: Dust characterization on DART is done by two instruments: the dust microscope and the "MAE" commandable dust cover. The dust mitigation tests on DART consists of two tests: the tilted cell tests, and the electrostatic dust repulsion test. In addition, DART will have a set of sun position sensors.

Microscope. The DART microscope is a fixed-focus microscope which images a transparent glass settling plate from below. As atmospheric dust settles on this settling plate, it is imaged. The settling plate also includes photolithographically defined reference markings which for determination of scale and black level of the image. The microscope uses a 40X objective which focuses onto a 512x512 3-transistor active-pixel focal plane array. The pixel width is 12.5 microns. A blue filter is used to enhance the image sharpness, allowing resolution near the diffraction limit of about 0.5 microns.

Total mass of the microscope is 200 grams.

The microscope is intended to furnish information about the size distribution of the settled dust. Since settled dust may be different in character from the dust which remains suspended in the atmosphere, this information is of considerable interest to the design of dust mitigation strategies. For the larger component particles (>1 micron) of the dust, the DART microscope will also gather shape information, which is of interest tribology engineering.

Dust Cover. The "MAE" dust cover is based on the experiment flown on Pathfinder [3,4], and consists of a transparent plate onto which dust settles. This plate is located above three small solar cells, used in short-circuit current mode as solar intensity measurement in three wavelength bands. A commandable retraction mechanism allows the cover to be removed from its position above the solar cells. The comparison of solar intensity with and without the dust settling plate allows a direct measurement of the decrease of intensity of sunlight due to dust settling on the plate, by a method that does not depend on other possible sources of degradation in the cell performance or changes in the optical properties of the atmosphere.

A second MAE settling plate is designed to move over the input to the spectrometer of the MATE experiment. By taking a spectrum of the sunlight through the MAE settling plate, we hope to be able to obtain a transmission spectrum of the settled dust.

Tilted Cell Experiment. Measurements of the camera window on the Viking lander showed no dust adhering to the vertical surface. Observations of the thermal shell of the Viking landers seemed to show that dust also did not build up on the tilted surfaces. Unfortunately, no quantitative measurement of accumulation could be made. Due to this observation, we have decided that a high priority is to verify the conjecture that tilted solar cells do not accumulate dust, and to get an indication of what angle is required to avoid dust coverage. The tilted cell measurement consists of solar cells tilted at 30°, 45°, and 60°, plus a horizontal control, plus a solar cell tilted at 30° with low friction (diamond-like carbon) coating. A horizon mask is used to insure that the field of view of the cells includes only the sky, in order to remove albedo illumination from the surface.

Electrostatic Mitigation Experiment. Martian atmospheric dust is expected to be charged. In order to test whether electrostatic fields can be used to mitigate the deposition of dust on solar arrays, the electrostatic experiment will test three configurations. A vertical multi-junction high-voltage solar cell will provide a potential of about 80 volts between a transparent conductor on the front surface of the solar cell coverglass and a thin wire used as a ground. The configurations tested will be positive potential applied to the cell cover, negative potential applied to the cell, and transverse field across the cell. These will be compared to the control horizontal cell with no potential applied.

Sun Position Sensors. Finally, the DART experiment will include a set of three sun position sensors. Each sensor consists of a cylindrical lens focusing light onto a 512 element linear photodiode array. Two orthogonal elements will locate the sun in the N-S and the E-W directions; a third element, tilted at an angle of 45°, will find the sun position in one dimension in the evening.

The sun position sensors have a mass of 18 grams each. While primary purpose of these sensors is to allow solar cell measurements to be referenced to the true sun position relative to the solar cells, they will also provide data in the form of one-dimensional scans of the sunlight intensity across the sky.

Conclusion: The DART experiment on the Mars-2001 Surveyor lander mission will measure the deposition rate and properties of Martian dust, and will test two methods for mitigating the effect of dust accumulation on solar arrays. A companion experiment, the Mars Array Technology Experiment [5], will test the operation of different solar cell types and gather data on the spectrum and intensity of sunlight on the surface of Mars.

Further information can be found on the NASA Glenn Photovoltaics branch page, at http://powerweb.grc.nasa.gov/pvsee/experiments/2001.html

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TRIBOELECTRIC CHARGING IN SIMULATED MARS ENVIRONMENT. R. Lee[1] and R. Barile[2], [1]LO-G3-T, Kennedy Space Center, FL 32899 (Rupert.Lee-1@ksc.nasa.gov), [2]DNX-15, Kennedy Space Center, FL 32899 (Ronald.Barile-1@ksc.nasa.gov)

Introduction: Triboelectric charging of non-conducting materials followed by sudden electrostatic discharge (ESD) can damage electronic equipment and become ignition hazard to combustible materials. Mars atmosphere has near zero humidity and therefore natural charge bleeding to surroundings is anticipated to be limited. Potential mitigation of ESD problems has been conjectured based upon strong extraterrestrial radiation on Mars compared to earth. A hypothesis was formulated that ESD problem is less significant in simulated Mars condition since strong radiation and presence of argon will generate an ionized environment; this will be conducive to rapid bleeding of static charge into the surroundings.

Experiment: An aluminum wheel of 95 mm diameter was covered with a thin PVC film. Another wheel of the same diameter was covered with a Teflon felt. Rubbing was done by rotating one against the other at 30 rpm. Charge was measured with a Keithley 610C Electrometer. The setup was put inside a vacuum bell jar maintained at about 8 torr. Mixed gas of CO2 and Ar was used. Two levels of radiation was used, a black lamp and a mercury arc lamp, yielding 0.02 mW/cm^2 and 2 mW/cm^2 ultraviolet intensity between 300 and 400 nm wavelength. The first number was actual measurement but the latter was based upon manufacturers' data with partial measurement. Results are shown in Table 1.

Results and Discussion: Data shown in Table 1 indicates that triboelectric charging becomes less pronounced in 8 torr, regardless of gas composition. Initial charge decreased to about half. There was no noticeable charge decay for the duration of measurement which was typically about 10 seconds. The charge of 1.0×10^{-7} Coul on the specimen is equivalent to 1.4×10^{-5} $Coul/m^2$. It needs to be noted that the surface charge density of 2.7×10^{-5} $Coul/m^2$ will result in breakdown of air in 1 atm. Increase in UV intensity and Ar content did not change initial charge or charge decay behavior.

Based upon this study, the hypothesis was rejected. It is believed that variation of UV level and Argon content between Mars atmosphere and earth air did not change triboelectric charging behavior. The only major influential variable was change of pressure from 1 atm to about 8 torr.

Future Study: ESD related issues in earth atmosphere are expected to be of equal significance in Mars atmosphere. In order to understand electrostatics adequately, both charging and discharging behaviors need to be studied. Current investigation was focused on charge generation. The authors will continue to investigate discharge behavior in simulated Mars atmosphere.

TABLE 1 Triboelectric Charge Measurement

Pressure	Gas mix	Radiation	1st run	2nd run
1 atm	lab air	lab light	2.0	2.0
8.1 torr	CO2	lab light	1.1	1.3
8.1 torr	CO2	black lamp	0.8	1.0
8.2 torr	CO2 with 0.16% Ar	black lamo	1.0	1.1
8.1 torr	CO2 with 1.6% Ar	mercury arc lamp	0.8	1.2

Note: Unit for charge is 10^{-7} Coul.

THE 2001 MARS DESCENT IMAGER. M. C. Malin[1] and K. E. Herkenhoff[2], [1]Malin Space Science Systems, P. O. Box 910148, San Diego, CA 92191-0148, [2]U. S. Geological Survey, Flagstaff, AZ 86001-1698.

Introduction: The overall objective of the 2001 Mars Descent Imager (MARDI) experiment is to acquire and analyze close-up pictures of surface features at and in the immediate vicinity of the Mars Surveyor 2001 (MS'01) landing site, in order to provide geologic and physical context for the results of lander and rover investigations, to provide near-realtime planning information for lander and rover operations, and to study specific attributes of the geology and geomorphology of Mars.

Observational goals include studies of: 1) surface morphology (*e.g.*, nature and distribution of landforms indicating past and present environmental processes); 2) local and regional geography (*e.g.*, context for other lander instruments--precise location, detailed local relief); and 3) relationships to features seen in orbiter data. Based on the MS'98 MARDI experiment [1], it is anticipated that the MS'01 descent imager will provide panchromatic images of the landing site over a 73.4° field-of-view (FOV) with a resolution of 1.25 mrad/pixel (12.5 cm/pixel from 100 m). Nested images at a scale ratios of 2.5:1 or better will be acquired.

The anticipated results of this investigation include: 1) detailed knowledge of the local and regional setting of the MS'01 landing site, documented using geologic and topographic maps, 2) a specific link between the landing site and the rest of Mars as seen from orbit, and 3) serendipitous discovery of geomorphic processes at scales between those seen from orbit and those seen from the surface.

MARDI consists of optics and four small electronics boards: the focal plane assembly, clock board, data acquisition system electronics, and power supply. The original design was developed under Planetary Definition and Development Program funding, although the flight design is considerably simplified for reliability and ease of manufacturing. It is characterized by relatively small physical size (~5.5 × 8.5 × 12 cm, ~500 gm), low power (<4 W, including power supply losses), and high science performance (1000 × 1000 pixel, low noise images, and ultimate geometric resolution better than 1 cm/pixel). Depending on the descent profile that actually occurs, MARDI will acquire up to 100 Mbits of image data, spanning three orders of magnitude in scale, during the roughly 60 seconds between heatshield jettison and spacecraft touchdown.

Background and Motivation: Among the most dramatic images returned from space over the past forty years were those transmitted by the Ranger spacecraft, and those filmed by the Apollo astronauts, during their descents to the lunar surface. These images provided not only impressive views of the Moon, they did so in a particularly memorable way. In addition to unambiguously telling where a spacecraft has landed, images acquired during descent to a planet's surface provide the public with a visual perspective of spectacular, often breathtaking, beauty and excitement. The process of acquiring such images is simple and the results easily understood by all who see them. Descent imaging provides tangible results for early release to the public, and engenders a sense of "being there" not usually available with planetary missions.

Landing Site Context: Descent imaging systems provide a crucial link between orbiter and lander observations. They provide context for the lander data as a function of scale (resolution) and area. No other form of observation provides such context. Among the most important questions to be asked about a spacecraft sitting on a planetary surface is "Where is it?" Radiometric tracking and orbit determination (both spacecraft-to-Earth and spacecraft-to-spacecraft) and integration of inertial reference system variations (accelerometers tied to inertial measurement units) provide answers to this question to varying degrees of accuracy, but at best can only tell the position to perhaps a few hundred meters. Surface imaging of features also visible from orbit can be used to pinpoint lander positions to a few tens of meters or better, *provided* that such features are found. However, if the orbiter image resolution is insufficient to see features visible to the lander, the local, meter-scale relief is too great (so that the lander cannot see very far), the surface is relatively featureless, or the surface has many features but they all look the same, then the lander cannot be located. The Viking Landers and Mars Pathfinder provide good examples of such circumstances. Through a combination of 20-40 m/pixel, relatively low-sun orbiter photography, excellent radiometric tracking from Earth over a long period of time combined with good inertial position measurements during landing, and fortuitously landing near craters and hills large enough to be seen on the horizon in lander images, VL-1 and Pathfinder were located to within 40-100 m [2]. However, despite good inertial position measurements during landing and good radiometric tracking data both during the descent and for a number of weeks thereafter, the homogeneously rugged local relief, nearly featureless horizon, and the lack of spatially variable landforms in the 40 m/pixel images orbiter images defeated attempts to determine the location of the VL-2 to better than 10 km.

Why is it important to know "exactly" where a lander is located? The principal reason is context. It is necessary to determine if the locale is representative of the region, and indeed of the planet. It is usually not possible, just from a lander's perspective, to relate what is visible to what is just over the horizon. The locale may be anomalous; this must be determined before general interpretations can be made. Knowing that a nearby escarpment affects local meteorology, or that the lander sits on ejecta from a nearby crater, is important both for local interpretation, and for extending it farther afield. The context of relating lander observations to those seen from the orbiter is also important. The simplest and most obvious example is to place surface imaging into the context of orbiter images (extending and linking crater and boulder size/frequency relationships, extending surface observations of eolian bedform attributes to larger scale, *etc.*). Other examples include relating color and/or albedo boundaries seen in orbiter data down to lander scales (which is particularly difficult to do from the surface owing to the extremely oblique viewing geometry from the lander instruments), and providing data to test models used to calculate rock abundance and other granulometric properties of the surface from thermal emission measurements.

Descent imaging can also provide a context for operations after landing. For example, the final few images should cover the area around the lander out to 10 meters or more at spatial scales of a centimeter or better. Such images can be used to plan sampling activities and/or rover traverses, both before surface imaging and combined with landed data after they are received. The easily interpreted, overhead perspective provides such planning activities considerable speed and flexibility. Advanced techniques in computer graphics and data visualization have been used to merge lander images with distance measurements, derived from stereoscopic images or laser rangefinding, in efforts to mimic the overhead perspective. However, the inability to see surfaces hidden from direct view from the lander perspective seriously limits such efforts. The simplest, most comprehensive way to achieve overhead viewing is from a descent camera.

Science Studies from Descent Imaging: The scales at which processes modify a planet's surface are dependent on the vigor of the processes and the timescales over which they act. For Mars, the vigor of environmental processes has varied with time: recent phenomena appear to be relatively weak (*e.g.*, wind transport of dust and sand), while ancient processes appear to have been much more vigorous (*e.g.*, channel formation by catastrophic flood). Some processes are exceptions to this general rule, such as occasional contemporary mass movements. Based on cratering relationships (both the number of craters on surfaces and the degree of degradation of the ensemble of craters), a crude relationship between size and age can be formulated: craters a few meters across are unlikely to be more than a few millions of years old, while those hundreds of meters across are unlikely to be younger than a few hundred of millions of years old. This relationship suggests that features visible in descent images will cover a range in ages from hundreds of millions of years to as young as a few years in age.

Table 1 outlines the basic capabilities of the MARDI experiment, including science requirements based on either science or context arguments and mission constraints.

Table 1: Science Requirements for Descent Imaging

Resolution (highest)	~2 cm/pixel
Landing site visibility	must be seen in last frame; desire to see throughout descent
Field of View	landing site visible in last frame that covers ≥10 m @ 2 cm/pixel
Nesting scale ratio	better than 5:1 (≤2:1 goal)
MTF @ Nyquist	>0.10
SNR	≥ 20:1 for albedo = 0.10 at aphelion, with incidence angle $i \leq 75°$ (sun elevation ≥ 15°)
Photometry	5% relative (within an image), 10% absolute (between images)
Images Returned	~8–16
Spectral Response	500 to 800 nm

Known Issues Affecting Science Return from MARDI. MARDI is mounted to a cruise rocket engine motor mounting bracket. Its 73.4° FOV is canted 22.5° outboard from the nominal descent axis. The primary reason for this cant is that much of the view in the descent direction will be through the overlapping plumes of the descent engines; the optical distortion of the plume owing to temperature and density differences may be quite extreme. Canting the instrument was an attempt to acquire *some* undistorted imaging during powered descent.

The camera also observes rapid body angular rates and substantial vibration during powered descent. The maximum composite effect of these motions is about 3-5 pixels of motion blur (smear) for a 20 ms exposure. No effort was expended by the MS'98 Project to mitigate this problem. In order to reduce the effect, the exposure time was reduced to roughly 4 ms with a concomitant loss of signal (and hence signal to noise). Additionally, at short exposures, detector smear (created by light impinging on the detector during electronic transfer of an exposed image off the detector) contributes a moderately large fraction (>20% of total signal) of non-coherent, spatially-varying brightness patterns to each image. Taken together, solid body and vibrational motion blur and detector smear may substantially reduce spatial resolution and image fidelity during powered descent.

A major limitation on the MS'98 descent imaging system is the MS'98 Project requirement (in response to a spacecraft desire) that all image acquisitions be "pre-determined" (or "deterministic") with respect to the entry, descent, and landing (EDL) sequence. At the time of this decision, this meant that altitude could not be used as a trigger for imaging sequences. To attempt to acquire adequate overlap in resolution and coverage, a "roll camera" approach was taken: images are planned to be taken continuously at fixed intervals. However, since the descent rate will vary during the landing, the fixed interval must either be very short (to accommodate the terminal descent), thus acquiring large numbers of pictures, or long, potentially creating gaps in resolution or areal coverage.

Anticipated Results: Upon receipt on Earth, the images are decompressed and pre-flight photometric and geometric corrections are applied. Science analyses will include extraction of relief from stereo images (created as the lander moves laterally during the descent) and production of maps of the landing site in "near-realtime" in support of lander operations. A highlight of the data processing will be the recreation of the descent in animated form.

Under nominal circumstances, and limited by the available storage volume, the equivalent of 10-12 1000 × 1000 pixel images will be acquired from altitudes below 6 km. The number of images can be traded against their size, but the total data volume is constrained by the 1 Mbps data transfer rate, the descent time, and the 100 Mb buffer allocation. Figure 1 shows a representative descent profile with MARDI image acquisition locations indicated by large dots. The characteristics of the images acquired of the surface are summarized in Table 2. A few additional images of the heatshield jettison will be acquired for calibration. The last image may be affected by dust raised by the landing rocket exhaust plumes.

Table 2: MARDI 2001 imaging scenario

Time to TD (sec)	Altitude (m)	Resolution (cm/pixel)	Image width (m)
61	3121	550.4	5636
48	2196	333.7	3417
37	1408	194.8	1778
32	1039	137.7	1257
27	695	89.4	816
22	405	51.2	468
17	192	24.0	196
13	84	10.4	74
10	37	4.6	33
7	15	1.9	13
4	7	0.9	8

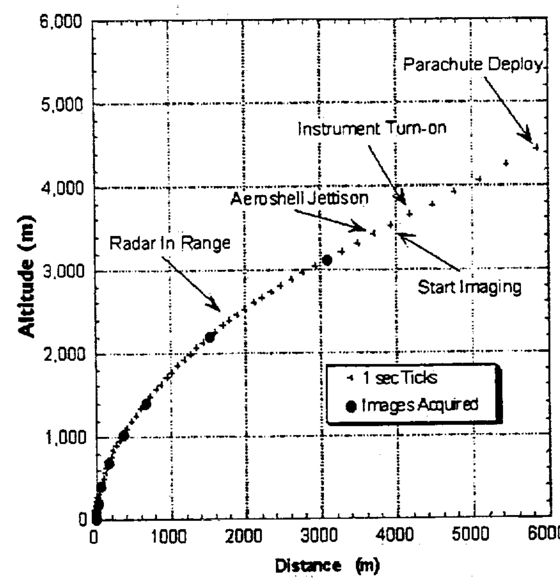

Figure 1. MS'01 descent profile

In addition to the individual images, derived information will include:

- detailed geologic, geomorphic, and traverse planning maps of the landing site, ranging in scale from 1:24K to 1:30
- relief maps of the landing site, at scales from 1:14K to 1:80, with vertical resolution ranging between 4 m and 2 cm
- time-sequential "realtime" descent animation, showing the 30 second descent to the surface

References: [1] Malin, M. C. *et al.* (1999) *JGR*, in press. [2] Parker, T. J. and Kirk, R. L. (1999) In 5^{th} *International Conference on Mars*, Abstract #6124 (CD-ROM).

OPTIMIZING SITE SELECTION FOR HEDS. J. R. Marshall[1], [1] SETI Institute/NASA Ames Research Center, MS 239-12, Moffett Field, CA 94035-1000; jmarshall@mail.arc.nasa.gov.

MSP 2001 will be conducting environmental assessment for the HEDS Program in order to safeguard future human exploration of the planet, in addition to geological studies being addressed by the APEX payload. In particular, the MECA experiment (see other abstracts, this volume), will address chemical toxicity of the soil, the presence of adhesive or abrasive soil-dust components, and the geoelectrical-triboelectrical character of the surface environment. The attempt will be to quantify hazards to humans and machinery-structures deriving from compounds that poison, corrode, abrade, invade (lungs or machinery), contaminate, or electrically interfere with the human presence. The DART experiment (see other abstracts, this volume), will also address the size and electrical nature of airborne dust. Photo-imaging of the local scene with RAC and Pancam will be able to assess dust raising events such as local thermal vorticity-driven dust devils.

The need to introduce discussion of HEDS landing site requirements stems from potential conflict, but also potential synergism with other '01 site requirements. ISRU mission components desire as much solar radiation as possible, with some very limited amount of dust available; the planetary-astrobiology mission component desires sufficient rock abundance without inhibiting rover activities (and an interesting geological niche if available), the radiation component may again have special requirements, as will the engineers concerned with mission safety and mission longevity. The '01 mission affords an excellent opportunity to emphasize HEDS landing site requirements, given the constraint that both recent missions (Pathfinder, Mars '98) and future missions (MSP '03 & '05) have had or will have strong geological science drivers in the site selection process.

What type of landing site best facilitates investigation of the physical, chemical, and behavioral properties of soil and dust? There are various approaches to answering this question:

(1) Choose a site that has a high potential for presenting the worst-case conditions that are likely to be encountered by astronauts with respect to the above parameters. If such conditions prove to be "within (some arbitrarily defined) envelope" of safety, then all other sites on Mars might be relatively benign. The advantage of this approach is that we are able to define robust engineering and operational strategies with wide margins of safety that are capable of dealing with any foreseeable hazards. The disadvantages of such an approach are: (a) we have no idea where these various hazards reach their worst cases on Mars, (b) it is an absolute guarantee that they do not all reach their worst case at one single location, (c) if worst case dust electrification were to be encountered for example, the platform would have to be at the core of a dust storm, in which case, the mission would be terminated through loss of power as a result of dust accumulation and electrical interactions with the Lander. On the one hand, we need to study the worst case, but on the other hand, the mission cannot afford to.

(2) Choose a site that is totally benign with regard to the above parameters --the rationale being that this is the kind of site the astronauts may go to in order to minimize encounters with hazardous situations. The advantage of this approach is that the choice of a landing site for either robotic or manned missions tends to be strongly influenced by engineering considerations in addition to scientific curiosity. There is therefore a potentially strong correlation between landing choices for astronauts and this type of site. However, this choice of site might result in a false sense of security among mission planners, and potential underdesign of equipment for hazard mitigation.

This raises the issue of what we define as "benign" or "safe". A few terrestrial comparisons serve to illustrate the issue: Humans have been trying to predict meteorological, geological, and astronomical hazards for several thousand years. We are not doing an excellent job. No one knows when the next earthquake will hit, no one knows which direction a hurricane is going to turn, no one can predict ocean currents that cause dramatic meteorological shifts from one season to the next, and we cannot predict if a weather front will produce tornadoes or not, nor where they might strike. For 99.999....% of the time, California, Japan, or Turkey seem geologically benign. For 99.999...% of the time, "Tornado Alley" of the US great plains seems meteorologically benign with respect to the touchdown of a tornado at any given location. The point is, of course, that even quiet locations always hold surprises. It is safer to live where hazards are frequent but predictable, than to live where hazards are few (or unknown) and totally unpredictable.

Applying this seemingly obvious reasoning to Mars, only a few years ago, it was thought that astronauts would be safe if they avoided areas known for major dust storms. Yet from recent missions (Pathfinder and MGS), it has emerged that the apparent tranquillity of large tracts of Martian surface is in fact disturbed by swarms of thermal vortices that create dust devils. These are not expected to be life threatening in themselves, but for the duration of a human mission, several thousand dust devils may be encountered, with the threat being cumulative in terms of dust penetration of machinery, suits, and habitats, and possible damage to equipment from electrical charges generated within the vortices.

(3) Choose a site known to have hazard elements that occur at many locations on Mars. It is important to stress that this is not equivalent to choosing a site that might be regarded as "average" in terms of hazards. From some of the preceding rationale, it might be difficult to define what to expect as "average" -- average energy of a system?, average frequency?, average depth of a deposit? And this approach of finding the "middle ground" can be misleading because it seeks to take the worst case and the best case, and simply divide by two --in other words, an example might be to pick a location with mid-size storms because in terms of energy, they lie between large dust storm cores, and ephemeral, tiny dust devils. The problem is that this "average threat" may not have a frequency within one sigma of a normal distribution curve for storm frequency. There could be thresholds of atmospheric energy or highly variable underlying mechanics of dust raising that result in the binning of aeolian phenomena into a multimodal (energy) distribution. A similar argument can be made for avoiding an averaging or representative approach when considering the depth of the aeolian mantle. In some places it is probably hundreds if not thousands of meters thick. In some places it is absent. The "average" depth may be a few meters, but this might as well be several hundred meters if we can only dig to a depth of 50 cm.

However, this type of Category 3 site is the one preferred here, but it requires better definition of its characteristics. It is best described as a **"sampler" or "eclectic" site**. It is a type of location that does not have to be of scientific merit, it does not have to be represented by large tracts of similar land on Mars, it does not have to have "usual" or "typical" conditions, and it does not have to be the sort of area that would provide a feeling of comfort for mission planners and engineers when they finally consider a manned landing. What, therefore are the characteristics that the site should have? The site could be typical or it could be exotic, but it must contain materials and phenomena that are most likely to be encountered by astronauts. Even if the measurable quantities are only small and geologically-meteorologically non-representative, the site should have things to study that have ubiquity on Mars. We note that a site which samples a wide range of phenomena is probably by definition, an unusual type of area. Eating one spoonful of every type of food on a restaurant menu would be the equivalent, but the resulting culinary experience would hardly be considered typical. However, this sampling experience is what the site should aim for; it usually only takes one spoonful to know if the rest of the meal is edible or not.

Such a site is illustrated in Figure 1. It is a region with a thin layer of recently deposited dust, even though the deposit may be seasonally transient. This enables sampling of material that is known to become globally distributed, and the dust is likely to be distinguishable from other local materials. It also enables sampling of the most ubiquitous material for astronauts --the omnipresent hazardous adhesive dust. It could be argued that there is dust everywhere on Mars anyway, but a counter-argument is that an area undergoing active deflation of dust may not be exposing material that is representative of atmospheric aerosols. The site of choice should also be generally windswept on a seasonal basis so that observations can be made of local aeolian entrainment. It should be one of those apparently benign areas that nevertheless has seasonal swarms of dust devils. This affords an opportunity to

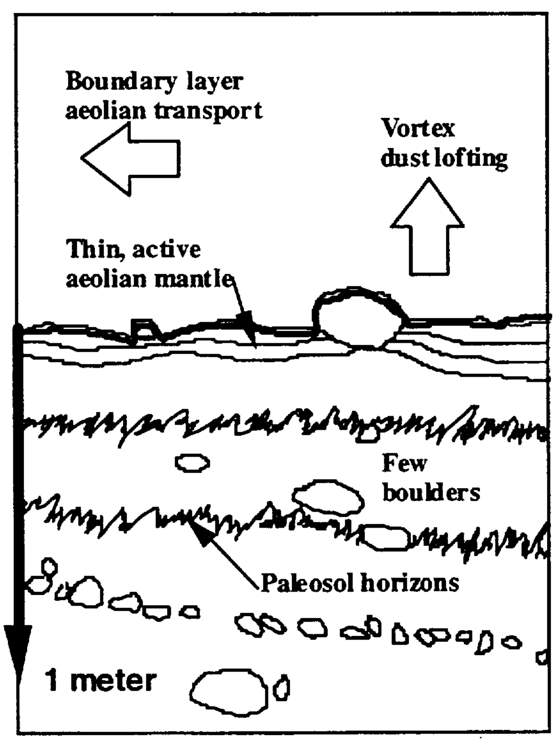

Figure 1: Site characteristics ideal for HEDS and astrobiology investigations

study causes of dust lofting in terms of aerodynamics and electrostatics, without there being too high risk for dust accumulation on the solar panels. The site should not be a dune field, nor an area of considerable aeolian deposition; it should not be one of the global sinks for windblown material, because this will prevent the mission from excavating soils and regolith that may never have been moved by wind (or that have been immobile for a long time). This material underlying the thin active aeolian veneer is likely to be compositionally different, perhaps in subtle ways, perhaps dramatically. And the site should be relatively free of large boulders that obstruct digging activities.

But what does the immobile substrate have in store for astronauts if they begin to excavate it when setting up camp? Are there accumulations of volcanic aerosol emissions or tephra rich in sulfur and other undesirable elements such as heavy metals? It is worth stating the well known fact that Mars has no hydrological cycle to remove accumulations of certain chemicals in the soil, and the lack of water and low thermal kinetics also prevent aqueous chemistry that would ordinarily lead to reaction buffering; the soil components might therefore be a "chemical timebomb" if trekked into a warm, high-humidity human habitat. The soil on Mars should be regarded as a dry geochemical equivalent of earth's oceans --which are the dumping ground or repository, of all the planetary emissions over the eons of geological time. It is therefore very important to search for elemental concentrations within soil horizons, and we can only do this if a thick aeolian mantle is absent from the site.

In conclusion, the "eclectic", boulder-free, windswept region potentially exposing paleosols is: (1) ideal for HEDS exploration owing to the presence of active aeolian material and ancient surface material with mineral concentrations, and relatively unimpeded digging opportunity --unless a hardpan is encountered, (2) ideal for astrobiology for the same reasons, and particularly because evidence of ancient hydrology is a key goal for this discipline, (3) ideal for engineering considerations for safe landing of the platform owing to the absence of large boulders.

CHEMICAL COMPOSITION OF THE MARTIAN SURFACE: A SEDIMENTARY PERSPECTIVE. Scott M. McLennan, Department of Geosciences, State University of New York at Stony Brook, Stony Brook, NY, 11794-2100 (Scott.McLennan@sunysb.edu).

Introduction: The sedimentary rock record is the primary repository of Earth history over the past four billion years [1]. Major and trace element geochemistry and radiogenic isotopes are routinely used to investigate the sources of sediment (provenance) and the various processes that affect sediments throughout their history (e.g., weathering, sedimentary transport and recycling, diagenesis). The most sophisticated analytical methods that are available have been employed in sedimentary geochemistry and in many cases include grain by grain analyses of mineralogy, chemistry and isotopic characteristics. In turn, this information has been used to address many important issues, such as tectonic associations, environments of deposition, paleoclimates, paleohydrology, and crust/mantle evolution [e.g., Ref. 2].

Photographic, spectroscopic and geochemical results, returned from the surface of Mars over many years and many missions, have increasingly pointed towards a wide variety of sedimentary processes playing a dominant role in shaping the Martian surface. Accordingly, there is great potential for applying the knowledge that has been learned from studying terrestrial sedimentary rocks towards evaluating Martian geological history. Chemical and mineralogical analyses from the Martian surface, especially those from the Viking, Pathfinder, and Mars 2001/2003 missions, coupled with greater understanding of basaltic sedimentation on the Earth should provide the sedimentological framework within which to study the chemistry and mineralogy of returned Martian samples.

Mars and Earth - Some Contrasts in Sedimentary Styles: In spite of the presence of "andesitic" rock compositions at the Pathfinder site [3], the chemistry of Viking and Pathfinder soils [3,4], SNC meteorites [5,6] and our general understanding of the chemical evolution of terrestrial planets [7] all lead to the conclusion that the magmatic history of Mars is probably dominated by basalts. Thus, basaltic sedimentation should also dominate the surficial processes. This stands in complete contrast to the Earth where purely basaltic sedimentation is very rare and restricted to localized parts of volcanic islands (e.g., Hawaii, Iceland), restricted horizons within basaltic constructs (e.g., interflow sediments in flood basalt provinces and Archean greenstone belts), and associated with early phases of oceanic island arc evolution. This distinction is mainly the result of the unique high standing continental crust on the Earth coupled with the presence of low standing basaltic terrains in the water covered ocean basins [1].

A second fundamental difference in sedimentation styles between Earth and Mars is the distribution of sediment types. Estimating lithological proportions of sedimentary rocks on Earth is largely model dependent and but clastic sediments dominate with the following approximate proportions: Shale - 59%; Unaltered volcanogenic sediment - 15%; Carbonate sediment - 13%; Sandstones - 10%; Evaporites - 2%; Siliceous biogenic sediment - 1% [e.g., Ref. 8]. On Mars, these proportions almost certainly differ greatly. Although much of the material incorporated into soils can be considered clastic sediment, the grain size distributions and amount of unaltered volcanogenic debris are largely unknown. Carbonate minerals have yet to be unambiguously identified on Mars. Assuming that sulfur and chlorine in Martian soils, amounting to as much as 4% and 1% respectively, is associated with evaporitic minerals, evaporite deposits may be far more important than on the Earth.

Other expected distinctions between terrestrial and Martian sedimentary styles center on the role of meteorite impacts as a sedimentary process and the level of meteoritic components within the sediments. On Earth, the sedimentary mass has grown over geological history and is very dynamic, being continuously recycled through cannibalistic processes (i.e., sediment - sediment recycling), through the continents (e.g., metamorphism and melting), and possibly through the mantle in association with plate tectonic processes (e.g., subduction, delamination of lower crust) [9]. Meteoritic components, especially those resulting from the intense early bombardment, have been largely obscured or lost from the record [1]. Only on relatively localized scales, such as in debris resulting from individual impacts (e.g. Cretaceous-Tertiary boundary layer; tektites) and in slowly accumulating deep sea pelagic sediments is evidence of meteoritic components clearly present.

On Mars, such recycling processes are much less likely to have occurred in the absence of plate tectonic processes and the Martian sedimentary mass is probably more ancient on average being recycled mainly by cannibalistic processes — that is only through sedimentary mixing processes at the surface. In this regard, the experience gained from study of the lunar regolith may prove useful in discriminating the role of meteoritic components in Martian soils [7].

Sedimentary Provenance: Although basaltic provenance most likely will dominate Martian sediments, data from SNC meteorites and Pathfinder rocks, that cover the range from ultramafic to intermediate, indicate that in detail much variability in source rock compositions is to be expected. Experience from terrestrial studies suggests that the best way to unravel provenance components using bulk samples is to analyze a diverse suite of samples, maximizing variations in mineralogy and grain size, as was attempted at the Viking and Pathfinder sites.

Evidence for Sediment Mixing on Mars: The composition of soils at the Viking and Pathfinder sites are broadly similar but significant differences appear to exist for MgO, TiO_2, SO_3, K_2O, and perhaps other elements and an important question is how homogeneous are soil compositions on a global scale? Pathfinder results provide compelling evidence for physical mixing between rocks and soils [10,11], however, some of the geochemical variations are inconsistent with simple two component mixing and accordingly other processes (and/or provenance components) have probably affected soil and rock compositions [12,13].

Sedimentary Processes: An important characteristic of Martian soils is their high S and Cl contents [3,4]. Correlations between these elements and Mg (and possibly Fe) point to a substantial secondary mineralogy and evaluating the processes that have given rise to this mineralogy is a critical issue that will constrain the sedimentary environments that have operated on the Martian surface over its history.

Weathering and/or Hydrothermal Alteration: Although a great deal of effort has gone into modeling various alteration scenarios for the Martian surface [e.g., 14-16], such studies are largely in the realm of speculation until further mineralogical and chemical constraints from surface measurements are available. Several lines of evidence point to a sulfur mineralogy dominated by magnesium sulfates. In addition, there is abundant evidence for substantial amounts of iron being associated with secondary iron oxide minerals (e.g., hematite, maghemite). Accordingly, regardless of the exact mechanism of surface alteration, it is clear that primary igneous minerals have been altered to a secondary 'sedimentary' mineralogy. Under a wide range of hydrological conditions on Earth (e.g., weathering, palagonitization), silica is highly mobile. The fact that up to half of the Mg and Fe contained in soils, and liberated during alteration processes, may be sequestered in non-silicate minerals leaves open the distinct possibility that sedimentary silica could be an important constituent of the near surface environment [13,17].

Mineral Fractionation during Sedimentary Transport: Sedimentary transport is expected to result in hydrodynamic separation of heavy minerals. Although no relevant studies have been conducted for terrestrial basaltic sedimentation, it is likely that Fe-Ti-Cr oxides (e.g., ilmenite, titanomagnetite, magnetite, chromite) will dominate Martian heavy mineral suites. Pathfinder and Viking soils and rocks show variations in TiO_2 contents that are consistent with such heavy mineral fractionation [12,13] and further measurements at the Mars 2001 site may confirm or refute this suggestion.

A second process that is likely to affect surface chemistry is the transport of fine grained iron-rich dust and deposition on rock surfaces and admixture into soils. Some soils at the Pathfinder and Viking sites may be more enriched in iron than predicted from simple soil - rock mixing and such variations are consistent with a component of iron oxide, presumably fine dust transported by eolian processes [12,13].

Crust/Mantle Evolution: It is well established on Earth that the average composition of sedimentary rocks approximates the bulk composition of the upper crust exposed to weathering and erosion and this observation has been used successfully to constrain the composition and chemical evolution of the Earth's continental crust [1]. There is good reason to evaluate if such an approach is applicable to Mars, where the thermal history of the planet may be especially sensitive to the transfer of incompatible elements (including the heat producing elements) to the crust.

On Earth, mainly shales have been used to evaluate upper crustal evolution due to the relatively homogeneous compositions of shales, the abundance of shale in the sedimentary record, and the fact that shales dominate the mass balance of most elements in the sedimentary record. In detail, however, it is the composition of the entire sedimentary mass that equates to the upper crust, after correction for added CO_2, H_2O, SO_3, O_2, and so forth [1].

For Mars, there is no *a priori* reason to assume that a homogeneous sedimentary composition exists [e.g. Ref. 11], analogous to shales on Earth, that can be used for such a purpose. Accordingly, it is important to evaluate the degree of homogeneity that exists among the soils. Sampling from Viking and Pathfinder does suggest some degree of homogeneity but some significant differences, notably in Ti, Mg, K and S, do exist among these sites. Within the uncertainties, several authors have noted the broad similarity between the average soil composition and the composition of basaltic shergottites [e.g., 6, 10-12], although the high K_2O abundances at the Pathfinder site may indicate a more incompatible element enriched composition [12].

The Mars 2001 mission should provide especially useful constraints on this problem. The Lander/Rover will provide additional analyses of surface soils thus further evaluating the level of homogeneity of the soils at four sites. The Orbiter will map the surface chemistry on a 300 km resolution using the gamma ray spectrometer [18], thus providing a means of estimating the bulk surface composition and of testing the degree to which soils provide a meaningful estimate of the upper Martian crust.

Some Priorities for Sedimentary Geochemistry Studies on Mars: Apart from the obvious need for more geochemical data at all scales, an evaluation of the sedimentary geochemistry of the Martian surface would benefit from a variety of mineralogical, textural and chemical data. On the most basic level, distinguishing sedimentary from igneous origin for analyzed rocks is critical, as demonstrated by the uncertainty in interpreting the geochemistry of Pathfinder rocks [19]. Distinguishing sedimentary from igneous rocks on Earth, in situations where it is not obvious such as in metamorphic rocks, tektites, and so forth, it is necessary to identify geochemical variations among samples that are uniquely characteristic of sedimentary processes (e.g., weathering, transport, diagenesis) [1,2]. For basaltic sediments in general, and on Mars in particular, such processes have not yet been adequately characterized.

Placing additional constraints on soil mineralogy is necessary for understanding the nature of low temperature alteration processes on and near the Martian surface. Evaluating chemical relationships would especially benefit from constraints on clay mineralogy and non-silicate mineralogy and more precise determination of elements forming anionic components (e.g., P_2O_5, CO_2, SO_3). The possibility that sedimentary silica may be an important constituent has broad implications and evaluating this possibility and the nature of sedimentary silica distribution at or near the Martian surface are important.

In order to evaluate the possible role of sedimentary transport on chemical and mineralogical compositions, it is also important to have measurements of the grain size of soils that are analyzed. In due course, setting priorities for selecting material for sample return also may be strongly influenced by grain size distributions, as will setting priorities on developing geochemical analytical approaches to returned samples.

The level of enrichment of incompatible elements in sedimentary rocks is critical for interpreting detailed provenance and for constraining geochemical models of crust/mantle evolution (the level of heat producing elements in the crust, for example). K_2O abundances at the Pathfinder site were unexpectedly high and contrasted with the relatively low levels at the two Viking sites. High quality measurements of potassium in soils and rocks will be especially useful geochemical data. The combination of additional surface rock and soil APXS data (mainly major elements) coupled with large scale orbital gamma ray geochemical data (major and trace elements) promises to provide major advances in our understanding of the geochemical evolution of Mars.

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THE MARS ENVIRONMENTAL COMPATIBILITY ASSESSMENT (MECA). Thomas P. Meloy[1], John Marshall[2], Michael Hecht[3], [1]Particle Analysis Center, West Virginia University, 338 Comer Bldg., Morgantown, WV 26506-6070 (tmeloy@wvu.edu), [2]SETI Institute, NASA Ames Research Center, [3]Jet Propulsion Laboratory

Introduction: The Mars Environmental Compatibility Assessment (MECA) will evaluate the Martian environment for soil and dust-related hazards to human exploration as part of the Mars Surveyor Program 2001 Lander. Sponsored by the Human Exploration and Development of Space (HEDS) enterprise, MECA's goal is to evaluate potential geochemical and environmental hazards that may confront future martian explorers, and to guide HEDS scientists in the development of high fidelity Mars soil simulants. In addition to objectives related to human exploration, the MECA data set will be rich in information relevant to basic geology, paleoclimate, and exobiology issues. The integrated MECA payload contains a wet-chemistry laboratory, a microscopy station, an electrometer to characterize the electrostatics of the soil and its environment, and arrays of material patches to study the abrasive and adhesive properties of soil grains. MECA is allocated a mass of 10 kg and a peak power usage of 15 W within an enclosure of 35 x 25 x 15 cm (figures 1 and 2).

The Wet Chemistry Laboratory (WCL) consists of four identical cells that will accept samples from surface and subsurface regions accessible to the Lander's robotic arm, mix them with water, and perform extensive analysis of the solution. Using an array of ion-specific electrodes (ISEs), cyclic voltammetry, and electrochemical techniques, the chemistry cells will wet soil samples for measurement of basic soil properties of pH, redox potential, and conductivity. Total dissolved material, as well as targeted ions will be detected to the ppm level, including important exobiological ions such as Na^+, K^+, Ca^{++}, Mg++, NH_4^+, Cl, SO_4^-, HCO_3^-, as well as more toxic ions such as Cu^{++}, Pb^{++}, Cd^{++}, Hg^{++}, and ClO_4^-.

MECA's microscopy station combines optical and atomic-force microscopy (AFM) to image dust and soil particles from millimeters to nanometers in size. Illumination by red, green, and blue LEDs is augmented by an ultraviolet LED intended to excite fluorescence in the sample. Substrates were chosen to allow experimental study of size distribution, adhesion, abrasion, hardness, color, shape, aggregation, magnetic and other properties. To aid in the detection of potentially dangerous quartz dust, an abrasion tool measures sample hardness relative to quartz and a hard glass (Zerodur).

Mounted on the end of the robot arm, MECA's electrometer actually consists of four types of sensors: an electric field meter, several triboelectricity monitors, an ion gauge, and a thermometer (figure 3). Tempered only by ultraviolet-light-induced ions and a low-voltage breakdown threshold, the dry, cold, dusty martian environment presents an imposing electrostatic hazard to both robots and humans. Over and above the potential threat to electronics, the electrostatic environment holds one of the keys to transport of dust and, consequently, martian meteorology.

MECA will also observe natural dust accumulation on engineering materials. Viewed with the robot arm camera, the abrasion and adhesion plates are strategically placed to allow direct observation of the interaction between materials and soils on a macroscopic scale. Materials of graded hardness are placed directly under the robot arm scoop to sense wear and soil hardness. A second array, placed on the lander deck, is deployed after the dust plume of landing has settled. It can be manipulated in a primitive fashion by the arm, first having dirt deposited on it from the scoop and subsequently shaken clean.

Dust Hazards: Properties that render dust a contaminant include the small grain size that enables penetration of space-suit joints, mechanical interfaces and bearings, seals, etc., and presents difficulty for filtration systems. Size also plays a critical role in the potential for lung disease in long-term habitats. Grain shape and hardness determine the abrasiveness of dust as it enters mechanical systems, or bombards helmet visors and habitat windows in dust-laden winds. Adhesive electrostatic and magnetic properties of dust will be prime causes of contamination of space suits and equipment. Contamination causes mechanical malfunction, tracking of dirt into habitats, "piggybacking" of toxins on dust into habitats, changes in albedo and efficiency of solar arrays and heat exchangers, and changes in electrical conductivity of suit surfaces and other materials that may have specific safety requirements regarding electrical conductivity.

In contact with a human habitat, soluble components of dust can result in reactive, oxidizing, or toxic solutions, including heavy metals. Because Mars has no active surface aqueous regime, volcanic emissions, meteoritic debris, weathering products, and photochemical products of Mars that would be metastable on Earth may persist for eons on the surfaces of martian dust.

From a planetology perspective, there are many enigmatic issues relating to dust and the aeolian regime in general. For example, if MECA determines a particular particle size distribution (size and sorting values), it will be possible to make inferences about the origin of the dust -- is it all aeolian, or a more primitive residue of weathering, volcanic emissions, and meteoritic gardening? Trenching with the Lander/MECA robot arm will enable local stratigraphy to be determined in terms of depositional rates, amounts and cyclicity in dust storms and/or local aeolian transport. Grain shape will betray the origin of the dust fragments as being the product of recent or ancient weathering, or the comminution products of aeolian transport --the dust-silt ratio might be a measure of aeolian comminution energy. Grain shapes, and the types of mechanical surface textures on grain surfaces (such as Hertzian, Boussinesq, conchoidal, blocky, or river fractures) provide clues about grain transport modes, and transport duration and energy. Some researchers have proposed that dune material on Mars may be sand-size aggregates rather than solid mineral grains. Certainly, it will be important to determine the aggregation and clumping tendency of the dust (aggregate shapes and packing densities) as indicators of the role that electrostatic meteorology plays on Mars in view of the unusual mixture of Paschen effects, superaridity, poor surface grounding, solar/cosmic ionizing radiation, and aeolian tribocharging of dust and atmosphere. Aggregation probably plays a key role in determining the rapidity of atmospheric cleansing after global dust storms.

Dust Analysis: The MECA instruments will assess potential hazards that the Martian soil might present to human explorers and their equipment. In addition, MECA will provide information on the composition of ancient surface water environments, observing microscopic evidence of geological (and biological?) processes, inferring soil and dust transport, comminution and weathering mechanisms, and characterizing soil horizons that might be encountered during excavation.

Types of data being sought for the dust include: (1) general textural and grain-size characterization of the soil as a whole --for example, is the soil essentially dust with other components or is it a clast-supported material in which dust resides only in the clast interstices, (2) size frequency distribution for dust particles in the range 0.01 to 10.00 microns, (3) particle-shape distribution of the soil components and of the fine dust fraction in particular, (4) soil fabric such as grain clustering into clods, aggregates, and cemented/indurated grain amalgamations, as well as related porosity, cohesiveness, and other mechanical soil properties, (5) cohesive relationship that dust has to certain types of rocks and minerals as a clue to which soil materials may be prime hosts for dust "piggybacking", (6) particle, aggregate, and bulk soil electrostatic properties, (7) particle hardness, (8) particle magnetic properties, (9) bulk dust geochemistry (solubility, reactivity, ionic and mineral species).

The role of water in surface processes is of course, key to the exobiological study of Mars; MECA wet chemistry essentially "reactivates" ancient aqueous settings. Although solution-dissolution dynamics are not always reversible, MECA will help constrain water soluble species in the soil that may have derived from ancient hydrothermal mineralization, from chemical precipitation in lake beds and carbonate-rich ocean basins, from flood waters episodically disgorged from the upper crust, or from moisture-driven mineral differentiation in the pedogenic surface. Counterbalancing the preservation of organic biodetritus potentially derived from a more clement martian past, are the postulated soil oxidants. These must be studied as key to carbon/life preservation for both extinct and potentially extant life on Mars. The oxidant issue is addressed by MECA by electrochemical detection techniques.

Trenching with the robot arm and use of the MECA microscope and RAC will enable examination of soil layers, horizons, crusts, strata, nodules, and rock varnishes and rinds. These are clues to the migration of water in the soil. From such data may be inferred weathering rates, water volumes, thermal & wetting/drying regimes, and the general role of surface moisture on the planet. Examination of soil microscopically will enable aggregates/clods, grain packing, cementation structures, phyllosilicate cardhouse structures, and so forth, to be scrutinized. These features are important clues to soil porosity and thus to the transport of water and other volatiles through the martian surface which regulates the volatile budget of the atmosphere and polar caps.

Additional compositional information that can be cross-referenced with the wet-chemistry is obtained under the microscope from grain features such as cleavage, crystal shape, fracture patterns, grain color, grain surface coatings, pitting/etching, as well as from UV-excited fluorescence. Of exobiological interest would be the detection of calcite, dolomite, silica, fibrous evaporitic minerals, etc. Microscopy will enable discrimination (for millimeter-size fragments) of lithological species of exobiological interest such as amygdaloidal vesicular clasts indicative of hydrothermal activity, clastic sediments indicative of fluvial, lacustrine, or littoral activity, microlayered evaporitic materials, and so forth. Many lithic species betray aqueous or hydrothermal processes.

AFM provides imaging capabilities comparable to SEM, and has resolution in the nanometer range. It will enable, along with microscopy, determination of microstructures such as those of the clay minerals (important indicators of water weathering), precise micro- and nano-scale mineral/grain shapes, and the surface textures of some of the larger grains. Sedimentologists routinely use mechanical grain-surface textures to evaluate transport history of sand grains, such as water or wind action. Additionally, AFM enables imaging of chemical surface textures such as etch features, which are clues to weathering.

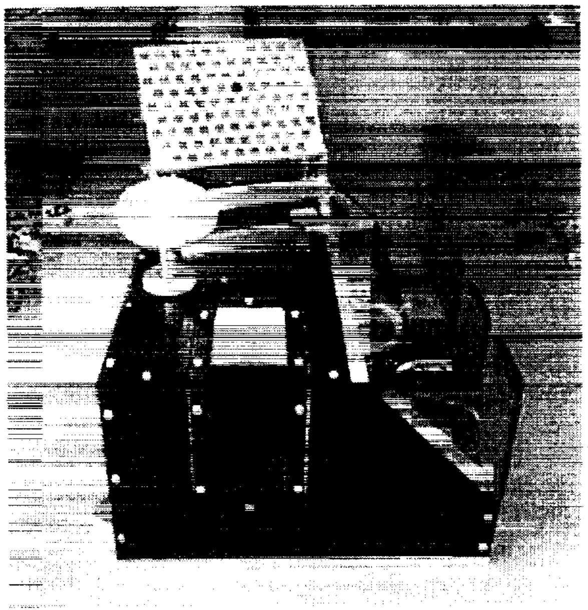

Figure 1: The MECA enclosure with four chemistry cells at right, deployed patch plate on top, and the chute for microscope sample introduction in the front. The canted disk at the top is a calibration target for the APEX Mossbauer spectrometer.

Figure 2: Side view showing single chemistry cell (left) and three mass models. The microscope sample wheel can be seen rear left.

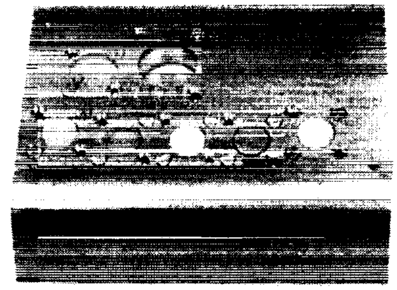

Figure 3: The MECA electrometer, to be mounted in the heel of the robot arm scoop. The electrometer incorporates five triboelectric soil sensors, a static charge meter, an ionization chamber and a thermometer.

THERMAL INFRARED SPECTROSCOPY FROM MARS LANDERS AND ROVERS: A NEW ANGLE ON REMOTE SENSING.

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Introduction: The Mini-TES instrument of the Athena Precursor Experiment (APEX) on the Mars Surveyor 2001 lander mission [1] will perform the first thermal infrared remote sensing observations from the surface of another planet. Experience gained from this experiment will be used to guide observations from identical instruments mounted on the Athena rovers, to be launched in 2003 and 2005. The utility of infrared spectrometers in determining the mineralogic composition of geologic surfaces from airborne and spaceborne platforms has been amply demonstrated (e.g., [3,4]). However, relatively little experience exists in using functionally similar instruments on the ground in the context of planetary science. What work has been done on this problem (e.g., [5,6]) has mostly utilized field spectrometers that are designed to look *down* on nearby target rocks. While many Mini-TES observations will be made with this type of geometry, it is likely that other observations will be made looking *horizontally* at the more vertically-oriented facets of rock targets, to avoid spectral contamination from dust mantles (e.g., [7]). On rover missions, the Mini-TES may also be pointed horizontally at rocks several meters away, to determine if they are worthy of approaching for *in situ* observations and possible sample cacheing. While these observations will undoubtedly prove useful, there are important, and perhaps unappreciated, differences between horizontal-viewing, surface-based spectroscopy and the more traditional nadir-viewing, orbit or aircraft-based observations. Plans also exist to step the Mini-TES in a rastering motion to build hyperspectral scenes [2,8]. Horizontal-viewing hyperspectral cubes also possess unique qualities that call for innovative analysis techniques.

The effect of viewing geometry: In thermal emission spectroscopy, regardless of whether an instrument is looking down on or horizontally at a target, the same basic equation governs the radiance reaching the sensor [9]:

$$L_S(\lambda,T) = [\varepsilon_\lambda L_{bb}(\lambda,T) + R_\lambda L_E(\lambda)]\tau_A + L_A(\lambda)$$

where $L_S(\lambda,T)$ is the radiance measured by the sensor as a function of wavelength and target temperature, and ε_λ is the spectral emissivity of the target, which modulates $L_{bb}(\lambda,T)$, the radiance given by the Planck function at the temperature of the target. $L_E(\lambda)$ is the "environmental radiance" seen by the target, and it is reflected back to the sensor by the fraction R_λ, the reflectivity of the target. These two terms emanating from the target are modulated by the transmissivity of the atmospheric path between the target and the sensor, τ_A. Finally, direct emission from the atmosphere must be accounted for with the term $L_A(\lambda)$.

The relative magnitude of the terms in this equation can be quite different, depending on the geometry of the observation. Obviously, for targets near a lander or rover, the atmospheric transmission term, τ_A, will have a value much closer to one, and the atmospheric radiance term, $L_A(\lambda)$, will be closer to zero than would be the case in orbit-based observations because atmospheric pathlengths are smaller. Less obvious are effects related to differences in the environmental radiance term, $L_E(\lambda)$, between the two geometries. In the nadir-viewing case, this term is usually referred to as the "atmospheric downwelling" term – in other words, it describes emission from the atmosphere seen by a surface element on the target looking up at the sky. Typically, the effective brightness temperature of the sky seen by a horizontally oriented target facet is relatively cold compared to the temperature of the target itself, and therefore the radiance reaching the detector is dominated by direct emission from the target. In horizontal-viewing spectroscopy, however, the $L_E(\lambda)$ term is much more complicated because non-horizontally-oriented surface elements on target rocks will reflect not only radiance from the sky, but also from the ground or from other nearby rocks, which can be at temperatures comparable to to the target's temperature. Because of Kirchoff's Law ($R=1-\varepsilon$), this environmental radiance will be reflected most strongly at the same wavelengths where the emissivity of the target lowest. The net effect is that the spectral contrast of the target is reduced.

To demonstrate this effect, we have conducted a simple controlled experiment using a Designs and Prototypes (D&P) portable thermal infrared field spectrometer. A target was constructed by glueing quartz sand to a flat board. Laboratory measurements of the spectrum of this target board showed it to have the typical quartz double emissivity feature at ~9μm, with a depth of about 15%. This target board was then hinged to another board coated with a blackbody material. With the blackbody board fixed in a horizontal orientation (simulating, for example, a surface of fine particulates with low spectral contrast), spectra were taken of the target board pivoted at different angles from the blackbody board (Figure 1). In this manner, we were able to observe how the spectrum of the target changed as the environmental radiance seen by the target changed from sky-dominated to ground-dominated (Figure 2). Our results show quite clearly that the apparent emissivity spectrum of a target descreases in contrast as its orientation changes from skyward-facing, to vertical, to downward facing because of the increasing contribution of reflected environmental radiation.

Figure 1: Schematic of the experimental set-up used to understand the effect of target facet orientation. Spectra of the target were aquired at various angles θ. Both boards were left at ambient temperatures.

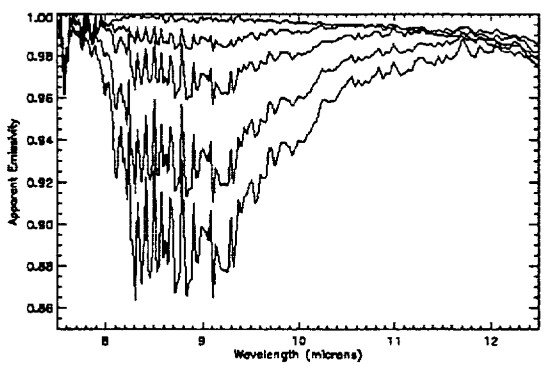

Figure 2: Spectra measured at $\theta = 150°$, 120°, 90°, 60°, and 30°. The spectrum with the greatest spectral contrast (deepest features) was taken with the target at $\theta = 150°$, with the contrast of the other six spectra decreasing monotonically to the featureless $\theta = 30°$ spectrum. The noisy appearance of the high-θ spectra is caused by reflection of narrow-band downwelling atmospheric emissions.

The effect of diurnal substrate/rock temperature contrasts: It is reasonable to expect that rocks at future landing sites may rest on, or be partially buried in, a substrate of fine particulates, just as at the Pathfinder and both Viking landing sites. The very low thermal inertia of a particulate substrate allows it to respond in temperature to insolation changes much more rapidly than high thermal inertia rocks. Kieffer et al. [10] calculated diurnal temperature curves for a 15 cm cube of basalt sitting on a surface with a thermal inertia equivalent to the martian global average (6.5 cal cm^{-2} $s^{-1/2}$ K^{-1}) at a latitude of 22°N. Their results showed that the rock was colder than the surface between the hours of approximately 7 am and 5 pm local time, with a maximum temperature difference of over 40K during mid-day. Because the power of a radiating source increases as T^4, one might expect that the spectrum of the side of a rock target would be strongly influenced by reflected radiance from the warm particulate substrate during these hours.

To test this hypothesis, we have performed another simple experiment. A limestone rock sample was placed on different blackbody substrates that were kept at different temperatures. A spectrum of the same, roughly vertically-oriented, facet of the sample was taken on each substrate, and temperatures of the sample and substrate were independently measured with a handheld radiometer. The temperatures of the substrates varied from being approximately the same as the sample, to about 20K warmer than the sample. A temperature difference of 20K at the room-temperature ranges used in the experiment gives roughly the same difference in blackbody radiance as 40K of temperature difference does at typical martian daytime temperatures.

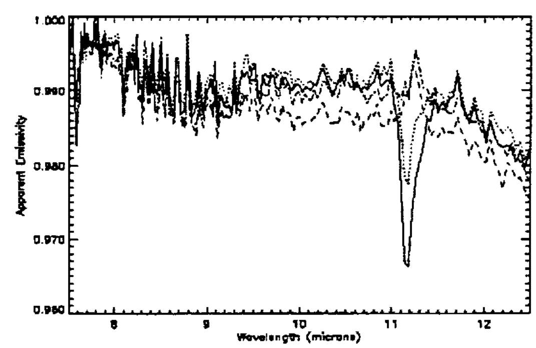

Figure 3: The effect of temperature differences between a rock target and the substrate it rests on. For each spectrum, the substrate was warmer than the target rock by: solid line: 2K; dotted line: 10K; dashed line: 19K; dot-dashed line: 23K.

The results of this experiment (Figure 3), show the effects of this difference in radiance. When the target and substrate are at approximately the same temperature, the spectrum of the target appears as one would expect for a limestone – relatively featureless, except for a single (if somewhat muted, in this case) emissivity minimum at 11.2 µm. However, as the temperature of the substrate increases, this feature is filled in by radiance from the substrate. In fact, at the largest temperature differences, the minimum in apparent emissivity becomes a small maximum – a result of the fact that the target reflects best at the same wavelengths where is emits most poorly.

The effect of confounding neighbors: Just as a flat particulate surface contributes to the environmental radiance a target is bathed in, so too will neighboring rocks and other topographic highs. If rocks on a surface are close enough to subtend significant solid angles as viewed from each other, this effect should become important. These neighboring sources could add an extra complication to the problem: while a surface composed of martian dust-sized particles will radiate as a near-perfect blackbody, nearby rocks may have significant spectral features. This means that the spectrum of the target rock would not be evenly filled-in (reduced in spectral contrast) by the environmental radiance it reflects. Rather, more infilling would occur at wavelengths where the neighbor rock has unit emissivity, and less infilling would occur where the neighbor rock has emissivity minima. In other words, the neighbor rock could actually induce new spectral features in the spectrum of the target rock, unrelated to the target rock's composition. We are presently designing a set of experiments to test this hypothesis.

Hyperspectral cubes: Horizontal-viewing hyperspectral cubes taken from the surface of Mars will present their own challenges, in addition to those already identified for individual spectra. Except for topographic variations, hyperspectral cubes obtained from airborne or orbital platforms have approximately the same target range over a single scene, simplifying the task of atmospheric correction. Lander or rover-based hyperspectral cubes, by contrast, are likely to contain several orders of magnitude variation in pixel ranges from the foreground to the horizon. Large depth of field also means a large range in spatial resolutions for pixels in a given scene. This will have the effect of producing data that are difficult to interpret compositionally: pixels in the foreground might contain relatively pure spectra of individual rocks, whereas more distant pixels will likely contain a mix of several different components. Existing hyperspectral data processing tools that are used to find pure spectral endmembers in a scene give equal statistical weight to all pixels. One approach to horizontal-viewing cubes, with their greater depth of field, would be to assign a statistically higher weight to foreground pixels.

One potential advantage available to lander and rover-based spectrometers is that their pointing precision is likely to be a small fraction of the size of the instrument's field of view (7 mrad in high-res mode for the Mini-TES). This means that hyperspectral cubes could be constructed with pixel spacings at, for example, 1/4 the diameter of the instrument's field of view, allowing the possibility of *superresolution* hyperspectral cubes, much in the same way that random sub-pixel offsets in Pathfinder images have been used to improve on the spatial resolution of the IMP camera (e.g., [11]).

We are currently employing a portable near-infrared spectrometer with a 1° field of view, mounted on an a computer-driven motorized pan-tilt platform to collect horizontal-viewing hyperspectral cubes and test these ideas.

Preliminary suggestions for observing strategies: While much remains to be explored in preparation for the new types of data that will be coming back from the Mini-TES experiments over the next decade, the early results shown here do suggest a number of strategies that might be followed in order to avoid the complications identified and maximize science return:

- When several facets of a target rock are available for observation, preference should be given to skyward-facing facets (if dust mantling is not present), where spectral contrast reduction from reflected surface radiance will be minimized.
- A comprehensive set of horizon-to-zenith atmospheric spectra should be obtained to completely characterize atmospheric emission incident on target rocks.
- When vertically-oriented rock target facets are all that are available for observation, they should be observed at several times over the course of a day, to help untangle the effect of warm surrounding particulate substrates reflecting off the target. If only one observation can be made (for example, if a rover needs to move), it should optimally be made in the evening hours, while the target rock is still warm but the substrate has cooled.
- For hyperspectral cube acquisition, coincident stereo imaging of the scene should be obtained, to aid in determining pixel ranges and spatial resolutions within the cube. Sub-field-of-view raster patterns may also help increase cube spatial resolutions.

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MARS '03-05: MISSION OUTLINE, SCIENCE GOALS, AND PLANETARY PROTECTION ISSUES: K. H. Nealson (Jet Propulsion Laboratory, MS 183-308, 4800 Oak Grove Dr., Pasadena, CA 91109, knealson@jpl.nasa.gov).

Introduction: The '03-05 mission to Mars will include many of the elements already discussed for the '01 mission. The Athena payload has been adopted for the analysis and selection of samples, and the will include many of the same measurements to be performed during the '01 mission. In addition, the missions will include yet to be determined experiments to be done on or from the lander. Several groups are now competing for instruments and science to be done on the lander for both '03 and '05.

Mission Outline: The major goal of the '03-'05 mission is the return of pristine samples for scientific analysis. If this is done, the mission will be considered a success. In addition, considerable scientific information will be obtained via in-situ experiments. Some of this work will involve analysis of rocks and soil samples by the rover instruments. After sufficient information is obtained from such analyses, samples will be obtained in individual core tubes (by the Athena drill), stored on the rover, for eventual return to the orbiting sample container (OS). The OS will be sealed with the sample cache inside, put into Mars orbit by a small rocket (Mars Ascent Vehicle or MAV), where it will remain until it is retrieved by the '05 orbiter, which will return it (along with the OS from the '05 lander-orbiter) to Earth. Upon return to Earth, the samples will be retrieved, moved to a containment facility, certified as safe for distribution, curated, and distributed. Details of these missions are still under development, and latest architectures and approaches will be discussed.

Science Goals: In addition to the return of Martian samples, a number of science goals will be addressed on the surface of Mars, including both analyses of the Martian surface and rocks by rover instruments, and a variety of as yet unspecified analyses of surface, and perhaps subsurface (drilled) samples by to-be-determined lander instruments. Insofar as they are available, these instruments and their scientific missions will be discussed.

Planetary Protection Issues: The Mars '03-'05 Mission presents a variety of problems heretofore not encountered in planetary missions, especially in the area of planetary protection. The mission must meet standards for protection of Mars (outbound contamination); for the protection of Earth from any potential Martian hazards (back contamination), and protection of the science from adventitious earthly contamination. All aspects of this present problems for the mission that are being addressed, and will be discussed. Given that the primary scientific goals involve the return of pristine samples for scientific analysis, the latter issues of science protection are particularly important.

LACUSTRINE ENVIRONMENTS AND LANDING SITES G.G. Ori and L. Marinangeli, *International Research School of Planetary Sciences*, Viale Pindaro 42, 65127 Pescara, Italy, e-mail: ggori@sci.unich.it, luciam@sci.unich.it

Introduction.
The most promising sites for landing exploration on Mars are lacustrine deposits because on Earth these environments bear a wealth of life varying form benthic to plantonic organisms. Based on the state-of-the-art geology, several areas are thought to be covered by standing bodies of water [1-7] and, among them, the ones contained in impact craters are the most recognisable. Craters provide a pre-formed basin with well defined rims and the body of water inside could form more evident morphological features than in lakes with broader and less defined margins. The undoubt identification of lacustrine environments will rise from the availability of mineralogical data and high resolution imaging from th e future missions. However, the current data of MGS mission do provide enough compelling evidence strongly suggesting the presence of these bodies of water.
Lacustrine deposits are quite good landing sites even in term of safety. Usually the floor is remarkably flat and, apart from coarse-grained basin margins, the sediment of the lake bottom is fine-grained. Moreover, the possible rough topography of the substratum can be buried by the lacustrine sedimentation that tends to smooth rough surfaces and relief.

Lacustrine environments and characteristics.
The structure and morphologies recognised and interpreted, along with theoretical models, suggest that two types of lacustrine basin could have been present. One formed by a standing body of water of appreciable depth and another with little or no water present at the surface. The former type would be called *deep water*, whereas the latter would be called *ephemeral lake*. The interpretation of these types of putative lacustrine deposits is strongly based on the analogies with Earth's lakes (Figure 1).

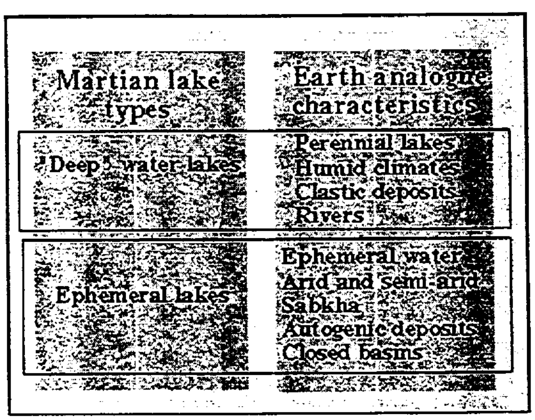

Figure 1. Comparison between lacustrine environments on Earth and Mars

The features suggesting the occurrence of deep water lakes are (i) terraces at the rim of the basins or around relief, (ii) Gilbert-type deltas at the mouths of inflowing channels, (iii) flat and uniform surfaces.
The presence of terraces (Figure 2) formed by standing bodies of water has been suggested extensively and a detailed discussion of this feature is out of the aim of the paper. Terraces form basically for the action of waves which can work as destructive or constructive agents. In the former case, the wave action erodes a flat platform at the level of the wave breaking and shape the so called wave-cut platform. In the latter case, the wave action builds a platform by accumulating sediments at the shore lines where most energy is consumed. The terraces can be also shaped using horizontal rock layering as preferential flat surfaces. However, even in this case, an eroding agent is needed in order to expose the flat surface of the stratification. On Earth, eolian activity does not have this capability due to its physical parameters, and only the water action bears energy to reshape strata.
Gilbert-type deltas form when a stream current with large bed-load flows into a water basin with a steep margin. This type of delta is characterised by upper flat surfaces (topset) corresponding to the water level and steep delta fronts (as steep as the angle of rest of the detritus - foreset).

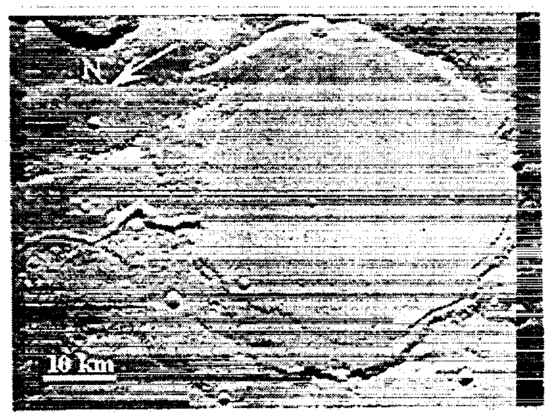

Figure 2. Example of a terraced "deep water" lake in Memnonia region (Viking image).

Frequently, the Gilbert-type delta bodies are entrenched by the channels and in some cases they form several topsets suggesting changes in the water level of the lakes [8]. They are good indicators of standing bodies of water and water level variations. Several fan-shaped features with flat upper surfaces and sharp frontal step have been observed at the mouth of channels in craters [7] and are remarkably similar to the terrestrial Gilbert-type deltas supporting the possibility of the presence of lacustrine environments on the Martian surface. Flat surfaces are not indicators of lacustrine or even sedimentary deposition. However, where they are associated to terraces and Gilbert-type deltas they can be interpreted as the sediment accumulated at the lake bottom.

The so called "ephemeral" lakes are dry for most time and they could be flooded only occasionally. The evidence for the presence of this kind of lakes on Mars are extremely scanty. The features characteristic of the deep water lakes may not be present in this kind of basins because the wave action would be negligible. The most probable feature are shoreline ridges at the margin. The most compelling evidence would be the mineralogical composition of the lake floor. Unfortunately, this kind of date is so far unavailable and the few data available are not conclusive at all. The evaporitic deposits are known to give high albedo surfaces and several of them have been observed on Mars. However, the interpretation is not unique and the high-albedo areas although similar to lacustrine environments cannot be easily interpreted. In one case, a high-albedo area has been observed covering the lowland of the crater leaving relief uncovered (with lower albedo) and with several ridge-like features at the border resembling shoreline structures (Figure 3).

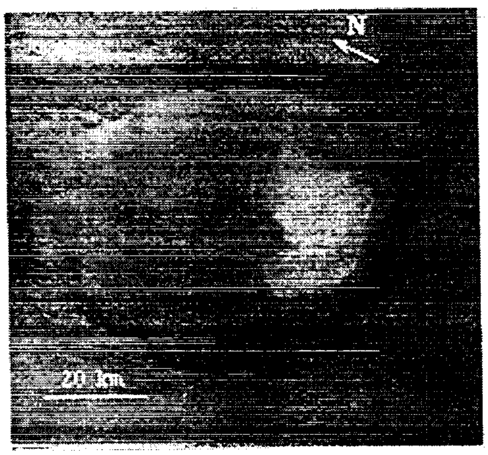

Figure 3. High albedo deposits in a crater in Argyre region as possible evidence of sabka-like deposits on Mars. (Viking image)

Lithologies and their distribution.
The lithologies associated to different geologic environments and their spatial distribution are basic requirements to define the characteristics of a landing site. Landing activities in particular drilling operations and sampling strongly depends on the mechanical properties of rocks.

In deep-water lakes the sedimentation accumulate siliciclastic coarse-grained detritus at the margins. Sand and gravel can be present in the terraces and in the deltaic bodies and they fines basinward. If the standing body of water is large enough, the central part of the basin sedimentation is basically dominated by settling of clay and other fine particles. Of course, this model is extremely simple and the facies distribution depends by a large number of variable such as lake dimension, water depth, wave energy, fluvial energy, etc. Micro-biota, on terrestrial deep-water lakes, is largely present in the fine-grained facies. The marginal coarse-grained shoreline and deltas can be covered by extensive algae and bacterial mats. However, erosional processes, due to the high energy of the wave and fluvial action can lower the potentiality of preservation of the biota.

In ephemeral lakes the common process of sediment accumulation is chemical or bio-chemical. The direct precipitation of minerals from surface water is almost negligible because these kind of lakes on Earth are permanently dry.

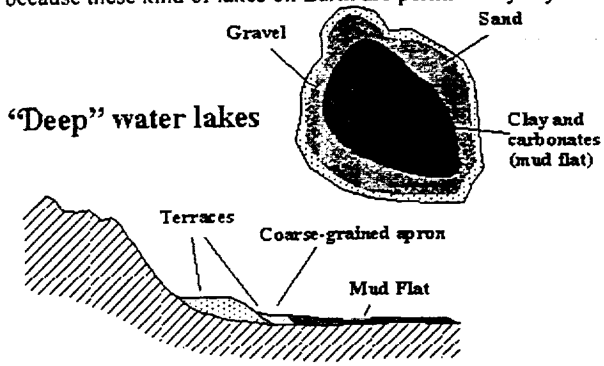

Figure 4. Lithologic types and their distribution in "deep" water lakes.

The precipitation of salts occurs in the subsurface where the interstitial waters, affected by dry and hot climate, evaporate and form nodules or crusts with composition depending by the salt content of the parent water. This process is quite efficient in deposition of carbonates and sulphates, which can displace the hosting material up to reach more than 90% of the total volume and can be exposed at the surface. The same type of salts can precipitate from superficial waters. In this case a crust of autigenic mineral is directly formed at the surface. The exobiological potentiality of these facies is huge because several of this mineral-forming processes are actually bio-chemical and, however, these environments are reach in bacterial colonies such as cyanobacterial mats.

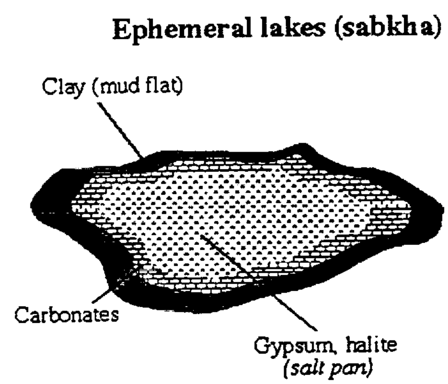

Figure 5. General distribution of mineral deposits associated to a terrestrial ephemeral lake.

References: [1] Parker T.J. et al., Icarus, 82, 111-145, 1989. [2] Scott D.H. et al., USGS Misc. Inest. Map, I-2416, 1995. [3] Robinson et al., LPSC XXVII, 1083-1084, 1996. [4] Cabrol et al., Icarus, 123, 1996. [5] Parker T.J. et al., JGR, 11061-11078, 1993. [6] Cabrol et al., Icarus, 133, 1998. [7] Ori and Baliva, LPCS, 1998. [8] Ori G.G., Geology, 17, 918-921, 1989.

MISSION PLAN FOR THE MARS SURVEYOR 2001 ORBITER AND LANDER. J. J. Plaut and D. A. Spencer, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109. Jeffrey.J.Plaut@jpl.nasa.gov, David.A.Spencer@jpl.nasa.gov.

Introduction: The Mars Surveyor 2001 Project consists of two missions to Mars, an Orbiter and a Lander, both to be launched in the spring of 2001 for October 2001 (Orbiter) and January 2002 (Lander) arrival at Mars. The Orbiter will support the Lander mission primarily as a communications relay system; the Lander will not have direct-to-Earth communications capability. Science data collected from the Orbiter will also be used to aid in the geologic interpretation of the landing site, along with data from past missions. Combining the Orbiter and Lander missions into a single Project has enabled the streamlining of many activities and an efficient use of personnel and other resources at the Jet Propulsion Laboratory and at the spacecraft contractor, Lockheed Martin Astronautics.

Orbiter Mission: The 2001 Orbiter spacecraft inherits many design features from the 1998 Mars Climate Orbiter. The spacecraft is 3-axis stabilized, with reaction wheel attitude control. The High Gain Antenna is mounted on a 2-axis gimbal assembly to allow continuous Earth tracking during orbital operations. The payload consists of 3 science instruments: Gamma-Ray Spectrometer (GRS) for surface elemental composition mapping and neutron spectroscopy detection of H and CO2, Thermal Emission Imaging System (THEMIS), for mineralogical and thermophyscial mapping of the surface using multispectral thermal and visible imaging, and Martian Radiation Environment Experiment (MARIE), for characterization of the near-space radiation environment for assessment of potential risk to human explorers. On arrival at Mars a propulsive maneuver will place the Orbiter into a 25-hour capture orbit. Aerobraking will then be used over the next 76 days to achieve the 2-hour science orbit (400 km altitude, 2 hour period). The near-polar orbit will "walk" slightly less than 1° of longitude at the equator every 25 orbits, or 2 Mars sols. At the start of the Science Phase the local time of observation will be 3:30 p.m., optimized for THEMIS, but unsuitable for GRS. After 304 days, the local time will become too late for THEMIS observations. For the following 340 days, only GRS and MARIE will operate. On day 659 of the Science Phase, a maneuver will place the Orbiter in a sun-synchronous orbit that allows THEMIS to resume observations for another 227 days. The Science Phase of the mission will end after 917 days, or 1.33 Mars years. During the remainder of the second Mars year, the Orbiter will serve as a communications relay platform for surface elements launched in 2003.

Lander Mission: The design of the 2001 Lander system is based on the 1998 Mars Polar Lander (MPL), but with a larger science payload and new flexible solar arrays. The Lander will also carry and deploy a rover, Marie Curie, similar to the Mars Pathfinder rover Sojourner. The Entry-Descent-Landing (EDL) Phase of the mission is also similar to that of MPL, with the addition of aeromaneuvering to improve the landing accuracy to about 10 km. The EDL will proceed with parachute deployment, jettison of the heat shield, landing radar activation, terminal descent engine firing and soft landing. The payload of the lander consists of 4 major science packages: APEX, MARIE, MECA and MIP. APEX, Athena Precursor Experiment, includes elements of the Athena package that will be part of the Mars Sample Return mission in 2003. These are the rover-mounted Alpha Proton X-ray Spectrometer, the lander-mounted camera system PANCAM/Min-TES, and the robotic-arm-mounted Mossbauer Spectrometer. MARIE, similar to the Orbiter MARIE, is designed to characterize the radiation environment at the surface. MECA, Mars Environmental Compatibility Assessment, is a package of instruments for analyzing soil. Working with samples delivered by the robotic arm, the package includes a microscopy station, electrometer, wet chemistry laboratory and adhesion/abrasion plates. MIP, Mars In-situ Propellant Production Precursor, will use solar power to demonstrate the manufacture of oxygen fuel from the ambient carbon dioxide atmosphere. The Lander mission has a 21-sol phase for achieving primary success, to be followed by a 70-sol phase for achieving full mission success. The Lander will communicate with Earth via the Orbiter, using 2 contacts per sol. The late afternoon contact will be the primary opportunity for downlink of the collected data. The first portion of the Lander mission involves return of image panoramas, deployment of the robotic arm and of the rover (by the robotic arm), and initial check-out and operation of the instrument suite. The Lander mission plan will be guided by science themes or "Campaigns," focused on the integrated use of the instruments to attack scientific problems.

HEDS GOALS. A. Pline[1], P. Ahlf[2]; [1]Microgravity Research Division, apline@hq.nasa.gov; [2]Life Science Division, pahlf@hq.nasa.gov; Office of Life and Microgravity Sciences and Applications, NASA Headquarters.

Introduction: In November of 1996, NASA made the decision to fully integrate several areas of robotic and human Mars exploration study and planning. As a result of this decision, requirements for unmanned robotic missions to support human Mars exploration were identified and a plan to meet these requirements was developed. Concrete progress in the implementation of this plan has been made. Three experiments have been selected and are in development for the Mars Surveyor Program 2001 Orbiter and Lander missions which will provide critical data for the planning of human missions to Mars. An Announcement of Opportunity for the Mars Surveyor Program 2003 Lander mission has recently been released which solicited proposals related to planning for a human mission.

In order to define HEDS objectives for Mars robotic missions, it is important to understand what information is required as a foundation for mounting a program of exploration of this magnitude. We identify areas of research on robotic missions that will enable future human missions. These areas include Site Selection for Human Missions, Hazards to Human Explorers, Living off the Land, and Testing Critical Technologies in the Mars Environment.

Site Selection for Human Missions: Landing sites for Human missions must meet three critical criteria. They must be of scientific interest, they present the opportunity for long duration productive research, and they must be safe. Current and planned robotic missions are expected to make considerable contributions toward the identification of such sites and others that may also yield significant biologic, geologic, and climatologic data. The broad spectrum of data from past and planned missions should be sufficient for identification of a number of candidate sites with suitable scientific interest for human exploration. Following the identification of these sites, and prior to actual human missions, additional imaging or surface missions to those sites will be critical in order to validate both the scientific interest of the landing site and the conditions at the landing site to ensure safety of the human mission. Human mission objectives and hardware designs could then be optimized to address specific science goals and accommodation of known conditions at a targeted landing site.

Hazards to Human Explorers: Hazards to human explorers need to be understood and relevant data must to be collected and analyzed in order to design missions, spacecraft and infrastructure to support future human missions. Currently we have identified the major hazards as Space Radiation and Soil, Dust and Environmental Interactions.

Space Radiation: Space radiation presents short- and long-term risks to crew health and has a significant impact on design of spacecraft and habitats, as well as mission duration. Space radiation consists of galactic cosmic rays (GCR) and solar particle events (SPE). GCR provides a constant background source of radiation, the intensity of which varies with the solar cycle. This radiation is characterized by very high energies and high penetrating ability. In fact, nuclear interactions which occur as GCR propagate through spacecraft material, the Martian atmosphere, and the surface of Mars and create secondary radiation which can be more harmful than the original radiation spectra. SPEs are associated with short term solar phenomena such as coronal mass ejections, and are therefore periodic, relatively short term, and intense in nature. However, the particle types and energies produced by SPEs are of a nature that can be relatively easily shielded and therefore the primary danger would be to crew members who are outside the shielding afforded by the spacecraft for a sufficient length of time during one of these events.

Two specific types of radiation risk are associated with highly charged energetic particles (HZE). Exposure to high doses, such as generated by an SPE, can result in nausea or vomiting caused by the destruction of cells in the intestinal lining. Long-term effects to exposure to GCR and SPE may include cataracts, organ atrophy, sterility, and increased probability of cancer. Clearly, understanding the expected radiation environment in transit and on the surface of Mars is essential to predict the anticipated exposures, assess their consequences, and develop mitigation options.

Uncertainties in our ability to predict radiation risk arise from three major factor: accuracy of our models of the radiation environment; accuracy of our models which predict the changes to the radiation as it passes through spacecraft materials, the Mars atmosphere and surface, or the human body; and uncertainty in our knowledge of the specific biological effect of exposure to the anticipated radiation environment over the mission's duration.

It is essential to measure radiation dose and radiation quality on the surface of Mars. No such surface data exists at this time, and it is not possible to obtain such data by another means with sufficient confidence. This is due mainly to the large uncertainties in the radiation transport models and the complexity of the radiation environment expected at the surface of Mars where the radiation intensity, content and quality are altered as the primary radiation is attenuated or converted to secondary radiation.

An instrument to measure the radiation environment on the surface of Mars is in development and will be carried on the MSP 2001 missions. This experiment, named the Martian Radiation Environment Experiment (MARIE) will include radiation dosimeters on both the orbiter and the lander, allowing a quantitative measurement of the effect of the Mars atmosphere on the radiation environment on the surface of Mars. The contribution of neutrons, which are a critical component of the predicted secondary radiation induced risk, will be characterized by their contribution to the total dose. Plans are in place to select an experiment for the MSP 2003 Lander mission which will allow greater characterization of this hazard by measuring the neutron spectra.

Soil, Dust and Environmental Interactions: The surface of Mars should be regarded as having a meteorological-aeolian-geoelectrical system, constituted by an integrated dynamic interdependence of a large suite of physical, electrical, and chemical phenomena. The soil and dust on Mars pose potential hazards to both the health of human explorers and to the operation of hardware and systems that will support them. As a first step, a thorough characterization of the soil and dust on Mars is necessary to anticipate potential hazards and how to avoid them. The properties of importance include adhesiveness, particle shape and size distribution, composition and chemical reactivity.

The MSP 2001 Lander mission holds great promise for soil characterization. The MSP 2001 Lander will carry the Mars Environmental Compatibility Assessment (MECA) package. MECA will characterize dust & soil in size, shape, adhesion and abrasion. The addition of this knowledge to the already known chemical characteristics of Martian soil will help to identify undesirable and harmful interactions of the soil/dust with human explorers and associated hardware systems.

The MECA Wet Chemistry Laboratory will look for hazardous chemical components of soil, including peroxides, strong acids/bases, or heavy metals. It will quantify the potential for corrosion and reaction through pH, conductivity, and redox potential measurements. MECA's Microscopy Station will study particle morphology, hardness, adhesion, and abrasion.

While the MECA experiments will measure individual physical characteristics, the next logical step is to take a systems approach to understanding the interactions of the soil and dust with the Mars environment. This systems approach includes the interaction and understanding of the particulate matter, Aeolian transport of surface materials, atmospheric instability, atmospheric electrical phenomena, and geoelectrical factors such as Paschen discharge/ionization and their effects on humans and machines.

While the MECA instrument suite on the MSP 2001 Lander mission will measure triboelectric charging during excavation using an electrometer mounted on the robot arm, there has been no systematic investigation of how the meteorology, resulting in lofted dust and surface dust redistribution, interact to create geoelectrical hazards.

Plans are in place to select an experiment for the MSP 2003 Lander mission which will perform such an investigation. This will be the first comprehensive attempt to understand and characterize these effects to determine the nature and extent of the hazards.

Living off the Land*: In situ* resource utilization (ISRU) means the use of indigenous resources. Living off the land implies that there are resources on Mars that can, if suitably exploited, meet some of the basic requirements for human activity. Any ISRU emphasis for initial human missions to Mars will be on resources that can be easily extracted and used in their purest form. Therefore, fundamental data regarding the composition of the atmosphere and surface composition is required in order to identify potential resources. The composition of the Mars atmosphere has been characterized sufficiently for the purposes of exploring potential for ISRU. Most important are extraction of oxygen from the atmosphere for use as a propellant or for life support systems. The importance of propellant production from Martian resources is the potential for significant launch mass reduction and for increased human mission safety. Use of argon for buffer gas makeup and extraction of water from atmospheric water vapor are two additional possibilities. The potential for extraction of water from the Martian regolith for use in life support systems or for electrolysis to produce hydrogen (a fuel) and oxygen represents a resource of significant potential. More data on locations, form, and quantities of ground water is required.

Testing Critical Technologies in the Mars Environment: Enabling propellant production on Mars is most dependent on *in situ* technology test and demonstration. The Mars *In Situ* Propellant Production (MIP) Precursor package planned for the MSP 2001 Lander will. The Mars MIP package is a set of experiments designed to demonstrate the component technologies required to produce oxygen from the Martian atmosphere. The five experiments comprising MIP will demonstrate the production of power by advanced solar-cell technologies, acquisition and compression of CO_2 from the Martian atmosphere, conversion of the compressed gas to oxygen by zirconia electrolysis, radiation of the waste heat from the compression process to the night sky and methods of mitigation of the effects of dust on the solar arrays.

Building on the MIP experience, HEDS is anticipating further technology demonstrations for the MSP 2003 Lander Mission, which build upon the component level technology demonstrations of the 2001 ISPP experiment. These will involve "end-to-end" system-level demonstrations of propellant and consumable production processes, including acquisition of resources, chemical processing, storage of products, and demonstration level use of the products.

THE MARTIAN RADIATION ENVIRONMENT FROM ORBIT AND ON THE SURFACE. R. C. Reedy[1] and S. D. Howe[2], [1]Mail Stop D436, Los Alamos National Laboratory, Los Alamos, NM 87545 (rreedy@lanl.gov), [2]Mail Stop B259, Los Alamos National Laboratory, Los Alamos, NM 87545 (sdh@lanl.gov).

Introduction: A good knowledge of the Martian radiation environment and its interactions with Mars is needed for many reasons. It is needed to help unfold the results of the Mars-2001 orbiter's gamma-ray spectrometer (GRS) and neutron spectrometers (NS) to determine elemental abundances on the Martian surface. It is needed to interpret the measurements of the Martian Radiation Environment Experiments (MARIE) on both the Mars 2001 orbiter and lander. It is needed to calculate production rates of cosmogenic nuclides that will be measured in samples returned from Mars. It is needed to determine the doses that astronauts would receive in Martian orbit and especially on the surface of Mars.

We discuss the two types of energetic particles in the vicinity of Mars and the nature of their interactions. Solar energetic particles (SEPs) occur very rarely but can have high fluxes that are dangerous in space. However, their energies are low enough that few solar energetic particles reach the surface of Mars. Their interactions can be fairly easily modeled because SEPs create few secondary particles. Galactic cosmic rays (GCRs) have high energies and are the dominant source of energetic particles on the Martian surface, mainly secondary neutrons. Modeling their interactions is complicated because of the range of nuclei in the GCR and their high energies. Work at Los Alamos on GCR interactions will be presented.

Energetic Particles Near Mars: There are two sources of particles near Mars that have enough energy (energies > ~10 MeV/nucleon) to penetrate matter and induced nuclear reaction: solar energetic particles and galactic cosmic rays. These two types of particles have different energies and different modes of interactions [e.g., 1].

Solar Energetic Particles. SEPs and their acceleration mechanism(s) are controlled by the Sun and the interplanetary fields that it generates. They are about 98% protons, have a proton-to-alpha-particle ratio of about 50 [2], and are ~1% heavier nuclei. Few SEPs have energies > 100 MeV/nucleon [2].

Intense solar particle events can have serious radiation effects to equipment and humans in space. Observations of solar energetic particles since 1956 have been used to develop models predicting the probability of solar particle events [e.g., 3].

SEP produce cosmogenic nuclides in the tops of lunar samples [4]. The average SEP fluxes determined from cosmogenic nuclides are not very different from the average flux during the last four solar cycles [4,5]. Measurements of SEP-produced nuclides also indicate that solar particle events larger than those observed during the last 50 years are very rare [5].

Galactic Cosmic Rays. Particles in the GCR are about 87% protons, 12% alpha particles, and 1% heavier nuclei [6]. Most GCR particles have energies of ~0.1-10 GeV/nucleon. The intensity of GCR particles is modulated by the 11-year solar-activity cycle. There are fewer GCR particles at times of high solar activity. The next period of maximum solar activity is expected to occur in 2000-2001, and the fluxes of GCR particles then will be lower than at most other times in the solar cycle.

On average, a GCR particle produces dozens of secondary particles, including many pi mesons and neutrons. In most objects, GCR-produced neutrons are the dominant particle because they are neutral and travel until they are stopped by nuclear interactions or they escape from the object into space. Neutrons are the main source of cosmogenic nuclides in matter [e.g., 1].

Energetic-Particle Interactions with Mars: The details of the interactions of SEPs and GCR particles with Mars need to be well known to fully understand the Martian radiation environment. The interactions of the relatively-low-energy SEPs with matter are fairly simple. The interactions of the high-energy GCR particles are complicated and very hard to model.

Solar Energetic Particles. SEPs interact with matter mainly by ionization-energy losses that slow and stop most particles. A few SEP particles induce nuclear reactions, but, because of their low energies, SEPs produce few secondary particles [7] in interacting with matter. The thickness of the Martian atmosphere, 15 g/cm^2 on average, stops almost all SEPs with only a few inducing nuclear reactions. SEPs should not be observable at the Martian surface. Some SEP-produced neutrons will reach the Martian surface during the peak fluxes of large solar particle events, as is the case for the Earth.

SEPs at Mars will be a serious radiation hazard above the atmosphere for the very large solar particle events that occur on average once or twice a decade [3,4]. Significant shielding (~5 g/cm^2 of matter) will also be needed to protect Martian samples being returned to Earth from SEPs, especially to prevent production of nuclides in the samples.

While SEPs are an important part of the Martian radiation environment, they will not be discussed much more.

Galactic Cosmic Rays. GCR particles have interaction lengths that are shorter than their ranges in matter. Thus most GCR particles interact before they are stopped in matter. Each GCR particle, because of its average energy of several GeV, induces a cascade of secondary particles. Many particles in this cascade have enough energy to produce additional particles, just as in the Earth, the Moon, and meteorites. In the Earth, very few GCR-produced particles reach the Earth's surface because the Earth's atmosphere is very thick (about 1000 g/cm^2).

At Mars with its thin atmosphere, most GCR proton and alpha-particle interactions will be in the Martian surface, similar to GCR interactions with the Moon [1,8] and meteorites [9]. The cascade of particles made by these interactions is complex and hard to model. Work on numerical simulations on GCR interactions in Mars will be presented below, and the implications of this work discussed.

Because high-Z GCR particles, such as C, O, Si, and Fe nuclei, have relatively-short interaction lengths, most of their interactions will be in the Martian atmosphere. Some primary nuclei or secondary fragments will reach the Martian surface, mainly those with lower charges (Z). The location of these interactions and their products are an important part of the Martian radiation environment.

Studies of GCR Interactions with Mars: Some work has been done at Los Alamos on the interactions of GCR protons and alpha particles with Mars. Most have been done with the LAHET Code System (LCS), which is the Los Alamos high-energy transport code LAHET [10] coupled to the Los Alamos code MCNP [11] for neutrons with energies below 20 MeV. LCS codes can handle 3-dimensional geometries. LCS has been well tested with cosmogenic nuclides in meteorites [9] and lunar samples [8]. Using LCS, studies of GCR interactions in Mars include calculation of the production of 14C in the Martian atmosphere [12] and the Martian surface [13], gamma rays made at Mars [14], and radionuclides made in samples in the Martian surface [15].

In these numerical simulations, the calculated rates for reactions in the Martian surface are similar to those in the Moon. In fact, the production of neutrons in the top 35 g/cm^2 of the Martian surface is higher in the case of a 15-g/cm^2 Martian atmosphere than for the same surface without an atmosphere above it [14]. This higher neutron flux at the surface below an atmosphere occurs because the secondary particles made in the atmosphere more than compensate for the removal of some GCR primary particles by the atmosphere. Most of these extra neutrons for the case with an atmosphere have relatively low (<~50 MeV) energies [15]. These calculations show that the flux of GCR particles (mainly neutrons and protons) at the surface of Mars are similar to those at the surface of an object without an atmosphere, such as the Moon.

Implications for Mars 2001 Experiments: There are two sets of experiments on Mars 2001 that measure energetic radiation at Mars and so are affected by the radiation environment at Mars, the GRS/NS on the orbiter and MARIE on both the orbiter and lander. Measurements by one set can be used to compare results from the other set. For example, the fluxes of neutrons and gamma rays from Mars will vary with GCR modulation, which will be directly measured by sensors on MARIE. The high-energy particles observed by MARIE can then compared with GCR/NS data to better map these variations in primary energetic particles.

Doses measured by MARIE should be sensitive to the fluxes of secondary particles, especially neutrons, as well as primary particles. Neutron fluxes measured by the neutron spectrometers will help to determine the neutron contributions to the dose measured by MARIE. The composition of the surface around the Mars 2001, as determined by the GRS/NS, will be needed to better interpret the measurements by MARIE. This particularly applies to doses.

Modeling of the production and transport of gamma rays made in Martian soil and atmosphere is needed to interpret the measurements of the GRS. The effects of different atmospheric thicknesses and surface water contents were investigated in a study done for Mars Observer [14]. Work is needed to extend this work to a range of surface compositions, such as those inferred from analyses by the Alpha Proton X-ray Spectrometer on the Mars Pathfinder. Data from the fast neutron spectrometer on Lunar Prospector show that the intensity of fast neutrons is sensitive to the surface composition [16], consistent with calculations done by LCS [17].

The measurements by the neutron spectrometers (NS) on Mars 2001 will be better than what would have been measured by the neutron mode of the Mars Observer GRS. As shown by the neutron spectrometers on Lunar Prospector, the neutron data should provide a great deal of information about the composition of Mars [16], especially hydrogen-containing materials [18]. These data will be very valuable in interpreting the GRS gamma-ray spectra and the MARIE dose measurements. The same LCS calculations performed for neutrons should be used for gamma-ray production calculations to couple the calculations done for the GRS and NS.

Martian Returned Samples: The modeling done with LCS for Mars 2001 experiments will determine the fluxes of particles that produce cosmogenic nuclides in Martian samples. These fluxes can then be used with existing sets of cross sections to calculate the production rates of these nuclides, such as has been done in some earlier work [13,15]. These production rates are necessary to convert measured concentrations of cosmogenic nuclides into ages and exposure records for the samples recovered from the Martian surface.

Doses to Martian Astronauts: Calculations done by LCS can be used to extend MARIE's results to the 3-dimensional shapes and the compositions of spacecraft and habitats. For example, certain thicknesses or compositions of shielding on the Martian surface could expose astronauts to higher doses than other thicknesses or compositions. Providing sufficient shielding on the habitat or the heavy equipment needed to cover the habitat may substantially increase the mass of a human mission. Thus, accurate assessment of the radiation levels are a necessity.

The LCS codes could be used to calculate the effects of an intense solar particle event to astronauts in a spacecraft or a Martian habitat. If these calculations show that the doses to astronauts by intense solar particle events would be serious, the timing of a human mission to Mars should be done during the about 4-year period around solar minimum when intense fluxes of solar energetic particles are relatively unlikely [3,5]. However, the fluxes of relativistic (MeV) electrons are the highest in space then [19], and such electrons could be a serious radiation hazard.

Good calculated doses are needed to plan the entire mission. If the doses that astronauts could receive in one mission scenario are too high, alternative scenarios will be needed to reduce doses. Options include better shielding or reducing the mission's duration.

One obvious option, heavily favored in previous Mars mission plans but currently not allowed in the design studies at NASA, is to utilize the performance of a nuclear rocket to enable an opposition-class mission of around 400 days round trip. Such a mission would allow 60 to 90 days on the Mars surface instead of the 500 days required by the conjunction-class missions. Thus, the use of a nuclear rocket could actually reduce the dose to the crew. Consequently, accurate determination of the radiation levels on the Mars surface are essential to any future planning.

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SEDIMENTOLOGICAL INVESTIGATIONS OF THE MARTIAN SURFACE USING THE MARS 2001 ROBOTIC ARM CAMERA AND MECA OPTICAL MICROSCOPE. J. W. Rice, Jr.,[1] P. H. Smith[1], and J. R. Marshall[2], [1]Lunar and Planetary Laboratory, 1629 E. University, Tucson, AZ 85721-0092, jrice@lpl.arizona.edu, [2]NASA Ames Research Center, MS 239-12, Moffett Field, CA 94035.

Introduction

The first microscopic sedimentological studies of the Martian surface will commence with the landing of the Mars Polar Lander (MPL) December 3, 1999. The Robotic Arm Camera (RAC) has a resolution of 25 µm/p which will permit detailed micromorphological analysis of surface and subsurface materials (Figure 1). The Robotic Arm will be able to dig up to 50 cm below the surface. The walls of the trench will also be inspected by RAC to look for evidence of stratigraphic and / or sedimentological relationships. The 2001 Mars Lander will build upon and expand the sedimentological research begun by the RAC on MPL. This will be accomplished by:

I. Macroscopic (dm to cm): Descent Imager, Pancam, RAC

II. Microscopic (mm to µm): RAC, MECA Optical Microscope (Figure 2), AFM

This paper will focus on investigations that can be conducted by the RAC and MECA Optical Microscope.

Sedimentary Structures and Textures

Sedimentary structures are large scale features such as laminae (layers <1 cm thick), beds (strata thicker than 1 cm), ripple marks, cross beds, and mud cracks. These structures indicate environmental conditions that prevailed at or shortly thereafter the time of deposition. These structures can also be used to evaluate water depth, current velocity, flow direction, and tops and bottoms of beds.

Sedimentary texture relates to small scale features that originate from the size, shape, and orientation of individual sediment grains. The texture of individual grains reflects the nature of transportation and depositional processes. The characterization of texture is crucial in interpreting ancient environmental settings.

1. Grain size – range of grain sizes present
2. Sorting – range of grain sizes present and the magnitude of the scatter around mean size
3. Shape - defined by form, roundness, and surface texture
   A. Form – overall configuration of particles reflected by proportions of major axes
   B. Roundness – measure of sharpness of grain corners
   C. Surface texture – small scale micro-relief markings (pits, scratches, ridges, etc.)
4. Fabric – grain orientation and grain to grain relations

Significance

1. Grain size - mean and maximum grain size reflects the average and maximum energy of the depositional medium.
2. Sorting – reflects the persistence of depositional processes.

3A. Form – function of the original shapes of minerals, affects the transportability of particles traveling in suspension

3B. Roundness – function of type of transport process and distance of transport

3C. Surface texture – indicates ancient transport conditions and depositional environment

4. Fabric – reflects transport direction, depositional processes, and degree of compaction

Stratigraphic Contacts

RAC images of trench walls (Figure 3) may also contain valuable information on layering, contact surfaces, post depositional structures (i.e., load structures, slumps, convolution, flame structures), and bedforms (i.e., cross bedding, imbrication). This information will be very important in determining the emplacement history of the individual layers.

1. Sharp Contacts: indicate sudden distinct changes in conditions when the layers were formed or abrupt changes in the materials being emplaced. This may suggest a hiatus in deposition and should be examined for evidence of any unconformities.

2. Gradational Contacts: suggest continuous accumulation or the mixing of materials already in place with newly deposited materials.

We will also discuss ongoing sedimentological tests of various soil samples from a variety of environments (impact crater, paleolacustrine, jokulhlaup floods, aeolian, volcanic, fluvial, periglacial, glacial, and mass wasting) collected from several Mars analog field sites in Antarctica, Devon Island High Arctic, Iceland, and the Channeled Scabland.

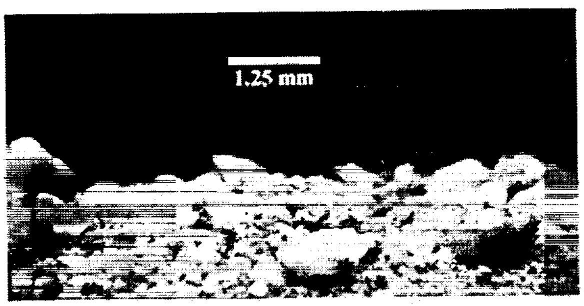

Figure 1. RAC image of grains in scoop

Figure 2. MECA Optical Microscope image

Figure 3. RAC mosaic of trench (bright areas saturated in GIF to show shadowed areas)

COMPOSITIONS OF MARS ROCKS: SNC METEORITES, DIFFERENTIATES, AND SOILS.
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Introduction: The 13 samples from Mars identified in the terrestrial meteorite collections vary from dunite to pyroxenite to microgabbro or basalt (1). All of these rocks appear to have formed from primitive melts with similar major element compositional characteristics; i.e., FeO-rich and Al_2O_3-poor melts relative to terrestrial basalt compositions. Although all of the SNC rocks can be derived by melting of the same Al-depleted mantle (1,2), contamination of SNC's by a Rb-enriched mantle or crustal source is required to explain the different REE characteristics of SNC rocks (3). Thus, there are indications of an old crustal rock-type on Mars, and this rock does not appear to have been sampled. This paper focuses primarily on the composition of the SNC basalts, however, and on the compositions of rocks which could be derived from SNC basaltic melt by magmatic processes. In particular, we consider the possible compositions which could be achieved through accumulation of early-formed crystals in the SNC primitive magma. Through a set of experiments we have determined (1) melt (magma) compositions which could be produced by melt evolution as crystals are removed from batches of this magma cooling at depth, and (2) which evolved (SiO_2-enriched, MgO-depleted) rock compositions could be produced from the SNC magma, and how these compare with the Pathfinder andesite composition. Finally, we compare the SNC magma compositions to the Mars soil composition in order to determine whether any source other than SNC is required.

Primitive SNC melt compositions: Some of the SNC meteorites are clearly the product of crystal accumulation which operated in a primitive SNC magma (i.e., they are a mixture of primitive melt + accumulated crystals). The Chassigny dunite and the Nakhla pyroxenites are good examples of olivine and pyroxene cumulates, respectively. Other SNC meteorites appear to have experienced little or no crystal cumulation, and their bulk compositions (Shergotty, Zagami, QUE 94201) probably approach that of a primitive SNC melt. Attempts to determine the primitive melt in obviously cumulate rocks yield compositions very similar to the Shergottites (Fig.1, Table 1), confirming that the major element composition of primitive SNC melts is fairly restricted. More Mg-rich magmas, e.g., the groundmass of 79001, may have erupted, but these probably represent mixtures of SNC melt (A*) and cumulus olivine ± pyroxene. Thus, if the SNC magma-type is the main basaltic melt on Mars, the main volcanic rocks at the surface should be low-Al basalts such as Sh (Fig.1), possibly carrying crystals and ranging toward Eg in composition.

Evolved rocks from SNC magma: What compositions of evolved (SiO_2-enriched) rocks could be produced from SNC magma, and in what quantity? We have investigated this question experimentally for equilibrium crystallization (and crystal separation) of SNC magma dry and with 1.5 wt.% dissolved H_2O (4). The results are summarized in Fig.1, and compared to the Pathfinder andesite composition. If the SNC magma is dry, the residual melt remains basaltic for >90% of the crystallization path, and becomes very Fe-rich. A few vol % of Si-rich melt is then produced, but this melt would be very difficult to separate because of its high viscosity. In contrast, if the magma contains as much as 1.5 wt % H_2O, either juvenile or incorporated from interaction with H_2O-bearing crust, the SNC melt evolution produces more SiO_2-enriched magma (Fig. 1). For example, the Pathfinder andesite composition is produced after ~ 75% crystallization of A*. Thus, with some H_2O in the magma it should be possible to physically separate andesitic and higher-Si melts from their crystal residues, and erupt these melts (magmas) at the surface or intrude them into higher levels of the crust. The role of H_2O in this process is critical; it is aided by increased oxidation.

Mars soils from SNC meteorites: The pathfinder and Viking site Mars soils are rich in S and Cl, but are Fe-rich and Low-Al like the SNC's (5). It has been proposed (6) that the soil compositions (except for S and Cl) can be approximated by a mix of ~ equal amounts of SNC meteorite and Pathfinder andesite. We have refined this calculation, recognizing that the SNC meteorites are a mix of primitive SNC melt (e.g., A*) and cumulate crystals. A mass balance calculation using all major oxides, indicates that the Mars soil is best approximated as a mixture of Fo_{75} olivine, SNC primitive melt, and andesite in the ratio 12:45:44. This reaffirms the possible importance of an evolved SiO_2-rich magma on the Mars surface.

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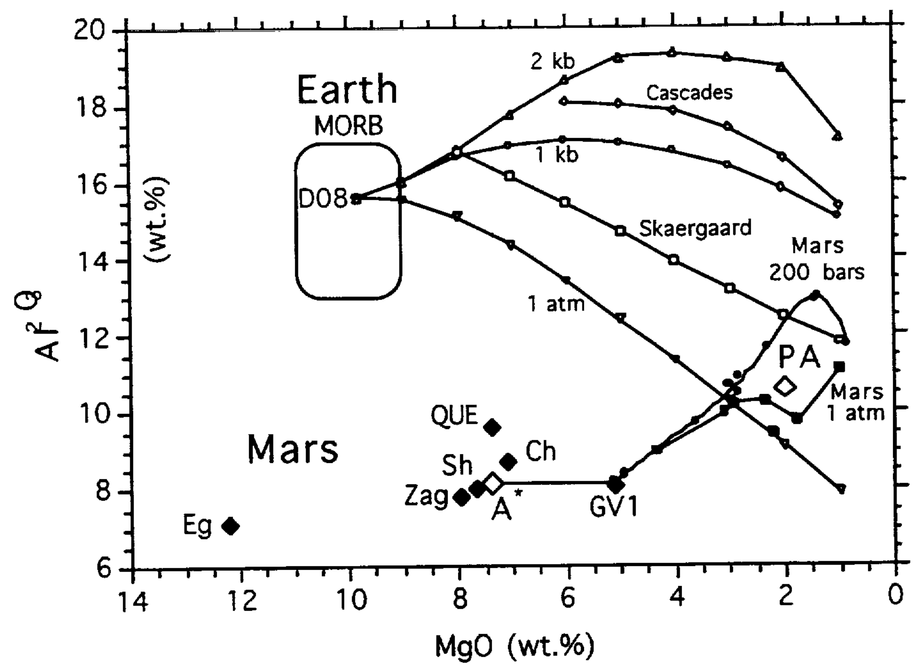

Figure 1. Plot showing basaltic melt evolution paths for dry (1 atm)fractional crystallization vs. crystallization with increasing water pressure (4). Upper curves are for a terrestrial tholeiite; low -er curves show evolution of Chassigny primitve (A*) melt. Compositions of SNC's as in Table 1.

Table 1: Early SNC melt/magma compositions (wt %)

	A* Chas	Shergotty (2)	Zagami (3)	E79001 gm (4)	Nakhla NK3 (5)	Gov Vald GV1 (6)
SiO_2	50.33	50.8	50.7	50.67	45.8	46.7
TiO_2	1.75	1.0	1.03	0.86	3.1	4.2
Al_2O_3	8.16	8.0	7.80	7.10	7.2	8.1
FeO	19.87	19.8	18.50	18.67	26.2	23.3
MgO	7.39	7.7	7.98	12.22	5.7	5.1
CaO	8.95	9.7	11.20	8.74	10.4	9.7
Na_2O	1.71	1.5	1.64	1.07	0.8	2.1
K_2O	0.43	0.2	0.18	0.07	1.4	1.2
P_2O_5	0.50	0.9	0.71	n.d.	n.d.	n.d.
MnO	0.52	0.5	0.54	0.52	n.d.	n.d.

Compositions (1) Chassigny from [7]; (2) Shergotty from [8]; (3) Zagami from [9]; (4) EETA79001 groundmass composition from [10]; (5) Nakhla NK3 and Govenor Valderas melt compositions from [11].

MARS SURVEYOR PROGRAM 2001 MISSION OVERVIEW. R. Stephen Saunders, Jet Propulsion Lab, MS 180-701, 4800 Oak Grove Dr., Pasadena, CA 91109 Ronald.S.Saunders@jpl.nasa.gov.

The Mars Surveyor Program 2001 mission to Mars was initially a key element in the Mars sample return sequence of missions. A capable rover, carrying the Cornell Athena instruments, would be placed on Mars to roam over several kilometers, select samples, and place them in a cache for return by a subsequent mission. Inevitably, budget constraints forced descopes. At one critical point, the landed payload consisted only of the HEDS (Human Exploration and Development of Space) payloads selected for testing environmental properties of the surface for future human exploration. Then Congress intervened and put back some of the funding that had been deleted. NASA Headquarters next redefined the payload to include as many of the Athena instruments as possible, to be distributed between the lander deck and a Sojourner class rover. This payload would then be placed on a modified version of the Mars Polar Lander (MSP'98) rather than on the much larger, and more expensive, lander that had been originally designed for the mission. With this functionality restored the '01 mission remains an important and pivotal element of the Mars Surveyor Program. It completes the Mars Observer objectives with the gamma ray spectrometer mapping. This mission will largely complete the global characterization phase of Mars exploration and mark the beginning of focused surface exploration leading to return of the first samples and the search for evidence of past martian life. MSP'01 also is the first mission in the combined Mars exploration strategy of the HEDS and Space Science Enterprises of NASA. This mission, and those to follow, will demonstrate technologies and collect environmental data that will provide the basis for a decision to send humans to Mars. The NASA exploration strategy for Mars includes orbiters, landers and rovers launched in 2001 and 2003 and a sample return mission to be launched in 2005, returning a sample by 2008. The purpose of the rovers is to explore and characterize sites on Mars. The 2003 and 2005 missions will select rocks, soil and atmosphere for return to Earth.

Potential landing sites for 2001 include ancient highlands where there might have been subsurface hydrothermal environments that have been excavated by recent impacts, and ancient channels and lakes. In addition to the GRS, the 2001 orbiter carries a thermal emission imaging system (THEMIS), consisting of a spectrometer and imager that will map the mineral abundance at selected sites, and a radiation experiment, MARIE, to assess radiation hazards to humans. The rover is similar to the 1997 Pathfinder Sojourner rover, with an upgraded Alpha Proton X-ray Spectrometer (APXS) experiment that will be carefully calibrated under Martian conditions on Earth, and again on Mars shortly after landing. The APXS will perform elemental analysis on rock and soil samples for all elements except H and He. The rover cameras will also be calibrated. The lander carries a suite of Space Science and HEDS instruments including a robotic arm with camera. The arm will deploy a Moessbauer spectrometer to determine the oxidation state of iron in the soil or rocks. The arm will be used to deploy the rover and dig to a depth of up to 0.5 m to deliver soil to the Mars Environmental Compatibility Assessment Experiment (MECA), the soil and dust characterization experiments. The Mars In Situ Propellant Precursor Experiment (MIP) will perform experiments to assess technology needs for in situ propellant production and produce oxygen from the Martian atmosphere. The lander counterpart to the orbital radiation experiment will allow assessment of how the radiation hazards on the surface might be mitigated by the atmosphere or other factors. The lander will carry a panoramic camera bore-sighted with a thermal emission spectrometer (PanCam/MiniTES). This combination will provide guidance to the rover and allow comparison between the mineralogical data from MiniTES and the elemental data from the APXS. The lander will carry a descent imaging system (MARDI) to provide nested images from parachute deployment down to the surface. The basic flight systems for the orbiter and lander use MSP'98 heritage. There will be extensive outreach activities using the rover and the robotic arm. Students all over the world will participate in Red Rover Goes to Mars, a program that will be carried out by the Planetary Society.

With safety as the first consideration, the process of site selection for the Mars 2001 lander is driven by science and heavily constrained by the Mars environment. NASA has established a long-range strategic framework for Mars exploration. The Mars Surveyor Program will explore Mars along three thematic lines: (1)search for life, (2) understand climate history, and (3) map resources including geology and geophysics.

The selection of a landing site will be constrained by cost driven requirements placed on spacecraft design by the Martian environment. The basic requirements on the landing site for the Mars Surveyor 2001 mission are as follows:

(1) The landing site latitude shall be within the latitude region from 12°S to 3°N.
(2) The maximum elevation of the landing site with respect to the Mars reference ellipsoid shall be less than or equal to 2.5 km. 99% of terrain within the predicted 3-sigma landing footprint ellipse must meet this requirement.
(3) The surface pressure at the landing site must be less than 10.66 mbar (and winds below 20 m/s) to open solar panels, This surface pressure exists at an elevation of roughly -3 km .

The following is a summary of the top level considerations for landing site location.

Lander lifetime as a function of landing site latitude and lander tilt:

Latitude	0° Tilt	16° Tilt
12°S	92 days	84 days
3°N	111 days	107 days

Note: The Mission Requirement for Lander lifetime is 21 days with a planned mission of at least 90 days.

Landing Accuracy:

3°N Landing footprint 26 km end-to-end,10 km cross-track (99-centile).

12°S Landing footprint 20 km end-to-end, 12 km cross-track (99-centile).

Landing Risk:

The project requires that the maximum fractional area of the landing site covered by rocks shall be no greater than 0.12, including uncertainties. Areas with excessive dust are to be avoided. The minimum acceptable rock abundance is 0.05. The maximum landing site surface slope the lander can tolerate is 10°. The project requires that the selected landing site shall provide a 0.95 probability that the terrain slope upon landing does not exceed 10°.

Power considerations could be an important factor in site selection for the rover. During the Mars Pathfinder mission, dust accumulation was observed on both the rover and lander solar panels. Solar panel energy production degraded by a factor of 0.2% per sol, apparently due to such dust accumulation. Assuming this rate of degradation without other compensation, the Rover would 'die' after 5 months at any latitude. A more detailed assessment of dust accumulation effects is currently underway.

In summary, safety considerations will be the primary factor in site selection. The collective wisdom of the NASA science community will be tapped to make the right decision. All of this will be constrained by the realities of the Mars environment. For more detailed and complete description of the constraints, see Golombek (this conference).

The Mars '01 lander payload is an excellent one for studying soils. Soils can be found virtually anywhere on Mars, so the mission will do substantial new science in the event of any safe landing. Safety is therefore of the utmost importance.

Consider the capabilities of the vehicle and the payload (particularly limits on landing accuracy and limited mobility). Given the instrument capabilities and those physical limits, the best new science is likely to come from landing somewhere within ancient highland crustal materials.

Within the above engineering and scientific constraints, the final site should be chosen so as to:
- maximize total mission duration
- maximize rock abundance
- maximize large-scale topography in the visible distance, particularly if
it exposes stratigraphy
- maximize the chances of finding aqueous minerals

NASA AMES REMOTE OPERATIONS CENTER FOR 2001. M. Sims[1], J. Marshall[2], S. Cox[3] and K. Galal[4]. [1]NASA Ames, MS 269-3, Moffett Field, CA 93035, (Michael.Sims@arc.nasa.gov) [2]SETI Institute, NASA Ames, 239-12, Moffett Field, CA 93035, (jmarshall@mail.arc.nasa.gov), [3]NASA Ames, MS 244-14, Moffett Field, CA 93035, (sacox@mail.arc.nasa.gov), , [4]NASA Ames, MS 244-14, Moffett Field, CA 93035, (kgalal@mail.arc.nasa.gov).

Introduction: There is a Memorandum of Agreement between NASA Ames, JPL, West Virginia University and University of Arizona which led to funding for the MECA microscope and to the establishment of an Ames facility for science analysis of microscopic and other data. The data and analysis will be by agreement of the MECA, RAC and other PI's. This facility is intended to complement other analysis efforts with one objective of this facility being to test the latest information technologies in support of actual mission science operations. Additionally, it will be used as a laboratory for the exploration of collaborative science activities. With an goal of enhancing the science return for both HEDS and Astrobiology we shall utilize various tools such as superresolution and the VEVI virtual reality visualization tools. In this presentation we will describe the current planning for this facility.

THE ROBOTIC ARM CAMERA FOR MARS SURVEYOR 2001. P. H. Smith[1] and H. U. Keller[2], [1]Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721, psmith@lpl.arizona.edu, [2]Max Planck Institute for Aeronomy, Katlenberg-Lindau, Germany.

Introduction: The Mars Surveyor 2001 mission will include a robotic arm with a camera attached to the wrist. The Robotic Arm Camera (RAC) is a build-to-print design based on the MVACS camera from the Mars Polar Lander mission. As with MVACS, it is a collaboration between the University of Arizona and the Max Planck Institute of Germany. It has 3-color LED lamps positioned on the front and a focusable lens that allows objects from 11 mm in front of the housing out to infinity to be brought into sharp focus. RAC supports the mission by monitoring the trench digging process, first surveying the work area with overlapping images that can be rendered into a range map, then imaging the sidewalls and bottom to look for fine-scale structures. The camera can be used to obtain about half of a horizon panorama, and by overlapping the frames these can be in stereoscopic mode. It can also view the scoop edge to give microscopic, color images with 23 micron per pixel resolution.

Science Goals: The science goals for the RAC include analyzing the low resolution panoramic views to learn about the local geomorphology, close up imaging of the digging area and the trench to learn about the surface and sub-surface stratigraphy, and obtaining microscopic views of the soil at different depths to study the size and shape of grains. In looking at the stereoscopic, panoramic views RAC will give a quick overview of about half of the local terrain. The arm cannot be pointed across the lander for safety reasons, but the views it provides give a unique perspective of the local landscape. The arm can be positioned both low and high when scanning to show features from standing height and "dachshund" height. The views are panchromatic, with a bandpass between 400 and 700 nm.

Since the arm is slightly less than 2 m in length, the digging area is tightly confined and the closeup views for RAC are restricted to this pie-shaped area. The ability to make stereoscopic views by overlapping frames allows the camera to characterize the digging area that is invisible to PanCam, including underneath the lander. Therefore, RAC becomes a useful tool for learning about the fine-scale structures of the surface, and by looking into the trench, the sub-surface soil horizons. As the trench deepens, it will be possible to use the LEDs built into the face of the camera to illuminate the trench bottom and make true-color images.

At selected levels on and below the surface, samples will be scooped up and retracted to place the scoop blade directly in front of RAC. By refocusing the lens to its microscopic position, the resolution can be increased to a maximum of 23 microns per pixel. LEDs are angled to illuminate the scoop blade in this position allowing individual grains to be analyzed. The shapes and fracture-types within these grains will give clues to the weathering history and composition of the soil.

MECA Support: The MECA instrument, the Mars Environmental Compatibility Assessment provided by the HEDS group at NASA, requires samples from the robotic arm to perform its scientific experiments. It has an internal microscope with 4 micron per pixel resolution that looks at various substrates coated with soil provided from the trench by the robotic arm. The microscope also has 3-color LED illuminators plus a UV lamp that will show any fluorescence in the grains. In addition, there are 4 chemistry cells with water reservoirs that need soil samples. The delivery of these samples is monitored by the RAC camera that provides an initial assessment of the type of soil in the scoop. If this sample is judged inadequate then the surface can be re-sampled before using one of the precious wet chemistry cells.

The interaction between the RAC and the MECA microscope gives a range of resolutions that start from the panoramic camera views of the local terrain to trench and soil close ups finally to microscopic views. This tremendous range in scale is heretofore unprecedented.

Operations: The RAC assists in the digging of the trench and provides support for sample delivery to MECA. In addition, it views the abrasion patches underneath the scoop, which can be rubbed against both soil and rock, and the adhesion patches on the lander deck. Normally these scenes are too bright to allow the lamps to be effective, but with nighttime operations RAC can obtain high quality color images of any nearby target.

Only the RAC can take images underneath the lander. These views may reveal the indurated soils seen at the Viking lander sites, or other subsurface structures. In addition, the RAC can be position to obtain unique scattering geometries to aid in deciphering the photometric functions of the soil.

The RAC camera is useful for its range of focus and its mobility. These properties will enhance every phase of the mission.

THE MARS 2001 ATHENA PRECURSOR EXPERIMENT (APEX). S.W. Squyres (Cornell University, Ithaca, NY 14853 squyres@astrosun.tn.cornell.edu), R. Arvidson (Washington University, St. Louis), J.F. Bell III (Cornell University), M. Carr (USGS, Menlo Park), P. Christensen (Arizona State University), D. Des Marais (NASA Ames), C. d'Uston (CESR, Toulouse), T. Economou (University of Chicago), S. Gorevan (Honeybee Robotics), G. Klingelhöfer (T.H. Darmstadt), L. Haskin (Washington University, St. Louis), K. Herkenhoff (USGS, Flagstaff), A. Knoll (Harvard University), J.M. Knudsen (Ørsted Institute, Copenhagen), A.L. Lane (JPL), V. Linkin (IKI), M. Malin (Malin Space Science Systems), H. McSween (University of Tennessee), R. Morris (NASA JSC), R. Rieder (Max Planck Institut für Chemie, Mainz), M. Sims (NASA Ames), L. Soderblom (USGS Flagstaff), H. Wänke (Max Planck Institut für Chemie, Mainz), T. Wdowiak (University of Alabama, Birmingham).

The Athena Precursor Experiment (APEX) is a suite of scientific instruments for the Mars Surveyor Program 2001 (MSP'01) lander. The major elements of the APEX payload are:

- Pancam/Mini-TES, a combined stereo color imager and mid-infrared point spectrometer.
- An Alpha-Proton-X-Ray Spectrometer (APXS) for in-situ elemental analysis.
- A Mössbauer Spectrometer for in-situ determination of the mineralogy of Fe-bearing rocks and soils.
- A Magnet Array that can separate magnetic soil particles from non-magnetic ones.

Pancam/Mini-TES is mounted on the lander deck, and uses a deployable mast to obtain a clear view of all the terrain around the lander. The APXS is mounted on the Marie Curie rover, which is able to deploy it against a range of martian soils and rocks. The Mössbauer Spectrometer is mounted on the Robotic Arm, which is able to deploy it to distances of up to ~1.5 m from the lander.

The APEX payload elements are designed and configured to be used in highly synergistic ways, both among themselves and with other elements of the MSP'01 lander payload:

- Pancam/Mini-TES, APXS, and Mössbauer data are highly complementary to one another, and together will provide an unprecedented suite of information on the composition of martian rocks and soils.
- Pancam/Mini-TES provides mineralogical and morphologic information that can be used effectively to select measurement targets for the APXS and the Mössbauer.
- APXS can make measurements of any materials measured by the Mössbauer, plus other more distant materials as well.
- All APEX instruments can be used to view soil that has adhered to magnets in the Magnet Array, providing the first definitive identification of the magnetic species in the martian soil.
- The Robotic Arm can obtain soil samples from depths of up to 50 cm and deposit them where they can be viewed by all of the APEX instruments. The instruments can thereby investigate vertical compositional gradients – e.g., in salt concentration or in oxidation state of Fe-bearing minerals.
- The measurements to be made by the APEX instruments (e.g., mm-scale morphology, mineralogy, major-element chemistry) are highly complementary to those to be made by the MECA instrument (e.g., μm-scale morphology, abundances of high-priority trace elements). APEX and MECA can therefore be used together on the same soil units to provide an extremely comprehensive picture of the martian soil at the landing site.

Pancam has an angular resolution of 0.31 mrad/pixel, 16 color spectral bands from 0.4 to 1.1 μm, and a nominal SNR of 200:1 in all spectral bands. A primary science objective of Pancam is to provide high spatial resolution information on the morphology of the landing site, on the lithology, texture, distribution, and shape of nearby rocks, and on local geologic features that may be present. This information will be relevant to understanding what geologic processes have affected the site, particularly when merged with compositional data.

Pancam also will provide information on the mineralogy of materials to supplement and complement data obtained by other instruments. Spectra of Mars in the 0.4-1.1 μm range are dominated by iron oxides and oxyhydroxides with varying degrees of crystallinity. These oxides are presumably mostly weathering products. Multispectral imaging will help determine the oxidation state of iron, identify the secondary iron minerals and their crystallinity, and identify primary mafic minerals.

Pancam can observe the full martian sky. A time series of atmospheric dust opacity in the visible can therefore be obtained by imaging the sun through neutral density filters and applying Beer's Law. Aerosol properties like mean size, single scattering phase function, and single scattering albedo can also be obtained from sky imaging.

Mini-TES has a wavelength range of 6-25 μm, angular spot sizes of 8 and 20 mrad, spectral resolution of 10 cm^{-1}, and a nominal SNR of 450:1. The primary objective of Mini-TES is to obtain mineralogical information for rocks and soils surrounding the lander. These data provide fundamental scientific information about Mars and, like Pancam images, can also be used to select materials to be investigated in more detail by APXS, Mössbauer, and MECA.

In the 6-25 μm range, vibrational energies of rock-forming minerals are controlled by anion compositions, coordination numbers, and bond lengths. Mini-TES measurements therefore will provide a direct means of identifying crystal structure, and hence mineralogy, of all geologic materials including silicates, carbonates, sulfates, phosphates, oxides, and hydroxides. In silicates, for example, the vibrational motions associated with the Si-O stretching modes occur between 8 and 12 μm. The Si-O absorption band decreases from 11 to 9 μm in a uniform succession for minerals with chain, sheet, and framework structure, and so provides a means of discriminating minerals with these structures.

Additional bands occur in silicates throughout the 12-25 μm region associated with a variety of Si, O and Al stretching and bending motions. Carbonates have strong absorption features associated with CO_3 internal vibrations in the 6-8 μm region that are easily distinguished from silicate bands. Hydroxide-bearing minerals like clays have spectral features due to fundamental bending modes of OH attached to various metal ions. Salts like phosphates, sulfates, nitrites, and chlorides all have characteristic bands. In addition, it will be possible to distinguish feldspar and pyroxene compositions within their respective solid solution. Such information will be used to constrain the pressure-temperature conditions under which these minerals formed. The spectra are also very specific for secondary minerals like carbonates and clays that are key indicators of past climate and water activity.

Another important objective for Mini-TES is investigation of soil mineralogy. Viking and Mars Pathfinder results and Earth-based spectra suggest that salts may be an important component of the soil. If carbonates, nitrates, phosphates, or sulfates are present, either in the regolith or as localized concentrations like exposed crusts, they will be detected in Mini-TES spectra. These minerals provide information about the evolution of the atmosphere, its interactions with the surface and the processes of salt deposition, and migration associated with volatile cycles. Specific clay minerals should also be identifiable.

Mini-TES can also view upward to provide high-resolution temperature profiles in the martian atmospheric boundary layer. Temperatures are retrieved from the wings of the 15-μm CO_2 band.

Mini-TES observations of rocks and soils also reveal these materials' temperatures. Data obtained over diurnal cycles can be used to determine thermophysical properties (primarily thermal inertia) of martian materials.

The APXS has three detection modes (alpha, proton, and x-ray) that together provide accurate determinations of all major rock-forming elements but H. For the APEX APXS, several instrument modifications have been made, correcting some problems that were observed with the Mars Pathfinder APXS. The APEX APXS has also undergone extensive preflight calibration under martian environmental conditions, and will fly with a calibration target.

One set of APXS objectives deals with the elemental chemistry of soils. Minerals produced by weathering in particular tend to be complex, and permit many substitutions, like halogens for water, or Al for Fe. The environmental conditions under which weathering took place on Mars, as well as the composition of the source rocks, are largely unknown, so it is important that mineralogical determinations of soils and weathering products be constrained by chemistry.

The primary objective of the APXS is to determine the chemistry of rocks. Such measurements are essential for understanding under what environmental conditions martian crustal rocks formed, and how they formed. For example, highland rocks are presumably a mixture of primordial crust, ancient volcanic rocks, and ancient sediments, all stirred by impact. Chemical analyses of several rocks at a highland site could therefore shed light on a variety of processes that were important during early martian history. Other APXS objectives are examination of the products of water-induced erosion, sedimentation, solution, and evaporation.

The Mössbauer Spectrometer unambiguously identifies Fe-bearing phases with low detection limits and high accuracy, complementing compositional information from other instruments. Objectives of the Mössbauer spectrometer are to:

- *Determine the oxidation state of iron:* The Fe^{2+}/Fe^{3+} ratio provides information on the oxidation state of the soils and rocks. Comparison of these oxidation states can indicate the extent to which the oxidation state was enhanced during weathering, and hence can give insights into the processes involved, the nature of surface-atmosphere interactions, and likelihood of the preservation of organics against the oxidation process.
- *Identify the iron oxides and the magnetic phase in the martian soil:* Individual iron oxide and oxyhydroxide minerals have different chemical pathways of formation. For instance, iron oxides or hydroxides formed via precipitation in abundant liquid water will be different from the oxidation products formed via solid-gas reactions. Identification of ferric phases in the soil can therefore contribute to the understanding of the history of martian water.
- *Identify iron-bearing minerals in rocks:* What igneous rocks are present? By Mössbauer spectroscopy, Fe-bearing silicate minerals like pyroxene and olivine, as well as ilmenite and other Fe oxides, can be identified.
- *Search for Fe-sulfates, Fe-nitrates and Fe-carbonates:* These could be important irreversible volatile reservoirs, and their identification would aid in understanding of martian volatile evolution.

Mössbauer spectroscopy is also particularly useful for the study of the properties of materials that have adhered to the Magnet Array. There is some evidence from reflectance spectroscopy that superparamagnetic particles (nanophase iron oxides with diameters of less than about 50 nm) are present on Mars. The shape of the Mössbauer spectrum, especially of such small particles, depends strongly on temperature and particle size. By measuring the spectrum at different temperatures one may obtain semiquantitative information on the crystallite size and whether superparamagnetic particles are indeed present. Whether the iron oxides are poorly crystalline (*e.g.*, nanophase or superparamagnetic) or well crystalline also has implications for the environmental conditions at the time they formed.

Instrument Synergy: In order to demonstrate the way in which the APEX instruments can be used synergistically, we have analyzed seven samples using prototypes of all four instruments. The materials examined were Zagami (a

SNC meteorite) that contains primary igneous phases, plus six analogs for Martian surface materials. TRATIV1 is a sample of massive calcite (travertine). The remaining samples are heavily oxidized. HWMK600 and HWMK24 are palagonitic and jarositic tephra samples from Mauna Kea (HI). BCS-301 is a chemical standard derived from an iron ore deposit. AKB-1 is an amygdaloidal basalt from the Keweenawan peninsula (MI). MAN-74-342A is an impact melt rock from Manicouagan Crater (CD).

A good example of how the instruments work together is HWMK24. Pancam reveals a band minimum near 900 nm, which could result from ferric-bearing materials including goethite, lepidocrocite, maghemite, nontronite, and jarosite. Mini-TES suggests that the sulfate jarosite is present. Mössbauer confirms that the dominant Fe-bearing phase is jarosite, and APXS elemental abundances are consistent with this interpretation. In AKB-1, Pancam suggests hematite is present, and Mini-TES shows that carbonate and phyllosilicates are present. Mössbauer confirms the hematite. Strong APXS peaks for Si, Ca, and Fe are consistent with the inferred assemblage.

The composition of Zagami, a probable martian rock, is established well. Pancam identifies pyroxene. Mini-TES, with its ability to separate solid-solution minerals, shows that both high-Ca (diopside) and low-Ca (hypersthene) pyroxenes are present, in roughly equal amounts, as well as plagioclase. APXS yields a CIPW normative composition also consistent with a diopside-hypersthene pyroxene mix, and gives a plagioclase composition of An_{58}. Ilmenite is also suggested by APXS, and confirmed and quantified by Mössbauer.

Together the instruments also provide powerful information about the oxidation states of the important variable-valence elements iron, carbon, and sulfur. The oxidation state of iron is best provided by Mössbauer. Zagami, which is an unaltered igneous rock, exhibits only trace Fe^{3+}. All the other samples have undergone oxidative alteration, and have Fe^{3+} in differing and easily measurable amounts. An indication of the temperatures involved in the oxidative alteration is provided by the relative proportions of the doublet from nanophase-oxide (low temperatures) and the sextet from highly-crystalline hematite (high temperatures). Therefore, we would correctly interpret low temperatures for palagonitic tephra HWMK600 and higher temperatures for the impact melt MAN-74-342A and amygdular basalt AKB-1. The oxidation states of sulfur and carbon are provided best by Mini-TES, and can also be provided by Mössbauer if they are combined with iron (as S is in HWMK24).

Together, the APEX instrument set provides the capability to learn about the past environmental history of Mars, and when combined with the other instruments on the MSP'01 lander should provide one of the most comprehensive pictures yet obtained of the geologic and climatic history of a site on the martian surface.

Sample	Elements- APXS X-Ray + Alpha	Minerals: Pancam	Mini-TES	Mössbauer	Minerals Identified in Sample (1)
TRATIV1, Cal.	C, O, Ca	None	Cal	(2)	Cal
Zagami, SNC Meteorite	C, O, Na, Mg, Al Si, Ca, Fe	Px	OPx, CPx, Pl	Px, Ilm	OPx, CPx, Ilm, , Pl, Ma, FeOx, FeSul
HWMK600, Palag. Tephra	C, O, Na, Mg, Al, Si, K, Ca, Ti, Fe	npOx	Pl, Px	Ol, npOx TiMt	Ol, Pl, npOx, TiMt
HWMK24, Jarositic Tephra	C, O, Na, Mg, Al, Si, S, K, Ca, Ti, Fe	Fe(3+) Phase	Sulfate	Jar	Jar
BCS-301, Brit. Chem. Std.	C, O, Na, Mg, Al, Si, Ca, Mn, Fe	Gt	Car	Gt, Car	Gt, Car
AKB-1, Amygd. Basalt	C, O, Na, Mg, Al, Si, Ca, Fe	Hm	Sil, FeOx, Phy	Hm, npOx	Hm, npOx, Phy, Sil
MAN-74-342A, Impact Melt Rk.	(2)	Hm	None	Hm, Phy npOx	Hm, npOx, Phy

1. Ol=olivine; Px=pyroxene; OPx=orthopyroxene; CPx=clinopyroxene; Pl=plagioclase; Sil=silicate; Phy=phyllosilicate; TiMt=titanomagnetite; Ilm=ilmenite; Hm=hematite; Gt=goethite; npOx=nanophase ferric oxide; FeOx=iron oxide; FeSul=iron sulfide; Jar=jarosite; Cal=calcite; Car=Fe,Mg,Ca-carbonate. 2. Not analyzed.

CHEMICAL MODELS OF SALTS IN THE MARTIAN REGOLITH A. H. Treiman, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058. (treiman@lpi.jsc.nasa.gov).

The martian regolith is rich in ionic salts, which affect its chemical and physical properties, and will affect its resource potential and toxicity. Sulphate, halide, and carbonate salts are expected from theory, chemical analyses, and martian meteorites. A new inference here is that chromate salts may be present and abundant in the regolith. The origin of these salts is not known; they have been ascribed to hydrothermal action, meteoritic contributions, and volcanic aerosols/gases. Low temperature alteration (diagenesis) is a potentially important contributor to regolith salts.

Introduction: Ionic salt minerals in the martian regolith are important tracers of global and local chemical processes on Mars, appear to be important in setting the physical properties (i.e. trafficability) of the martian surface, will likely be important resources for human exploitation, and could possibly present hazards to human health. MECA and other instruments on the MARS 2001 lander are designed to investigate the regolith, so it is appropriate to examine the current knowledge of likely salt mineral in the martian regolith.

Earlier Results: Current understanding of salt minerals at/near Mars surface comes from geochemical theory, and data from telescopic, orbital, and landed instruments (e.g., [1-3]). Lander data provide the strongest evidence for salts. The Viking XRF (VXRF) experiments found that the regolith is rich in Cl and S, and that duricrust is richer – SO_3 to 9.2%wt, and Cl to 0.7%wt [1]. Mars Pathfinder APX (MPAPX) analyses confirmed these enrichments and showed that they did not derive from local rocks [3,4].

The abundance of S and its enrichment in duricrust suggested that the regolith contains soluble sulfate salts, probably of Mg (e.g. kieserite) or Na and Mg (e.g. loeweite) [1]. Definitive spectroscopic signatures of sulfate have not been found [2,5].

Halide salts are also likely. VXRF and MPAPX all found regolith with 0.5-0.7%wt Cl. A likely host mineral is halite, NaCl [1], and the correlation of Mg and Cl in VXRF analyses suggests the presence of a magnesium-bearing chloride [6]. Bromine was detected in a few VXRF analyses, suggesting widespread enrichment in halogens.

Carbonates, especially of Ca, Mg, and Fe, have been suggested on theoretical grounds, but direct evidence is limited. Viking GCMS data are consistent with up to ~10% Ca-Mg-Fe carbonate minerals in the regolith, but LR data seem inconsistent with more than 1% Ca-Mg carbonates; the remainder could be (Ca-) Fe carbonate [2]. MPAPX data limit the abundance of carbon in regolith to < 0.5% atom [7,8]. Spectroscopic evidence for carbonates is limited and ambiguous [2].

Chromium salts have never been considered but appear in geochemical models (see below) and are hinted at in MPAPX data. Published MPAPX spectra of soils show a strong CrKα peak, while comparable rocks lack such a peak [7]; unpublished data presented in a poster gave ~0.06% Cr_2O_3 for rocks and ~0.35% Cr_2O_3 for soil [9]. Unfortunately, VXRF data did not yield Cr abundances, and MPAPX analyses are still being calibrated [7,8]. As noted below, a martian chromate mineral has been found in a martian meteorite [10,11].

Martian Meteorites: The martian meteorites all contain salt minerals (or remnants of them) that have been attributed to martian weathering or hydrothermal activity [12]. Most abundant are carbonate minerals, especially of Mg-Fe ALH84001 [13] and Fe in the nakhlites [14]. Ca- and Mg- carbonates and sulphates are also present in the nakhlites and the shergottites [10-15]. Meteorite EETA79001 contains a complex suite of salt minerals, including carbonates, sulphates, a lead chromate-sulphate [10,11], and an Mg phosphate [12]. Halite of preterrestrial origin is present in the nakhlites [14], and is probably present in the other martian meteorites. These salts commonly occur with other signs of low-temperature aqueous activity: clays, ferrihydrite, and/or marcasite or pyrite.

Source of Salts: From the high abundances of S and Cl (and Br) at the Viking 1, Viking 2, and Mars Pathfinder landing sites, its seems reasonable that salt components have been added to the regolith on a global (or northern hemisphere) scale. But the sources of salt-forming elements are not clear. Several models have been proposed, and each has implications for the abundances of water in the regolith and for enrichments of specific trace elements in the regolith. Lacking analyses of water and trace element abundances in the regolith, it is difficult now to reject or confirm the influence of any of these mechanisms.

Volcanic Emanations. It was suggested early on that the excess S and Cl in the regolith might derive from volcanic gases and aerosols [16], and this idea found support in the similarity between the composition of the Shergotty martian meteorite and that of the regolith minus S and Cl [17]. This concept has seen a recent revival [18], founded in part on the lack of spectroscopic evidence for well-crystalline minerals in martian dust (vis. [2]). In this model, regolith should be enriched in S and Cl, and also in a suite of volatile elements including: Pb, Br, Sb, Hg, U, Na, Zn, and As [16,19]. This mechanism, enticingly called "acid fog," is consistent with abundances of S, Cl, and Br in the regolith, and could be consistent with the Pb chromate-sulfate mineral in EETA79001 [11] and with excesses of Hg in the martian meteorite Lafayette [20]. However, Na in the regolith is lower than might be expected and Th is higher [1,3,4,19,21].

Hydrothermal Products. Products of high-temperature aqueous alteration have also been suggested as contributors to the regolith, both from volcanic- and impact-driven systems. Hydrothermal systems undoubtedly existed on Mars, and the alteration assemblages in the nakhlites have been ascribed to hydrothermal temperatures [15]. If hydrothermal products are important in the regolith, one should see enrichments in S and Cl, and a suite of elements soluble in hot water including: Na, K, Li, B, As, Br, Rb, Hg, and Pb [19]. As above, this mechanism may be consistent with Pb minerals and Hg excesses in martian meteorites, but it may not be consistent with the regolith's low abundances of Na and K, and its high abundance of Th.

Chondritic Infall. There is no doubt that chondritic material (mostly CM-composition IDPs) could be a significant contributor to the martian regolith – infall rates are higher than at Earth because of proximity to the asteroid belt, and regolith surfaces have been undisturbed (relatively) for long durations [22]. Ni is the element most characteristic of a chondritic component [19], and MPAPX spectra show a Ni peak for regolith but not for rock [7]. Similarly, micro-INAA analyses of martian meteorite EETA79001 show a minor component with a chondritic Ni/Co ratio [23]. Chondrites can contain abundant salt minerals (like halides, carbonates, and sulfates [24]) that could be mobilized and redistributed in the martian regolith. Chondritic infall cannot be the sole contributor to regolith salts [17], as it contains insufficient K and Th.

Weathering/Pedogenesis. A little-studied possible source of the regolith salts is groundwater alteration of igneous rock – chemical interaction at ambient T. While liquid pure water can be stable only transiently at low elevations on Mars (p<6.1 mbar), brines can be stable to <0°C and to lower pressure, and pure water can be stable in the subsurface. Under any of these conditions, water and igneous rock will react to form brine solutions, which then can be wicked toward the surface or expelled onto it.

On Earth, low-temperature reaction of igneous rock with water tends to produce Mg-SO_4-Na-Cl brines, from which Mg and Na sulfate minerals can precipitate (e.g., [25]). Under oxidizing conditions on Mars (buffered by 6 mbar CO_2), water equilibrated with Shergotty composition rock would also be a sulfate brine (vis. [26]); on evaporation, it would precipitate NaCl and Mg and Na sulfates (epsomite, $MgSO_4 \cdot 7H_2O$; mirabilite, $Na_2SO_4 \cdot 10H_2O$). Near the martian surface, these would dehydrate to kieserite $MgSO_4 \cdot H_2O$, and possibly thenardite, Na_2SO_4 (Figure 1). Thorium is immobile in these fluids (except as colloids [27]). If chromite does not alter, significant Pb can be transported. If chromite does alter, most of the Pb is immobilized as crocoite $PbCrO_4$.

If reaction is isolated from Mars' atmosphere , the system becomes highly reducing (H_2~15 bars) and Mg remains in silicate minerals, leaving an alkaline Na-Ca-OH-Cl brine (e.g., [28]). On exposure to atmospheric CO_2 and evaporation, it will produce calcite, silica, and eventually replace the calcite with alkali-bearing carbonates (e.g., gaylussite, $Na_2Ca(CO_3)_2 \cdot 5H_2O$). The original reduced, alkaline brines cannot carry significant Cr, Pb, or Th.

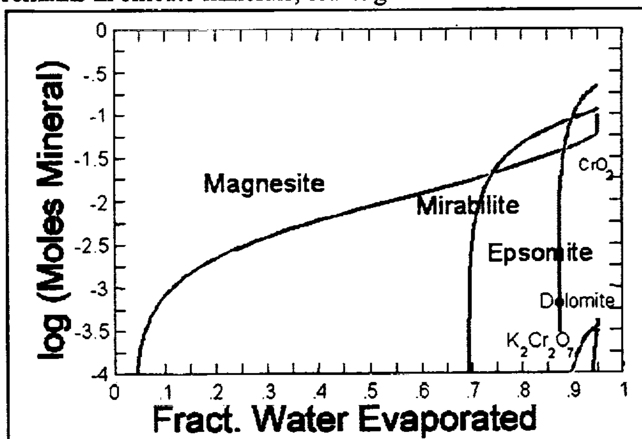

Figure 1. Minerals precipitated during evaporation of water equilibrated with Shergotty basalt composition (1:1 mass) at pCO_2=0.006 bar and log(fO_2)= -5. Calculation with Geochemist's Workbench®, Debye-Huckel activity model, so graph beyond evaporated fraction ~0.8 is illustrative only.

Conclusions: With available data, the source(s) of the salt minerals in the martian regolith cannot be defined. The regolith contains chondritic material, but the bulk of regolith salts are likely indigenous, martian. Newsom and Hagerty [17] compiled data on fluid compositions in terrestrial alteration regimes, and their list of critical elements forms a starting point for interpretation of MECA chemical analyses. However, volcanoes on Earth and Mars may produce gases of different compositions, in part because martian basalts are significantly drier than terrestrial. Similarly, hydrothermal systems on Mars may not carry the same solutes as Earth systems because their source rocks may be different. The putative Th content of the martian regolith [19] is an embarrassment for most models.

The excess abundance of Cr in martian regolith is unexpected, and could be reflect the presence of chromate salts.

Low-temperature alteration and weathering of local rock is an unappreciated potential contributor to regolith salts, and should be explored in more detail. In particular, it will be informative to compare trace element abundances of Mg-Na-SO4-Cl brines developed from igneous rocks with those of the source rocks.

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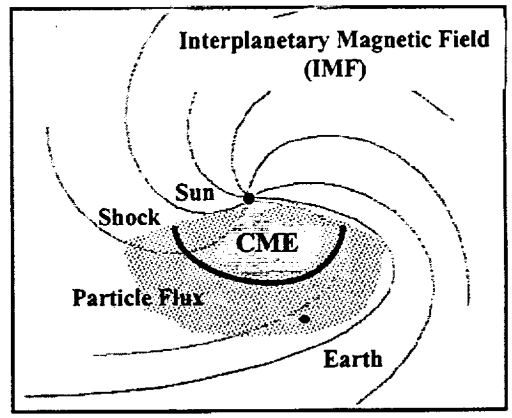
MARS 2001 CRUISE PHASE RADIATION MEASUREMENTS. R. E. Turner[1] and G. D. Badhwar[2], [1]ANSER, Suite 800, 1215 Jefferson Davis Hwy, Arlington, VA 22202, (turnerr@anser.org), [2]NASA Johnson Space Center, SN3, 2101 NASA Road One, Houston, TX 77058, (gbadhwar@ems.jsc.nasa.gov).

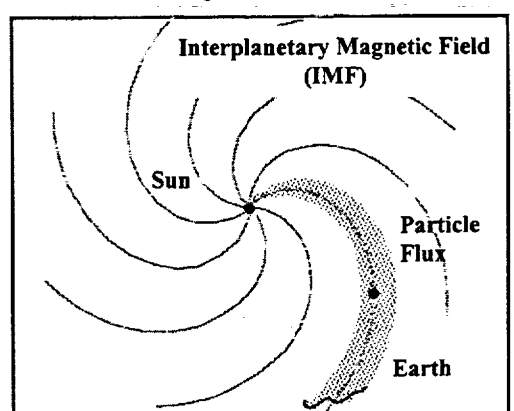
Introduction: Mars 2001 presents an exciting opportunity for advances in radiation risk management of a future human mission to Mars. The mission timing is particularly fortuitous, coming just after solar maximum, when there will be a high probability to observe significant solar particle events (SPEs). A major objective of this mission is to characterize the Martian radiation environment to support future human missions to Mars. In addition, the MARIE instruments on the Lander and Orbiter, designed to measure the energetic particle flux at Mars, can be used during the cruise phase to provide multipoint observations of SPEs in the critical region of the heliosphere (1 to 1.5 AU) needed to reduce the in-flight radiation risk to a future Mars-bound crew.

Physics background: It is generally accepted [1,2] that there are two classes of SPEs, each with distinct signatures and broad characteristics, as in figure 1. Impulsive flares may produce particle events that are electron-rich, relatively short-lived (hours), and generally limited to within a 30 degree longitude band about the footprint of the nominal field line connected to the active region. Gradual particle events by contrast are proton-rich, long-lived (days) and may be spread over a broad range of solar longitudes, in some cases over 180 degrees.

The very large SPEs that pose a risk to astronauts fit in the "Gradual Event" category. They are produced by the shock associated with fast CMEs [3,4,5]. For a fast CME, particle acceleration begins as the shock forms in the solar corona and continues as the shock moves out into the interplanetary medium. Energetic particles immediately stream out along the magnetic field lines to 1 AU. As the shock expands, it crosses other field lines, accelerating particles as it goes, and, within tens of minutes of shock formation, particles are flowing outward over an extremely broad front. Maximum acceleration occurs near the nose of the shock, ahead of the CME, and the intensity falls off around the flanks of the shock. As the structure propagates outward, the successive magnetic field lines that connect an observer with the shock sweeps counterclockwise across the shock's surface, averaging over diverse shock conditions.



CME-Associated (Gradual Event)
Proton-Rich, Long-Lived (Days)
60-180+ Degrees Solar Longitude



Impulsive Flare-Associated (Impulsive Event)
Electron-Rich, Short-Lived (Hours)
30-45 Degrees Solar Longitude
Figure 1. Two classes of Solar Particle Eventts

Need for additional observations: A complete picture matching the physics of particle acceleration to the detailed observation of any one event is very difficult due to the inherent three dimensional nature of the event, our lack of distributed observations, and the complex nature of the underlying processes occurring near the sun during CME production and within the ambient solar wind [6]. There are many things going on nearly simultaneously, and several of them may either be directly related to the production of large SPEs, or sufficiently correlated to act as proxies to tag an on-going event as likely to produce a significant SPE. Some SPEs have a secondary peak flux that occurs with the passage of the shock ahead of the CME. There is little observational data on the spatial and temporal variation of this shock-enhanced peak.

The need for correlated observations has been recognized by several workshops convened to examine SPE risk mitigation strategies. For example [7]:

"There is the potential to fill significant gaps in the current program by implementing additional observing techniques. The most important of these are:

- ***Multiple spacecraft to measure energetic particles at three or more points in the inner heliosphere, widely separated in heliolongitude***
- Coronograph observations of emerging CMEs from locations off-set from the sun-Earth line
- Radio imaging of type II and IV solar bursts"

(Foundations of Solar Particle Event Risk Management Strategies...Findings of the Risk Management Workshop for Solar Particle Events July 1996)

Recognizing this need, a workshop established to determine Mars radiation measurement objectives for the Mars 2001 mission recommended, as a secondary objective, to measure the radiation dose and radiation quality onboard the spacecraft en route to Mars [8].

Cruise phase opportunity: Through the nine or so months in transit during the declining phase of solar maximum, instrumentation on the two Mars-bound spacecraft would have the potential to observe 2 to 4 significant solar particle events. The cruise phase of the Orbiter and Lander provide a unique opportunity to increase our understanding of the acceleration mechanisms for energetic solar particles by providing multipoint *in situ* measurements of the environment. These measurements can be correlated with Earth-based observations of solar activity and particle flux. Figure 2 shows the heliospheric longitudinal separations of the Orbiter and Lander (launched at the beginning of the launch window) with each other and with Mars and Earth [9]. Of course, detailed interpretations of the data will also have to consider differences in solar latitude and distance from the sun.

MARIE Instruments: The MARIE instruments on the Lander and Orbiter are designed to measure the energetic particle background and the secondary particles generated in the Martian atmosphere and on the Martian surface. The combination of Orbiter and Lander measurements will provide particle flux above and below the Mars' atmosphere to validate transport codes to correlate with dose measured by the lander. The Orbiter instrument consists of an energetic particle spectrometer that can measure the elemental energy spectra of charged particles over energy range of 15-450 MeV/n. The spectrometer is mounted on the science deck and has an angular acceptance of 50°. The Lander instrument consists of a smaller particle telescope, and two proportional counters.

The orbiter spectrometer consists of a set of solid state detectors and a high refractive index Cherenkov detector. The basic telescope geometry is defined by two 25.4 x 25.4 x 1 mm thick ion-implanted silicon solid state detectors A1 and A2 that are operated near 160 V. In between A1 and A2 are two 25.4 x 25.4 mm position sensitive detectors PSD1 and PSD2, each with a 24 x 24 wire grid, to define the incident direction of charged particle. These are followed by a set of 5 mm thick lithium-drifted silicon solid state detectors (B1,B2,B3, and B4), and a Schot-glass Cherenkov (C) detector.

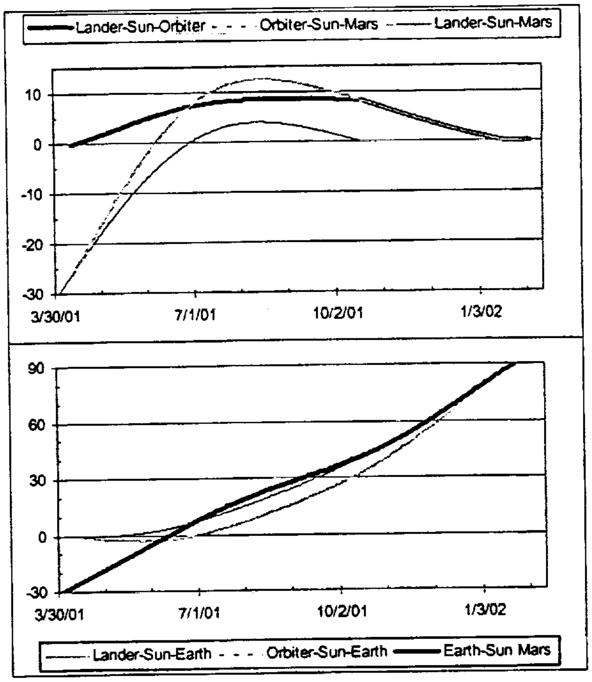


Figure 2. Longitudinal Separations relevant to Mars 2001

The Lander system consists of two ion-implanted 1 mm thick silicon detectors and two 24 x 24 position sensitive detectors, followed by two proportional counters. One of the proportional counters is surrounded by tissue equivalent A -10 plastic, and the second proportional counter by carbon. These right cylindrical (1.78 cm x 1.78 cm) proportional counters are filled with low pressure (40 torr) pure propane gas as the active volume. Under these conditions they simulate the response to radiation of a 2 μm diameter cell. This tissue equivalent proportional counter (TEPC) responds to both charged particles and neutrons, whereas the carbon proportional counter (CPC) responds to charged particles only.

The location of MARIE on the Orbiter is shown in figure 3. During the cruise phase, the orbiter instrument will be exposed to the interplanetary environment. The location of Marie on the Lander is shown in figure 4. During the cruise phase, the lander instrument will be enclosed in the aeroshell. When not in conflict with cruise phase operations, both instruments will be powered to collect and store data. The data will be time-tagged and relayed to Earth periodically.

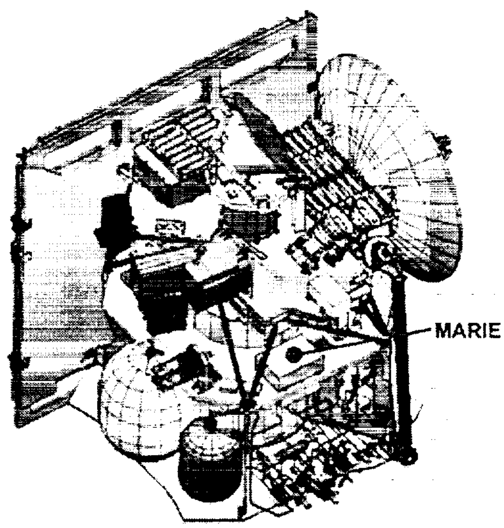


Figure 3 Location of MARIE on the Orbiter [9]

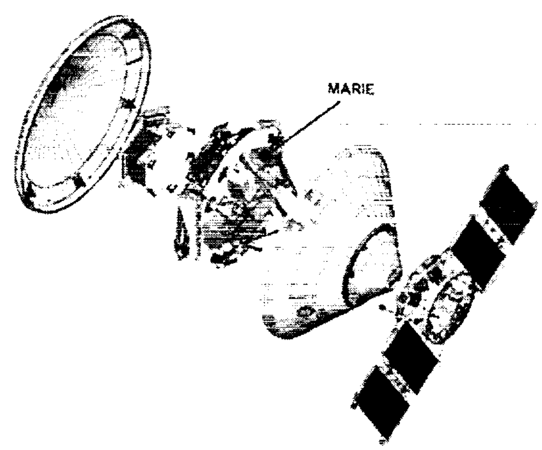


Figure 4. Location of MARIE on the Lander [9]

Conclusion: The coordinated launch of two spacecraft to Mars in 2001, along with Earth-based observations of solar activity and particle flux, provides a unique opportunity to advance our understanding of Solar Particle Events. Multipoint observations of energetic particle flux will provide insight into the acceleration mechanism and the evolution of SPEs. This in turn will support efforts to reduce the risk these events pose to humans in space.

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OVERVIEW OF EOLIAN PROCESSES ON MARS. A. W. Ward[1] and K. E. Herkenhoff[1], [1]U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff AZ 86001-1698 (wward@flagmail.wr.usgs.gov).

Recent observations: The Mars Pathfinder and Mars Global Surveyor (MGS) missions to Mars have given tremendous new insight into Martian eolian processes. We now recognize both bright and dark duneforms from orbit (bright dunes are ubiquitous over the Red Planet; dark dunes are prevalent in the highest northern latitudes and the middle southern latitudes) [1]. The pristine nature of Martian dunes and their rapid shedding of bright dust after storms suggest that some are currently active, at least seasonally.

Ventifacts have been recognized at the Mars Pathfinder site; at least 50% of rocks near the Sagan Memorial Station show evidence of eolian abrasion, as apparently does "Big Crater" as seen in MGS Mars Orbiter Camera (MOC) images. Effective winds indicated by depositional and erosional eolian features, however, are very different: bright streaks viewed from orbit, wind tails, and duneforms at the MPF site indicate winds from the northeast; ventifacts indicate that winds came from the east [2] (Fig. 1).

Polar dunes: The northern circumpolar erg appears as a dark crescent around the north polar residual ice cap. It is the largest concentration of dunes on Mars, with a total area of 7×10^5 km^2 [3]. Transverse dunes cover approximately 50% of the area with an estimated equivalent sediment thickness of 3-4 m [4], and barchan dunes occur at the margins of the erg. Observed wind streaks and the results of Mars global circulation model simulations suggest that the erg is latitudinally trapped by seasonally reversing winds [3, 4] and by winds generated by surface albedo contrasts [5].

Viking bistatic radar observations (at 3.6- and 13.1-cm wavelengths) of the north polar region indicate that areas known to be covered by sand dunes are rougher than average but otherwise “do not appear to scatter with distinctive signatures” [6]. The data show an inverse correlation between roughness and reflectivity, indicating that the roughest surfaces in the north polar region are composed of the least dense materials. Bistatic radar ground tracks that pass over the north polar erg show that it is rougher and less reflective than surrounding terrains [6]. Ground-based 3.5-cm radar images also show low surface reflectivities in the north polar region [7]. These observations suggest that the north polar erg is composed of low-density material.

The thermal inertia of the north polar erg is much less than that of dune fields at lower latitudes [8]. This difference suggests that the north polar dune material was formed by a different (probably uniquely polar) process than the dune materials at lower latitudes. The low thermal inertia of the north polar dunes implies that they are composed of very low-density material, probably aggregates of dust such as the filamentary sublimation residue particles formed by sublimation of dust-ice mixtures [9]. Micron-sized basalt or ferrous clay particles are likely components of the aggregates, as they can easily be transported into the polar regions via atmospheric suspension and are consistent with near-infrared spectra of the north polar erg [8].

Dunes in the south polar region show unusual albedo features associated with frost cap retreat. Many of the dunes are very crisp in form, which leads to the inference that they are most probably active in the current eolian regime. A variety of dune types are recognized, leading to the interpretation of simple primary and secondary winds in many regions, but MOC will provide many more observations for more precise investigations. At present, no noted differences in wind direction have been reported for dunes of greatly different sizes in the same region (for the operating model that different size dunes respond differently to winds of different strengths and directions) and dune migration or aspect changes have yet to be documented between MGS and the Viking missions, or within the lifetime of the MGS mission.

Intracrater dunes: At several locations at moderately high (40°-75°S) southern latitudes, there are groups of impact craters containing dark sediment; some of these intracrater features have been identified as dune fields. These deposits appear to be topographically trapped inside impact craters and are as thick as 100 m [10].

Little is known about the primary sources or physical properties of Martian intracrater dune fields, but their apparent thermal inertias have been interpreted in terms of solid silicate grains [11]. *Edgett and Christensen* [12] found that the thermophysical properties of intracrater dunes and dark splotches are similar within regional clusters but vary between clusters. They found some correlations between dune properties and the local sand supply and/or wind regime. The wind velocities required to move particles of the sizes inferred in these studies may be sufficient to destroy them upon impact with a rocky surface, so either they are locally derived or the apparent thermal inertia is affected by coarser material between dunes.

Conclusions: Significant questions remaining include the size and composition of eolian sediments; further considerations will also arise with respect to the type and distribution of their source units. Also, the "activity state 'of eolian features such as dunes (of any scale) remains to be determined. Finally, detailed coupling of the

General Circulation Model (GCM) for Mars (using parameters reflecting obliquity changes and possible past climatic regimes) with the observed erosional and depositional features seen on Mars remains to be conducted.

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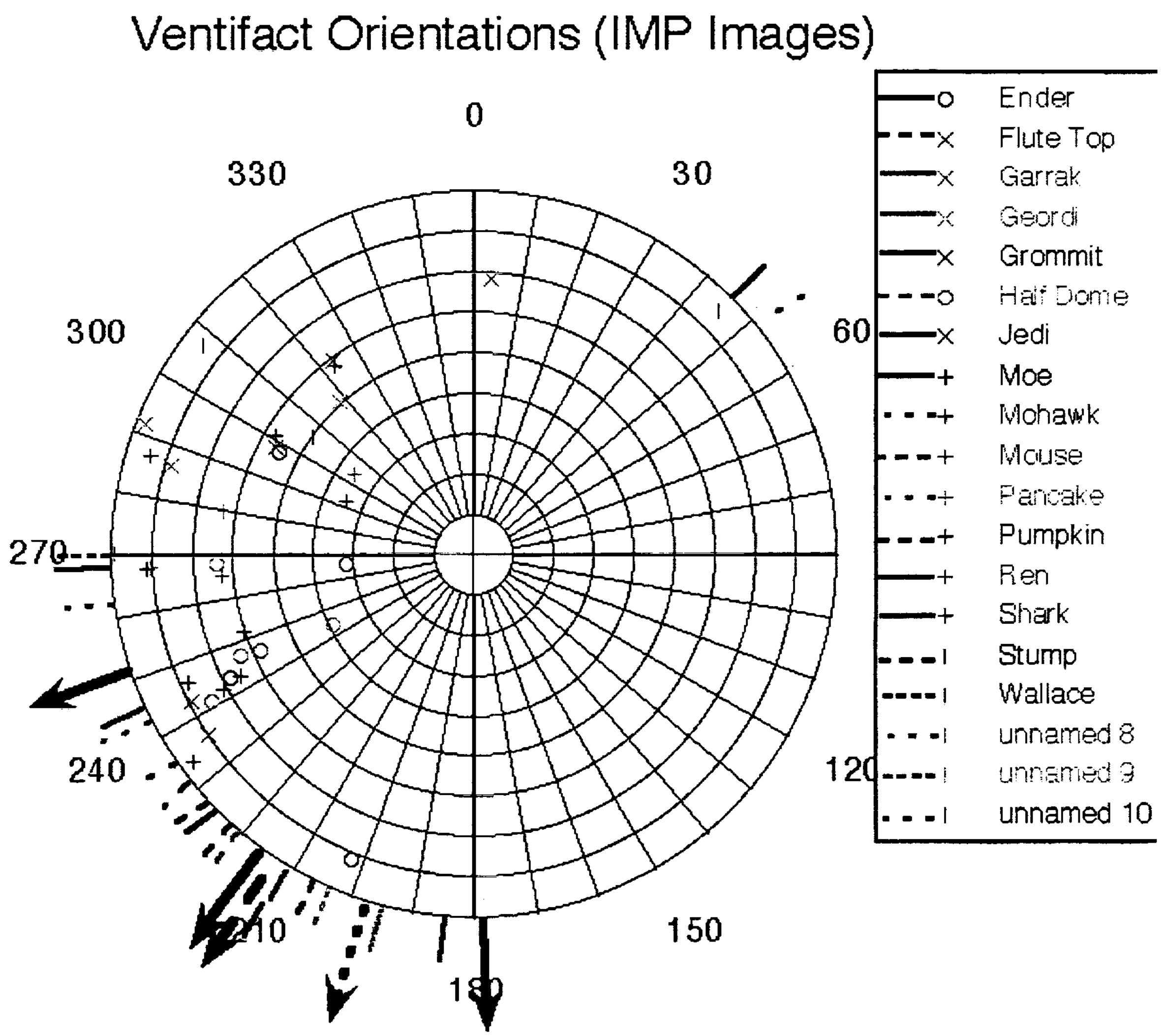

Figure 1: Orientations of eolian flutes observed by the IMP and rover cameras at the Pathfinder landing site. Polar projection with north at 0°. Rock position shown by colored tic marks on outside of circle. Solid arrows are minimum, average, and maximum values of local wind tail directions; dashed arrow is wind streak orientation from orbital images; arrow with small dashes is direction of strongest winds from the GCM. Unpublished data provided by N. Bridges.

LOOKING FOR FOSSIL BACTERIA IN MARTIAN MATERIALS. F. Westall[1], M. M. Walsh[2], D. S. Mckay[1], S. Wentworth[3], E. K. Gibson[1], A. Steele[1], J. Toporski[4], D. Lindstrom[1], R. Martinez[3], C. C. Allen[3], P. Morris-Smith[5], K. Thomas-Keprta[3], and M.S. Bell[3], [1]Mail Code SN, NASA Johnson Space Center, Houston TX 77058, USA (frances.westall1@jsc.nasa.gov), [2]Inst. Environmental Studies, Lousiana State University, 42 Atkinson Hall, Baton Rouge, LA 70803-5705; [3]Lockheed Martin Corp., 2400 Nasa Road 1, Houston TX 77058; [4]Dept. of Earth, Environmental and Physical Sciences, University of Portsmouth, Portsmouth PO12DT, U.K.; [5]Dept. Natural Sciences, University of Houston-Downtown, Houston 77002.

The rationale for looking for prokaryote fossils in Martian materials is based on our present understanding of the environmental evolution of that planet in comparison to the history of the terrestrial environments and the development and evolution of life on Earth.

On Earth we have clear, albeit indirect, evidence of life in 3.8 b.y.-old rocks from Greenland (Schidlowski, 1988; Mojzsis et al., 1996; Westall and Steele, unpub. data) and the first morphological fossils in 3.3-3.5 b.y.-old cherts from South Africa and Australia (Walsh, 1992; Schopf, 1993; Westall, 1999; Westall et al., 1999). Although some of these fossils were interpreted as possible cyanophytes (relatively sophisticated oxygenic photosynthesising bacteria) by Schopf (1993), there is no direct evidence for this interpretation. Moreover, the Early Archaean stromatolites, which had been believed to be cyanobacterial buildups (Lowe, 1980) could have been constructed by non-oxygenic photosynthesisers (Walter, 1983). The microfossils, however, show clear morphological affinities with modern prokaryotes. An interpretation as such is supported by the association of the microfossils with microbial biofilms or mats (Walsh, 1992; Walsh and Lowe, 1999; Westall and Gerneke, 1998; Westall et al., 1999), the association of $\delta^{13}C$ isotopes indicative of bacterial fractionation (Schidlowski, 1988; Walsh and Lowe, 1999; Westall et al., 1999), and the direct measurement of derivation products of a biochemical marker for bacterial polymer in these Early Archaean samples (Westall, Steele, unpub. data).

Recently biomarker evidence for cyanophytes in 2.7 b.y.-old shales from the Hamersley Group in Australia has been presented (Summons et al., 1999; Brocks et al., 1999), although clearly identifiable morphological fossils are younger (Golubic et al., 1995). In terms of evolution, the molecular fossils in the Hamersley Shales suggest that some of the organisms from which they were derived had some eukaryotic attributes, although the oldest eukaryotic microfossils found to date are 2.1 b.y.-old (Han and Runnegar, 1992). Despite the fact that this latest study has accelerated the known rate of terrestrial evolution, there is still a large time gap between the appearance of the first prokaryotes and those using the more sophisticated oxygenic photosynthetic metabolism.

Life on Earth could have arisen at any time after the condensation of liquid water on the surface of the cooled planet (after about 4.4 b.y). By 3.8 b.y. we have indirect evidence for the presence of prokaryotes. Although there is much debate concerning how life started and what the first common ancestor was like, or how close it was to the Bacteria or Archaea branches of the tree of life, it all had to have occurred by 3.8 b.y. Thereafter further evolution may have been linked to the presence of a small amount of O2 in the atmosphere (1% PAL) by the late Archaean (Rye and Holland, 1989; Rasmussen and Buick, 1999; Knoll and Holland, 1995; Knoll, 1999).

In comparison, Mars, being smaller, probably cooled down after initial aggregation faster than the Earth. Consequently, there could have been liquid water on its surface earlier than on Earth. With a similar exogenous and endogenous input of organics and life-sustaining nutrients as is proposed for the Earth (McKay et al., 1991), life could have arisen on that planet, possibly slightly earlier than it did on Earth. Whereas on Earth liquid water has remained at the surface of the planet since about 4.4 b.y. (with some possible interregnums caused by planet-sterilising impacts before 3.8. b.y. (Maher and Stevenson, 1988) and perhaps a number of periods of a totally frozen Earth (Hoffman et al., 1998), this was not the case with Mars. Although it is not known exactly when surficial water disappeared from the surface, there would have been sufficient time for life to have developed into something similar to the terrestrial prokaryote stage. However, given the earlier environmental deterioration, it is unlikely that it evolved into the eukaryote stage and even evolution of oxygenic photosynthesis may not have been reached. Thus, the impetus of research is on single celled life similar to prokaryotes.

If life did evolve on the planet, it may be extinct now because of the limited availability of liquid water for sufficiently continuous periods of time (Friedmann and Kofiem, 1989). We would therefore search for the fossilised remains of Martian life. Even if life had taken refuge in the deep frozen subsurface aquifers believed to exist

(Fanale et al., 1986; Squyres and Carr, 1986), with intermittent reappearance during impact-related reheating events, its remains would still be preserved as fossils both on the surface and in the subsurface.

Fossil bacteria

In order to be able to identify possible fossil bacteria or bacteria-like structures in Martian materials with any degree of confidence, it is necessary, in the first place, to be able to do the same with terrestrial materials. Fossil prokaryotes of a certain complexity, such as cyanophytes, are readily recognisable so long as they are relatively well preserved. However, in terrestrial rocks of comparable age to the ancient, water influenced Martian terrain, the microbial fossils are relatively simple (Walsh, 1992; Schopf, 1993; Westall, 1999; Westall et al., 1999) and additional information apart from morphology is valuable in order to correctly identify them. Such additional information includes macroscopic sedimentological and environmental studies (e.g. biolamination, evaporite deposits, hot spring deposits etc.), microscopic studies showing a relationship between the purported fossils and biofilm laminae, and biogeochemical studies, such as *in situ* carbon isotope measurements, concentrations of heavy minerals associated with the possible microbial structures (e.g. U, Cr, Ti), and *in situ* analysis of specific molecular biomarkers derived from microbes (e.g. hopanes, steranes, etc.).

One of the problems in this field is that for so long the emphasis in the search for ancient fossil bacteria was on identifying cyanophytes although researchers theoretically knew that there had to be all the "other" non-cyanophyte types of bacteria. With the exception of long filamentous forms, these "other" types were not looked for mainly because reliance on optical petrography as a means of observation limited the size of structures that could be observed with sufficient resolution. Numerous electron microscope studies of non-cyanophyte fossil bacteria (Wuttke, 1983; Monty et al., 1991; Westall, 1994; Martill and Wilby, 1994; Westall et al., 1995; Westall, 1997; Liebig et al., 1996; Westall and Gerneke, 1998; Westall, 1999; Westall et al., 1999) have proved the validity of these instruments in providing superb structural detail, as well as elemental analyses of the fossil structures.

There are few well-preserved, terrestrial sedimentary successions which overlap in age the period in which there may potentially have been life at the surface of Mars. Although the 3.8 b.y.-year old Isua and Akilia supracrustals on Greenland fall well within this period, these rocks have been severely metamorphosed. Despite the isotopic evidence for the existence of microorganisms at the time of deposition of these sediments (Schidlowski, 1988; Mojzsis et al., 1996), there are no remains of recognisable microbial morphology. However, SEM imaging of kerogen/graphite trapped within metaquartzites, combined with preliminary TOF-SIMS indications of a biomarker trace for bacterial polymer support interpretations of a microbial presence (Westall, Steele, unpub. data). On the other hand, slightly younger sedimentary and early diagenetic cherts from the Early Archaean sediments (3.3-3.5 b.y.) from the Barberton greenstone belt and the North Pole area in Australia are exceptionally well-preserved and the fossils contained in them represent excellent analogues for potential Martian fossils. Combined petrological and high resolution scanning electron microscope (field emission gun, FEG-SEM) observations of these rocks have documented well-preserved simple bacterial structures (Walsh, 1992; Westall, 1999; Westall et al., 1999; Westall, unpub. data). An electron dispersive system attached to the FEG-SEM can map remnant carbon associated with the fossil structures.

We are investigating a number of methods of trace element analysis with respect to the Early Archaean microbial fossils. Preliminary neutron activation analysis of carbonaceous layers in the Early Archaean cherts from South Africa and Australia shows some partitioning of elements such as As, Sb, Cr with an especial enrichment of lanthanides in a carbonaceous-rich banded iron sediment (Westall, Lindstrom, Martinez, unpub. data). More significantly, preliminary TOF-SIMS investigations of organics in the cherts reveals the presence of a biomarker, which appears to be a derivative of bacterial polymer, in the carbonaceous parts of the rocks (Westall, Steele, unpub. data).

We conclude that a combination of morphological, isotope and biogeochemical methods can be used to successfully identify signs of life in terrestrial material, and that these methods will be useful in searching for signs of life in extraterrestrial materials.

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MARS SURFACE IONIZING RADIATION ENVIRONMENT: NEED FOR VALIDATION. J. W. Wilson[1], M. Y. Kim[2], M. S. Clowdsley[1], J. H. Heinbockel[3], R. K. Tripathi[1], R. C. Singleterry[1], J. L. Shinn[1], and R. Suggs[4], [1]NASA Langley Research Center, Hampton, VA 23681, [2]College of William and Mary, Williamsburg, VA 23187, [3]Old Dominion University, Norfolk, VA 23508, [4]Marshall Space Flight Center, Huntsville, AL 35812.

Introduction: Protection against the hazards from exposure to ionizing radiation remains an unresolved issue in the Human Exploration and Development of Space (HEDS) enterprise [1]. The major uncertainty is the lack of data on biological response to galactic cosmic ray (GCR) exposures but even a full understanding of the physical interaction of GCR with shielding and body tissues is not yet available and has a potentially large impact on mission costs [2]. "The general opinion is that the initial flights should be short-stay missions performed as fast as possible (so-called 'Sprint' missions) to minimize crew exposure to the zero-g and space radiation environment, to ease requirements on system reliability, and to enhance the probability of mission success." [1] The short-stay missions tend to have long transit times and may not be the best option due to the relatively long exposure to zero-g and ionizing radiation [1]. On the other-hand the short-transit missions tend to have long stays on the surface requiring an adequate knowledge of the surface radiation environment to estimate risks and to design shield configurations. Our knowledge of the surface environment is theoretically based and suffers from an incomplete understanding of the physical interactions of GCR with the Martian atmosphere, Martian surface, and intervening shield materials. An important component of Mars surface robotic exploration is the opportunity to test our understanding of the Mars surface environment.

The Mars surface environment is generated by the interaction of Galactic Cosmic Rays (GCR) and Solar Particle Events (SPEs) with the Mars atmosphere and Mars surface materials. In these interactions, multiple charged ions are reduced in size and secondary particles are generated, including neutrons. Upon impact with the Martian surface, the character of the interactions changes as a result of the differing nuclear constituents of the surface materials. Among the surface environment are many neutrons diffusing from the Martian surface and especially prominent are energetic neutrons with energies up to a few hundred MeV. Testing of these computational results is first supported by ongoing experiments at the Brookhaven National Laboratory but equally important is the validation to the extent possible by measurements on the Martian surface. Such surface measurements are limited by power and weight requirements of the specific mission and simplified instrumentation by necessity lacks the full discernment of particle type and spectra as is possible with laboratory experimental equipment. Yet, the surface measurements are precise and a necessary requisite to validate our understanding of the surface environment. At the very minimum, the surface measurements need to provide some spectral information on the charged component and limited spectral information on the neutron environment. Of absolute necessity is the precise knowledge of the detector response functions for absolute comparisons between the computational model of the surface environment and the detector measurements on the surface [3].

Computational Model: The Mars 2001 mission has a planned launch date of April 2001 with an expected landing for a 90 day mission on the Mars surface in Jan. 2002 (about one to two years after Solar Cycle 23 maximum). We use the projected Badhwar-O'Neill model [4,5] for GCR and the estimated Feb. 23, 1956 SPE model (the largest directly observed event) [6] as boundary conditions at the top of the Martian atmosphere. We assume the Martian atmosphere to be CO_2 and distributed according to the COSPAR low-density model [7]. The Martian surface is taken as regolith (58.2% SiO_2, 23.7% Fe_2O_3, 10.8% MgO, 7.3% CaO) with minimal differences in transport properties from Martian bedrock [8]. The transport code used to describe the interaction of the space environment with the Martian atmosphere and surface is the HZETRN code [2], which has been recently improved in the description of angular dependent neutron transport and corresponding boundary conditions [9].

The interplanetary environment at Mars excluding the low-energy anomalous cosmic rays is shown in fig. 1. The GCR environment is for the months of Jan. to Mar. of 2002 representing the expected 90-day surface mission. We have assumed an isotropic interplanetary diffusion coefficient with a r radial dependence. The SPE considered is the Feb. 23, 1956 event and the particles arrived over a several hour period. The radial dependence of SPE is controversial and we have assumed the SPE flux intensities are the same as for Earth. Although the multiple charged ions are of lower intensity their effects are magnified by their large charge. The SPE can dominate the GCR environment if one occurs. There is only a small probability of an event like the Feb. 23, 1956 event occurring.

Mars Surface Environment: The surface environment generated by the GCR is shown in fig. 2(a). The highly charged ions are attenuated by the interaction with the Martian atmosphere contributing to the lighter ion fields and neutrons. Impact with the Martian surface generates a backward flux of neutrons extending to a few hundred MeV as seen in the figure. Due to the higher atomic weight elements of the regolith (and bedrock) the backward neutron flux is appreciable compared to the forward propagating component produced in collision with atmospheric components. This effect is also seen in the surface environment generated by a high energy SPE as that which occurred on Feb. 23, 1956 as shown in fig. 2(b). The spectral distribution in LET(Si) as a function of regolith shielding is given in fig. 3. These results are available as graphs and tables at http://SIREST.larc.nasa.gov.

Validation Issues: Model validation has followed two paths. The basic interaction models are validated in laboratory experiments using monoenergetic ion beams and high-resolution detectors for which specific particle types and energies can be measured [10, 11]. These are combined in the transport equation and integrated for the specific boundary conditions [12]. These solutions are then tested in the space environment on specific spacecraft with simplified detection equipment. For example, a test of the HZETRN results on Shuttle is shown in fig. 4. The TEPC detectors were developed to measure LET distributions of radiation fields but are limited by detector geometry, fluctuations in energy loss, and diffusive processes. Only by knowledge of the detector response can meaningful comparisons with measurements be made. Details are given by Shinn et al. [3]. The simplified detection systems in most spacecraft measurements will require detailed knowledge of the detector response to each radiation component for a meaningful validation. Even then, one would hope to have some degree of separation of particle type in either the detector spectral response or as difference between differing detectors. In the case of neutrons, it would be desirable to differentiate between those generated in the atmosphere and the backward propagating neutrons produced in the surface. Not only would this allow the validation of the basic model but it has important implications for shielding technology on the Martian surface.

Concluding Remarks: The Martian surface environment integrated over the Mars 2001 mission has been evaluated. A large SPE could dominate the environment exceeding the accumulated GCR environment in a few hours. A prominant feature of the surface environment evaluation is the large number of neutrons produced as secondaries in the atmosphere and Martian surface materials. The backward propagating neutrons from the GCR are predicted to dominate those produced in the atmosphere below 20 MeV. The backward propagating neutrons from the SPE are predicted to be nearly equal in number to those produced in the atmosphere. The GCR LET spectrum can be modified above 150 keV/micron by the addition of regolith shielding with little change in the lower LET components. In distinction, the SPE LET spectrum is mainly attenuated at the lowest LET values with little affect on the highest LET components.

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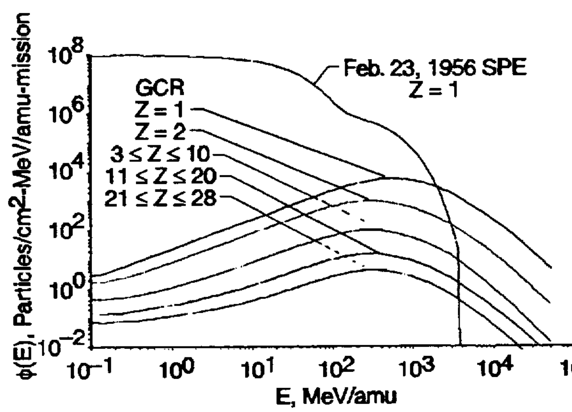

Figure 1. Local interplanetary environment model for surface 2001 mission.

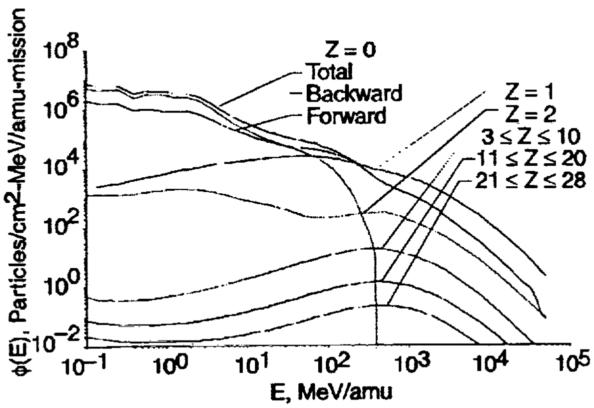

Figure 2a. Mars 2001 surface environment (GCR).

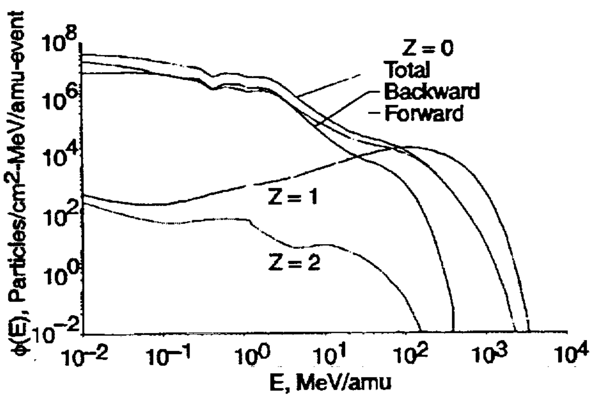

Figure 2b. Mars 2001 surface environment (SPE).

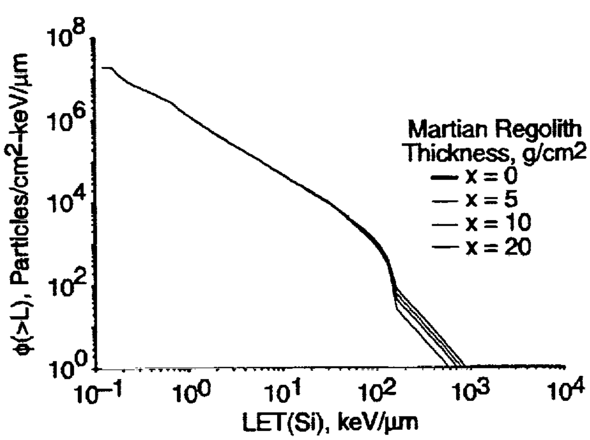

Figure 3a. LET (in silicon) spectra of GCR as function of depth in regolith.

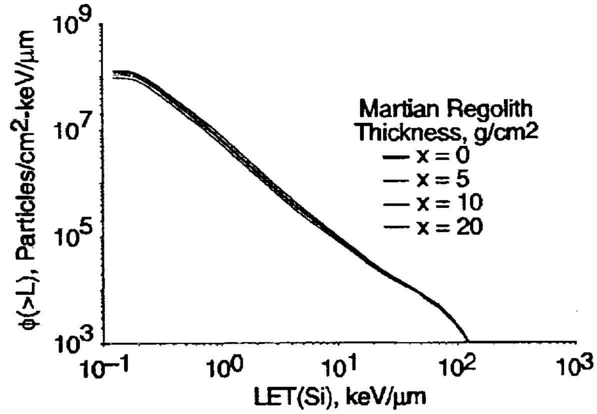

Figure 3b. LET (in silicon) spectra of Feb. 23, 1956 SPE as function of depth in regolith.

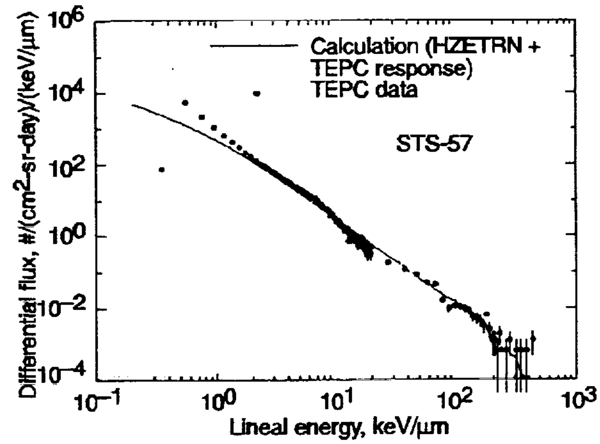

Figure 4a. Measured and calculated lineal energy spectra induced by galactic cosmic rays in a 252 nmi × 28.5° orbit in June 1993 aboard STS-57.

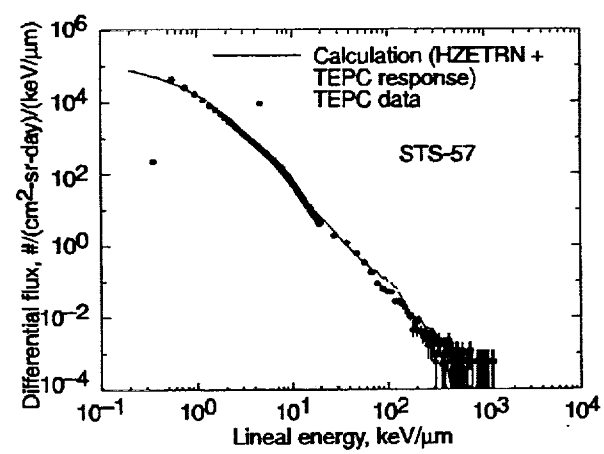

Figure 4b. Measured and calculated lineal energy spectra induced by trapped protons in a 252 nmi × 28.5° orbit in June 1993 aboard STS-57.

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Introduction. Volcanism is a fundamental process in transferring heat and volatiles from the interior and shaping the surfaces of planetary bodies [1]. Basic magmatic processes on planetary bodies (magma generation, ascent, storage and eruption) are modulated by initial conditions and composition, thermal and chemical structure, and a variety of factors related to the fundamental properties of the body (gravity, presence and nature of an atmosphere, etc.). Volcanism in the geological and geomorphological record of a planet thus provides key information about the location, style and amount of heat loss with time, mantle convection patterns, the evolution of the interior, and the role of volatiles in the formation and evolution of the atmosphere. An assessment of the theory of magma ascent and eruption [e.g., 2] is an important aid in the interpretation of the planetary record.

Planetary exploration missions provide key information to assess and understand volcanism in the geological and geomorphological record, and each type of mission (e.g., orbiter, lander, rover) provides significant and complementary insight. In this contribution we outline some of the major outstanding problems relative to magmatism (plutonism and volcanism) on Mars [3], describe the potential relevance to orbital and surface aspects of 2001, including landing site selection and mission operations, and then assess the implications of these questions for future Mars exploration program missions, including sample return and human exploration.

What do we know about volcanism on Mars?: Prior to Mars Global Surveyor, magmatism was viewed largely through the lunar lens, but with some important variations. Early crustal formation processes were not well understood, but when the geologic record first emerged from obscuration by the early high impact flux, volcanism was seen to be an important resurfacing process whose rates generally dwindled with time [4,5], extending more toward the present than the lunar record, but generally resurfacing a one-plate planet. In contrast to the Moon [6], water appeared to play a role in eruptions, particularly in earlier history [7,8], gigantic edifices were formed [9], and the most significant later activity was focused at major centers (Tharsis and Elysium) [7,9,10]. Analysis of meteorites from Mars provided some insight into petrogenesis [11], and thermal evolution models were compared to these data [12].

Specifically, our knowledge of martian magmatism could be summarized as follows [4,5]: The geological record showed that volcanic deposits in the form of cratered plains may have been significant in the early crustal formation and evolution of Mars, but the unknown role of other smoothing processes (e.g., eolian, water-related), together with the large number of superposed craters, hindered the unique identification of these plains as of volcanic origin. Volcanic rocks (lava flows and pyroclastic deposits) were estimated to cover about 60% of the surface, based on the assumption that most heavily cratered terrains are volcanic. On this basis, volcanism evolved from a globally pervasive process (resurfacing rates of ~1 $km^2\ yr^{-1}$), to local activity (resurfacing rates of ~$10^{-2}\ km^2\ yr^{-1}$) with time. The Hesperian-aged highland paterae represent the earliest recognizable central-vent type volcanism, are commonly interpreted to have involved significant amounts of explosive volcanism, and four out of five are located around Hellas. Hesperian and Amazonian volcanism was concentrated in the Tharsis region, was probably built on Noachian volcanic plains, and was intimately involved in the tectonic evolution of this large region. These shields are the locus of the Tharsis Montes Formation, a Late Hesperian-Late Amazonian veneer of effusive deposits, some flows of which are up to 1500 km long. Recent Tharsis flows average >100 km^2, and it has been estimated that in the last several hundred million years, a lava flow has erupted about every 10^4 years. Smaller shields and domical constructs are also found in Tharsis, and some of these may be composite volcanoes. Extensive Hesperian and Amazonian volcanism was also focused marginal to Tharsis in the form of Alba Patera (a gigantic broad shield largely in the northern lowlands north of Tharsis Montes, and probably a composite volcano) and Olympus Mons (a massive 26 km high edifice to the west of Tharsis with a basal scarp caused by flank collapse; some of the youngest flows on Mars emanate from fractures east of the edifice). Extensive plains deposits south of Tharsis paved Syria Planum during the Late Hesperian. Hesperian-aged faulting produced Valles Marineris and exposed extensive deposits of the plateau sequence in the walls; during Late Hesperian the valley floors were filled with layered sedimentary materials, some of possible pyroclastic origin. Some dark volcanic material may have been emplaced inside the canyon during the Amazonian. The eastern volcanic assemblage is focused in Elysium and Syrtis Major. Elysium volcanic edifices are Late Hesperian-Early Amazonian, differ from the Tharsis Montes, are likely composite, and there is much evidence for the interaction of volcanism and ground ice. Syrtis Major is dominated by a low-relief shield and associated Hesperian-aged deposits, and on the basis of Phobos ISM data these appear to have a distinctive composition linked to SNC meteorites [13]. Edifices and deposits contain evidence for morphologic evolution, with pyroclastic eruptions more common earlier than later [6-8]. Calderas associated with volcanic edifices can be classified and the size and geometry provide insight into magma reservoir activity [14]. Little was actually known about the plutonic aspect of magmatism or the formation and evolution of the subsurface part of the crust, although some postulated that seafloor spreading mechanisms had created the northern lowlands [15].

Theoretical analysis of the ascent, emplacement, and eruption of magma on Mars illustrated how martian conditions would influence these processes [2]. Because of the lower gravity, fluid convective motions and crystal settling processes driven by positive and negative buoyancy forces, and overall diapiric ascent rates will be slower on Mars than on Earth, permitting larger diapirs to ascend to shallower depths. The mean width of a dike should be inversely proportional to the cube root of the acceleration due to gravity; when motion is laminar, flow velocities of magmas in dikes are proportional to the total pressure gradient acting on the magma and to the square of the dike width. The magma flow speed when conditions are laminar will be ~1.8 times greater than on Earth for the same excess reservoir pressure and the discharge rate will be ~5 times greater; clearly, this will influence lava flow lengths and other eruption factors. The combination of lower martian gravity and lower atmospheric pressure ensures that both gas nucleation and disruption of magma occur at systematically greater depths than on Earth. Pyroclastic eruptions will be common and their relative significance and key parameters, such as plume height, flow runout distance, and pyroclastic dispersal patterns and edifice sizes, different from on Earth. The density structure of the crust in which a reservoir forms and on which a volcano builds is crucial to the determination of reservoir depth and edifice growth. As a result of the differences in lithospheric bulk density profile, which in turn depend on differences in both gravity and surface atmospheric pressure, magma reservoirs are expected to be deeper on Mars than on Earth by a factor of about four. The martian atmosphere is about 100 times less efficient at removing heat from exposed hot surfaces by both forced and natural convection than the Earth's atmosphere; radiation losses dominate on Mars but surface cooling differences are not in themselves a significant factor in causing systematic differences between the lengths and widths of lava flows on Mars and the Earth [2].

What are some fundamental outstanding questions and how might they be addressed by Mars 2001 and beyond?: In addition to the basic information described above, Mars Pathfinder analyses [16] and Mars Global Surveyor data [17, and the Mars 5 conference] provide important new insight into fundamental questions about Mars volcanism. What are some of the outstanding issues, how can we address them with new missions and data, and what contributions do we think the new data may provide?

Crustal Formation and Evolution: *What is the mode of formation of the early crust and how has it changed with time?*: Did plate tectonics play a role in this period and does a geologic record remain? Was crustal formation largely by vertical crustal accretion, and if so, what were the effects of mantle depletion as a function of time? Does the layering in the walls of Valles Marineris reveal local or global conditions?

What is the role of plutonism in the formation of the martian crust and how has it contributed to crustal diversity? What is the nature of intrusion as a function of space and time? What form does it take (dike swarms, plutons, sills, etc.) and how is it linked to surface volcanism?

What is the relationship of plutonism to the formation of the surface volcanic record? What is the relative proportion of intrusion and extrusion? How are they related in specific environments (edifices, dikes, northern lowlands)?

Some of these questions can be addressed by landing in Noachian-aged plains and determining the role of volcanic processes in their emplacement, and by examining the stratigraphy of the walls of volcanic sequences such as in Valles Marineris. Examination of vertical sequences may also reveal evidence for plutonism and dike emplacement processes.

Role of Magmatism in Planetary Evolution: *What is the role and significance of the large rises (Tharsis and Elysium) and how are they related to interior processes?* What is the beginning of magmatism in Tharsis and Elysium? How is the volcanic record of Tharsis linked to models for the long-term generation and ascent of magma in prolonged hot spots? Do endothermic and exothermic phase changes govern the centralization of upwelling and are the predictions of these types of hypotheses [18] consistent with the geologic record? Are these types of features unique to Mars?

What is the role of pyroclastic volcanism in the geologic history of Mars and what influence has it had on contributions to the atmosphere and the surface soil record? Does pyroclastic volcanism play a significant on Mars? What is its contribution to soils? Could it account for aspects of the nature of dust, sediment, and chemistry at the landing sites [21]? Does pyroclastic volcanism account for unusual deposits such as the Medusae Fossae Formation, the 'stealth' area, etc. How can we use these data to determine the input of volatiles into the atmosphere?

How important is volcanism as a resurfacing processess and how can we successfully distinguish it from other processes? Can orbital remote sensing data (imaging, mineralogy, thermal inertia) be used to distinguish the origin of plains in the uplands and lowlands?

What is the volcanic flux (rate of volcanism) and how does it change in space and time? How can we further constrain the wide range of ages of each of the observed stratigraphic units? Which units should be landing sites for return sample missions to determine the age of the units and to establish reference points on the geological history and the volcanic flux curves?

Many of these questions can be addressed with landers and orbiters. Lander and rover missions can determine the local nature of the compositon of fines, compare it with other missions, and assess the relative roles of globally emplaced pyroclastics [21], local alteration, eolian deposition, or aqueous processes [22] in their formation. Determination of rock composition at several landing sites can aid in the evaluation of the interpretation of varous units as of volcanic origin, and differences in composition can provide information on evolutionary changes in space and time. High spatial and spectral resolution orbital remote sensing will be of fundamental importance in extending these landing-site-scale results to more global issues. Integrated and global information is required in order to improve flux estimates.

Nature of Magmatism as a Process: *What is the true range of eruption styles and how do they vary with time?* How can we determine if the true range predicted by theory exists, what the relative proportions are, and if there are styles in the record which are not predicted by theory? What is the nature of the fundamental change in style of volcanism with time, and what are its origins? Could these be linked to the history of water on Mars?

How are mineralogic remote sensing data linked to the geologic record of volcanism? Evidence suggests that there are variations in crustal mineralogy in space and time. How are these linked to deposit characteristics? Do we see any evidence for surface features in the andesitic range?

How are the major edifices linked to source regions and how do they grow? What it the depth of origin of edifice magmas? What is the depth and scale of intermediate magma reservoirs? How do reservoirs evolve and migrate with time? How much differentiation do they undergo and how is it related to morphology and structure? What accounts for the distinctive flank deposits on some edifices (Tharsis Montes) and not on others (Olympus Mons)? What is the volume and frequency of edifice eruptions and how do they change with time? Could the major Tharsis edifices have had an early phase of pyroclastic volcanism? Do any of them represent stratovolcanoes [19]?

What is the rheology of the volcanic deposits that we see and are they consistent with other data? Morphology and morphometry of volcanic flows can be used to determine rheology. Can new altimetry and image data be used to quantify these parameters? What processes (inflation, erosion) might be influencing our view on this?

How are rocks from the Mars meteorites linked to magmatic processes and surface features? Are these materials consistent with the known or suspected range of compositions and eruption conditions? Do they provide additional information about flow cooling rates, thicknesses, shallow intrusions, interaction with volatiles, shallow differentation processes, deeper source regions?

Absolutely essential to progress in this area are high resolution image data to address the relation of morphology to rheology and to provide more details of eruption conditions and products. These same data will help in distinguishing between pyroclastic emplacement and eolian modification. Also essential are links between surface soil and rock materials and units and deposits viewed from orbit. Sample return strategies must address determination of the ages of significant volcanic units so that changes can be referenced to an absolute age scheme.

Relation of Magmatism to Other Processes: *How does the process of magmatism relate to and interact with tectonism?* What are the links betwen tectonism and volcanism in early crustal formation in terms of plate tectonics or alternative volcanic/tectonic processes [20]? How are these processes related in terms of dike emplacement and tectonic provinces, such as Tharsis and Elysium? Can flow directions and topography be used to test for post-emplacement tectonic movement?

Impact cratering? Why are major edifices and deposits associated with the Hellas rim? Are floor-fractured craters evidence of sills and why don't we see more? Can impact craters be used to learn more about crustal stratigraphy? Does impact cratering ever initiate or enhance volcanism?

Water and ice processes? Does magmatism lead to the formation of outflow channels? Do unusual landforms represent the interaction of magma, lava and ice? Does a more active ground water environment in early Mars history lead to changes in eruption style? Is there any evidence of interaction between volcanic eruptions and standing bodies of water (lakes, oceans), or polar deposits (melt depressions, jokulhlaups)?

Candidate biological environments and processes? Are some magmatic environments and processes more likely than others to be sites where life might have originated or evolved? How might dike emplacement processes be linked to hydrothermal processes? Is the flux and repetitiveness of igneous events sufficient to maintain long-term enclaves conducive to life? If so, how can we determine and recognize these? If standing bodies of water existed in the history of Mars, what types of volcanic eruptions would be most effective at producing and sustaining environments conducive to biology?

Among the most significant aspects of these questions that can be addressed by upcoming orbital and surface exploration are those associated with the relation of magmatism, water, and potential biological environments and processes. Water has been a key ingredient in the geological history of Mars [23], but detailed knowledge of its relation to volcanic and petrogenetic processes is poor. In addition, near-surface emplacement of dikes may form important environments that might be candidate enclaves for life [24]. Characterization of surface and near surface hydrothermal alteration and related signatures may be one of the most fundamental contributions and synergistic aspects of upcoming exploration. Determining the nature of alteration and its related mineralogy through lander and rover exploration, and characterization of orbital remote sensing instrument signatures to identify regions of such alteration globally, could be a major factor in the selection of upcoming sample return sites, and planning for human exploration.

Summary: Volcanological questions, like those in other areas [e.g., 22], are multi-faceted and multi-scaled. We list in [22] several steps that need to be accomplished to link volcanological questions and exploration strategy and to address effectively many of the questions outlined above. Among the key volcanological questions that can be addressed through the exploration strategy elements of the Mars exploration program are: Are Noachian and Hesperian plains of volcanic origin? What is the role of pyroclastic volcanism in the formation of martian soils? What is the volcanological significance of layered sequences seen in the walls of Valles Marineris? What is the absolute chronology of the volcanic stratigraphic record? What is the relationship of volcanic surface units to SNC meteorites and how do we use this information to choose sample return sites? What are the signatures of localized hydrothermal zones and what is their global distribution and significance? What are the major differences in petrology and mode of emplacement of volcanic deposits in time and space?

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