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MARS PATHFINDER LANDING SITE WORKSHOP

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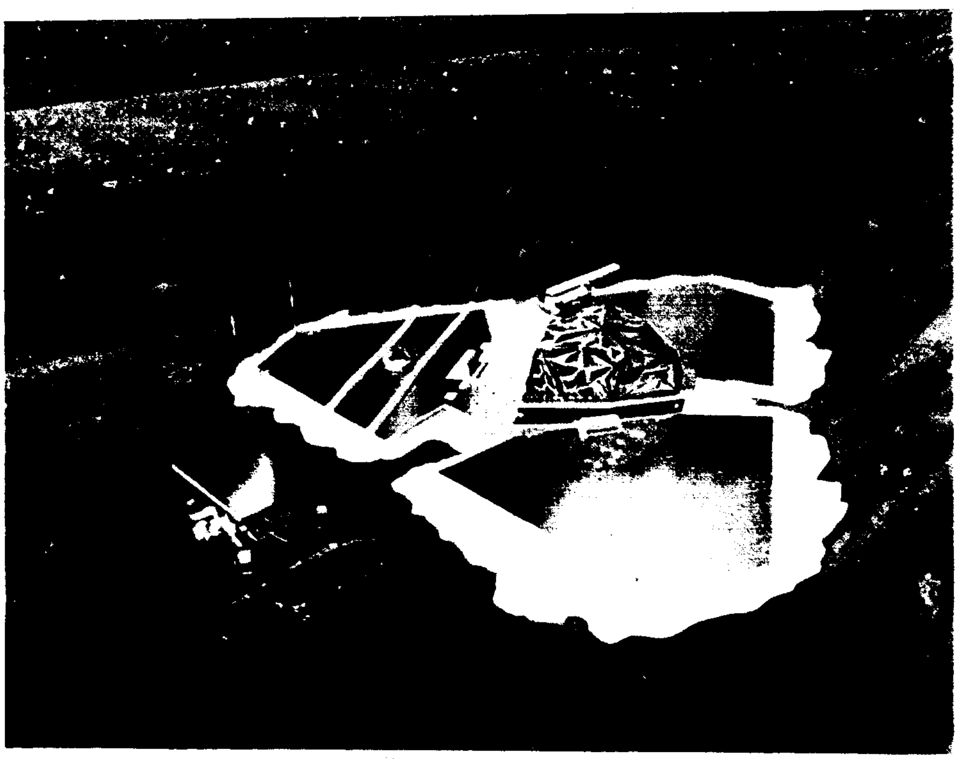

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Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113
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MARS PATHFINDER

LANDING SITE WORKSHOP

Edited by

M. Golombek

Held at
Houston, Texas

April 18–19, 1994

Sponsored by
Lunar and Planetary Institute

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

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Preface

The Mars Pathfinder Project is an approved Discovery-class mission that will place a lander and rover on the surface of the Red Planet in July 1997. On April 18–19, 1994, a Mars Pathfinder Landing Site Workshop was held at the Lunar and Planetary Institute in Houston, Texas, under the auspices of the Jet Propulsion Laboratory Mars Pathfinder Project and the Lunar and Planetary Institute. The workshop was designed to allow the Mars scientific community to provide input as to where to land Pathfinder on Mars. The workshop was attended by over 60 people from around the United States and from Europe. Over 20 landing sites were proposed at the workshop, and the scientific questions and problems concerning each were addressed. The workshop and the discussion that occurred during and afterward have significantly improved our ability to select a scientifically exciting but safe landing site on Mars.

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Mission Description

The Mars Pathfinder Project received a new start in October 1993 as the next mission in NASA's long-term Mars exploration program. The mission involves landing a single vehicle on the surface of Mars in 1997. The project is required to be low cost ($150M development cost cap), have a fast schedule (less than three years' development period), and achieve a set of significant but focused engineering, science, and technology objectives. The primary objective is to demonstrate low-cost cruise, entry, descent, and landing systems required to place a payload on the martian surface in a safe, operational configuration. Additional objectives include the deployment and operation of various science instruments and a microrover. Pathfinder paves the way for a cost-effective implementation of future Mars lander missions as part of a comprehensive Mars exploration program.

Pathfinder will be launched on a Type 1 Earth-Mars transfer trajectory on a McDonnell Douglas Delta II 7925 launch vehicle. Current planning assumes a 30-day launch period extending from December 5, 1996, to January 3, 1997, with a fixed Mars arrival date of July 4, 1997.

The 6–7-month cruise phase is a relatively quiescent period in which spacecraft activities are minimized. The primary activities include periodic attitude control maneuvers required to remain Earth pointed, and four trajectory correction maneuvers needed to ensure accurate arrival targeting at Mars. Spacecraft engineering status data is transmitted at a low rate throughout cruise. No science investigations are conducted during cruise, but science instrument and rover health checks will be performed twice.

At Mars arrival, the spacecraft enters the atmosphere directly from the hyperbolic approach trajectory at a velocity of 7.65 km/s. The lander velocity is reduced from this high entry speed through the sequential application of aerodynamic braking by an aeroshell and parachute, propulsive deceleration using small solid tractor rockets, and airbags to null the remaining vertical and horizontal velocity components at surface impact. Key engineering status data will be collected and returned in real time during entry. In addition, all engineering and science data obtained during the entry, descent, and landing phase are recorded for playback at the initiation of lander surface operations. The duration of the entry phase is approximately 5 min.

The landing site for Pathfinder must be between 0°N and 30°N so that the lander and rover solar arrays can generate the maximum possible power (the subsolar latitude on July 4, 1997, is 15°N) and to facilitate communication with Earth (the sub-Earth latitude at this time is 25°N). The reference altitude of the site must be below 0 km so that the descent parachute has sufficient time to open and slow the lander to the correct terminal velocity. Landing will occur within a 100-km × 200-km ellipse along a N74E axis around the targeted site due to navigational uncertainties during cruise and atmospheric entry. All parts of this landing ellipse must satisfy the specified latitude and elevation constraints.

Landing occurs just after Earth rise and approximately four hours before sunrise. The highest-priority activities on the landing sol are to achieve an upright landed configuration, return the recorded entry science and engineering data, establish a high-rate telecommunications link, acquire and return a panoramic image of the surrounding terrain, and deploy the rover. Surface operations for the remainder of the 30-sol primary mission are focused on extensive use of the rover and science instruments.

SPACECRAFT DESCRIPTION

The Pathfinder flight system consists of three major elements: the cruise stage, the deceleration subsystems, and the lander (containing the rover and science instruments). The current spacecraft launch mass is approximately 710 kg, including 25 kg of payload (science instruments, rover, and rover support equipment).

The cruise stage is used to perform launch vehicle separation, spin-stabilized attitude control, trajectory correction maneuvers, cruise telecommunications, and final Mars entry attitude placement. The cruise stage is jettisoned prior to entry into the martian atmosphere. Cruise stage hardware consists of a solar array and additional related power equipment, a medium-gain antenna, propulsion thrusters, propulsion valves and tanks, and attitude determination sensors.

Deceleration subsystems are required to reduce Pathfinder's entry velocity and allow a safe and survivable landing on the martian surface. The deceleration subsystems consist of a Viking heritage aeroshell, engineering instrumentation used to characterize the performance of the aeroshell during entry, a Viking heritage disk-gap-band parachute, an incremental tether, small solid retrorockets, a radar altimeter, and airbags. The retrorockets and airbags are designed in such a way as to minimize surface and atmospheric contamination due to propellant effluence.

The lander is a tetrahedron-shaped structure containing the science instruments, rover, and all electronic and mechanical devices required to operate on the surface of Mars. The tetrahedron consists of four similarly shaped triangular panels. All lander equipment except the solar arrays and rover are attached to a single center panel. The other three panels are attached to the edges of the center panel using actuators that are used to right the lander after touchdown. This active self-righting scheme is needed because of the passive nature of the Pathfinder deceleration subsystems. All thermally sensitive electronics are contained in an insulated enclosure on the center panel. Specific hardware components inside this enclosure include a high-performance central computer, a Cassini-heritage transponder, a solid-state power amplifier for telecommunications, and a high-capacity rechargeable battery. Hardware outside the thermal enclosure includes a steerable high-gain antenna capable of approximately 5.5 kbps into a 70-m DSN antenna and solar arrays capable of providing enough power to transmit for at least 2 hr per sol and maintain 128 MB of dynamic memory through the night. The lander is capable of surviving for a minimum of 30 sols, with a likely lifetime of up to one Earth year.

ROVER

The rover on Mars Pathfinder is a small (10 kg), six-wheel-drive rocker bogie design vehicle, which is 65 cm long × 48 cm wide × 32 cm high. The rocker-bogie chassis has demonstrated remarkable mobility, including the ability to climb obstacles up to a wheel diameter and the capability of turning in place. The vehicle communicates through the lander via a UHF antenna link and operates almost entirely within view of the lander cameras, or within a few tens of meters of the lander. It is a solar-powered vehicle (with a primary battery backup) that moves at 0.4 m/min, and carries 1.5 kg of payload. The payload consists of monochrome stereo forward cameras for hazard detection and terrain imaging and a single rear camera. On the rear of the vehicle is the alpha-proton X-ray spectrometer (APXS) mounted on a deployment device that enables placing the APXS sensor head up against both rocks and the soil. The rear-facing camera will image the APXS measurement site with 1-mm resolution. The rover also carries two technology experiments described next and a variety of hazard detection systems for safing the vehicle.

The rover will also perform a number of technology experiments designed to provide information that will improve future planetary rovers. These experiments include terrain geometry reconstruction from lander/rover imagery, basic soil mechanics by imaging wheel tracks and wheel sinkage, dead reckoning sensor performance and path reconstruction/recovery, logging/trending of vehicle data, rover thermal characterization, rover vision sensor performance, UHF link effectiveness, material abrasion by sensing abrasion of different thicknesses of paint on a rover wheel, and material adherence by measuring dust accumulation on a reference solar cell with a removable cover and by directly measuring the mass of the accumulated dust on a quartz crystal microbalance.

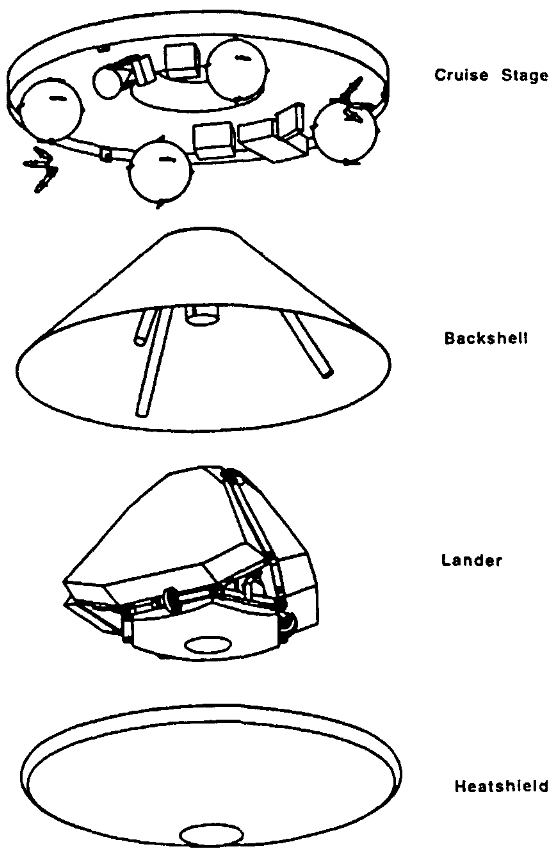

Fig. 1. Exploded view of Mars Pathfinder flight system, showing pack-pack-style cruise stage; backshell with three solid rockets, tetrahedron-shaped lander; and aeroshell.

MARS PATHFINDER SCIENCE PAYLOAD AND INVESTIGATIONS

The science payload chosen for the Mars Pathfinder includes an imaging system, an elemental composition instrument, and an atmospheric structure instrument/meteorology package. These instruments, used in conjunction with selected engineering subsystems onboard both the lander and rover vehicles, provide the opportunity for a number of scientific investigations. The scientific objectives and investigations afforded by Pathfinder include surface morphology and geology at meter scale, elemental composition and mineralogy of surface materials, and a variety of atmospheric science investigations.

The surface imaging system will reveal the geologic processes and surface-atmosphere interactions at a scale currently known only at the two Viking landing sites. The alpha-proton X-ray spectrometer and the spectral filters on the imaging system will determine the elemental composition and mineralogy of surface materials, which can be used to address questions concerning the composition of the crust, its differentiation, and the development of weathering products. These investigations will represent a calibration point ("ground truth") for orbital remote sensing observations. In addition, a series of small magnets and a reference test chart will determine the magnetic component of the martian dust and any deposition of airborne dust over time. The atmospheric structure instrument will determine a pressure, temperature, and density profile of the atmosphere (with respect to altitude) during entry and descent at a new location, time, and season. Diurnal variations in the atmospheric boundary layer will be characterized by regular surface meteorology measurements (pressure, temperature, atmospheric opacity, and wind speed and direction). In addition, the imager will determine dust particle size and shape and water vapor abundance from sky and solar spectral observations. The instruments are described below.

Imager for Mars Pathfinder (IMP): The Imager for Mars Pathfinder (IMP), proposed by P. Smith of the University of Arizona, was selected through a NASA Announcement of Opportunity as a Principal Investigator experiment. In addition to the camera hardware, the investigation includes a variety of spacecraft targets, including radiometric calibration targets, magnetic properties targets, and wind socks.

The stereoscopic imager is deployed on a jack-in-the-box pop-up mast that is roughly 1.5 m above the surface (0.85 m above the lander). It includes two imaging triplets, two-fold mirrors separated by 150 mm for stereo viewing, a 12-space filter wheel in each path, and a fold prism to place the images side by side on the CCD focal plane. Fused silica windows at each path entrance prevent dust intrusion. The optical triplets are an f/10 design, stopped down to f/18 with 23-mm effective focal lengths and a 14.4° field of view. The focal plane consists of a CCD mounted at the foci of two optical paths. Its image section is divided into two square frames, one for each half of the stereo pairs. Each of the stereo frames has 256 × 256 active elements, each with an instantaneous field of view of 1 mrad. The primary filter wheel has 12 positions: 8 channels for geologic studies (0.4–1.1 μm, which are particularly sensitive to iron oxides and pyroxene); 2 for water vapor; a blue filter for atmospheric dust; and a broadband filter for stereo viewing. Additional filter positions are available in the second optical channel. Azimuth and elevation drives provide a field of regard of 370° in azimuth and +90° to –79° in elevation, relative to lander coordinates.

A magnetic properties investigation is being provided by the Niels Bohr Institute of the University of Copenhagen. A set of magnets of differing field strengths will be mounted to a plate and attached to the lander at two different locations. Images taken over the duration of the mission will be used to determine the accumulation of magnetic species in the wind-blown dust. Multispectral images of these accumulations may be used to differentiate among the several proposed mineral compositions.

The IMP investigation also includes the observation of wind direction and speed using small wind socks mounted on lander appendages. Calibration and reference targets mounted to the lander complete the hardware complement.

Alpha Proton X-Ray Spectrometer (APXS): This instrument is a foreign-provided copy of an instrument design flown on the Russian Vega and Phobos missions and is planned for flight on the Russian Mars '94 and Mars '96 missions. Accordingly, the instrument has extensive, applicable flight heritage. The α and proton spectrometer portions are provided by the Max-Planck-Institute for Chemistry, Mainz, Germany, under the direction of R. Rieder, P.I. The X-ray spectrometer

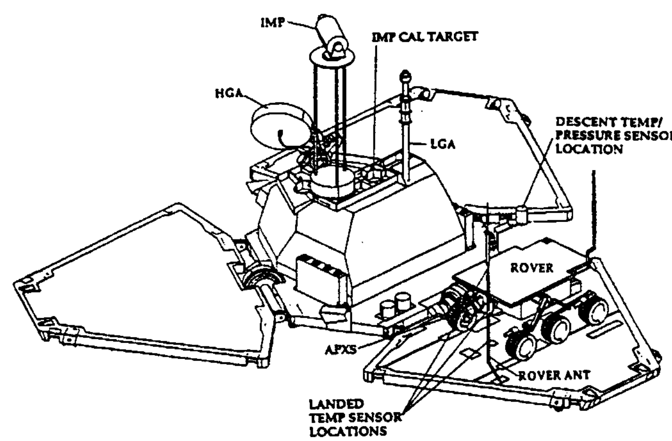

Fig. 2. Perspective view of lander opened on the surface showing the location of the instruments and rover. IMP is the imager for Mars Pathfinder. IMP Cal Target is the IMP calibration target. APXS is the a proton X-ray spectrometer mounted on the back of the rover. HGA and LGA are high-gain and low-gain antennas respectively. Temperature and wind sensors for the surface meteorology experiment are mounted on the rover antenna. Entry and descent pressure and temperature sensors are located in indicated triangular space between the lander panels.

portion is provided by T. Economou of the University of Chicago.

This elemental composition instrument consists of α particle sources and detectors for backscattered α particles, protons, and X-rays. The APXS will determine elemental chemistry of surface materials for all major elements except hydrogen and helium. The analytical process is based on three interactions of α particles with matter: elastic scattering of α particles by nuclei, α-proton nuclear reactions with certain light elements, and excitation of the atomic structure of atoms by α particles, leading to the emission of characteristic X-rays. The approach used is to expose material to a radioactive source that produces α particles with a known energy, and to acquire energy spectra of the α particles, protons, and X-rays returned from the sample. Accordingly, the instrument can identify and determine the amounts of most chemical elements.

The basis of the α mode of the instrument is the dependence of the energy spectrum of α particles scattered from a surface on the composition of the surface material. The method has the best resolving power for the lighter elements.

The proton spectra for α particles interacting with elements with atomic numbers from 9 to 14 are very characteristic of the individual elements, reflecting the resonance nature of the nuclear interactions involved. The proton mode allows their detection and measurement.

The addition of a third detector for X-rays results in a significant extension of the accuracy and sensitivity of the instrument, particularly for the heavier, less-abundant elements.

The APXS sensor head is mounted external to the rover chassis on a deployment mechanism that allows the instrument sensor to be placed in contact with both rock and soil surfaces. The APXS electronics are mounted within the rover, in a temperature-controlled environment.

Atmospheric Structure Instrument/Meteorology Package (ASI/MET): The ASI/MET is implemented as a facility experiment, developed by JPL, to provide engineering support to the measurement of the entry descent and landing conditions and to acquire science data both before and after landing.

Data acquired during the entry and descent of the lander permits the reconstruction of profiles of atmospheric density, temperature, and pressure from altitudes in excess of 100 km to the surface.

The accelerometer portion of the experiment is provided by the Attitude and Information Management Subsystem (AIMS). It consists of redundant x-, y-, and z-axis sensors. Three gain states are provided to cover the wide dynamic range from the microgravity accelerations experienced upon entering the atmosphere to the peak deceleration experienced during entry into the atmosphere.

The ASI/MET instrument hardware consists of a set of temperature, pressure, and wind sensors mounted on the lander and an electronics board for operating the sensors and digitizing their outputs. Temperature, pressure, and wind sensors are located onboard the lander at locations suitable for measuring descent and postlanded conditions.

Pressure and temperature sensors are sampled twice per second during entry and descent. Temperature, pressure, wind speed, and direction are sampled at least hourly throughout the landed mission at multiple heights above the local surface.

SURFACE OPERATIONS SCENARIO HIGHLIGHTS

The prime mission period is 30 sol. The most important data to return is the entry, descent, and landing data, which should be completed in the first few hours. Nominally, in addition, the first sol has much concentrated activity, including panoramic imaging for mission baseline planning and rover deployment. Science may be able to conduct 10 APXS tests, acquire and downlink 160 Mbits of compressed image data, and obtain meteorology and images of magnetic plates during the course of the mission. After the first week, it may be possible to perform APXS tests on a magnetic plate on the rover-petal ramps and attempt to scrape weathering rind off rocks and dig a trench using a rotating rover wheel for more complete APXS tests. Technologists will obtain image and soil mechanics data related to traversing through as many soil types as may be accessible at the site, and performance of the rover's autonomous "behavior" control paradigm in martian terrains. The performance of low-power UHF links on Mars will be baselined later in the mission using long traverses. Other project requirements are to obtain images of the lander from the rover and lander cameras and perhaps images of the surface divots left by the landing. Fallback mission plans are being considered in an attempt to be ready for less-than-nominal conditions.

Summary of Technical Sessions

INTRODUCTION

The workshop agenda was organized to give the participants an introduction to the mission and instruments, followed by general site selection perspectives and priorities from different science disciplines, safety issues, and finally individual landing sites arranged by longitude. Each individual session was summarized by a different attendee and edited for continuity by the editor.

HOW WILL WE GET THERE? MISSION INTRODUCTION

Summary by J. Wellman

M. Golombek presented an introduction, science overview, and Mars exploration context for the landing site discussions to follow. A. Spear described the Mars Pathfinder Mission status and its primary goals as a Discovery-class mission. In response to H. Moore's question whether Pathfinder is primarily a science mission or an engineering demonstration, the group was told it is mainly a demonstration of a low-cost mission to land a payload on Mars. If Pathfinder is successful, following missions with increased science capability will be enabled. Mission success for Pathfinder is defined around a 30-day nominal mission, with a year of operation included in its budget. Other questions revolved around the timeline for selecting the Pathfinder landing site. After this meeting a subset of the sites will be evaluated in more detail and a selection made at the June Project Science Group meeting. The results will be announced at the Mars Geologic Mappers Meeting in July. Pathfinder anticipates a robust participating scientist program, with an announcement at about the time of launch.

R. Cook described the Pathfinder mission design and the resulting targeting constraints. A. Seiff asked whether we could deviate by up to 5° from the 15° subsolar latitude target. Cook answered that although the specific case has not been worked in detail, he would expect that the power constraints would limit the total telemetry downlink capability. S. Saunders asked about the after-the-fact knowledge of the lander location. After landing, the knowledge of the lander's location in inertial space will be about 10 km on the first day and will be improved to about 1 km over time. The largest remaining errors are those due to converting from an inertial coordinate system to a cartographic coordinate system, which can be up to a few kilometers.

Seiff asked whether the power constraints that Pathfinder will be working within could be relaxed on future missions? Cook answered that if we have more efficient electronics and a communication orbiter, yes. Mass is the driver for site elevation, so mass reduction will be important in the future. Golombek pointed out that even on the previous Network mission study, the constraint to use solar power kept the landers in tropical latitudes. W. Dias answered J. Wellman's question saying that it would be acceptable to reduce transmit time to save power, but we need as much data transmission time as possible on the first landed day to send back all the entry, descent, and landing data as well as the imaging data.

After impact on the air bags the lander is likely to bounce a number of times. In answer to the question of how the airbag retraction system will work on Pathfinder, it was explained that cables within the airbags pull the bags in as they deflate after landing. This approach will be tested this summer. Concern was noted regarding the possible difficulty in deploying the rover over the bags. Presently, ramps are planned to assist the rover in exiting over the retracted airbags.

The project's approach to planetary protection issues were explained as allowing a simpler procedure than that used by Viking. The project will use a process similar to the Viking presterilization procedure, then conduct spore assays. This is not viewed as a significant cost issue on Pathfinder as the vehicle will not have to be heat soaked.

Dias described the rover operations scenario and the lander constraints on power and telemetry. The answer to P. Smith's question was that Pathfinder could operate during the day on batteries alone, but at night the lander temperatures would fall below qualification limits and greatly increase the risk of failure. J. Barnes said that an average optical depth of 0.5 is too conservative. How much better would be Pathfinder's power situation for $\tau < 0.5$? Viking experienced optical depths of 0.3–0.4 for what was, evidence suggests, an unusually dusty period. In addition, a 15° tilt to the lander is also likely to be an extreme case. Dias said that further analysis was needed to address these more representative cases. R. Rieder suggested using RHUs to help keep the lander warm at night; however, although this could alleviate the thermal problems, the regulatory complexity gets prohibitively expensive. Also, during cruise, it is difficult to keep the vehicle temperatures from exceeding the upper qualification temperature limits.

A. Treiman asked if the spacecraft is so narrowly optimized that it can only survive a few degrees from subsolar, since the subsolar latitude will move significantly to the south within a month. Cook responded that after the nominal mission objectives have been met, the operating scenario can be changed, i.e., transmit less, or shut down at night. If Pathfinder survives into the winter season a low-power mode at night would be utilized. In addition, the mission could survive as a low-power meteorology station. Finally, the solar panels could be actively adjusted to increase solar power in this situation.

WHAT MEASUREMENTS WILL WE MAKE AFTER WE GET THERE? INSTRUMENT DESCRIPTIONS

Summary by K. S. Edgett

Although the main objectives of the Pathfinder mission are to test designs for new cruise, entry, descent, and landing systems for future Mars missions, the spacecraft sports a robust set of three main instruments: the Imager for Mars Pathfinder (IMP), the Alpha Proton X-Ray Spectrometer (APXS), and the Atmospheric Structure Instrument-Meteorology Package (ASI/MET). The main science objectives for Pathfinder are to characterize the martian surface and atmosphere at a single site on Mars. Specific objectives include characterizing the morphology, geology, elemental abundance, and mineralogic (including airborne magnetic dust) information about the surface, obtaining atmospheric pressure temperature and wind information during descent and on the surface, and obtaining information about soil mechanics and surface properties from the rover.

The first speaker, Smith, presented a detailed description of the IMP capabilities. The IMP experiment includes multispectral imaging from 0.4 to 1.0 μm and stereo imaging at 0.75 μm. The IMP package includes magnets for collecting magnetic fractions from dust settled out of suspension and a wind sock assemblage mounted to the lander's rover antenna to observe variations in wind velocity.

Smith concluded his presentation with a suggestion for a landing site that was not listed in the regular program. Smith would like to see Pathfinder land at a site that has a mountain view. A volcano, scarp, crater rim, or other object at or near the horizon would provide an appealing esthetic view. The science rationale was that a mountain view would (1) extend the effective horizon by 3–200 km, (2) provide a new geologic perspective, (3) may contribute to active cloud formation on a diurnal or seasonal basis, and (4) allow cloud heights to be estimated, especially if the cloud layer is lower than the peak elevation of the mountainous feature. In particular, Smith indicated a site in the Lycus Sulci region northwest of Olympus Mons (approximately 25°N, 145°W) that might provide a view of the Olympus Mons basal scarp. Following Smith's presentation, Wellman reminded the workshop participants that there would be considerable complementarity between Pathfinder instruments. Such complementarity would maximize science return. With reference to Smith's desire for a mountain view at the Pathfinder landing site, N. Budden asked how high a topographic feature would have to be to induce local cloud formation. Smith replied that there is not an obvious answer. Golombek noted that Viking observed clouds near the summit of Olympus Mons, which is ~25 km in height; however, it is not obvious whether mountains with heights less than 10 or 20 km will induce cloud formation near their summits.

The second presentation was given by R. Singer, whose primary responsibility as IMP co-investigator has been to recommend selection of filters for identification of geologic materials on the martian surface. The IMP will have two filter wheels, one in each of its two "eyes." Singer has suggested there will be ~13 filters designed to maximize geologic interpretation (surface composition, particularly oxidation state of Fe-bearing materials) and ~5 for atmospheric observations (clouds, dust opacity, etc.). Stereo coverage will be available at 0.75 μm. Singer showed examples of different Fe-bearing samples as they looked in his laboratory through simulated filter functions for the geologic investigation. The recommended filters work "pretty well" at distinguishing hematite, palagonite, and unaltered basaltic material.

Following his presentation, Singer was asked if we should expect to see more than one type of material (mineral, chemical) at the Pathfinder landing site. Singer replied that we should look for a site with the greatest variability in surface composition, that we should want to see great variability in both rock and soil image spectra. Subpixel mixing of materials of different composition will also be an interesting issue at the landing site. J. Plescia inquired about the absolute calibration of reflectance in the IMP channels. Singer indicated that the IMP is expected to be within 1% of absolute reflectance, and that multiple or longer exposures might improve the signal-to-noise so as to improve resolution of absolute reflectance values. A. Zent expressed interest in identification of clay minerals (if present) using IMP, but most clay spectral features (e.g., HO absorptions) occur longward of the 1.0-μm channel. R. Morris asked whether Singer plans to look at a variety of substances prior to Pathfinder landing, particularly impact-produced Fe-rich soil materials, to prepare for the surface multispectral investigation. Singer suggested that he might solicit the community for representative spectra of various materials that Pathfinder might see. Regret was expressed regarding the 1.0-μm cut-off, as there are key pyroxene spectral features that go out to about 1.2 μm.

Rieder described the principles and expected outcome of the APXS experiment. The APXS is carried to various sample sites via the microrover. It is hoped that APXS will collect element abundance observations from a wide variety of rock and soil types. The instrument design heritage includes APXS measurements on previous Lunar Surveyor and Venera missions, but Pathfinder would present the first opportunity to move (using the rover) an APXS to observe different materials up to tens of meters away from the spacecraft. It takes approximately 10 hr to collect data for each rock surface in α proton mode, and about 1 hr in X-ray mode.

Answering Treiman's question, Rieder said that the radioisotopic heat generator on board the microrover would not present a problem for the APXS. C. Allen received an affirmative answer to his question as to whether the APXS can be placed on sloping rock surfaces. R. Craddock expressed concern about assurance that APXS will measure dust-free rock surfaces, wondering how dust-free surfaces can be assured or obtained? Rieder suggested that perhaps we should look at both a dust-coated surface and a dust-free surface. A rover wheel will attempt to mechanically scrape dust from a rock surface. A question was raised about the

APXS depth of penetration, to which Rieder replied that it measures to depths of tens of micrometers or less. Moore wondered if APXS would provide information about rock densities, but APXS can only provide element abundance. Another workshop participant asked if the 10-hr observation time would preclude analysis of condensates that might form on the martian surface, but Rieder indicated that O in a condensate (as in H_2O or CO_2) could be seen after only 1–2 hr integration time. When asked about trace-element observations, Rieder indicated that no trace elements can be observed, nor extrapolated, by comparison of bulk-rock chemistry to terrestrial samples.

The surfaces over which APXS will collect observations will be imaged by one of the three small, monochrome cameras aboard the microrover. These imagers can provide resolution at the scale of hundreds of micrometers, capable of showing phenocrysts and vesicles in volcanic rocks. No presentation on the potential science contribution of the micro-rover imaging system was presented at the workshop.

Seiff described the third set of experiments on Pathfinder, ASI/MET, which includes both atmosphere profiling during descent and temperature-pressure observations from the surface. This experiment does not measure composition of atmospheric gas. The surface observations will be complemented by the IMP wind-sock experiment and any observations IMP might make regarding surface eolian activity. The main difficulty with the ASI/MET experiment is that there are no external sensors on the descent package, in particular because they might interfere with airbag deployment. During descent, air is sampled as it comes in through gaps at the corners of the lander solar panels.

Following the presentation, Seiff was asked about the experiment design heritage, which is largely a derivative of the Viking lander systems. The basic physical principles that govern the interaction between the atmosphere and sensors are well known. Because the surface temperature sensors are mounted on the lander's rover antenna, Dias wondered whether they are transparent at radio frequencies. The issue of radio interference is not considered to be a problem. Seiff would like an additional set of sensors on the low-gain mast, and Golombek indicated that there is some possibility that these sensors will be added to provide better information about wind and thermal variations at the landing site.

As the Instrument Description Session came to a close, it was clear that there is a multitude of scientific possibilities with Pathfinder's otherwise small complement of instruments, and these experiment packages have great potential to provide complementary information. For example, the IMP can provide an image of wind-sock orientation while the ASI/MET sensors give simultaneous pressure and temperature data. Likewise, IMP might also see eolian ripples on the surface, which would provide a third measure of wind properties at the site. The IMP and APXS both provide information about surface composition, and IMP can help identify candidate sites for APXS measurements. While Pathfinder's main objectives are engineering in nature, the science instruments will provide considerable new information about Mars and its surface. Overall, workshop participants expressed interest in the opportunity to detect and measure chemical composition of *in situ* martian surface materials, regardless of where Pathfinder eventually lands on Mars.

WHY SHOULD WE GO TO THAT SITE? GENERAL LANDING SITE PERSPECTIVES

Summary by D. McCleese

Moore described the Viking landing site selection experience as being significant in that the environmental assessments were sufficiently good that both landers landed safely. Six sites were preselected from Mariner 9 data, but none of these were used. However, site selection procedures were worked out, making the preselection process valuable for training and learning. The Viking Mars Environmental Engineering Document was a tool for planning all phases from cruise down to surface properties. The Viking landers came down to the surface at a velocity of 2.3 m/s, utilizing retrothrusters. The presence of fine particulate matter at the landing site was important for one of the onboard experiments; a scoop on a boom was used to obtain samples. Particle size will not be significant in the case of Pathfinder. The difference in size of Viking vs. Pathfinder landers will also be a consideration.

Haze in the atmosphere during the Mariner 9 period (dust from global storms) caused great difficulty in the use of that data for Viking site selection. Uncertainties in elevations and in slopes as known at that time were also complicating factors. Radar observations from Goldstone were used to great effect in distinguishing rough surfaces from smooth, low vs. high bulk densities, dust vs. rock, and other mechanical properties of potential landing sites. The Viking Landing Site Working Group, led by H. Masursky, considered the following criteria: low elevation, large spatial separation of the two landers, direct links with ground for at least two hours, orbiters supporting both landers, surface reflectivity of 5–7%, RMS slope 3.5°–4°, and a warm and wet environment.

With the coming of Mission Operations, the Landing Site Working Group was augmented by the Viking Flight Team and renamed the Landing Site Staff. Site certification criteria used by this group were much the same as those in the earlier site selection. Radar echoes newly available from Arecibo and from Goldstone, as well as Viking orbiter observations, provided the data that caused the shift to the two actual landing sites from the originally selected ones. A lunarlike site was found for the first lander northwest of the original prime (Chryse) location. After the first successful landing, a northern location, where atmospheric water vapor abundances were high, was sought for the second. Orbiter (IRTM) temperature observations were now used to assess surface material properties. However, they proved insufficiently discriminatory, and the second lander placed down in an unexpectedly rocky location.

Moore presented a specific and detailed approach to selecting a landing site for Pathfinder. He stressed safety issues as there can be no returned science data if there is no safe landing, and recommended evaluation of image, thermal inertias, radar, and spectral data for each candidate site. Using the Viking experience and interpretations and observations of lander and remote sensing data, he proposed an acceptable landing site in terms of detailed ranges in thermal inertia, rock abundance, radar reflectivity, slopes, color ratios, and smooth hazard-free areas.

R. Greeley described a number of approaches to selecting Mars Pathfinder landing sites in terms of complementing Mars '94 sites and maximizing total returned information. One approach to site selection is to choose an area representing a key geologic unit that is widespread on Mars and used frequently as a datum in various investigations. One example would be a site on Lunae Planum, an area on Hesperian-age ridged plains. Compositional measurements and rover observation of rocks would address the origin of ridged plains, contributing substantially to understanding martian geologic history. The disadvantage of this approach is that it does not address the compositional diversity of the planet. Alternatively, a location could be sought that displays geological diversity in a small area that could be sampled over the limited traverses of the Pathfinder rover. An impact crater might be used as a subsurface sampling tool. Canyons are not practical, but wind-blown material may be. Sedimentary deposits such as channel deltas potentially contain rocks from a variety of sources. The disadvantage of this approach is that the geological context of the rocks is not known. Simulated Mars landing site studies have been conducted on the Furnace Creek alluvial fan in Death Valley. Six rock types were found within a 1-m radius of the site, and additional types within a 2-m radius. With the addition of remote sensing, one could begin to address the site of origin of alluvial material sampled by a rover.

In either case, the selected site should include eolian deposits, and provision should be made for analysis of them. The martian fine dust has probably been globally mixed by dust storms. Sand will be from upwind local or regional sources; wind-streak orientations and atmospheric circulation models provide clues to those sources. The soil may also include material derived from local weathering, which may require scraping through dust and sand to uncover.

A test of the Russian Marsokhod rover in the Mojave Desert showed the importance of descent images from orbit down in determining the geologic setting of the site; these will not be available on Pathfinder. Finding lander position via panorama views from the lander was also tested. Height of the rover camera above the surface was found to be very significant in translating field geologists' experience to operation of landers and rovers.

Summary recommendations for Mars Pathfinder landing site selection are (1) fan deposits from large outflow channels are most attractive for sampling, (2) evidence of eolian activity is important, and (3) field operation tests should be conducted.

J. Farmer asserted that although present martian surface conditions appear unfavorable for life as we know it, there is compelling geological evidence that the climate of early Mars was much more Earth-like. Therefore the focus for exobiology site priorities should be on the possibility of ancient life on Mars. By analogy with the Earth, an early martian biosphere is likely to have been microbial and a fossil record may be present. This exploration for fossils on other planets has been termed "exopaleontology"; its core concepts are derived from Earth-based Precambrian paleontology, microbial ecology, and sedimentology. The reduced rates of chemical weathering on Mars suggest that there should be a greater likelihood that a fossil record would be preserved.

The Precambrian record of the Earth shows biostratification structures (e.g., stromatolites) providing a record of early life fossils. Microbial records on Earth show the best preservation of microorganisms as fossils occurs when they are entombed early by aqueous minerals. Targets for fossil search include clays, which can bind organic material, mineralized soils (where the oldest microbiota on Earth are found), and evaporites that might have captured organisms.

Suggested landing sites on Mars include outflow channels on volcanic flanks or adjacent to thermokarst features. Suitable examples of such sites appear to exist on Mars. Terminal paleolake basins free of younger cover are also logical targets. Fluid inclusions incorporated into aqueous mineral deposits during crystallization potentially may also contain microorganisms. The chanceof finding such sites with future missions can be improved by using Pathfinder to determine the range of rock types on the planet, which could be sampled at an outflow site.

Seiff noted that Pathfinder offers a very different opportunity compared with those expected from the old MESUR Network. The question posed is what is the best site type for atmosphere structure observations? Strong contrast with the Viking thermal structure profiles would call for winter season in the southern hemisphere or at polar latitudes, but this is not possible within Pathfinder constraints.

Within Pathfinder constraints, the best possibilities for extending observations to other conditions are (1) move toward the equator for latitude contrast from Viking; (2) study the influence of prominent terrain features on structure and circulation; and (3) examine the effect of dark albedo features on the overlying structure, since radiative equilibrium with the surface controls the temperature structure to first order.

A priority site would be in Amazonis Planitia due west of Olympus Mons at 150°W, 18°N with an elevation of −1.5 km. This terrain will affect the atmospheric circulation below 20 km; radiation effects from the inclined terrain could influence thermal structure; the descending terrain will also have a slope wind signature. Winds at several landing sites have been examined using the Ames GCM. Ten-day averages at sites near large terrain obstacles such as that near Olympus Mons are ~20 m/s, with extremes of 5 and 35 m/s. These could prove problematical for landing, but if verified would establish the validity of the GCM for use in future mission design as well as understanding Mars circulation.

WHERE ARE WE? WHAT WILL IT LOOK LIKE? HOW SAFE WILL IT BE? WHAT WILL THE WEATHER BE? WHAT WAS THE WEATHER LIKE?

Summary by K. Herkenhoff

U. Keller gave a brief description of the Mars '94 mission, which is scheduled for an October 1994 launch and Mars orbital insertion in September 1995. The orbiter will carry a high-resolution stereo camera (HRSC), a wide-angle opto-electric stereo scanner, and an imaging spectrometer. The camera will obtain 10 m/pixel images at periapsis, but only about 4% of the surface will be covered at this resolution. However, more than 25% of the surface will be imaged at 40 m/pixel or better. Keller discussed the advantages of coordinating Mars '94 and Pathfinder data: Mars '94 will be able to perform high-resolution imaging of the Pathfinder landing site, will yield information on the topography of the site, and allow mineralogical classification on a regional scale (verified by IMP). Conversely, the photometric properties of the surface at the Pathfinder landing site, as observed by the IMP, will provide calibration of Mars '94 photometric observations. Mars '94 will make climate and weather observations, making it possible to compare global wind patterns with Pathfinder observations of winds and aerosol opacity. Periapsis locations will be separated by 72° in longitude, and will be on the nightside of Mars for the first 2–3 months of the orbital mission. Mars '94 will obtain good coverage in certain areas: Cerberus Rupes and western Isidis Planitia, so these sites are preferred for Pathfinder/Mars '94 coordination. In response to questions, Keller noted that Mars '94 will not have a good orbit for remote sensing, as it will be too elliptical. The IMP filters have narrower bandpasses than the HRSC filters.

B. Betts discussed the implications of PHOBOS '88 Termoscan data for Pathfinder landing site selection. Thermal infrared observations are useful for estimating the physical properties of the upper few centimeters of the martian surface. He considered both science return and safety issues. The 300 m/pixel to 3 km/pixel Termoscan resolution is better than any existing thermal data, with no shadows (near zero solar phase). Termoscan coverage is all in the equatorial region (6°N to 30°S), so there is not much overlap with the range of possible Pathfinder landing sites. He showed Termoscan images of thermally distinct ejecta blankets, where the thermal properties correspond to the observed morphology, which is rare on Mars. He is pretty sure that these areas have material at the surface that was excavated by cratering from some depth. The thermal boundaries of channel features follow the morphologic boundaries of the channels. There are both homogeneous and heterogeneous areas in terms of thermal properties, and Pathfinder should avoid the heterogeneous areas because they may be unsafe. Surface variations are observed down to the 300-m scale. There are no areas where the thermal inertias come close to that of solid rock, so fine material is present everywhere in the areas observed by Termoscan. In response to questions, Betts stated that Termoscan instruments are scheduled to fly on both Mars '94 and Mars '96, with somewhat better spatial resolution and more spectral channels than the PHOBOS '88 instrument. Observed thermal inertias range from 1 to 15 cgs units. The visible channel calibration is poorly known, but the thermal data are well calibrated. Betts stated that it is impossible to distinguish a dust/rock mixture from uniform sand based only on thermal inertias.

M. Slade described the available groundbased radar data for Mars. He listed the contributions to Mars studies that have been made by radar: ephemeris improvement, topography, subsurface probing for hazards, and RMS slopes. The northern latitudes of Mars are now available for radar observations. Slade showed the Butler et al. global radar reflectance maps. There is no reflectance from the "stealth" region, indicating that the radar was probing the subsurface of vast piles of ash. This would not be a good place to go with Pathfinder. Likewise, very rough (radar-bright) areas are not good sites. Delay-Doppler radar data yield higher spatial resolution. The 1995 opposition will be a good one for radar data at latitudes (~17°N) that are good for Pathfinder, and he felt that he should be able to get antenna time. The existing topographic data provide good regional control with 100-m vertical resolution in 55–110 km (latitude) by 3–10 km (longitude) footprints. There is agreement to about 0.5 km between the USGS digital terrain models and radar profiles in some areas, but >1 km discrepancies in others. There are some gores in the 1988 radar data due to the round-trip travel time. Sometimes it is difficult to get a good radar solution when regional slopes are large.

Barnes explained that Mars has interesting weather, with the largest variations at midlatitudes, decreasing toward lower latitudes. The variations almost completely disappear in the northern summer, when there are only diurnal variations due to thermal tides and slope effects. Pathfinder will land late in northern summer, not long after the Viking landing season, near the seasonal minimum in atmospheric pressure. There were minimal weather changes after the 1977 global dust storm at the Viking landers, then large variations later in the northern winter. There is large interannual variability in the weather, perhaps due to dust storms. More observations from Pathfinder will be very useful. There were sizeable wind variations during the late winter weather disturbances at the Viking lander 2 site, but no data from lander 1 as its wind sensor broke early in the mission. Lander 1 day-to-day pressure variations were very small during the early northern winter. The Ames GCM can model weather variations, and Barnes showed a weather map for the northern winter solstice. Weather systems travel west to east in northern midlatitudes, decreasing toward the equator. The GCM simulates the magnitude of disturbances well at the lander 2 site except during dust storms, but does less well at the lander 1 site. Very-large-amplitude pressure variations were observed during the third Viking year. These are very interesting but the data are sparse. Midlatitude weather systems are most active at certain longitudes, typically at lower elevations. Pathfinder may observe substantial weather changes if it lands at subtropical (20°–30°N) latitudes and lasts for several months. However, Pathfinder may not see much if it lands within 10° of the equator. In response to a question, Barnes replied that 15°N latitude is right in a transition zone, so he is not sure what will be seen there. However, there is good reason to go there, as no lander has been there yet.

F. Forget presented a simulation of Pathfinder meteorology using a French GCM, which is somewhat faster than the Ames GCM, with slightly better spatial resolution. He was able to fit the Viking seasonal pressure curves by varying the poorly known optical properties of polar CO_2 frost. The simulated pressure curves for the southern hemisphere are quite different from the Viking curves. He showed model results for Isidis and various locations in Chryse. He compared the amplitude of transient pressure variations at various locations, including the Viking lander sites. At 22.5°N, transient pressure variations are greatest at the longitude of the Viking 1 site. He calculated the total mass of CO_2 in the martian atmosphere and caps by removing the meteorological component using GCM results. The meteorological component of seasonal pressure variations at the equator is indicative of the global atmospheric mass if the global surface topography is known. The GCM results indicate that some areas on Mars have strong winds. In response to a question, Forget stated that the inferred longitudinal variations are due primarily to topography.

Zent proposed selecting a landing site at which questions regarding the climate history of Mars could be addressed. An area of exposed sedimentary units with both clastic and chemical sediments would be ideal. Experience with recent Marsokhod rover tests in the Mojave desert indicates that images with 1-mm resolution should reveal evidence of fluvial transport. If weathering rinds are present and abraded by saltating grains, they may be detected by taking APXS data at both the windward and leeward sides of rocks. Zent suggested landing in the southeast Elysium Basin along an inferred paleo-shoreline, where albedo and thermal data indicate moderate rock coverage and lack of a thick dust mantle.

WHAT LONGITUDE ARE WE GOING TO? (i.e., WHERE DO WE TARGET THE ROCKET?) WHAT WILL WE LEARN AFTER WE GET THERE?

25°W–55°W LONGITUDE

Summary by T. J. Parker

The talks in this session consisted of Chryse Basin sites (Craddock, L. Crumpler, J. Rice, R. DeHon) that provide grab-bag sampling opportunities from catastrophically emplaced material from the highlands and hesperian ridged plains, and highland sites (DeHon, Treiman) that are intended to "do something different" from Viking, by sampling a surface representative of more than half of Mars for which we have no groundtruth.

Probably the highest-profile argument made against returning to sites in the Chryse Basin, not even specifically to the Viking 1 site, is the perception that we would be "wasting" our third trip to Mars by going where we already have gone. Both presenters of Chryse Basin sites were aware of this perception problem.

Craddock defended this approach by suggesting that we can build on the knowledge gained from Viking 1, thereby allowing us to better understand the processes and materials observable in the Chryse Basin than would be possible with Viking or Pathfinder data alone. Both Craddock and Crumpler argued that we know more about the potential hazards and the diversity of blocks that Pathfinder might sample in the vicinity of Viking 1 than elsewhere on the planet, so the safety of landing in Chryse and the science that Pathfinder could do there can probably be anticipated in advance of the landing better than anywhere else on the planet. Craddock also described the engineering value of returning to the Viking 1 landing site, if Pathfinder were to land near it or the jettisoned Viking aeroshell and examine eolian and chemical erosion of the Viking component materials.

Crumpler's proposal to land in Chryse took a similar approach to that described by Craddock. He emphasized the need to build on our existing groundtruth from Viking, and characterized it as taking an "Apollo 10 approach" to exploring Mars by "building on our previous successes."

Rice and DeHon proposed landing on the outwash fan from Maja Valles as a grab-bag site with a more positive link to a specific source region than provided by a central Chryse site. For similar objectives, DeHon proposed landing on the plains beyond the mouth of Mawrth Vallis to sample highland materials cut by that channel. A point of caution raised by T. Parker with regard to placing the ellipse close to the mouth of one of the outflow channels is that the chance of landing on or among (in the shadow of) truly huge boulders is a possibility. Rice pointed out, however, that the largest blocks should quickly drop out of suspension beyond the mouth of the channel.

The remaining sites (presented by DeHon and by Treiman and S. Murchie) are highland sites. DeHon pointed out that the Pathfinder latitude and elevation constraints severely limit the number of potential landing sites in highland (Noachian) regions to southern Isidis and western Arabia Terra. He placed two landing ellipses on the highlands: one north of Mawrth Vallis in Arabia Terra and the other east of Ares Valles in the Meridiani Sinus dark-albedo feature. The chief concern raised with regard to these sites is that they lie at the extremes of the latitudinal range stated in the initial workshop announcement.

Treiman and Murchie proposed landing within Melas Chasma, at 10°S latitude, 73°W longitude. The site would be near mesas of the massive layered deposits found in many places within Valles Marineris that are generally interpreted to be lake sediments. An additional bonus provided by the site would be horizon views of the walls of the canyon, providing cross sections of the upper few kilometers of the martian crust, which would subtend as much as 100 pixels vertically in an IMP image. Though this site is outside the latitudinal constraints of the Pathfinder mission, it probably should be considered as a potential target for a subsequent lander mission.

145°W–200°W LONGITUDE

Summary by R. Craddock

Parker suggested that the area in northern Eumenides Dorsum would make an interesting site because it contains the enigmatic Medusae Fossae Formation. Several investigators have proposed that this material is volcanic ash (i.e., an ignimbrite deposit); however, Parker showed slides of terrestrial carbonate platforms located near the Bahaman Islands that contain features morphologically similar to those comprising the Medusae Fossae Formation. Off-handedly Parker remarked that although the features he was presenting were several times smaller than their putative martian counterparts, that had never stopped anyone else before. Perhaps the most attractive aspect of this site was safety. Earth-based radar measurements show that this material has a very low radar return, which has led to the nickname "Stealth." Viking Infrared Thermal Mapper (IRTM) data also show that this material has a low thermal inertia and rock abundance, suggesting a small effective grain size with a bare surface. In fact it may be too safe; as Parker remarked, the spacecraft might actually disappear under a poorly consolidated surface layer. The audience pointed out that the stealth region doesn't correlate exactly with the Medusae Fossae Formation as material with this radar signature actually extends into the surrounding highlands. The issue of safety vs. science in terms of the number of rocks on the surface was also discussed. Big rocks would make things more difficult for orienting the solar panels on the lander. No rocks, however, would make for a low science return. Parker also stated that he thought the Medusae Fossae Formation would still be interesting if it were a volcanic deposit.

N. Barlow also suggested landing in the Medusae Fossae Formation. Aside from the possibility that this material is a volcanic ash or carbonate deposit, other investigators have proposed that it may be a paleopole deposit or, alternatively, an exhumed chemical boundary layer caused by a subregolith paleowater table. Barlow's analyses of crater morphology in the area suggested that the Medusae Fossae Formation does have some strength, so it would appear unlikely that the Mars Pathfinder would disappear below the surface as remarked by Parker. Within her proposed landing ellipse, centered at 4°N, 162°W, there is also the Amazonian-aged member 1 of the Arcadia Formation and the Hesperian/Noachian undivided material consisting of knobby terrain. These materials have been interpreted as volcanic deposits and highland material respectively. A small channellike feature is also located in the Medusae Fossae Formation so there may be the opportunity to sample a variety of materials at this site. Audience comments centered primarily on the use and limitation of available remote sensing data. Thermal data measure only the upper few centimeters of the surface (i.e., the diurnal skin depth). Although the thermal inertia and rock abundance data for the Medusae Fossae region suggest a bland surface, it does not preclude the possibility of rock blanketed by dust. Such blanketing may also preserve fresh rock faces, which would be ideal for analysis.

The possibility that Mars Pathfinder could also be used as a sample return mission "for free" was presented by Golombek. He discussed landing in the Amazonian-aged Tharsis volcanic provinces, which contain a few of the large, oblique impact craters suggested as being the source of the SNC meteorites. Because we have age dates for the SNCs, the absolute ages of the martian periods could be determined if we could identify their protolithologic unit. Depending on the proximity of the final landing site to Olympus Mons, it may also be possible to identify stratigraphy in the surrounding basal scarp from the IMP experiment. Landing sites near several craters located on a few different geologic units would meet the engineering constraints; however, there are no guarantees that any of these craters is the source of the SNCs. In addition, Golombek suggested that the APX spectrometer and IMP experiments are not capable of definitively identifying the impact site because minor and trace elements may be necessary for this purpose. Reider stated that the APX is capable of measuring elemental abundances greater than about 0.1 wt%.

The remaining series of talks in this session converged on the low-albedo area of Cerberus. Rice outlined the geology of the Marte Valles channel system, which may have acted as a spillway to a lake contained in Amazonis Planitia. Plenty of streamlined features support the idea that this is an outflow channel, which may be one of the youngest on Mars. The source area for the channel is unclear, however. Moderate-to-low thermal inertia in this proposed landing region (16°N, 177°W) also suggests that there are no boulders to interfere with landing the Pathfinder spacecraft. Viking orbiter images are as high as 13 m/pixel in some areas as well, which some people had suggested is necessary for supporting Pathfinder science investigations. R. Brakenridge also supported this site as a potentially wet area in the past. He suggested the possibility of finding chemically cemented fine sediments or even near-surface ice in this location. Some audience members, however, felt uncertain about finding water ice near the surface, especially at such a low latitude.

Plescia presented a different interpretation of the geology and suggested that the Cerberus plains would make a most excellent landing site. He presented the possibility that the Cerberus Formation is actually composed of volcanic material. The morphology of this unit resembles terrestrial flood basalt provinces in most areas. He has also mapped six low-shield volcanos in the western region that may have aided fissure eruptions in depositing this material. The rock abundance of ~7%, together with a fine-grained thermal inertia component of ~2.4 cgs units, suggests that the area (5°N, 190°W) would be relatively safe, but still offer the potential for finding exposed rock. Plescia also reminded investigators that the Cerberus Plains may also be a source region for the SNC meteorites, although no large craters are superposed on the unit. *In situ* analysis of Cerberus materials could test the proposed hypotheses—fluvial erosion or volcanism—each of which is equally important for understanding very young martian geologic history. Ultimately both processes may have been involved.

K. Edgett emphasized the importance of analyzing material that is compositionally different from anything measured by the Viking landers for calibrating remote sensing data. Dark material similar to that contained in the Cerberus region is common to all low-albedo regions on Mars. The Cerberus region may also offer sampling of a variety of materials including volcanic rock, highland materials, and fluviolacustrine sediments. Remote sensing data suggests that this area is not as rocky as the Viking landing site (average rock abundances of ~7%) and is not blanketed by dust because the thermal inertia data imply sand-sized particles (100–1000 µm), which could actually keep the region relatively free of bright wind-blown dust. This material, however, blankets several different geomorphic features. Edgett suggested that this area probably represents an active eolian environment similar to the bright sand that streaks across the Amboy lava flows in southern California. The low-albedo material may be pyroclastic in origin or may have come from weathered basalt. Farmer also suggested hydrothermal alteration as another possible explanation. It was argued that landing in the Cerberus region or other areas with low surface albedo would provide a surface that looked different from either Viking site.

Murchie also presented support for the Cerberus region as a landing site. His proposed site in the Tartarus Colles region (12°N, 198°W) is located in the Cerberus low-albedo feature (a surficial deposit) and contained entirely within Hesperian/Noachian-aged undivided material. He presented several characteristics that could make this site appealing: (1) The landing ellipse occurs completely within HNu materials, so the geologic unit containing the lander is known. (2) The presence of knobby terrain, the high block abundance (~10–15%), and the absence of erosional features such as channels suggest that the surface materials will be derived locally. (3) The location fits within the mission constraints and might contain a "mountain view" of knobs within the unit. (4) The unit may be composed of highland materials. (5) Phobos 2 NIR spectroscopic measurements suggest the surface contains unaltered basaltic particles. (6) Bright red dust in the area suggests that the site may also contain weathering products. Experiments contained on the Mars Pathfinder spacecraft could identify the bedrock lithology, the morphometry of the knobby mesas, and the composition and texture of weathering products contained in this area. Audience comments pointed out that the origin of the HNu unit was essentially unknown, although the potential of analyzing highland material seemed attractive.

220°W–280°W LONGITUDE

Summary by J. Rice

Allen proposed sampling Elysium lavas north of Cerberus Rupes in a region of dark material (13°N, 203°W). The objectives are to provide chemical composition and mineralogy of an Elysium lava flow. It was argued that determining the composition and mineralogy of major rock units are important in deciphering Mars' geologic history and interior structure. The Elysium lavas cover the entire landing ellipse. The area is mapped as Lower Amazonian in age, lavas originating from Elysium Mons and associated fissures. Pathfinder analysis of these lavas could help resolve whether or not these lavas are the source of the dust at the Viking lander sites and/or the SNC meteorites, and provide groundtruth for photogeologic interpretation. The composition of the flows can also be used to determine lava viscosity. The site meets the engineering constraints and the imagery shows no scarps or large craters. The site would also sample the dark eolian unit of interest in this region. Questions centered on whether the lavas erupted from a central vent volcano (Elysium Mons), in which case they might exhibit substantial local variability, or are from fissure eruption, in which case they might be more uniform in composition.

Craddock proposed a site in Isidis Planitia (15°N, 275°W). The site meets the mission constraints and would sample materials suggested to have been deposited in wet climatic periods of the region. Rocks deposited in lakes due to glacial/periglacial processes and from small-scale volcanos have been proposed in this region and could be available for study by Pathfinder instruments. The rock abundance is similar to that at the Viking 1 lander site, and high-resolution images (50 m/pixel) are available in the northwest corner of the region. These images show evidence for lakes (from curvilinear ridges), channels, terraces, possible pingos, and shorelines (from arcuate ridges). Measurements of grain size distribution should help define what processes were active in this region (lacustrine, periglacial, volcanic). APXS measurements would also help answer these questions. The surface materials are Upper Hesperian in age and are bright red spectrally, and thus different from those at the Viking 1 landing site. Isidis is also an ideal basin to study because it represents a simple basin as opposed to a more complex one such as Hellas. Some questioned whether it would be possible to tell from images if hills were pingos or cinder cones? It might not be possible from imaging alone, but APXS measurements of the rocks making up the hills would go a long way toward answering this question. Some questioned the safety of landing on small hills, but their height of only tens of meters might not represent a problem.

Parker also proposed a site in Isidis Planitia (15°N, 280°W), which is a smooth, flat region. Science objectives at this site include determining the origin and composition of the smooth plains (lacustrine, marine, eolian, periglacial, and/or volcanic); determining the origin of domes in the area (pingos or cinder cones); determining the origin of the thumbprint terrain; and determining the composition and stratigraphy of the fretted terrain. Features of interest in the area are curvilinear ridges, thumbprint terrain, small domes, inselbergs, Syrtis Major volcanic plains, craters, and shoreline morphology (arcuate boundaries and terraces). Some inselbergs display a cut-and-fill terrace morphology indicative of a former highstand of water. The domes are thought to be pingos, which have summit craters from dilation cracks caused by the expansion of ice in the core of the hill. Closed-system pingos typically form in recently drained lakes. The slopes of these domes should define whether they are pingos or cinder cones. Determining the composition of the hills using the APXS would help determine the origin of these enigmatic landforms. It was admitted that it might be difficult to distinguish pingos from endogenous domes with images only, but compositional data from the APXS would solve this problem. The small hills could even be salt domes, which should be distinguishable by a mission to this region, provided that the hills are within roving distance from the lander. Someone commented that theoretical ice stability work indicates that ice could still be in the ground of Amazonian-aged materials at depths of a few meters.

POSTER AND DISCUSSION

Summary by J. Crisp and D. Britt

The poster by R. Kuzmin, R. Landheim, and Greeley examined 12 potential landing sites and also noted the landing sites of the Mars '94/'96 stations and penetrators. Given that Mars '94/ '96 landers will be going to higher latitudes, Pathfinder can concentrate on units and processes that are not represented at the latitude to which the Russian missions will go. This group took two approaches: (1) the single-unit approach, which emphasizes landing within a single morphological unit; or (2) the grab-bag approach, which requires landing in areas that will have a wide variety of rocks (outflow channel deltas). Generally this group prefers outflow deltas.

A poster by P. Christensen and Edgett provided some basic surface properties information for landing-site selection. Using a model based on albedo, thermal inertia, and rock abundance they defined four broad surface property units. In general, units 1 (low rock abundance, heavy dust mantle) and 4 (high rock, dusty, like Viking sites) should be avoided. Outflow channels have enhanced thermal inertias, which are probably related to blocky material on the channel floors.

Golombek was hoping that this workshop would make it clear what the best choices for a landing site would be. A handful of site candidates have been proposed, and in the next few months the Pathfinder project will be looking into the detailed engineering hazards and science issues for those sites. Moore noted that only some of the workshop talks included a full analysis of the hazards (fluffiness of the soil, rms slopes, expected fraction of rocks, etc.). He emphasized that we need to consider all the data available (violet/red ratios, albedos, thermal inertias, radar, etc.) to assess the sites from an engineering point of view. He thought all of Mars has the potential for interesting, exciting science. Zent said a landing site decision boiled down to a decision between hard-rock vs. soft-rock geology. Will we choose a pristine igneous site or a sedimentary environment? Craddock said this was like the decision between a grab-bag (sedimentary) and single homogeneous unit (igneous).

From an engineering perspective, Golombek gave two worst-case scenarios. (1) Amazonis is a dusty site. After one week, the solar panels are covered with dust, the APX is covered with dust, we only measure dust, and the rover chokes to death in the dust. (2) There is very little dust. We land in a sea of black sand and the rover and lander are sand blasted up to a few meters in height. The windows on the cameras and APX are completely pitted. These two extreme scenarios are unlikely—at least our experience at the Viking lander sites suggests they are unlikely. Plescia mentioned that the dust accumulation at Viking was optically thin, and the dust piles did not move for years. Dust did not significantly affect the Viking landers. However, Golombek pointed out that we have a roving vehicle that will kick up dust. Moore suggested that we check with E. Guinness for the best information about dust at the Viking landing sites. Herkenhoff noted that most of the sand should be transported during dust storms or in transient dust devils. Edgett said that sand transport does not occur during all seasons, and that northern summer is generally a good time of year and location for low or no dust storm activity. Golombek commented on Zent's statement by adding that we have a better chance of inferring mineralogy from the bulk composition of an igneous rock (or a coherent rock) than from a soil. We have a good chance of sampling fresh igneous rocks from Cerberus. Moore cautioned against landing anywhere near the dikes in Cerberus, especially since we may not see the smaller ones in Viking images, and they could pose a significant topographic threat.

High-resolution Viking images will be important for picking out craters and assessing the local geology for potential topographic hazards. Craddock said that without high-resolution images, we might send the rover to what the rover and lander cameras seem to indicate is a crater rim crest, in the hope of sampling different levels of crust. Later we might discover that it was not a crater rim and that we had sampled the same material all along. This sort of accident might be avoided if we had high-resolution Viking images of our landing site and could identify our location within the Viking image. High-resolution images could be used to examine small-scale structures and features, and perhaps could help target where the rover should go. Others said that high-resolution images would help put the landing site in a geologic context and would improve our ability to interpret our close-up observations and measurements. Moore wasn't sure how helpful this would be. His experience in lunar mapping was that the coarser the resolution, the deeper the map is. Very different features are apparent at each different order-of-magnitude resolution. At the finest resolution, all that is mapped is the surface material, but the context of the site is not changed. Moore thought it was not necessarily that important to have Viking high-resolution imagery for our Pathfinder landing site. On the Moon, the geologic context does not change very much with scale. Crumpler said that the rover will have a very close-up local view, and that high-resolution images would be helpful for geologic context.

Murchie was impressed by Greeley's Marsokhod test, which showed how difficult it will be to determine our landing site location on Viking scale images using the Pathfinder lander camera. Golombek added that we will not know for sure exactly where we have landed (or what unit at a local scale). The location precision of Earth tracking will be about 1 km in inertial space; we will not know our location on the cartographic net (relative to martian landforms) to better than a couple of kilometers. D. Britt asked whether we should choose a landing site that is close enough to some topographic features that could be used for triangulation. Plescia said we may land in a spot where we will not see anything to triangulate from.

Treiman asked whether we will encounter large rocks if we go to an outflow channel that has only cut through a few ridges. Someone noted that there is no guarantee that we will see heterogeneity at a local rover scale if we land in an outflow channel. Treiman suggested that in outflow areas, ponding will cause the large sediment to drop out early. In any smooth downstream area, you might not get an assortment of material.

In summary, we have three choices: (1) grab-bag sites like the outflow channels, (2) a single unit of well-understood origin and context (like the Elysium flows), or (3) a single unit of mysterious origin (like Medusa Fossae). What are the best science questions? Should we go to the highlands? It might be all old weathered material or an old basalt flow. Anywhere we land we will find weathered material. A fundamental question for Mars is whether or not there are carbonates, which we ought to look for. It was pointed out that landing on a lava flow and analyzing volcanic rocks on Mars might not be as interesting as landing on a different rock unit, given that we probably already have samples of martian basalts on the Earth (SNC meteorites). One strategy might be to have a science question or hypothesis in mind, and pick a landing ellipse such that any "pinprick" landing site anywhere within that ellipse would answer our question or test our hypothesis. The projectionist indicated that a grab-bag site would provide something of interest for everyone, and would have good public relations value. Singer noted that a fundamental question is whether there is a more silicic component to the martian crust, and a grab-bag site would give us a better chance to determine this. It would also give us a better chance of finding carbonates. There is concern that if we land at a site like Viking 1, all the rocks could turn out to be the same. The "grab-bag" from an outflow channel will not be a completely random jumble of rocks with no geologic context, given that we will have some idea where the rocks came from. Future orbital remote sensing observations could also help narrow down where outflow debris types originated. A wider variety of rock types would heighten public interest in the mission. Anywhere in Chryse should provide a good chance of the rover finding a grab-bag of samples.

The meteorologists would prefer to land at a different latitude closer to the equator, or land over a dark-albedo area. On the other hand, a return to a Viking site could extend the meteorology dataset for that site, to allow the study of changes over a longer period of time. The meteorology science return appears to be much less dependent on the site location than the geology science return.

Golombek liked the idea of Murchie's site, which may be a bit less weathered, with some dark sand and degraded craters. This site could provide a mini-grab-bag sample of rocks eroded from units just tens of kilometers away. Singer asked what would the chances be of finding a variety of rock types in the very limited area the rover will explore. Murchie suggested that the outflows in his area have eroded the top 3–4 km of the higher regions, and should have sampled numerous layers. To the southeast there are several unknown highland units mapped (on the basis of their different morphology). Edgett said that Oxia Palus is another potential site where there are fairly abundant rocks, wind streaks, cratered highlands, and lots of impact ejecta. Oxia would provide the potential for sampling crust, rocks, sand, and ejecta blocks. Golombek noted the danger posed by craters and indicated that Murchie's area could be less hazardous. Murchie asked whether Oxia Palus is heavily weathered. The only unaltered material in Oxia might be the dark "dunes," and the rocks might not be representative of the highlands. Singer said it would be useful if we could sample "dark red" material and aerosol fallout dust. The dark red material could be weathering products, evaporites, or carbonates. If we also had a chance of finding dark sand, it would provide a good mix of different materials from a remote sensing groundtruth perspective. Plescia asked what fundamental science question would be addressed by studying the sand, since we probably would not know where the sand came from. Edgett believes that if it is sand, sand blasting could clean off the rock surfaces. Singer suggested we could try to determine whether the sand has the same composition as SNC basalts, or is the same as the local bedrock, or whether it has a lacustrine source. The Cerberus areas had merit, in particular, the highland area of Tartarus Colles that could provide a grab-bag of early rocks that are of interest. The other advantage of this site is its apparent deflationary eolian erosion and the relatively fresh dark sands.

Someone familiar with the Apollo mission noted that all the Apollo 11 and 12 rock samples looked alike from the outside. It was not until the rocks were cracked open that we could see differences. It should be worse on Mars because of the higher degree of alteration. Smith noted that if the IMP imaging camera does a 12-color panorama and it all looks the same, we have lost an opportunity ("See one rock, you've seen them all"). An outflow channel would give us a better chance of sampling a variety of rock types.

Abstracts

SAMPLING ELYSIUM LAVAS (13°N, 203°W). C. C. Allen, Lockheed Engineering and Sciences Company, 2400 NASA Road 1, Houston TX 77058, USA.

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Elysium is the second largest volcanic province on Mars. A landing site on this unit is proposed at 13°N, 203°W, in a dark region north of Cerberus Rupes. The site was chosen to provide the chemical composition and mineralogy of an Elysium lava flow.

Criteria for Landing Site Selection: The proposed landing site was selected to usethe Pathfinder APXS and multispectral cameras in order to characterize rock chemistry and mineralogy. Site selection was based on three criteria:

Is the site important? Will the data from this site have planetary significance?

Is the site accessible? Can the Pathfinder spacecraft land safely at this site and perform the desired analyses?

Is the site representative? Will the samples analyzed by Pathfinder be representative of the geology for which the site was chosen?

Is the Site Important? The chemical and mineralogical compositions of major rock units are of extreme importance in deciphering a planet's geologic history and interior structure. Our current knowledge of Mars is deficient in this regard, lacking any analyses of unequivocal martian rocks. Chemical and mineralogical analysis of at least one major rock type should be a primary goal of any Mars lander.

The most widespread map unit in the Elysium province, and one of the largest in the entire Pathfinder landing zone, is member 2 of Tanaka et al. [1]. This unit, covering 1.06×10^6 km^2, is interpreted as lava flows from the latest widespread volcanic activity in the area. Member 2 is mapped as lower Amazonian in age, with a cumulative crater density (>2 km) of 329 ± 18 per 10^6 km^2. The lavas originated from Elysium Mons and associated fissures. Flow fronts over 100 km in length have been mapped. The landing site was chosen to sample this major volcanic unit.

The friable material analyzed by the Viking landers is generally interpreted as weathering products of mafic rocks [2]. The chemical compositions of samples from both Viking sites were essentially identical, and the samples' spectral signatures matched those of widespread martian bright areas. Thus, much of the planet's surface is thought to be mantled with windblown dust. Pathfinder analyses can show whether or not the Elysium lavas are possible sources for this dust.

The SNC meteorites, generally believed to be derived from Mars, are all basalts [3]. Chemical and isotopic differences among the meteorites show derivations from several lavas, separated either vertically or horizontally on the martian surface. The SNCs strongly indicate that basalts occur somewhere on Mars. Compositional data from Elysium lavas can show whether or not they are a reasonable source for the SNCs.

A lava analysis from a known site would provide valuable ground truth for photogeologic interpretation. Chemical and mineralogical composition can be used to determine lava viscosity. With this calibration point, measurements of flow dimensions can be used to derive eruption parameters basic to the understanding of the volcanic province.

Geophysical models require the compositions and densities of martian crust and mantle rocks. The current uncertainty as to rock type allows for a wide range in geophysical parameters. Knowledge of the chemical composition of an extensive unit like the Elysium lavas could strongly constrain these models.

Knowledge of martian lava composition is of considerable importance to the study of comparative planetology. To zero order the surface of the Earth is dominated by eruptive mafic and intrusive sialic rocks. Knowledge that the lunar rocks show the same basic dichotomy is fundamental to our understanding of that body. The Venera and Vega analyses strongly suggest that the same two rock types dominate the surface of Venus [4]. Pathfinder should provide the composition of one of these major rock types on Mars.

Is the Site Accessible? The proposed site, 13°N, 203°W, is within the Pathfinder landing zone. The site lies between the 0 and −1 km contours, on a regional slope of approximately 1:500 [5]. Viking orbiter imagery shows no scarps or large craters at the landing site.

The landing ellipse is entirely within an east-northeast/west-southwest trending dark area that measures 1500 km × 300 km. A small percentage of the area is covered by light-toned northeast-southwest-trending streaks, interpreted as dust deposits in the wind shadows of topographic obstructions. The dark material is interpreted as lava flows denuded of dust by the wind [6]. Thus, Pathfinder should have a high probability of landing on a relatively dust-free lava flow.

The Viking landers touched down in bright areas dominated by windblown dust deposits. Both sites, however, contained numerous large rocks, which could have been analyzed by a mobile system such as that on the Pathfinder rover. Thus, even if Pathfinder were to touch down on a dust deposit, it should be able to find lava outcrops or boulders to analyze.

Is the Site Representative? The Columbia River Basalt Group (CRBG) in the U.S. Pacific northwest is one of the largest (200,000 km^2) and youngest (17–6 Ma) flood basalt provinces on Earth [7]. Fissure eruptions produced flows tens to hundreds of meters thick, with some flows traceable for over 300 km. Over 5000 samples, representing all the flows in the CRBG, have recently been analyzed by XRF [8]. These analyses are a unique dataset by which to judge Pathfinder analyses from Elysium.

The CRBG can be divided into six chemically distinct formations, with the Grande Ronde Formation comprising 85% of the volume of the entire group [9]. Individual lava flows within the Grande Ronde display striking chemical uniformity. Flows can be reliably distinguished, based on major- and minor-element compositions, even hundreds of kilometers from their sources [9].

If Pathfinder landed anywhere in the Columbia River basalts, APXS analysis of a random dark rock would be indistinguishable from any other analysis of the same lava flow, which could be hundreds of kilometers in length. To first order, in fact, such a random analysis would be highly representative of the entire CRBG. By analogy, the composition of any lava rock from 13°N, 203°W on Mars should be representative of the fresh lavas across much of the Elysium province.

Conclusions: The proposed Pathfinder landing site presents the opportunity to determine chemical and mineralogical compositions of an Elysium lava flow. The flow is part of a geologic unit of planetary significance. The proposed site appears suitable for landing, and lava surfaces should be accessible to the Pathfinder instruments. By analogy to terrestrial flood basalts, any lava analyzed by Pathfinder is likely to be representative of the entire Elysium province.

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N95-16178

MARS PATHFINDER AND THE EXPLORATION OF SOUTHERN AMAZONIS PLANITIA. N. G. Barlow, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058, USA.

The southern region of Amazonis Planitia provides a variety of target terrains for a roving vehicle such as the Mars Pathfinder Mission. A landing site is proposed at 4°N latitude 162°W longitude. This area has a reference altitude of between 0 and −1 km and consists of relatively smooth Amazonian-aged deposits within the entire 100 × 200 km landing ellipse. The proposed landing site is within the Upper Member Medusae Fossae Formation deposits (Amu) and near the boundary with Middle Member Medusae Fossae Formation deposits (Amm) and Member 1 Arcadia Formation plains (Aa_1). Slightly further afield are 107-km-diameter Nicholson crater, its ejecta deposits, and knobby terrain of proposed Hesperian age (HNu) [1]. Depending on the exact landing site of the spacecraft and the traverse distance of the rover, these materials also may be sampled.

Regional Geologic Setting: The Medusae Fossae Formation consists of a series of fine-grained, layered deposits of enigmatic origin generally within the area 12°N–11°S and 127°–190°W. The fine-grained nature of the material is revealed through low thermal inertia values [2,3], little to no radar return [4], greater than expected crater depth-diameter ratios for fresh impact craters [5], and the presence of eolian erosional features such as yardangs [6]. The origin of this material remains controversial—theories include ignimbrite deposits from explosive volcanic eruptions [7], ancient polar deposits that have ended up in their present location as a result of extensive polar wander [8], an exhumed chemical boundary layer caused by a subregolith paleowater table [4], or simply thick deposits of eolian-emplaced debris [1]. Analysis of the chemical composition of the material may help to resolve the origin of this mysterious and unique martian terrain.

The proposed landing site lies within the Upper Member of the Medusae Fossae Formation, a discontinuous region of deposits that tend to be smooth and flat to gently rolling. In some locations, this material has been sculpted by eolian processes into ridges and grooves, which may allow direct observation of different layers within the material. To the west lies the Middle Member of the Medusae Fossae Formation, which is similar to the Upper Member except for appearing rougher and more deeply eroded. The rover probably will have difficulty traversing this terrain and therefore sampling of only the outlying regions is desired for comparison with the Upper Member.

To the northwest of the proposed landing site is the Member 1 Arcadia Formation plains. These plains are characterized by smooth, flat topography occasionally interrupted by knobs and hills of presumed Hesperian- or Noachian-aged material. Mare-type wrinkle ridges are common, suggesting that these plains are of volcanic origin. Since this area is located to the southwest of Olympus Mons, the volcanism of the region is likely related to volcanism of the Tharsis region. The Member 1 plains are the oldest unit of the Arcadia Formation and are stratigraphically similar in age to portions of Alba Patera and the Olympus Mons aureole [1,9].

Approximately 200 km southwest of the proposed landing site is the 107-km-diameter crater Nicholson. Although relatively fresh in appearance, Nicholson is partially embayed by the Medusae Fossae deposits and therefore appears to be intermediate in age between the Member 1 Arcadia formation on which it is superposed and the Upper and Middle Members of the Medusae Fossae Formation. The ejecta blanket of the crater is still preserved although slightly reworked. Analysis of this ejected material should provide information about changes in target composition with depth in this vicinity.

Information from Mars Pathfinder Rover: The instruments onboard the Mars Pathfinder Rover can help address several questions regarding the terrain in this region. Among these questions are: (1) What are the chemical composition and mineralogy of the different geologic units at the landing site and within the traverse distance of the rover? (2) Are there regional variations in chemical composition/mineralogy within the same stratigraphic unit? (3) What is the magnetic susceptibility of the material at the lander site? (4) What is the ratio of fine-grained to rocky material at each location? (5) What is the composition of the dust that will probably accumulate on the rover during its traverse? (6) What is the appearance of different geologic features from surface level and what can the resolution of the imaging system reveal about layering in, erosion of, and possible origin of these features? (7) What is the trafficability of the different units traversed by the rover?

The camera systems and the APXS sensor will provide the answers to most of these questions. The ability of the APXS sensor to analyze both soil and rocks should provide a much better understanding of the materials composing the martian surface in this region. Analysis of exposed layers within ridges, grooves, and hills by the APXS and multispectral capabilities of the imaging system can provide information about chemical and mineralogic variations within the near-surface region. This information will provide constraints on the potential origin(s) of the features studied.

This particular landing site was selected primarily to address the question of the composition and possible origin of the Medusae Fossae Formation deposits. These deposits appear to be a unique landform on Mars and have intrigued a large number of investigators. Why are the deposits concentrated in this region of the planet? The crater density and superposition relationship to surrounding terrain suggests a young age for this material. What process or processes occurred to create this material in relatively recent time? Do these deposits imply anything about possible environmental changes for Mars? It is hoped that the instruments onboard the Mars Pathfinder lander and rover can provide new constraints on the theories advanced about this enigmatic region of Mars.

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53-91 ABS. ONLY N95-16179

METEOROLOGICAL OBSERVATIONS OF SYNOPTIC DISTURBANCES: SENSITIVITY TO LATITUDE.

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The Mars Pathfinder MET experiment will make pressure, temperature, and wind measurments on the surface of Mars. The Viking Lander Meteorology Experiment measurements were marked by the presence of variations associated with synoptic weather disturbances throughout the fall and winter seasons. These variations were characterized by periods in the broad range of about 2–10 days, and were most prominent at the midlatitude (48°N) Viking Lander 2 site. The synoptic disturbances were observed to essentially disappear during the summer season. At the subtropical (22.5°N) Viking Lander 1 site, variations with similar periodicities were seen, but the amplitudes of these were reduced in comparison to those at Lander 2 by factors of 2–3 or more. The identification of the weather variations has been helped greatly by numerical simulations of the Mars atmospheric circulation performed with various models.

These models show that the winter midlatitudes are the center of activity for traveling disturbances of planetary scale, disturbances that have their fundamental origin in the baroclinic instability of the wintertime Mars atmospheric circulation. The numerical studies are consistent with the Viking observations in that the disturbances decay in amplitude toward lower latitudes; direct comparisons of the models with the Viking data are quite favorable, although the models seem to produce larger amplitudes in the subtropics than were seen at the Lander 1 site. If Mars Pathfinder is able to survive for 2–3 months, then it will observe the transition from the very quiescent summer season into the much more active winter season. The further north it is located, the more clearly will it be able to detect the signatures of the midlatitude weather systems. The basic mission constraint of a low-elevation landing site should favor the observation of the weather disturbances: The model simulations show that the weather activity is enhanced in the subtropics in the three low regions of the northern hemisphere.

This is at least partly due to the presence of "standing eddies" in the circulation that are forced by the topography. A landing site close to 15°N should allow measurement of the weather disturbances, along with observations of the thermal tides, slope winds, and the relatively steady winds associated with the general circulation—the "trade winds" of Mars. Model simulations show that the latter can be very strong in certain locations, especially near the western edges of low-elevation regions. A landing site near 15°N would be significantly further equatorward than the Viking Lander 1 site, and thus would provide more of a view of tropical circulation processes. There could be some "surprises" in such observations.

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IMPLICATIONS OF HIGH-SPATIAL-RESOLUTION THERMAL INFRARED (TERMOSKAN) DATA FOR MARS LANDING SITE SELECTION.

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Thermal infrared observations of Mars from spacecraft provide physical information about the upper thermal skin depth of the surface, which is on the order of a few centimeters in depth and thus very significant for lander site selection. The Termoskan instrument onboard the Soviet Phobos '88 spacecraft acquired the highest-spatial-resolution thermal infrared data obtained for Mars, ranging in resolution from 300 m to 3 km per pixel [1–3]. It simultaneously obtained broadband reflected solar flux data. Although the 6°N–30°S Termoskan coverage only slightly overlaps the nominal Mars Pathfinder target range, the implications of Termoskan data for that overlap region and the extrapolations that can be made to other regions give important clues for optimal landing site selection.

For example, Termoskan highlighted two types of features that would yield high lander science return: thermally distinct ejecta blankets and channels. Both types of features are rare examples (on Mars) where morphology correlates strongly with thermal inertia. This indicates that evidence of the processes that formed these morphologic features probably still exists at the surface. Thermally distinct ejecta blankets (Fig. 1) are not significantly mantled by eolian material, and material ejected from depth should be exposed at the surface [4]. In addition, their unmantled surfaces should still contain morphologic clues to the exact process that formed the uniquely martian fluidized ejecta blankets. Thermally distinctive channel floors (e.g., Fig. 2) probably have material exposed from various stratigraphic layers and locations. In addition, the possibility that flat channel floors owe their enhanced inertias to water-related processing (bonding) of fines makes these sites intriguing

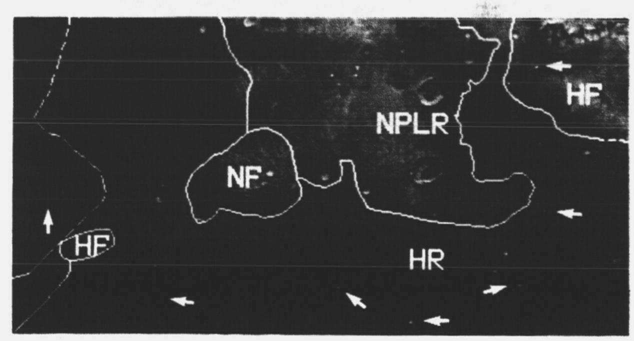

Fig. 1. Ejecta blankets distinct in the thermal infrared (EDITHs): Termoskan thermal infrared image. North is top. A small part of Valles Marineris appears at top right. Time of day is near local noon. Darker areas are cooler, lighter areas are warmer. Note the thermally distinct ejecta blankets, which appear as bright or dark rings surrounding craters (examples denoted by arrows). EDITH boundaries usually closely match fluidized ejecta termini. White lines are geologic map boundaries (from [6,7]). Throughout the data, almost all EDITHs observed are on Hesperian-aged terrains with almost none on the older Noachian units, presumably due to a lack of distinctive layering in Noachian terrains (see [4] for more information). EDITHs are excellent locations for future landers because of relatively dust-free surface exposures of material excavated from depth.

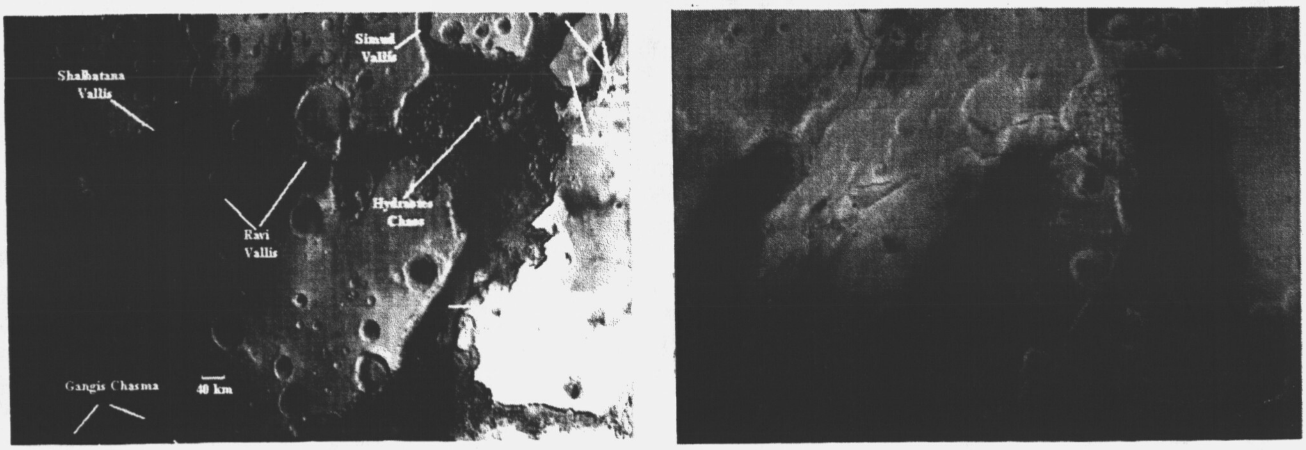

Fig. 2. (Top) Termoskan thermal and (bottom) visible images centered approximately upon 1°S, 39°W. North is top. In all thermal images shown here, darker is cooler. Shalbatana, Simud, and Tiu Valles all continue for several hundred kilometers north of this image. Note the cool and generally uniform floors of all channels except the eastern (and rough floored) end of Ravi Vallis. Note also that the thermal boundaries closely match the boundaries of the channel floors and depart significantly from albedo boundaries seen in the visible image. Note also the dark, presumably eolian deposits localized within the southern portions of Shalbatana Vallis and the southwestern portion of Hydraotes Chaos and spreading onto the surrounding plains in both cases. Buttes, including the large labeled one in the northeast of the image, within the channels appear similar in temperature and appearance to the surrounding plains, not the channels. We favor noneolian explanations of the overall channel inertia enhancements based primarily upon the channel floors' thermal homogeneity and the strong correlation of thermal boundaries with floor boundaries. See [5] for more information.

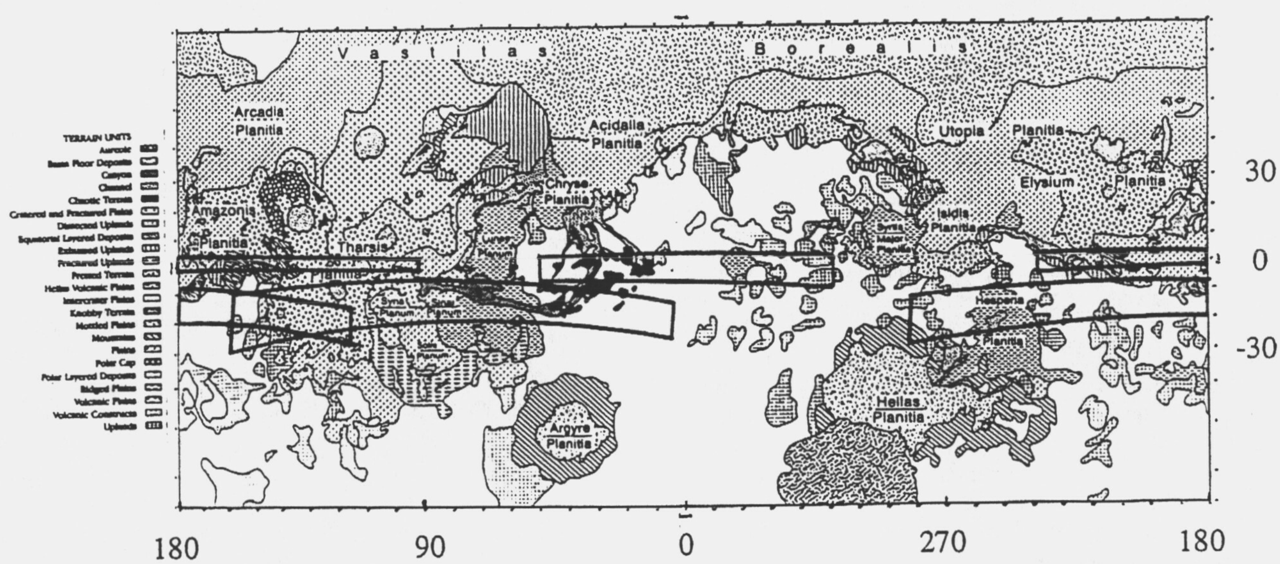

Fig. 3. Coverage of Termoskan's four panoramas (boxed regions) overlaid on a simplified geologic map of Mars from Barlow and Bradley (1990). Note that on this simplified map, ridged plains are not split into Noachian and Hesperian ages. Note also that regions near the outer edges of each panorama are badly foreshortened because they were observed near the limb.

[5].

Where coverage exists (Fig. 3), Termoskan can also be used to assess thermal inertias and the degree of thermal inertia homogeneity. These are important for lander safety considerations as well as science. Those interested in particular regions are encouraged to contact the author for more details.

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p. 1

N95-16181

A MARS PATHFINDER LANDING ON A RECENTLY DRAINED EPHEMERAL SEA: CERBERUS PLAINS, 6°N, 188°W. G. R. Brakenridge, Surficial Processes Laboratory, Department of Geography, Dartmouth College, Hanover NH 03755, USA.

Along a 500 km-wide belt extending between 202° and 180°W and lying astride the martian equator, moderately low-albedo, uncratered smooth plains exhibit low thermal inertia and potentially favorable conditions for the preservation of near-surface ice. The Cerberus Plains occupy a topographic trough as much as 2 km below the planetary datum [1,2], and the denser atmosphere at these altitudes would also favor long residence times for near-surface ice once emplaced [3]. The plains have previously been interpreted as the result of young (Late Amazonian) low-viscosity lava flows [4] or similarly youthful fluvial deposition [5,6]. However, the plains are also included in maps of possibly extensive martian paleoseas or paleolakes [7,8]. Ice emplaced as such seas dissipated could still be preserved under thin (a few tens of centimeters) sedimentary cover [9]. In any case, and if a sea once existed, aqueous-born interstitial cementation, probably including hydrated iron oxides and sulfate minerals, would have been favored and is now susceptible to investigation by the Pathfinder alpha proton X-ray spectrometer and multispectral imager.

There is interesting supporting evidence indicating an aqueous origin for the Cerberus Plains. On Viking Orbiter high-resolution images, some near-shoreline portions of the plains exhibit intersecting, very-low-relief linear or curvilinear ridges that may define ridge-interior, polygon-shaped, angular-to-rounded ice cakes and ice flows [10]. Lead- and pressure-ridge-like forms can be mapped, although local relief is very low. The shelf icelike pattern outlines flows that are similar in size to those that occur on Earth, and the general fragmental character is quite different from the smooth surface morphology imaged at Viking resolution on unmantled plains confidently known to have formed by lava flows. Finally, a suite of landforms elsewhere considered to be coastal in origin [11] occur along the southern margin of the plains: These are compatible with a marine or lacustral model but not with a lava flow origin. Such landforms include peninsulas and bays, spits, strandlines, and stepped massifs, and all are consistent with a maximum sea level reaching to ~−1000 m altitude.

For example, at 3°S, 197°W, the dark-albedo, low-thermal-inertia plains unit embays and overlaps the knobby terrains to the south along or very close to the −1000-m contour. Four hundred kilometers to the northeast, the "sea floor" plain reaches to below −2000 m, implying maximum stage water depths of at least 1000 m. In the deep region, two isolated massifs (Hibes Montes) extend to above −1000 m altitude, and both exhibit topographic steps at that altitude: These may be wave-cut or other coastal features. In contrast, if lava extrusions were instead centered in this deepest part of the basin and formed the Cerberus Plains [4], these lavas must have flowed uphill and at relatively steep gradients to reach the southern margin of the plains. Either the topography as now mapped is greatly in error (and there is no trough), or water is the more likely fluid to have formed the embayment features along the southern margin.

A 180-km-wide outflow channel typical in its morphology but unusual in its youthfulness (it too is uncratered) extends from the Cerberus Plain trough northeastward to a "spillway" at 24°N, 172°W. The spillway lies at −1000 m altitude and some 1100 km from the Hibes Montes islands. In agreement with [4], streamlined interchannel islands indicate fluid flow to the northeast, from Cerberus and into Amazonis Planitia and the deeper (−3000 m altitude) basin therein. This could not have occurred unless fluid levels reached over the spillway; again, the basin must have once filled to ~−1000 m altitude, and this too suggests water and not lava as the fluid involved. The Cerberus Sea probably formed in much the same manner as did the outflow channels, but the surface discharge occurred within a topographic basin, and the basin itself was first filled before overtopping the lowest spillway and discharging excess water and ice into Amazonia Planitia. Slow filling, perhaps under a perennial ice cover, could instead have occurred if a global groundwater system exists [12] or if regional geothermal sources such as recently present at Elysium or Orcus Patera stimulated large-scale hydrothermal circulation [7] and water discharge along faults and fractures (in this case, at Cerberus Rupes). Whether filling was slow or rapid, much evidence indicates that an ice-covered sea recently existed at the location of the present-day Cerberus Plains, and this poses unique opportunities for a Pathfinder landing that would investigate the sedimentary and soil geochemical traces of the planet's water cycle.

At the suggested landing location, shelf ice may still exist, and be frozen together into extensive grounded composite flows and thinly mantled by cemented low-thermal-inertia eolian deposits. Alternatively, sediment-laden and perhaps mantled shelf ice existed here late in Mars history and has since sublimed or melted. In either event, the present sedimentary cover is resistant to wind erosion and thus probably cemented. There exists here the uncertain possibility of detecting near-surface ice, but the probable opportunity to analyze in detail chemically cemented fine sediment and thus learn much about interstitial water characteristics.

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N95-16182 2

PHYSICAL PROPERTIES (PARTICLE SIZE, ROCK ABUNDANCE) FROM THERMAL INFRARED REMOTE OBSERVATIONS: IMPLICATIONS FOR MARS LANDING SITES. P. R. Christensen and K. S. Edgett, Department of Geology, Box 871404, Arizona State University, Tempe AZ 85287-1404, USA.

Critical to the assessment of potential sites for the 1997 Pathfinder landing is estimation of general physical properties of the martian surface. Surface properties have been studied using a variety of spacecraft and Earth-based remote sensing observations [1,2], plus *in situ* studies at the Viking lander sites [2,3]. Because of their value in identifying landing hazards and defining scientific objectives, we focus this discussion on thermal inertia and rock abundance derived from middle-infrared (6–30 μm) observations. Used in conjunction with other datasets, particularly albedo and Viking orbiter images, thermal inertia and rock abundance provide clues about the properties of potential Mars landing sites.

Here we discuss the combined albedo [4], thermal inertia [2,5], and rock abundance [6] results [derived from Viking Infrared Thermal Mapper (IRTM) data collected 1976–1980] for regions that fit the Pathfinder landing constraints: areas below ~0 km elevation between 0° and 30°N latitude. Lately there has been considerable discussion of the uncertainty in thermal inertia derived under a relatively dusty martian atmosphere [7–11]. In particular, Hayashi et al. [8] suggest that the thermal inertias, which we describe below, are 50–100 (units of $J\ m^{-2}\ s^{-0.5}\ K^{-1}$, hereafter referred to as "units"), too high for regions with moderate and high inertias (>300 units) and 0–50 units high for regions of low inertia (<300 units). However, our interpretation of physical properties is general and accounts for uncertainty due to modeling of suspended dust.

Thermal inertia is related to average particle size of an assumed smooth, homogeneous surface to depths of 2–10 cm [12]. Rock abundance is derived from multiwavelength observations to resolve surface materials into fine (sub-centimeter-scale) and rocky (~10-cm) components, based on the fact that temperature of rocks and fines can differ by up to 60 K at night [6]. Low rock abundances generally indicate areas with dust or sand deposits, while areas of high rock abundance are commonly outflow channel deposits and/or regions deflated by wind [2,5,6].

Christensen and Moore (Fig. 11, [2]) identified four physical units that describe the general variation in surface properties on Mars. The data products used in this analysis include a 0.5°/bin-resolution thermal inertia map [5], a 1°/bin-resolution Viking-era albedo map [4], and the 1°/bin rock abundance map [6].

Unit 1 is defined by low thermal inertia (40–150 units), high albedo (0.26–0.40), and low rock abundance (<5%). Unit 1 surfaces are interpreted as being mantled by dust up to 1 m thick. Most of these surfaces are in the high-elevation Tharsis, Arabia, and Elysium regions; however, two regions lower than 0 km elevation between 0° and 30°N have similar deposits: Amazonis Planitia and Elysium Basin (150°W–210°W).

Unit 2 is characterized by high thermal inertia (300–850 units) and low albedo (0.1–0.2), with rock abundances high but variable. Southern Acidalia and Oxia Palus (0°–60°W) fit this description, and are considered to be regions of active sand transport and rocky lag deposits. Other Unit 2 surfaces include Syrtis Major (elevation >0 km) and Cerberus (elevation <0 km), which have lower rock abundances (<7%) and are probably more sandy and less rocky than Acidalia.

Unit 3 surfaces have moderate thermal inertias (150–350 units), average albedos (0.15–0.25), and moderate to low rock abundances. Parts of Western Arabia near Oxia Palus and parts of Xanthe Terra and Lunae Planum fit this description. These have been interpreted as possible surface exposures of indurated dust/soil deposits similar to the crusted materials seen a few centimeters beneath the surface at the Viking lander sites.

Unit 4 has moderate-to-high inertias (210–380 units), a relatively high albedo (0.25–0.30), and a high rock abundance (>7%). This unit includes the two Viking lander sites [13]. The Viking sites have elements of all the above Mars surface deposit types (dust, rocks, crust) except the low-albedo, sandy material of Unit 2 [2]. Much of Chryse Planitia and parts of Isidis Planitia and Elysium Planitia (210°W–250°W) can be described as possible Unit 4 surfaces.

Finally, there is some interest in landing sites in or at the mouths of outflow channels. Henry and Zimbelman [14] and Betts and Murray [15] have provided IRTM and Phobos 2 Termoskan evidence (respectively) that channel floors tend to have enhanced thermal inertias probably related, in part, to the presence of blocky material on the channel floors. Henry and Zimbelman saw a general "downstream" decrease in thermal inertia in Ares Vallis, consistent with a decrease in clast size down the channel. Surfaces at the mouths of major outflow channels, however, have enhanced rock abundances [6].

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N95-16183

RATIONALE FOR A MARS PATHFINDER MISSION TO CHRYSE PLANITIA AND THE VIKING 1 LANDER.

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Presently the landing site for Mars Pathfinder will be constrained to latitudes between 0° and 30°N to facilitate communication with Earth and to allow the lander and rover solar arrays to generate the maximum possible power. The reference elevation of the site must also be below 0 km so that the descent parachute, a Viking derivative, has sufficient time to open and slow the lander to the correct terminal velocity. Although Mars has as much land surface area as the continental crust of the Earth, such engineering constraints immediately limit the number of possible landing sites to only three broad regions: Amazonis, Chryse, and Isidis Planitiae. Of these, both Chryse and Isidis Planitiae stand out as the sites offering the most information to address several broad scientific topics.

An immediate reaction to proposing Chryse Planitia as a potential landing site is, "Why go back to an area previously explored by the Viking 1 lander?" However, this question answers itself. Viking 1 landed successfully, proving that it is safe and providing us with valuable ground-truth observations of the martian surface. For example, Viking Lander 1 data have provided information useful in determining the physical properties of the martian surface materials [1]. Observations such as these have undoubtingly been incorporated into the Mars Pathfinder spacecraft and rover design, making them well equipped to successfully operate in the Chryse Planitia environment. We simply don't know with any level of certainty what the hazards may be in the other areas. The extensive photographic coverage of Chryse Planitia by the Viking Orbiters and Earth-based radar observations has provided 100-m-resolution topography in the vicinity of the Viking 1 lander [2]. Analysis of these data and lander photographs indicate that Chryse Planitia may be unique in that features >50 km away from the lander (such as the rims of Lexington and Yorktown Craters) are visible over the horizon [3]. This type of information could potentially aid in roving-vehicle navigation. However, the most important use of the Viking orbiter data will be in simply determining the location of the Mars Pathfinder spacecraft on the surface. These same data were useful in determining the location of the Viking 1 lander to within ~50 m [4].

A landing site should ideally include access to as many different geologic units as possible. In addition to the materials debouched into the Chryse Basin by the large martian channel complex [5], the Hesperian-age ridged plains covering much of the region [6] represent the single most important geologic unit needed for age-dating materials on Mars. Composing ~3% of the total Mars surface area [7], the ridged plains are fairly widespread in comparison to other geologic units, and, more importantly, are the Hesperian epoch referent [8]. Because the Hesperian epoch represents the interval of time immediately following the period of heavy bombardment (~3.8 Ga [9]), an absolute age determined from a ridged plain sample would allow estimates of the postheavy bombardment impact flux on Mars to be calibrated. It may then be possible to determine the absolute ages of every younger geologic unit on Mars based on crater statistics. Potential Hesperian ridged plains outcrops identified in Viking 1 lander images may represent the only known bedrock exposures on Mars. Mars Pathfinder rover analyses of these materials could provide data to support the hypothesis that these are bedrock materials, which could be crucial for future sample return missions. In addition, materials washed down from the highlands may be present in Chryse Planitia. Although the absolute ages of these materials almost certainly correspond to the period of heavy bombardment, analysis of their composition could provide some insight into the early geologic history of Mars. Also, the distribution of the materials in Chryse Planitia as determined by a long rover traverse may be indicative of the channel formation mechanism. For example, catastrophic flooding would lead to a Bouma sequence deposit in the Chryse basin [10]; in liquefaction, an accretionary lobe in the debouching area results in larger particles dropping out first with smaller particles being transported greater distances [11]. The Mars Pathfinder Meteorology Package (MET) would almost certainly augment the data obtained from the Viking Meteorology Experiment. The Viking Meteorology Experiment was capable of providing information at only one height, which is insufficient for determining the boundary layer profile in Chryse Planitia. However, because the MET will provide information from multiple heights, profiles from the Viking data may be derived.

Because of the likelihood of running water debouching into Chryse Planitia in the past, the Viking 1 landing site was considered an ideal place to look for complex organic molecules [12]. Although the Viking biological experiments did not identify the presence of organic life [13], controversy still exists as to the meaning of the Labeled-Release Experiment [14]. A landing in Chryse Planitia would make it possible to investigate the composition of the same soil samples investigated by the Viking 1 lander. Rocks seen in lander images could also be analyzed, answering questions concerning their compositional and erosional properties. Depending on the exact Mars Pathfinder landing site and the accuracy of rover navigation, it may be possible to examine the Viking 1 lander 1 itself! *In situ* erosional analysis of Lander 1 could allow the current martian weathering rate and eolian deposition to be determined. Such information could also serve as a valuable aid in developing future martian spacecraft materials. Alternatively, it may be possible to navigate from the lander to the crater caused by the jettisoned Viking aeroshell. Ejecta from this fresh crater would represent Chryse stratigraphy to a depth of ~1 m, providing additional information on the nature of the surface materials observed by the Viking 1 lander. Although crater ejecta is frequently suggested as material that should be sampled by a spacecraft during a traverse, such stops are rarely justified. Crater ejecta, especially the outer ejecta blanket, typically has the same composition as the surrounding rock. It is the traverse up to the crater rim crest where material at depth is gradually exposed, the deepest material being exposed directly at the rim crest, typically from a depth equivalent to one-tenth the crater diameter. However, a simple examination of crater ejecta from a larger-diameter crater could potentially provide some valuable information. "Rampart" [15] or "fluidized ejecta" craters [16] have been suggested as forming from the incorporation of volatile material from depth [15] or from the interaction of the ejecta curtain with a thin atmosphere during emplacement [17]. The derived volatile content and/or sediment distribution from a rampart crater (e.g., Yorktown, 7.9 km diameter, ~45 km northwest of the Viking 1 landing site) could provide clues as to which formation mechanism is the most viable.

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N95-16184

p-2

RATIONALE FOR ISIDIS PLANITIA AS A BACK-UP LANDING SITE FOR THE MARS PATHFINDER MISSION.

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As discussed previously [1], the present engineering constraints imposed on the Mars Pathfinder mission leave only three broad regions available for site selection: Amazonis, Chryse, and Isidis Planitiae. Because of the knowledge gained by the Viking 1 mission, Chryse Planitia would make an ideal primary landing site. The principal objectives of this mission should be to determine the composition and distribution of surface materials. Analysis of rocks in Chryse Planitia would build upon results obtained by the Viking 1 lander and answers questions concerning composition and origin of these materials. Of particular interest would be determining whether proposed bedrock materials are indeed *in situ* materials and the degree of weathering these materials may have undergone. Because these materials may represent Hesperian-aged ridged plains, they could potentially be the key to understanding the absolute ages of the martian epochs. Results of the Mars Pathfinder could determine whether the bedrock materials are indeed Hesperian ridged plains materials, which could influence the priorities of future sample return missions.

Isidis Planitia also contains material that is Hesperian in age [2]. These materials, however, are from the Late Hesperian epoch and mark the end of this period. Nonetheless, identifying exposed bedrock materials from this unit would also be important as radiometric age dates obtained by future missions could determine which model for the absolute ages of the martian periods is correct (Fig. 1). Analysis of the temperature contrast measured by the Viking Infrared Thermal Mapper [3] suggests that the spatial distribution of rocks in Isidis Planitia may be as high as 20%, similar to that observed at both Viking landing sites. Central and northeastern Isidis Planitia appear to be much smoother, containing <10% rocks. These data suggest that Mars Pathfinder could expect to find similar or perhaps more favorable conditions than observed at the Viking 1 landing site. In addition, extensive Viking orbiter data with resolution ≤50 m/pixel exists for most of Isidis Planitia. Without an additional orbiter imaging system, these data will be critical for determining the location of the lander once on the surface. Similar data were useful in determining the location of the Viking 1 lander to within ~50 m [4].

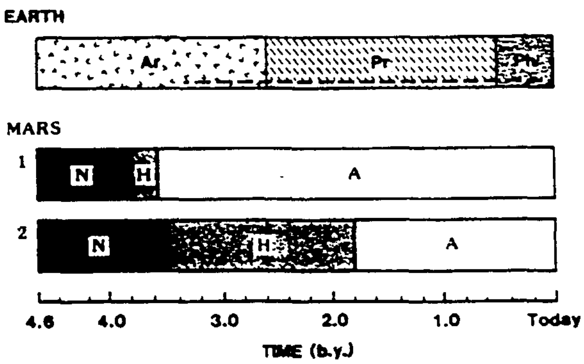

Fig. 1. Geologic time for the Earth can be broken into the Archean (Ar), Proterozoic (Pr), and Phanerozoic (Ph) periods. The dashed line represents the amount of time life is known to have existed on this planet. Geologic time for Mars is divided into the Noachian (N), Hesperian (H), and Amazonian (A) periods. The absolute ages are estimated from two different models of cratering rates. A sample of Hesperian material could determine whether model 1 [17] or model 2 [18] is correct. Because geologic evidence suggests that liquid water existed on the martian surface during both the Noachian and Hesperian, absolute ages based on model 2 imply that microbial life may have also evolved on Mars. (Reproduced from [19].)

The material contained in the interior of Isidis Planitia is frequently interpreted to be an eolian deposit [2,5,6] based on the morphology and relative ages of these units. Examination of high-resolution Viking orbiter images suggest that these materials also exhibit a systematic pattern of terrains from the interior outward to the basin rim [6]. These investigators suggested that Isidis Planitia had been the location of a thick, volatile-rich debris layer that was subsequently removed. Crater statistics and the buried morphology of craters contained within the annulus of material surrounding the basin also suggest some type of resurfacing event. However, it has also been proposed that water may have stood in Isidis Planitia [7], perhaps as part of an ocean covering the northern hemisphere of Mars [8]. Such a hypothesis may also explain the stratigraphy. Examination of the grain size and distribution of surface materials may yield clues as to the viability of either of these hypotheses. Particularly useful may be the analysis of material excavated by the crater resulting from the jettisoned Mars Pathfinder aeroshell, if it could be located. A long rover traverse (i.e., several kilometers and out of the view of the lander), however, may ultimately be required to examine such unit differences on the surface.

A variety of mechanisms has been proposed to explain the enigmatic mounds and arcuate ridges in the interior of Isidis Planitia, including volcanic cinder cones [9–11], pingoes [12], and glacial features [6,12,13]. Because of their close spacing (tens of meters), it is very likely that Mars Pathfinder would land in the vicinity of one of these features. Surface images and compositional analyses of surface material would provide valuable clues as to their origin. Such information is important for understanding the geologic history of Mars and the climatic transition that planet may have experienced from the late Hesperian into the Amazonian.

As in Chryse Planitia, the Isidis Basin contains both lunarlike and rampart craters. "Rampart" [14] or "fluidized ejecta" craters [15] have been suggested as forming from the incorporation of volatile material from depth [14] or from the interaction of the ejecta curtain with a thin atmosphere during emplacement [16]. The derived volatile content and/or sediment distribution from a rampart crater near the Mars Pathfinder landing site could provide clues as to which formation mechanism is the most viable.

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CHRYSE PLANITIA AS A MARS PATHFINDER LANDING SITE: THE IMPERATIVE OF BUILDING ON PREVIOUS GROUND TRUTH. L. S. Crumpler, Department of Geological Sciences, Brown University, Providence RI 02912, USA.

Introduction: Based on consideration of the geological characteristics of Chryse Planitia, the requirements for Mars Pathfinder landing sites, the nature of the mission, the scale of the observations to be made, and the need to build outward from previous experience, a new mission to Chryse Planitia offers several advantages that are difficult to ignore and offers a low-gamble/high-return mission scenario. Considering the need to ensure a successful mission, and to ensure the continued health of planetary exploration, the reasons for a new mission to Chryse Planitia are compelling.

Results of 1:500,000 Mapping: Based on recent geologic mapping [1,2], Chryse Planitia is the result of the following generalized sequence of erosional and depositional events: (1) an early impact basin [3] centered at 32.5°N, 35.5°W [4]; (2) basin resurfaced during emplacement of an unspecified material, possibly lavas; (3) geologic unit on which the Viking Lander is situated was buried to a depth of several hundred meters by an early mare-type ridged plains surface and superposed impact craters; (4) sediments shed from the highlands formed a uniform unit over much of the southern and southeastern basin; (5) subsequent impact cratering and regional mare-type ridge formation; (6) catastrophic outflows of water from Maja Valles to the west and Kasei Valles to the northwest scoured and incised all preexisting units and resulted in additional deposition in the basin interior; and (7) the Viking Landing site was resurfaced at least in part by the deposition of sediments carried by Maja Valles and Kasei Valles.

Operational Benefits of Chryse Planitia: All potential landing sites within Chryse Planitia satisfy the primary operational requirements for the Mars Pathfinder mission: (1) low latitude = 22°N ± 2° and 46.5°W ± 5°; (2) altitude below 0 km = –1 to –3 km below datum; (3) landing ellipse free of large-scale hazards = Chryse Planitia has some of the largest expanses of low-hazard terrain on Mars. A critical advantage is that the engineering requirements for landing in Chryse are well known at lander scales. The block size distribution is known and predictable: blocks ≥1 m account for ≤4% of the surface area. Known meteorological conditions during predawn landing of Mars pathfinder indicate very low winds at the surface and aloft, and high-resolution regional images exist for local landing site selection. Based on my experience on the Viking Lander 2 site selection effort, landing ellipses are difficult to situate at large scales and these additional considerations are likely to be overriding during final landing decisions.

Science Benefits of Chryse Planitia: Different scale features require different path lengths in order to accumulate adequate "truth" (N) about that feature; the cumulative rate is an inverse exponential (to some constant, n) of traverse length (R) such that (N~ ((R)exp(1/n))/C). The proposed Mars Pathfinder rover capabilities are excellent for addressing many of the small-scale mineralogical and lithological questions raised by initial Viking Lander study, but regional lithologic questions cannot be addressed with the same rover capabilities. The probable diverse lithologies of blocks at small scale in the Chryse Basin deposited from outflow events in Maja and Kasei take advantage of the ability of Mars Pathfinder rover to make small-scale mineralogical investigations while increasing the information content of small-scale investigations during short traverse lengths.

Knowing the detailed questions that will be asked greatly increase the ability to design a successful experimental test: Viking Lander 1 raised detailed questions that Mars Pathfinder may be designed and engineered specifically to address. For example, what are the dense, coarse, and pitted lithologies? What is the origin of the block distribution? Impact? Outwash? *In situ* weathering? What is the grain size of the surface fines, sand or silt? What is the microstratigraphy of the fines? Is there a stable substrate in Chryse at lander scales of observation? Other regional geological issues remain: What is the geological unit of central Chryse, volcanic or sedimentary? Is there microscale evidence for standing water or water-derived precipitates? If these questions cannot be answered in Chryse with carefully designed experiments and some prior

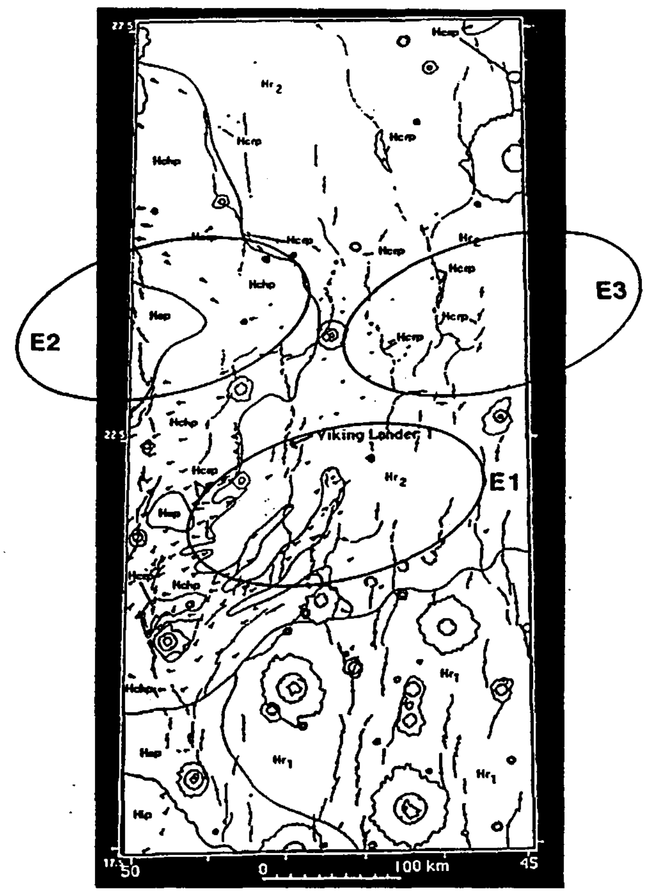

Fig. 1. Geologic map of the MTM 25047 and 20047 photomosaic sheets in the Viking Lander 1 region of Chryse Planitia. Map units: Hr_2 = upper ridged plains; Hr_1 = lower ridged plains; Hsp = smooth plains; Hcrp = channel and ridge plateau; Hchp = channel plains; Hip = incised plains. See Crumpler et al. [1] for more detailed description and interpretation of units. Numbered landing ellipses are 100 km × 200 km and indicate recommended sites: E1 = safest; E2 = less safe; E3 = intermediate level of safety based on degree of similarity to VL-1 site.

knowledge, then they will be more difficult elsewhere where the questions are unknown.

Conclusions and Site Recommendations: It is tempting to set the sights for future prospects on many of the additional interesting areas defined on Mars since the Viking mission and expand the database for ground truth to new and different terrains. This desire should be balanced with the critical need for success in planetary exploration in general and avoidance of an inconclusive mission result in particular. An important goal should be learning how to operate on Mars and addressing answerable questions. A firm start on the latter can be attained by a new mission to Chryse Planitia in the region specified, in which the existing ground truth of the Viking Lander 1 is used to constrain the engineering choices and to design appropriate instrument goals to fully utilize the lander limitations and capabilities. Three proposed sites are indicated on Fig. 1 along with the currently defined landing ellipses. Site E1 is most likely to be similar to VL-1; site E2 is less well constrained and is likely to differ from VL-1 in some respects; and site E3 is likely to be similar to VL-1, but incorporates slightly less hazardous, but slightly different terrain.

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A HIGHLAND SAMPLE STRATEGY FOR PATHFINDER.
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Mission Constraints: Potential landing sites are confined to latitudes between 0° and 30°N and surfaces below 0 km elevation. The landing ellipse is 100 × 200 km oriented N74°E. The constraints essentially eliminate the slopes of Elysium Mons, Olympus Mons, Tharsis Ridge, Lunae Plaunum, all the southern highlands, and almost all the Noachian material of Arabia Terra. Those areas that remain as potential landing sites are chiefly lowland plains of Amazonis Chryse, Isidis, and Elysium Planitiae.

Siting Strategy: With only two previous Viking landing sites in widely separate locations, almost any landing will provide new data. Viking 1 landed on Chryse Planitia on a surface that is presumed to be Hesperian ridged plains material, which is interpreted to consist of volcanic flows [1]. Viking 2 landed on knobby material in Utopia Planitia, which is interpreted as eolian and volcanic materials [2]. The large landing ellipse precludes a finely targeted sampling strategy. Several site selection strategies are equally valid. Presumably, Noachian materials are more representative of the geochemical character of the planet than the volumetrically less important surficial flows and sedimentary materials.

Any attempt to sample highland material further constrains the possible landing sites by eliminating areas of Hesperian or Amazonian lavas and sediments. Materials of possible Noachian age are primarily located above 0 km elevation and at southern latitudes, except for minor occurrences in Arabia Terra and a narrow zone along the southern edge of Elysium Planitia.

One possible sampling strategy is to sample materials within those few "highland" terrains that extend to low elevations. Minor occurrences of Noachian materials are exposed at low elevations as outliers flanked by younger material within Nepenthes Mensas and Aeolis Mensas, but such areas are rugged and unsuitable for a safe landing. However, parts of western Arabia Terra extend to acceptable elevations and are reasonably smooth.

A second strategy is to sample materials at the mouth of an outflow channel that drains from the highlands. Channels may terminate in deltas, alluvial fans, or sheet deposits. For simplicity these deposits will be refered to as "fans." Fans provide materials from a large sampling area, and dissected fans offer the advantage of providing a vertical section of exposed stratification that records the history of the outflow.

On first appraisal, any fan at the mouth of a channel draining from highlands offers a potential target, but not all fans offer equal opportunities. Many outflow channels have ponded along their length; hence, any sediment carried by the discharge at the mouth is derived only from the last site of ponding [3]. Further, although catastrophic outflows are characterized by high sediment load and large caliper, the last sediments deposited during waning discharge are generally fine grained.

Potential Landing Sites: Potential landing sites include outflow channel material at the edge of Chryse Planitia and highland materials bordering southern Amazonis Planitia. The circum-Chryse channels include Kasei Valles into northwest Chryse Planitia; Bahram Vallis, Vedra Valles, Maumee Valles, and Maja Valles into western Chryse; Shalbatana Vallis into southwest Chryse; channels draining from Capri and Eos Chasmata into southern Chryse (Simud. Tiu, and Ares Valles); and Mawrth Vallis into northeast Chryse Planitia. With so many large outflow systems terminating within Chryse Basin, it is probable that any landing site within the basin (including Viking 1 landing site) will be blanketed by sediments from catastrophic outflows or outflow sediments reworked by eolian activity. Channels in southern Chryse Planitia, originating within Vallis Marineris or chaotic terrain south of Chryse Planitia, traverse Noachian material before entering the basin, but they do not provide readily identifiable fans.

Best Bets: Mawrth Vallis of the Oxia Palus region cuts Noachian cratered plateau material, which is interpreted to be largely impact breccia of ancient crust [4]. The plateau surface bordering the lower reaches of the channel, below 0 and –1 km elevation, is one of the few places on Mars where typical highland material can be found below 0 km elevation. Three landing sites are feasible. One potential site is at the mouth of the channel (29°N, 21°W); an alternate site is on the plateau surface adjacent to the valley (28°N, 18°W); and a third site is south of Mawrth Vallis and east of Ares Vallis (2°N, 2°W). The highland site adjacent to Mawrth Vallis is more likely to contain less surficial cover than the site east of Ares Vallis. If not covered by surficial material, highland sites are likely to consist of highly commuted materials; they would provide an estimate of the geochemical character of the homogenized early crust.

The mouth of Maja Canyon (18°N, 50°W), with remnant fan material cut by late-stage discharges [5,6], offers the best channel mouth target. The chief constituents here are likely to be detritus from Noachian material of the Xanthe Terra region carried by outflow that spilled onto Chryse Planitia following ponding behind a barrier massif of Noachian basement material.

Pitfalls and Predictions: The large landing ellipse and low resolution of Viking images do not allow assurance that the landing site will contain any particular anticipated material. Extremely localized deposits of young materials are possible in the highlands, and mature, winnowed sediments are possible in the plains. Interpretation of chemical anlyses of fan materials without corresponding petrologic comparison will be challenging.

In all probability, the final choice of a landing site will be a level lowland within the planatiae. A sedimentary surface of an essentially monomineralic, eolian (sand or loesslike) material or a lacustrine deposit should not be a surprise.

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OPPORTUNITY TO SAMPLE SOMETHING DIFFERENT: THE DARK, UNWEATHERED, MAFIC SANDS OF CERBERUS AND THE PATHFINDER 1997 MARS LANDING.

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Dark Material Critical to Understanding Mars Surface: A very important surface component, typically described as "dark gray material" [1], was not seen at the Viking lander sites, but is common to all low-albedo regions on Mars. Dark material probably includes unaltered mafic volcanic and/or crustal rock and soil not coated by dust, weathering rinds, or varnish [2].

A Pathfinder landing in Cerberus (9°N– 16°N, 194°W–215°W) will guarantee examination of materials that are distinctly different from the two Viking lander sites. *In situ* study of dark material will provide vital ground truth for orbiter-based observations like those anticipated from Mars '94/'96 and Mars Global Surveyor.

Surface Properties and Regional Context: The Cerberus region is (1) not as rocky as the Viking sites, (2) not blanketed by dust, and (3) offers sampling of a range of rock and soil types including lava flows of different ages, ancient crustal rock, dark sand, bright dust, and possible fluviolacustrine materials. Cerberus lies between 0 and –1 km elevation (±1 km; USGS 1991 topography), and is large enough to meet our main objective within the landing ellipse constraints. Cerberus is an active eolian environment, but major dune fields are absent and activity is not as vigorous as in Syrtis Major [3]. The landing will occur in northern summer, a period when predicted winds are not at their strongest in the region [4].

The dark surfaces have low albedos (<0.15) and intermediate thermal inertias [5] (300–400 J m^{-2} $s^{-0.5}$ K^{-1}), which indicate that much of this material is sand (100–1000 µm). Rock abundance [6] varies from ~12% in the east, where the surface has many knobs and mesas, to ~1% in the west, with average over most of Cerberus ~7%. (Viking 1 rock abundance was ~10% and Viking 2 was ~20% [5]).

The dark soil of Cerberus is superposed on several different geomorphic features. Central and western Cerberus is underlain by Early Amazonian volcanic flows originating on the Elysium Rise [7]. Cerberus is bounded in the south and east by interpreted paleolake deposits [7,8] and very recent (0 to 700 Ma) lava flows [9]. Eastern Cerberus includes a smooth surface of Late Amazonian fluvial, lacustrine, and/or volcanic deposits [7–9] and Noachian(?) mesas and knobs of the Tartarus Colles [7].

Dark Material and Source: Dark sand has been transported through and deposited within Cerberus [3,10,11]. Lateral variation in sand deposit thickness is probable, with sand filling low areas on and between lava flows. Dark material has blown from east to west over the lava flows of southern Elysium, perhaps making Cerberus similar to the Amboy volcanic field of Southern California. Amboy has lava flows overlain by windblown sand stripped from an upwind dry lake [12].

Dark material might be eroded from sediments of the proposed lacustrine basin [8] east of Cerberus. Alternatively, the sand may have a volcanic source, perhaps pyroclastic material from the Elysium volcanos or from eruptions along the Cerberus Rupes fractures. Dark material appears to emanate from some Cerberus Rupes fractures ([11], Viking image 883A09). Do the fractures expose a layer of dark material that is now eroding [10,11]? Did dark material from the east fill the fractures, and now is being deflated? Or were the fractures the sites of pyroclastic eruptions? One fracture seen in the upper left corner of Viking frame 385S23 has a dark, semi-elliptical mantle deposit similar to pyroclastic deposits on the Moon and Io.

Pathfinder Science: Cerberus is large enough that several landing sites could be chosen. Although any landing in Cerberus will satisfy our main objective, we suggest a site near 13°N, 200.5°W (see Viking frame 883A06), because it has both dark material and proximity to the three major geomorphic units in the region (lava flows, possible lake sediments, and knobs of ancient crust). In addition, at this site there is a dark lobe that appears to emanate from a Cerberus Rupes fracture (Viking frames #883A04-06) that might be one of the youngest, unaltered lava flows on Mars. Although not reporting on this specific flow, Plescia [9] proposed that the Cerberus Rupes were the source of some very young lava flows (<700 Ma).

The main objective for a Cerberus landing will be to determine the composition and physical properties of dark soils thought to be derived from unaltered primary igneous crustal material. Characterization of the size, shape, and mineralogy of dark grains 0.1 mm to 10 cm will allow assessment of sediment maturity. Is martian sand formed of ancient, resistant mineral grains or fresher, easily altered material? The answer to this question will place constraints on chemical weathering and eolian abrasion rates. Bright wind streaks in the lee of craters in Cerberus suggest that dust might also be available for sampling, particularly in the lee of meter-scale obstacles. Finally, the presence of sand or granule wind ripples would provide insight into the nature of surface-atmosphere interactions on Mars.

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EXOBIOLOGY SITE PRIORITIES FOR MARS PATHFINDER. J. D. Farmer and D. J. Des Marais, NASA Ames Research Center, Moffet Field CA 94035, USA.

Although present martian surface conditions appear unfavorable for life as we know it [1], there is compelling geological evidence that the climate of early Mars was much more Earth-like, with a denser atmosphere and abundant surface water [2]. Three key post-Viking discoveries mandate a more rigorous search for a martian biosphere. First, 3.5-b.y.-old fossils indicate that our own biosphere might be almost as old as Earth itself [3]. Second, climates on both Earth and Mars have evolved through time. Third, the range of Earth's habitable environments is greater than previously known. Extremes for terrestrial life include polar deserts, deep subsurface aquifers and hydrothermal systems, and high-salinity ponds and lakes. The fact that life developed on the Earth within the first billion years of its history makes it quite plausible that life may have also developed on Mars [4]. If life did develop on Mars, it undoubtedly left behind a fossil record. Such a fossil record is likely to be more accessible than either subsurface environments that may harbor life, or scattered "oases" that may be present at the surface. Consequently, the post-Viking approach of Mars exobiology has shifted focus to search for evidence of an ancient martian biosphere. This has led to the emergence of a new subdiscipline of paleontology, herein termed "exopaleontology" [5], which deals with the exploration for fossils on other planets and whose core concepts derive from Earth-based Precambrian paleontology, microbial ecology, and sedimentology [6,7].

By analogy with the Precambrian record of the Earth, an early martian biosphere is likely to have been microbial. The types of micropaleontological information we could expect to find on Mars include microbial body and trace fossils, biostratification structures (e.g., stromatolites), and biomolecular fossils. Based on what we have learned from the Precambrian record on Earth, the best preservation of microorganisms as fossils occurs when they are rapidly entombed by aqueous minerals while the organisms are still viable, or at least prior to cellular degradation [6,7]. For long-term preservation (i.e., billions of years), organic materials must be incorporated into or replaced by fine-grained, stable phases (e.g., silica, phosphate, or carbonate). Terrestrial microfossils were preserved in this way, being permineralized in siliceous sediments (cherts) associated with ancient volcanic terrains in Australia and South Africa [8,9].

The above observations lie at the core of the proposed exploration strategy to search for a fossil record on Mars. Terrestrial environments where high rates of aqueous mineral precipitation and microbial activity coincide include subaerial thermal springs and shallow hydrothermal systems, sublacustrine springs and evaporitic lakes, subsurface soils where "hardpans" (e.g., calcretes, silcretes) form, vadose zone karst deposits and silcretes associated with karst paleosols, and high-latitude frozen soils or ground ice [6,7].

Subaerial thermal spring deposits are key targets for a fossil record on Mars [10] because high rates of mineral precipitation may occur together with microbial activity. Volcanic terrains are widespread on Mars and some possess outflow channels that are likely to have formed by spring sapping [11]. The association of such features with potential heat sources, such as volcanic cones or thermokarst features, indicates the possibility of past hydrothermal activity on Mars. Within the landing site constraints for Mars Pathfinder, a number of potential exploration targets meet the basic requirements for hydrothermal activity and associated mineralization, based on analysis of Viking images. These include thermokarst features and areas possibly affected by hydrothermal processes, including (1) the head reaches of small channels in the Ares and Tiu Vallis outflow systems, which originate from areas of chaos, and (2) the floors of chasmata, such as Echus Chasma. Target deposits in such areas include the common subaerial spring minerals, silica and carbonate, as well as hydrothermal alteration halos associated with shallow igneous intrusives (including dike swarms) where hydrous clays may have been formed through hydrothermal alteration of host rocks.

Reliable identification of aqueous mineral phases requires that we incorporate rover-based techniques for *in situ* compositional analysis that provide structural information, in addition to elemental abundance. Target minerals for exopaleontology have characteristic signatures in the near- and midinfrared that should be detectable using rover-based spectroscopy. Future landed missions should incorporate such approaches, along with fiber-optic-based visible and UV microscopy, as standard payload exploration tools for Exopaleontology. Even if life never developed on Mars, aqueous mineral deposits still hold great interest as potential sources of information about the nature and abundance of the precursor organic molecules available in the early solar system. Fluid inclusions incorporated into aqueous minerals during their crystallization provide valuable samples of primary liquid and vapor phases and potentially microorganisms and biomolecules [12]. Although more research is needed, rover-based spectral analysis may provide a sensitive, *in situ* method for distinguishing fluid-inclusion-rich mineral deposits from "dry" rocks [13].

Through Earth-based analog studies, we have also been investigating the paleontology and sedimentology of subaqueous spring deposits formed over a range of temperatures as potential targets for Mars exopaleontology. Rates of mineral precipitation within such environments are often high enough to entomb associated microbial mat communities, and deposits formed at lower temperatures have the advantage of preserving a higher proportion of organic matter [14]. Thus, in contrast to subaerial thermal spring deposits, tufas and evaporites often contain abundant microbial fossils and organic matter. Sublacustrine springs are common in many water-rich volcanic settings, particularly in association with crater and caldera lakes [7]. Sediments deposited in such settings are frequently heavily mineralized and are important exploration targets for many types of economic ore deposits. Some of our finest examples of excellent preservation in the terrestrial fossil record are found in such facies [15].

In pluvial lake basins in western North America, subaqueous spring deposits and sedimentary cements are commonly found along the distal margins of fan delta deposits within mixing zones where fresh ground water encounters alkaline lake water [16,17]. In such terminal lake settings, evaporites are commonly deposited in basinward locations during lake low stands. Evaporite minerals frequently entrap halobacteria and organic matter within fluid inclusions during crystallization. Although the long-term viability of salt-entrapped organisms is debatable [18], entombed organics appear to survive for long periods of geologic time. Consequently, "evaporites" are regarded to be prime targets for Mars exopaleontology for reasons outlined above. The major disadvantage is that, in the presence of an active hydrological system, evaporites tend to have short crustal residence times and are easily lost from the stratigraphic record by dissolution. Thus, terrestrial evaporites are quite rare in Precambrian sequences. However, this may not apply to Mars. Given the early decline of a martian hydrological cycle involving liquid water, it is possible that Archean-aged evaporites have survived there.

Potential targets on Mars for subaqueous spring deposits, sedimentary cements, and evaporites are ancient terminal lake basins where hydrological systems could have endured for some time under arid conditions [19,20]. Potential targets for the Mars Pathfinder mission include channeled impact craters and areas of deranged drainage associated with outflows in northwest Arabia and Xanthe Terra, where water may have ponded temporarily to form lakes. The major uncertainty of such targets is their comparatively younger age and the potentially short duration of hydrological activity compared to older paleolake basins found in the southern hemisphere. However, it has been suggested that cycles of catastrophic flooding associated with Tharsis volcanism may have sustained a large body of water, Oceanus Borealis, in the northern plains area until quite late in martian history [21,22]. Although problematic, the shoreline areas of the proposed northern ocean (e.g., along the Isidis impact basin and the plains of Elysium, Chryse, and Amazonis) provide potential targets for a Mars Pathfinder mission aimed at exploring for carbonates or other potentially fossiliferous marine deposits. Carbonates and evaporites possess characteristic spectral signatures in the near-infrared [23] and should be detectable using rover-based spectroscopy and other methods for *in situ* mineralogical analysis.

Many terrestrial soils are known to preserve microbial fossils and biogenic fabrics within the mineralized subzones of soils, such as calcretes, silcretes, or other types of "hard-pans" [24]. For example, the oldest terrestrial microbiota are preserved in silcretes associated with 1.7-Ga karst. Viking biology experiments indicate that surface soils on Mars are highly oxidizing and destructive to organic compounds. However, mineralized soil horizons could protect fossil organic matter from oxidation and should not be overlooked as potential targets for exopaleontology. At the Viking Lander 2 site, soils showed the development of duricrust, suggesting cementation [25], and sulfate and carbonate minerals are inferred to be present in the martian regolith based on elemental analysis by X-ray fluoresence. Although Viking conclusively demonstrated the absence of organic compounds in the soils analyzed, the presence of cements in martian surface sediments suggests a possibility for hard-pan mineralization that could afford protection to organic materials against oxidation. The best places to explore for mineralized paleosols are deflational areas where wind erosion may have stripped away surface sediments, exposing indurated zones formed at depth. Such sites are widespread within the potential landing area for Mars Pathfinder.

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N95- 16189

MARS PATHFINDER METEOROLOGICAL OBSERVATIONS ON THE BASIS OF RESULTS OF AN ATMOSPHERIC GLOBAL CIRCULATION MODEL. F. Forget, F. Hourdin, and O. Talagrand, Laboratoire de Météorologie Dynamique, E.N.S, Paris, France.

The Mars Pathfinder Meteorological Package (ASI/MET) will measure the local pressure, temperature, and winds at its future landing site, somewhere between the latitudes 0°N and 30°N.

Comparable measurements have already been obtained at the surface of Mars by the Viking Landers at 22°N (VL1) and 48°N (VL2), providing much useful information on the martian atmosphere. In particular, the pressure measurements contain very instructive information on the global atmospheric circulation. The large-amplitude seasonal oscillations of the pressure are due to the variations of the atmospheric mass (which result from condensation-sublimation of a substantial fraction of the atmospheric carbon dioxide in the polar caps), but also to internal latitudinal mass redistribution associated with atmospheric circulation.

The more rapid oscillations of the surface pressure, with periods of 2–5 sols, are signatures of the transient planetary waves that are present, at least in the northern hemisphere, during autumn and winter.

At the Laboratoire de Météorologie Dynamique (LMD), we have analyzed and simulated these measurements with a martian atmospheric global circulation model (GCM), which was the first to simulate the martian atmospheric circulation over more than 1 yr [1,2]. The model is able to reproduce rather accurately many observed features of the martian atmosphere, including the long- and short-period oscillations of the surface pressure observed by the Viking landers (Fig. 1).

Both the annual pressure cycle and the characteristics of the rapid oscillations have been shown to be highly variable with the location on the planet. For instance, simulated surface pressure obtained in the middle latitudes of the southern hemisphere look very different than the Viking landers measurements because of the effect of an opposite meteorological seasonal component. From this

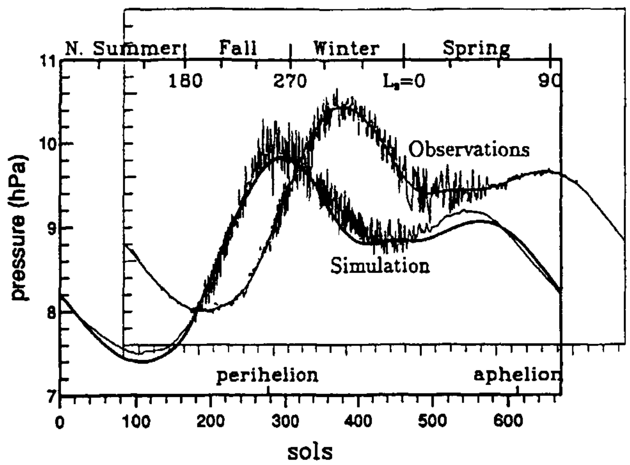

Fig. 1. Observations and simulation of the VL2 site surface pressure.

particular point of view, much could be learned from a future lander located in the southern hemisphere. As we were able to simulate the surface-pressure variation from any point on the planet, we have used the LMD GCM to investigate the climatological properties of the different possible landing sites. Figure 2 shows the surface pressure as simulated at three different points in Isidis Planitia. As in the other possible landing areas, the amplitude of the transient eddies is found to decrease with latitude. Longitudinal differences between the areas below 0 km are small, except that the VL1 site in Chryse Planitia seems to be surprisingly more active than any other possible landing site at the same latitude. The seasonal meteorological component of the annual pressure cycle is minimum at the

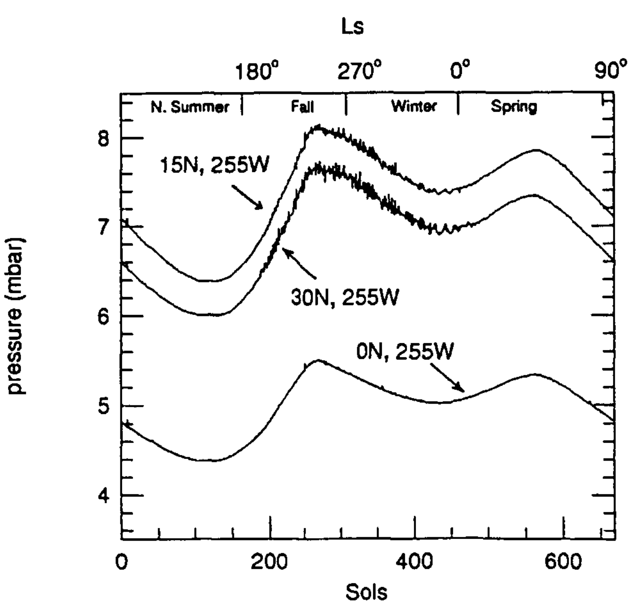

Fig. 2. Simulation of the surface pressure of Isidis Planitia.

equator, thus the local pressure oscillations should reflect the oscillation of the planetary averaged surface pressure, providing a more accurate estimation of the total atmospheric mass than with the Viking data. Such a location near the equator would extend the latitudunal coverage of the Viking Landers. It should also be interesting to observe the behavior of the atmospheric waves and local winds, where the Coriolis force is negligible. Therefore, from a meteorological point of view, we think that a landing site located near or at the equator would be an interesting choice.

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N95-16190

PATHFINDER LANDING SITES AT CANDIDATE SNC IMPACT EJECTION SITES. M. P. Golombek, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

If Mars Pathfinder were able to land at a site on Mars from which the SNC meteorites were ejected by impact, the Pathfinder mission would essentially represent a very inexpensive sample return mission. If this were possible, a particularly significant benefit to Mars science would be having a radiometric age date on a sample from a known location on Mars, which would enable a more precise assignment of absolute ages to the crater/stratigraphic timescale for Mars. Providing such a date would substantially improve our interpretation of the absolute age of virtually all events in the geological, climatological, and atmospheric evolution of Mars. This abstract evaluates the possibility of landing at potential SNC ejection sites and the ability of Pathfinder to identify the landing site as the place from which a SNC meteorite came. Unfortunately, although considerable information could be gained from Pathfinder that might support the hypothesis that the SNC meteorites have indeed come from Mars, it is likely not possible to uniquely identify a site on Mars as being a SNC meteorite ejection site.

Shergottites, nakhlites, and Chassigny (SNC meteorites) are unique mafic to ultramafic meteorites with young crystallization ages that are believed to have been ejected from the martian surface by impact and traveled to Earth [1,2]. Recent interpretations suggest that the shergottites have different crystallization ages and cosmic ray exposure times from Chassigny and the nakhlites (180 m.y. and <2.5 m.y. vs. 1.3 b.y. and 11 m.y. respectively), implying different impact ejection events on Mars [see 3 and references therein]. The young ages of these meteorites and crater-absolute age timescales [4] related to martian stratigraphy [5] limit their place of origin on Mars to Upper Amazonian (shergottites) and Middle or Early Amazonian (Chassigny and the nakhlites) volcanics on Mars. Tharsis is the only area on Mars that has regionally extensive lava flows of Middle and Upper Amazonian age with fresh impact craters larger than 10 km diameter, required to eject the rocks from Mars [6]. Nine fresh (young) impact craters greater than 10 km diameter have been identified on Amazonian volcanics around the Tharsis region [6]. Of these, craters 1 and 2 are below 2 km elevation and within 10° latitude of 15°N. In addition, two other craters in Middle Amazonian lava flows of Amazonis Planitia, northwest of Olympus Mons, are possible SNC craters that are between 20°N and 30°N latitude and below 0 km elevation. Geologic units in which these craters are found could be visited by Pathfinder. These four sites are described below.

Crater 1 is 11.6 km in diameter, located at 10.8°N, 135.2°W (1.5 km elevation) on Upper Amazonian lava flows (Unit Aop [7]) around Olympus Mons. This unit is composed of some of the youngest lava flows on Mars with crater densities suggesting ages of less than 250 or 700 m.y. (depending on crater-absolute age timescale [4]), which makes the crater a candidate ejection site for the shergottites. A 200-km × 100-km landing ellipse would easily fit in this unit. From the crater, the Olympus Rupes scarp is about 1° above the horizon and Olympus Mons is about 1.5° above the horizon, which would register on 15 and 26 pixels respectively in the Imager for Mars Pathfinder (IMP). Landing on unit Aop directly adjacent to Olympus Rupes would result in 9° of scarp above the horizon (or ~160 IMP pixels). As a result, imaging of a large scarp (and any exposed stratigraphy) and volcano (and clouds referenced to an altitude) should be possible at this landing site, provided they are not obscured by local obstacles or topography.

Crater 2 is a 29.2-km-diameter oblique impact crater located at 24.8°N, 142.1°W (0 km elevation) on Upper Amazonian Olympus Mons aureole material (unit Ae [7]). This unit is also very young, although the origin of the aureole material is quite uncertain. Landing on unit Ae directly adjacent to Olympus Rupes (100 km away due to landing uncertainty) would result in ~5° of scarp above the horizon (or 85 IMP pixels), although Olympus Mons would not be in view.

Two other craters 26 km and 28 km in diameter located at 29.5°N, 153°W and 23.5°N, 152°W (elevations between -1 km and -3 km) respectively are located in Middle Amazonian lava flows (unit Ae3 [7]) in Amazonis Planitia, northwest of Olympus Mons. These craters, originally proposed for the SNC meteorites by Jones [8], were dismissed by Mouginis-Mark [6] due to their mantling by smooth plains of apparent windblown origin. Nevertheless, geological relations nearby indicate this smooth material is underlain by lava flows, so that impacts into this unit by these two fairly large craters could have easily excavated underlying lavas.

Pathfinder is equipped with three instruments that could help identify the rock types near the landing site. The alpha proton X-ray spectrometer (APXS) will determine the elemental abundances of most light elements except hydrogen. This instrument, mounted on the rover, will measure the composition of rocks and surface materials surrounding the lander. In addition, the cameras on the rover will take millimeter-scale images of every APXS measurement site, so that when combined with the spectral images from the lander IMP, the basic rock type and its mineralogy should be decipherable. For the most part this data should be enough to determine if the rocks at the Pathfinder landing site are consistent with SNC mineralogy; i.e., are the rocks mafic to ultramafic cumulates or fine-grained lavas? If the answer is affirmative, the observation significantly strengthens the interpretation that the SNC meteorites do, in fact, come from Mars. Unfortunately, this does not by itself establish that the SNC meteorites came from the Pathfinder landing site. Establishing this may be difficult if not impossible for a remotely operated lander on Mars. The kinds of tests required might include minor- and trace-element chemistry, as well as oxygen and carbon isotopes, and it is not clear that these measurements, by themselves, uniquely identify that the SNC meteorites came from a particular site as opposed to coming from Mars in general. In addition, most lava flow fields are heterogeneous on a local scale, exhibiting a variety of mineralogies in close proximity. Thus, landing on a flow that has a mineralogy closely matching that of a SNC meteorite would be serendipitous.

Geologic units that contain four potential impact craters from which SNC meteorites could have been ejected from Mars are accessible to the Mars Pathfinder lander. Determining that SNC meteorites came from a particular spot on Mars raises the intriguing possibility of using Pathfinder as a sample return mission and providing a radiometric age for the considerably uncertain martian crater-age timescale. Pathfinder instruments are capable of determining if the rock type at the landing site is similar to that of one or more of the SNC meteorites, which would strengthen the hypothesis that the SNC meteorites did, in fact, come from Mars. Unfortunately, instrument observations from Pathfinder (or any remotely operated landed vehicle) are probably not capable of determining if the geologic unit sampled by the lander is definitively the unit from which a SNC meteorite came from as opposed to Mars in general or perhaps a particular region on Mars.

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N95-16191

STRATEGY FOR SELECTING MARS PATHFINDER LANDING SITES. R. Greeley[1] and R. Kuzmin[2], [1]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287, USA, [2]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Kosygin Street, 19, Moscow, 117975, Russia.

Many feasibility studies have been undertaken for martian roving vehicles. Most studies assumed rovers that would be capable of traversing tens, hundreds, or even thousands of kilometers over diverse terrains. Such capabilities are scientifically desirable but operationally unrealistic with current budget limitations. Instead, attention must focus on rovers traversing less than a few hundred meters and involving a relatively limited scientific payload. Consequently, a strategy for Pathfinder site selection must be developed that is fundamentally different from most previous considerations. At least two approaches can be identified.

In one approach, the objective is to select a site representing a key geologic unit on Mars, i.e., a unit that is widespread, easily recognized, and used frequently as a datum in various investigations. An example is a site on Lunae Planum (20°N, 61°W; +1 km elevation). This site is on Hesperian-aged ridged plains, a unit that is widespread on Mars and serves as a key datum for geologic mapping. This material is of very high priority for a future sample return in order to obtain an absolute age for the base of the Hesperian system. Although ridged plains are inferred to be volcanic and interpreted to be basaltic lava flows, this interpretation is based on analogy with lunar mare units and is open to question. Compositional measurements and observations of rocks at the site via a rover would address the origin of ridged plains and contribute substantially to understanding martian history. For example, should ridged plains not be basalts or other igneous rocks, the interpretation of the volcanic evolution on Mars would be very different from current models. The disadvantage to the approach of landing on a homogeneous unit, such as the ridged plains, is that the measurements would be primarily for a single rock type (but of known geologic context) and would not address questions of compositional diversity on Mars.

The second approach is to select a site that potentially affords access to a wide variety of rock types. Because rover range is limited, rocks from a variety of sources must be assembled in a small area for sampling. Sedimentary deposits, such as channel deltas, derived from sources of various ages and rock types, potentially afford this opportunity. For example, a site in southeast Chryse Planitia (19.3°N, 35°W; −1.5 to −1.0 km elevation) is on outwash plains from Ares, Tiu, Shalbatana, and Simud Valles. Headwind regions for these channels include assemblages of ancient crust (Noachian plateau material) and Hesperian ridged plains, as well as modern eolian deposits indicated by local wind streaks. This general approach is demonstrated in Death Valley, where landing site studies were conducted, simulating Mars. A randomly located "touch down" was made on the Furnace Creek alluvial fan. Within a 1-m radius of the landing site, samples of rock included basalt, rhyolite, diorite, quartzite, limestone, and siltstone; within a 2-m radius, additional rocks included sedimentary breccia, carbonate siltstone, and gabbro. All these rocks were transported from the surrounding mountains. Although Death Valley is not a complete analog to Mars, the area shows that alluvial fans and river mouths may be good sites to collect a wide variety of rocks. The disadvantage of this approach on Mars is that the geological context of the rocks in the deposit is not known, and the compositions of the potential contributing source units must be inferred.

Regardless of the approach taken in site selection, the Pathfinder site should include eolian deposits and provisions should be made to obtain measurements on soils. It is important to note the fundamental difference between dust (known to exist on Mars) and sand (suggested to exist). Martian dust is <10 μm in diameter and is settled from suspension. The dust is probably derived from a wide variety of sources and is thoroughly mixed through repeated cycles of global dust storms. As such, dust represents a global "homogenization." In contrast, sand is deposited from transport in saltation and reflects mostly local and regional sources upwind from the site. Sand grains are probably a few hundred micrometers in diameter or larger. Wind streak orientations and general circulation models of the atmosphere provide clues to the sources for sand. In addition to sand and dust, soils may include material derived from local weathering. Thus, it is desirable to be able to handle and analyze all three potential components of martian soil: dust, sand, and locally weathered material.

Tests conducted in March 1994 at Amboy lava field in the Mojave Desert with the Russian Marsokhod rover provide insight into the scientific use and operation of small rovers. The range was <100 m and the imaging system was limited in resolution. "Descent" images (a series of progressively higher-resolution images from orbital scales down to ~20 cm/pixel) were available for planning the science tests and rover operations. Initial results indicate (1) without the context provided by the descent images, the geologic setting of the site would have been difficult or impossible to determine (Pathfinder, for example, will not have descent imaging); (2) the low height (~1 m) of the stereo camera on the rover gives a different perspective of the terrain than is obtained from standing in the field; (3) the stereo imaging system developed for navigation by the rover was inadequate for most science analyses; and (4) the use of a simulated hand lens (×10) and microscope (×100) was extremely valuable for analysis of sand, dust, and rock samples.

Based on these considerations, a recommended approach for selecting the Mars Pathfinder landing site is to identify a deltaic deposit, composed of sediments derived from sources of various ages and geologic units, that shows evidence of eolian activity. The site should be located as close as possible to the part of the outwash where rapid deposition occurred (as at the mouth of a channel), because the likelihood of "sorting" by size and composition increases with distance, decreasing the probability of heterogeneity. In addition, it is recommended that field operation tests be conducted to gain experience and insight into conducting science with Pathfinder.

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OBSERVATIONS BY THE MARS '94 ORBITER AND POSSIBLE CORRELATIONS WITH MARS PATHFINDER. H. U. Keller, Max-Planck-Institut für Aeronomie, D-37189 Katlenburg-Lindau, Germany.

The Mars '94 spacecraft will still be operational when Mars Pathfinder begins its observations. While it will probably not be possible to detect the lander directly, the terrain, including the landing error ellipse, can be covered in high resolution (10 m) in various color bands. The stereo capability of the high-resolution camera will provide a three-dimensional terrain map. The landing site of Pathfinder could possibly be chosen so that correlated observations of IMP and the remote sensing instruments onboard Mars '94 may be possible. We will discuss this scenario based on the presently adopted Mars '94 orbit and resulting enhancements stemming from correlations of data obtained by both spacecraft.

N95- 16193

POTENTIAL LANDING SITES FOR MARS PATHFINDER. R. Kuzmin[1], R. Landheim[2], and R. Greeley[3], [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Kosygin Street, 19, Moscow, 117975, Russia, [2]Departments of Botany and Geology, Arizona State University, Box 871404, Tempe AZ 85287, USA, [3]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287, USA.

The last successful landing on Mars occurred in 1976 with the Viking mission. In the ensuing years, much has been learned about Mars and the characteristics of its surface. In addition to a better understanding of the geological evolution of Mars, new techniques for processing available data have emerged, new data have been acquired, and the engineering approaches for placing spacecraft on the surface have evolved. Selection of the Mars Pathfinder landing site must take these issues into account, along with mission constraints. In addition, consideration should be given to complementary sites chosen for the Russian Mars '94/'96 lander. The Mars '94 mission will establish a network of two small stations and two penetrators (Table 1) in Arcadia Planitia. Sedimentary and volcanic deposits are characteristic of the northern and southern regions respectively.

TABLE 1. Potential Mars Pathfinder landing sites.

Prior. #	Location	Lat/Long.	Elevation	Geology	MC Chart
1	Ares Vallis/Tiu Vallis	19.3°N, 35°W	−1.5 to −1 km	Fluvial dep. (delta?) (N, H, A)*	11 NW/Amazonis Planitia
10	Mawrth Vallis	27°N, 23°W	< 1 km	Fluvial dep. (delta?) (N, A)*	11 NE/Oxia Palus
11	Hypanis Valles	11.5°N, 45.5°W	0 to 1 km	Fluvial dep. (delta?) (N)*	10 SE/Lunae Palus
9	Kasei Valles	26°N, 48.5°W	−3 to 0 km	Fluvial dep. (delta) (N, H, A)*	10 NE/Lunae Palus
8	Maja Valles	17.5°N, 53°W	−1 to 0 km	Fluvial dep. (delta?) (N, H)*	10 NE/Chryse Planitia
2	Kasei Valles	21°N, 75.5°W	0 to 1 km	Fluvial and eolian mat. (N, H, A)*	10 NW/Lunae Palus
12	Arago Crater	10.2°N, 330°W	1 to 2 km	Fluvial and eolian mat. (N, A)*	12 SE/Arabia Terra
6	Marti Valles	6.5°N, 183.5°W	−1 to −2 km	Fluvial and volcanic mat.? (A)*	15 SE/Elysium Planitia
7	Marti Valles	2.5°N, 191°W	−1 to −2 km	Fluvial and volcanic mat.? (A)*	15 SE/Elysium Planitia
3	Medusae Fossae	1°N, 160°W	0 to 1 km	Eolian and volcanic mat.? (A)*	8 SW/Amazonis Planitia
4	Medusae Fossae	1°N, 146°W	1 to 2 km	Eolian and volcanic mat.? (A)*	8 SE/Amazonis Planitia
5	Lunae Planum	20°N, 61°W	0 to 2 km	Volcanic mat. (H)*	10 NE/Lunae Palus
			Mars '94/'96 Landing Sites *Small Stations*		
	Arcadia Planitia	40.6°N, 158.5°W	−1 to −2 km	Young sedimentary mat. (A)*	2SW,2SC/Diacria
	Northern Amazonia	30.5°N, 165°W	−1 to −2 km	Young volcanic mat. (A)* with eolian mantling	2SW,2SC/Arcadia
			Penetrators		
	Arcadia Planitia	38°N, 162°W	−1 to −2 km	Young sedimentary mat. (A)*	2SW,2SC/Diacria
	Arcadia Planitia	39°N, 154°W	−1 to −2 km	Young sedimentary mat. (A)*	2SW,2SC/Diacria

* N - Noachian system, H - Hesperian system, A - Amazonian system.

An advantage of Mars Pathfinder is the rover for sampling surface materials over a range of tens of meters. However, engineering constraints and the limited scientific payload of this mission require new approaches for landing site selection [1]. One approach is to select sites exhibiting a wide variety of rocks near the lander (e.g., Arago Crater, Site 12). An alternative approach is to select sites in which the regional geology consists of a single rock type representing a key datum for the geological study of Mars, and is uniformly distributed within the landing ellipse. Examples of this approach include (1) landing sites on rocks of Hesperian age, e.g., ridged plains (site 5), (2) sites that contain sedimentary deposits of Amazonian age with sharply distinct individual surface morphology, e.g., deposits of the Medusae Fossae Formation (sites 3 and 4), and (3) young volcanic deposits, e.g., Marti Vallis (sites 6 and 7).

Based on these approaches and consideration of landing safety, 12 sites were selected for Mars Pathfinder (Table 1). Of these landing sites, six sites (sites 1, 6, 7, 8, 9, and 10) are consistent with the nominal mission requirements. Three additional sites (sites 4, 5, and 12) can be considered if elevation constraints are increased to 2 km. Three other sites (sites 2, 3, and 11) are located between 0 and 1 km. Six of the sites (sites 2, 3, 4, 6, 7, and 12) are included in the area occupied by surface Unit 1 [2]. Another three sites (sites 5, 8, and 11) are located within Unit 3, and the remaining three sites (sites 1, 9, and 10) are located in the boundary zone between units 2 and 3. From the 12 proposed sites, nine sites (sites 2, 3, 4, 5, 6, 7, 8, 11, and 12) have a rock abundance of 3–8%. Three other sites (sites 1, 9, and 10) have a rock abundance of 8–15%. All selected sites are in regions with different surface roughness characteristics (meters to tens of meters scale) expressed as RMS slope values. From the 12 sites, only one site (site 3) is characterized by the highest RMS slope value (10°–15°), but exhibits the lowest values of thermal inertia ($<3 \times 10^{-3}$ cal/cm^{2}s$^{1/2}$K) and rock abundance (<6%). The remaining eleven sites have RMS values <8°.

Under nominal elevation constraints, especially with regard to Mars Pathfinder, we propose the Ares-Tiu Valles and Maja Valles delta areas (sites 1 and 8), and Marti Vallis (sites 6 and 7) as high-priority targets. If the maximum elevation constraints are increased to 2 km, the more favorable sites are the Ares-Tiu Vallis delta area (site 1), Kasei Vallis bend area (site 2), Medusae Fossae (sites 3 and 4), and Lunae Planum (site 5).

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N95- 16194

A PERSPECTIVE OF LANDING-SITE SELECTION. H. J. Moore, U. S. Geological Survey, Menlo Park CA 94025, USA.

The Viking '75 Project began examining the problems of landing two spacecraft on Mars immediately after project authorization in 1969. This examination resulted in the Viking-Mars Engineering Model [1], which addresses the interplanetary, near-Mars (>60 km), atmospheric (<60 km), and surface environments and astrodynamical data.

During the Mariner 9 Mission, a Viking Data Analysis Team examined images and other data in near-real time, assessed Earth-based radar echo data, and prepared terrain maps with the intent of identifying potential landing sites [2]. No sites were identified because of uncertainties in image interpretation engendered by a hazy atmosphere, conflicting elevations from different sources, and other factors.

A Viking Landing Site Working Group was convened in early 1972 to identify site-selection criteria compatible with landing safety, system capabilities, and science objectives [3]. Among numerous criteria were low elevation (for parachute performance), large separations of site pairs (for communications), and a "warm and wet" environment (favorable for life).

Eleven landing sites between 30°N and 30°S were selected and considered by the Landing Site Working Group [4,5]. Later, six sites from about 43° to 73°N were considered because of their relative abundance of water vapor [5]. Still later, four equatorial sites were added because of existing radar data on them and their accessibility to future radar observations. Most of the sites were rejected for various reasons.

Four landing sites were approved by NASA Headquarters: (1) Chryse (prime A1; 19°N, 34°W), (2) Tritonis Lacus (back-up A2; 20°N, 252°W), (3) Cydonia (prime B1; 43°N, 11°W), and (4) Alba (back-up B2; 43°N, 110°W). The northern B sites replaced earlier southern sites (Apollinares and Memnonia) because the B sites were thought to have higher atmospheric water contents. Two equatorial sites were retained because of their radar signatures: (1) Capri (C1; 6°S, 43°W) and (2) Meridiani Sinus (C2; 5°S, 5°W).

For mission operations, the Landing Site Working Group was augmented by the Viking Flight Team and renamed the Landing Site Staff [3]. This latter group was responsible for Site Certification when the first orbiter's instruments could observe the prime site (A1) and ongoing radar observations could be analyzed; its responsibilities included certification of the second landing site. Certification criteria were much the same as those for selection: (1) landing ellipse size, (2) elevation, (3) surface temperatures, (4) geology, (5) surface roughness (slopes), (6) protuberances (rocks), (7) "soil" properties (bulk density, etc.), (8) radar reflectivity, (9) density-temperature profile of atmosphere, (10) atmospheric composition, (11) dust storms, and (12) winds.

There was no landing at any preselected site. Plans to land the first spacecraft at the initial Chryse site on July 4, 1976, were discarded because the surface, which appeared to be smooth and nearly featureless in hazy Mariner 9 images, appeared extremely rough, complicated, and eroded (and probably rocky) in the Viking images [6–8]. Arecibo quasispecular radar echoes at 12.6 cm from the vicinity of the site suggested a rough surface (RMS slopes near 5°–7°) but near-average reflectivity [9]. Small signal-to-noise ratios of Goldstone echoes (3.5-cm wavelength) from the site were particularly worrisome because they contrasted with large signal-to-noise ratios from Tritonis Lacus [9], and scenarios to explain the small ratios were all unfavorable. Other criteria appeared to be satisfied.

Viking 1 then began a search for a new site to the northwest of the original site based on images and Arecibo quasispecular radar observations [6,9]. *A priori* selection and certification of the final site were satisfying and defensible, because the project could say (1) there is evidence for abundant soillike materials in the images, (2) the rms slopes (4.5°–5.5°) are like those of lunar maria where Surveyors had landed, and (3) the reflectivity (0.07) is average for Mars [6–9]. The Viking Project made a sincere effort to find a safe landing site and was rewarded with a successful landing.

After the first lander demonstrated Viking's capabilities for entry, descent, and landing, almost everyone wanted to explore to the north, where atmospheric water vapor abundances were high [3,10]. A new northern site, Utopia Planitia (B3), was added, and orbiter temperature observations replaced the radar as a tool to assess surface material properties. Both the Cydonia (B1) and Alba (B2) sites appeared unexpectedly rough; again, Mariner 9 images taken through hazy skies had suggested smooth and mantled surfaces. B1 was rejected because large areas appeared rough and eroded; extensive "mantles" and "dune fields" were not found. B3 was chosen over a western extension of B2 because of the operational complexity that would be introduced; the modest difference in water-vapor abundance and inferred thicknesses and extents of "mantles" and "dunes" did not warrant the increased risk engendered by the increased operational complexity [3,10]. Thermal inertia at the B3 site was judged to be about the same as that of the Lander 1 site, but it was not possible to distinguish between a surface of sand and a surface like that around Lander 1 [10]. The B2 site had a lower thermal inertia than the B3 site [10]. Lander 2 was a success, but those expecting to see extensive mantling deposits or abundant sand dunes were surprised by the rocky scene.

The problems that now confront Mars Pathfinder are much the same as those that confronted Viking, but more and better information exists today. Like Viking, Mars Pathfinder must select a landing site compatible with lander and rover designs as evidenced by available data (Viking images, radar and thermal observations, albedo and color observations, visible-infrared spectra, etc.). Most regions at low elevations probably contain favorable sites, but some sites at low elevations with weak quasispecular echoes and low thermal inertias may be unfavorable [11].

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TARTARUS COLLES: A SAMPLING OF THE MARTIAN HIGHLANDS. S. Murchie and A. Treiman, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058, USA.

Several of the most fundamental issues about the geology of Mars can be addressed using information on composition and structure of the plateau plains ("highlands") that cover approximately half the planet [1,2]. The units that compose the highlands are interpreted as a mixture of volcanic, fluvial, lacustrine, and impact ejecta deposits. A more precise inventory of differing of igneous and sedimentary lithologies in highland rock units would not only lead to a better understanding of how the plateau plains formed, but would also clarify the nature of the surface environment during the first 800 m.y. of martian history. Structural features including bedforms, joints, and small faults that are unresolved from orbit record a history of the emplacement and deformation of the highlands. In addition, weathering products present in this very ancient terrain represent a mineralogic record of past climate and of the pathways by which bedrock is altered chemically [3]. Their similarity or dissimilarity to bright soils observed spectroscopically and *in situ* at the Viking Lander sites [4–6] will be evidence for the relative roles of regional sources and global eolian transport in producing the widespread cover of "dust."

Unfortunately, these issues are difficult to address in the plateau plains proper, because bedrock is covered by mobile sand and weathering products, which dominate both surface composition and remotely measurable spectral properties [5]. However, the "Tartarus Colles" site (Fig. 1), located at 11.41°N, 197.69°W at an elevation of –1 km, provides an excellent opportunity to address the highland geology within the mission constraints of Mars Pathfinder. The site is mapped as unit HNu [7], and consists of knobby remnants of deeply eroded highlands. It contains rolling hills, but lacks steep escarpments and massifs common in most highland remnants, and is free of large channels that would have removed colluvium from eroded upper portions of the stratigraphic column. These characteristics indicate that a variety of bedrock types from thoughout the Noachian-Hesperian stratigraphic column may remain at the site.

Six characteristics of the site indicate that Mars Pathfinder can successfully be used here to address the fundamental issues outlined above:

Provenance of the Site is Known: This occurrence of unit HNu completely encompasses the landing ellipse, so that the geologic context of the landing site would be known independently of refinements in lander location.

Site Contains Locally Derived Material: The knobby morphology of the site, the lack of channels, and a measured block abundance of ~10–15% [5] are all consistent with the presence of decimeter-sized rock fragments derived from within several kilometers of their present locations.

Exposed Unit is of Global Import: The highlands bedrock accessible here contains a record of early martian history absent from the younger northern plains assemblage [1,2], which dominates most locations within the elevation and latitude range intended for Mars Pathfinder. Comparable exposures do occur in walls of outflow channels, the walls of Valles Marineris, and walls and massifs of large craters and basins, but these sites generally are characterized by very rough topography and/or they form targets much smaller than the Mars Pathfinder landing ellipse.

Site Contains Nearly Unaltered Material: The presence of relatively unaltered material is critical to an accurate compositional determination of the substrate. Visible color of the landing ellipse is dominated by "dark gray" materials, which are shown by near-infrared spectroscopic studies to consist of relatively unaltered, basaltic particles [4,5]. In addition, the thermal inertia of the site is $\sim 8 \times 10^{-3}$, consistent with abundant sand [5]. Saltating sand may have partially abraded weathered rinds from locally derived blocks.

Site Also Contains Weathering Products: Albedo patterns at the site reveal the presence of segregated patches of bright red dust. Furthermore, the ancient origin of the block cover is consistent with substantial chemical alteration of at least portions of exposed rock particles.

Site Contains Evidence to Address Tractable Questions: The major issues about highland geology outlined above can be summarized in three questions, which can be meaningfully addressed using measurements from instruments on the Pathfinder lander and rover:

Fig. 1. Digital image model covering the Tartarus Colles region, showing the Pathfinder landing ellipse. Coordinates are latitudes and longitudes of image corners.

Bedrock lithology. The camera filters on the Imager for Mars Pathfinder (IMP) can discriminate major rock-forming minerals containing ferrous or ferric iron. IMP is thus able to distinguish different spectral types of blocks. Their elemental compositions can then be measured by the alpha-proton-X-ray spectrometer (APXS) on the rover, and their texures observed by the rover camera.

Nature of macrostructures. The stereo capability and spatial resolution of IMP will show fractures and bedforms in near-field blocks, and structurally influenced block and knob shapes in the far-field.

Composition and texture of weathering products. Spectral measurements of "dust" by IMP will provide a basis for comparison with telescopic and spacecraft spectral data and determinations of elemental composition by APXS will allow comparison with the Viking Lander sites. Both instruments and the rover camera, by observing fresh and weathered surfaces of the same blocks, can together determine the compositional and textural properties of weathered coatings. Finally, measurements of any indurated "duricrust" may be able to identify what phases are mobile and "enriched" in this material.

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SCIENTIFIC RATIONALE FOR SELECTING NORTHERN EUMENIDES DORSUM (9°–11°N LATITUDE, 159°–162° LONGITUDE) AS A POTENTIAL MARS PATHFINDER LANDING SITE. T. J. Parker, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

The proposed site is the northernmost occurrence of the Medusae Fossae Formation (MFF), and lies at or below the –2-km contour. The MFF is the famous radar "stealth" deposit that extends from south of Olympus Mons westward across southern Amazonis Planitia to southern Elysium Planitia. The MFF appears to be composed of some kind of wind-eroded friable material, the origin of which is very problematic. It appears to be a radar-absorbing material [1], whereas Mars' south polar layered deposits appear bright in the same scenes. Synthetic aperture radar images of young terrestrial ash deposits in the Andes also appear relatively bright. The MFF's radar signature appears to require a uniformly fine-grained material (on the order of dust-sized to fine sand-sized) at least several meters thick, in order not to transmit reflections off underlying terrain or internal reflective horizons. A number of very different hypotheses have been proposed over the years to explain this formation. It has been interpreted as either a large, wind-blown volcanic ash deposit [2] or other wind-blown material trapped along the escarpment between highlands and lowlands [3,4]; ancient polar layered deposits [5] requiring a massive change in the planet's rotation axis; and finally as carbonate platform deposits [6] or banks of low-density volcanic material deposited in an ocean [7].

Accumulation of tens to thousands of meters of unwelded, friable ash blankets, necessary to avoid formation of internal reflectors, would seem to require a large number of discrete, relatively thin deposits. The radar signature, therefore, seems inconsistent with the volcanic ash and polar layered material interpretations. The "stealth" requirement may be met by an uncemented sand or loess material, thus supporting the suggested eolian hypothesis. It might also be met by inferring chemically precipitated but largely uncemented carbonates. If correct, this last model would have important implications with regard to search strategies for fossil organic materials or the environments that might be conducive to their development. In 1991, I suggested that the surface morphology of the MFF is comparable to terrestrial carbonate platform deposits [6]. The best modern analogs would be oolitic deposits, such as found over large regions of the Bahama Banks. To fit the observed morphologies and radar signature, a process akin to inorganic oolite precipitation and transport by oceanic currents or agitation by waves [8,9], with little cementation, was proposed. An oolitic grain size is necessary both to provide the "stealth" radar signature and to allow the development of sand wavelike bedforms visible in some high-resolution images of the deposit. A largely uncemented state is also needed to explain the radar signature, requiring relatively rapid deposition and little to no subsequent cementation or diagenesis.

This requirement probably can be met because ocean transgressions on Mars were likely short-lived and separated by long periods with temperatures below freezing, thus preventing dissolution and cementation through rain or groundwater migration within the deposit. Finally, carbonate precipitation would have taken place fairly rapidly when liquid water was present due to the planet's high atmospheric CO_2 content. Surface science that can address the chemical/mineralogical composition and physical properties of this material would be very important to understanding a relatively recent (Amazonian) volcanic or paleoclimatic process that resulted in a 2,700,000-km^2 deposit along the martian equator. Based on assumptions about the average thickness of this deposit, this area corresponds to a total volume of material on the order of 27,000–2,700,000 km^3. The proposed Pathfinder landing site lies on a relatively smooth, "unmodified" portion of the MFF, more than 100 km away from its northern and western edges, which exhibit evidence of eolian etching in the form of closely spaced yardangs. There are no large craters or steep slopes within a few hundred kilometers of the landing site.

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SCIENTIFIC RATIONALE FOR SELECTING NORTHWEST ISIDIS PLANITIA (14°–17°N LATITUDE, 278°–281° LONGITUDE) AS A POTENTIAL MARS PATHFINDER LANDING SITE. T. J. Parker[1] and J. W. Rice[2], Jet Propulsion Laboratory, [1]California Institute of Technology, Pasadena CA 91109, USA, [2]Department of Geography, Arizona State University, Tempe AZ 85282, USA.

The northwest Isidis Basin offers a unique opportunity to land near a fretted terrain lowland/upland boundary that meets both the latitudinal and elevation requirements imposed on the spacecraft. The landing site lies east of erosional scarps and among remnant massif inselbergs of the Syrtis Major volcanic plains. The plains surface throughout Isidis exhibits abundant, low-relief mounds that are the local expression of the "thumbprint terrain" that is common within a few hundred kilometers of the lowland/upland boundary. These typically occur in arcuate chains, often with a summit pit or trough. They have been variously interpreted as volcanic cinder cones or psuedocraters [1], pingos [2], or eolian deposits that formed at the edge of a sublimating ice sheet [3]. We have used photoclinometry to measure similar mounds in Cydonia, using photoclinometry, at no more than a few tens of meters high, implying very gentle slopes. Cinder cones should exhibit slopes determined by the ballistic emplacement of unconsolidated material, and so they commonly approach the angle of repose.

Pingos are typically conical-shaped ice cored hills up to 100 m high and 600 m in diameter [4]. Many pingos often exhibit dilation cracks radiating from the apex of the hill. These fractures are created as a result of the growth of the ice core. This process exposes the ice core and allows it to thaw out, thereby producing a collapsed summit area. Pingos are usually located in lowland areas, especially lake beds and deltas. Lander and rover observations should be able to confirm whether these landforms are pingos or cinder cones based on the presence of dilation cracks or slopes approaching the angle of repose. The discovery of pingos would be of high importance to future missions to Mars, both robotic and "folked." The pingo ice core could contain relatively pure water ice within several meters of the surface.

The massif inselbergs are not as numerous nor as massive as those in fretted terrains to the northwest, so local slopes are not expected to be steep. Neither feature should pose a serious threat to the lander. Landing on or adjacent to one of these features would enhance the science return and would help to pinpoint the landing site in Viking and subsequent orbiter images by offering views of landmarks beyond the local horizon.

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CERBERUS PLAINS: A MOST EXCELLENT PATHFINDER LANDING SITE. J. B. Plescia, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

Introduction: The Cerberus Plains in southeastern Elysium and western Amazonis cover >10^5 km^2, extending an east-west distance of ~3000 km and a north-south distance of up to 700 km near 195°. Crater numbers are 89 ± 15 craters >1 km/10^6 km^2, similar to values obtained by [2,3], indicating a stratigraphic age of Upper Amazonian and an absolute age of 200–500 Ma [1]. The material forming the surface is referred to as the Cerberus Formation. The unit's origin is controversial; two ideas have been postulated, fluvial [4,1] and volcanic [5]. Regardless of which interpretation is correct, the Cerberus Plains is an important candidate for a Pathfinder landing site because it represents the youngest major geologic event (be it fluvial or volcanic) on Mars.

Geology: The unit exhibits lobate albedo patterns and embayment relations with older terrane. These patterns suggest flow eastward across Cerberus, then northeastward through the knobby terrane into Amazonis (exploiting a series of older channels carved into knobby terrane and ridged plains). Albedo patterns in the east are regionally organized into bands up to 40 km wide; in the west, albedo patterns are complex and intricate with digitate boundaries. Small-scale surface texture is variable. Near 19°N, 174°W, where the unit fills a channel, the floor appears smooth, whereas the surrounding terrane has significant texture. The southern margin exhibits pressure ridges, flow fronts, and flowage around obstacles.

The morphology of the Cerberus Plains is interpreted to indicate that it is an example of flood-basalt volcanism (e.g., Deccan Traps, Columbia Plateau); the morphology of the western part indicates plains-style volcanism (e.g., Snake River Plains). Terrestrial flood basalt provinces [6,7] are characterized by flows 5–45 m thick extending over large areas having little relief. Eruption rates are very high with fissure vents tens to hundreds of kilometers long in zones several kilometers wide. Six low shields have been identified in the western plains. Some of the Cerberus shields are elongate, having elliptical vents; others are more symmetric.

Pathfinder Mission Implications: The Cerberus Formation occurs between longitudes 165° and 220° and latitudes 5°S and 30°N, although the material does not completely cover this area. The largest expanse occurs at 180°–210°W and 5°S–10°N. Thus, the area of exposure is within the Pathfinder constraints (0°–30°N). Elevations [8] are at altitudes <–1 km; a northeast-trending band from 5°N, 197°W toward 10°N, 180°W has elevations <–2 km. These altitudes are within the Pathfinder range (<0 km). A 100-km × 200-km ellipse along a N74°E trend is easily found within the unit; a target for the center of the landing ellipse is 6°N, 183°W, a location ensuring landing within in the unit. The Cerberus region has low thermal inertia [9] ($<4 \times 10^{-3}$ cal cm^{-2} s$^{-1/2}$ K^{-1}), interpreted to indicate a low rock fraction exposed at the surface [10], <10%. This suggests the area would be relatively safe for landing, but still offers the potential for finding exposed rock.

Possible Scientific Implications: The first question to be resolved is whether the Cerberus Formation is of volcanic or fluvial origin. This alternative is testable with both imaging and elemental data. A volcanic flood basalt terrain should show a level, possibly slightly rolling surface; flow fronts and pressure ridges may be present. Rock analysis, both spectral and elemental, should show a relatively uniform composition. A fluvial environment should show channels and a scoured surface, and evidence of erosion should be abundant at all scales. Since debris on the surface would be from many sources, significant heterogeneity would be expected in the spectral and elemental analysis of the rocks.

It can be postulated that the Cerberus Plains are the source for some of the SNC meteorites, specifically shergottites, on the basis of age and volcanic style. Shergotty, Zagami, ALHA 77005, and EETA 79001 have ages of 160–180 Ma [11,12]. Only the Cerberus Formation is of sufficient size and age to be a statistically significant source region. Major-element chemistry for the shergottites is SiO_2 at 43–51%, FeO at 18–20%, Al_2O_3 at 3–9%, MgO at 9–28%, and CaO at 3–11%. The apx unit will provide key elemental data at the percent level. Shergottites are dominated by pigeonite (~26–40%), augite (11–37%), and plagioclase-maskelynite (10–29%). The presence of these minerals may be detectable by the filters in the imaging system, depending on the choice of band passes. These two instruments should provide sufficient data to determine whether the Cerberus Formation is the unit from which the shergottites were derived.

The interpretation that Cerberus Plains results from flood volcanism late in martian history carries implications for martian thermal history. Although central vent volcanism has been recognized as occurring late, flood volcanism has not. Flood volcanism in the period <700 Ma indicates that, at least in the Elysium region, sufficient heat remained to generate large volumes of low viscosity lavas.

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N95-16199

MAJA VALLES AND THE CHRYSE OUTFLOW COMPLEX SITES. J. W. Rice, Department of Geography, Arizona State University, Tempe AZ 85287, USA.

Maja Valles Region: This candidate landing site is located at 19°N, 53.5°W near the mouth of a major outflow channel, Maja Valles, and two "valley network" channel systems, Maumee and Vedra Valles. This region has been mapped in detail by Rice and De Hon and is in press as a USGS 1:500,000 scale geologic map. The advantages to this site are the following: Two distinct channel forms (outflow and dendritic valley network) in one location. These channels were formed by different processes. The outflow channels are believed to have formed by catastrophic release of water and the valley networks by surface runoff and or sapping. The ideal landing site, if it could be pinpointed, would be on the fan delta complex located at the terminus of the three channels (Maja, Maumee, and Vedra Valles). The fan delta complex would be a fairly smooth surface with shallow slopes.

Water was impounded behind the wrinkle ridge system, Xanthe Scopulus, forming a temporal lake. This paleolake bed would also present itself as a safe landing site, perhaps similar to playas. Once the wrinkle ridges were breached the water flowed northeastward in the direction of the Viking 1 lander, some 350 km away.

Objectives to be analyzed in this region are (1) origin and paleohydrology of outflow and valley network channels, (2) fan delta complex composition (this deposit located in this area is one of the few deposits identified at the mouths of any channels on the planet), and (3) analysis of any paleolake sediments (carbonates, evaporites). Another advantage to this area will be any blocks and boulders that were plucked out and carried along the 1600-km course of Maja Valles. These samples would provide a virtual grab bag of lithologies. For example, the oldest mappable rock unit (Nb, Noachian basement material) and the Hesperian ridged plains (Hr) are cut by Maja Valles before it empties into Chryse. It can be argued that we will not know their exact location, which is true, but it will provide us with information about the variety of rock types on Mars by only landing in one site. Other questions to be investigated in the area are the origin of wrinkle ridges by viewing ridge walls that were incised by the outflow, streamlined islands/bars; whether they are erosional or depositional, and if the location permits view channel wall stratigraphy, fan delta stratigraphy, and perhaps send the rover up a channel mouth near the end of its mission.

This site is below the 0-km elevation datum, within the latitude restrictions (19°N), and all the objectives stated above are within the 150-km landing error ellipse. This region is also imaged at resolutions of 40–50 m/p.

The Chrsye Outflow Complex Region (Ares, Tiu, Mawrth, Simud, and Shalbatana Valles): The overall philosophy and objectives described above for the Maja Valles region apply here as well. The primary objectives here would be outflow channel dynamics (paleohydrology) of five different channel systems. One question to be answered might be whether all outflow channels are of the same origin and type. They are probably all somewhat different in terms of duration, age, source, and perhaps even origin. The grab-bag philosophy of various rock types being deposited near channel mouths would apply here also. The site is located at 15°N, 35°W. However, the longitudinal coordinate can be relaxed or slid farther to either side of 35°W. Sliding the ellipse farther to the east would allow investigations of Mawrth Valles. The region near the mouth of Mawrth Valles would be of interest because this area contains material that appears to have been dissected, thus exposing the stratigraphy of what may possibly be deltaic sediments.

N95-16200

MARTE VALLES SITE. J. W. Rice, Department of Geography, Arizona State University, Tempe AZ 85287, USA.

This site is located at 16°N, 177°W on the flood plains of Marte Valles, which is perhaps the youngest channel system on Mars. However, the coordinates for the landing site are flexible. Moving the site more to the southwest would allow investigations of possible lacustrine sediments. The channel extends for about 3000 km from southeastern Elysium Planitia into western Amazonis Planitia. This system appears to originate within the knobby cratered material around Cerberus Rupes, a set of en echelon fractures that extend for more than 1000 km. Crater counts indicate that this system is Amazonian in age. This channel may have also acted as a spillway between paleolakes located in Elysium and Amazonis Planitia. The young age of this channel warrants investigation because of climatic implications for fluvial activity in recent geologic time. The paucity of craters makes this an excellent site in terms of safety requirements. Detailed work by Tanaka and Scott indicate that embayed craters larger than 1 km diameter appear embayed by the channeled plains unit, suggesting that it is only tens of meters thick. This material contributed to the resurfacing of the northern lowlands of the planet. Some of the objectives stated previously for the Maja Valles Region would also apply to this site (grab bag of rock types, etc.). This site is below the 0-km datum, located at 16°N, and has the young channeled plains, bars, terraces, and streamlined albedo patterns located within the 150-km landing error ellipse. Resolution coverage in some areas is as high as 13 m/p.

N95-16201

ALPHA PROTON X-RAY SPECTROMETER. R. Rieder[1], H. Wänke[1], and T. Economou[2], [1]Max-Planck-Institut für Chemie, Mainz, Germany, [2]University of Chicago, Chicago IL 60637, USA.

Mars Pathfinder will carry an alpha-proton X-ray spectrometer (APX) for the determination of the elemental chemical composition of martian rocks and soils. The instrument will measure the concentration of all major and some minor elements, including C, N, and O, at levels above typically 1%.

The method employed consists of bombarding a sample 50 mm in diameter with alpha particles from a radioactive source (50 mCi of ^{244}Cm) and measuring (1) backscattered alpha particles (Rutherford backscatter = RBS mode), (2) protons from A(,p)B reactions (proton mode) and (3) characteristic X-rays emitted from the sample (X-ray mode). In RBS mode all elements with atomic mass greater than four are registered, thus permitting normalization of results to 100% concentration. This feature permits accurate quantitative analysis independent (within limits) of the actual measurement geometry. Data obtained from proton and X-ray modes are used to enhance selectivity of the RBS mode for the rock-forming elements Mg, Al, and Si and for heavier elements (K and Ca, Fe-group):

Resolving power in the RBS mode is determined by the energy spread of the alpha source and the range of backscatter angles observed by the detectors. These parameters in turn determine the number of backscattered alpha particles per unit time. In the present design the use of proton and X-ray data permits us to trade selectivity for sensitivity.

The instrument has a long standing space heritage, going back to the days of Surveyors V, VI, and VII (1968–1969) and Phobos (1988). The present design is the result of an endeavor to reduce mass and power consumption (Surveyor: 10 kg/10 W; Phobos: 2.7 kg/2.5 W; this instrument: 0.6 kg/0.3 W); four instruments are scheduled to fly on the Russian Mars '94 mission: two on penetrators (without X-ray mode) and two on small stations (including the X-ray mode, using "room temperature" mercuric iodide detectors provided by the University of Chicago). These are currently being calibrated and prepared for integration.

The instrument for Mars Pathfinder will be a duplicate of the instruments for the Mars '94 small stations but with minor changes. It consists of a sensor head, incorporating the alpha sources, a telescope of silicon detectors (35 and 700 m thick) for the detection of alpha particles and protons and a mercuric iodide X-ray detector with preamplifier, and an electronics box (80 × 70 × 60 mm) containing a microcontroller-based multichannel spectrometer. The sensor head will be mounted on the rear of the Mars Pathfinder Microrover on a deployment mechanism that permits placement of the sensor in contact with sample surfaces inclined at any angle from horizontal to vertical, thus permitting measurement of the composition of soil and rock sample. The electronic box will be contained in the microrover's "warm" container and will communicate with the microrover control system through a standard RS 232 serial interface.

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ATMOSPHERE STRUCTURE AND METEOROLOGY INSTRUMENT FOR MARS PATHFINDER. A. Seiff, San Jose State University Foundation, Mail Stop 245-1, NASA Ames Research Center, Moffett Field CA 94035, USA.

The MESUR Science Definition Team recommended that all MESUR probes, including Pathfinder, carry an ASI/MET experiment, in order that no opportunity be lost to characterize the atmosphere of Mars in passing through it. The experiment was thus included on Pathfinder from the start (February 1992), but on an essentially noninterference basis: It was to make no unusual demands on the spacecraft. A Science Advisory Team appointed by NASA Headquarters in September 1993 first met on November 3 to initiate formal science participation, and the level of activity has since been high. The instrument passed its Preliminary Design Review on February 28.

The structure of the atmosphere is measured during entry and descent; meteorological parameters, pressure, temperature, and wind velocity are collected during the mission lifetime after landing. The structure experiment has two phases. During high-speed entry, from 160 km to near 8 km (where the parachute is deployed), accelerometers define the density structure. In the parachute descent, atmospheric pressure and temperature are measured until airbags are deployed ~150 m above touchdown. Entry phase pressures are obtained by integrating measured densities assuming hydrostatic equilibrium (the technique used on the Viking and Pioneer Venus missions and to be used on the Galileo Probe); the equation of state then yields temperatures. The sensors employed are guidance-quality accelerometers, Tavis and Vaisalla pressure sensors, and chromel-constantan thermocouples with platinum resistance thermometers at their cold junctions.

Constraints imposed do not allow the descent phase sensors to project outside the lander envelope, nor are the accelerometers in an optimum configuration about the center of gravity. The Science Advisory Team (SAT) is exploring the effects of these limitations, but they should not prevent the acquisition of valuable data.

The meteorology measurements were originally limited to pressure and temperature, but were extended to include winds because of the apparent simplicity of the hardware. The measurement resolution will be 256× better than that of Viking, which was resolution limited. Temperature measurements at three elevations above the surface, and wind measurements at two heights (if affordable within available lander resources), will define profiles not available from the Viking instrument. Rapid sampling for 5 min/hr will define both diurnal and seasonal variations and turbulence. Consideration is being given to sampling over selected 1-hr intervals for better definition of fluctuations. Pressure sensors are shared with the ASI. Temperature sensors are chromel-constantan thermocouples of 75-μm wire diameter. Wind is sensed from the convective heat loss of heated wires. Sensors have been designed and evaluated analytically. They will be evaluated experimentally and refined if necessary from tests at Mars surface conditions in the Mars Wind Tunnel at NASA Ames Research Center (operated by Arizona State University).

To move them away from thermal influence of the lander electronics, the temperature and baseline wind sensor are mounted on the whip antenna, which communicates with the rover, about 1 m away from the lander core. The wind sensor and primary temperature sensors are about 0.5 m above the surface; two other temperature sensors are 0.25 m and 0.125 m above the surface. The second wind sensor is proposed to be mounted on the low-gain antenna, about 1 m above the surface. Pressure sensors are in the Warm Electronics Box in the lander core. The temperature profiles will differentiate between stable and convective near-surface conditions, and define atmospheric heating rate. Wind profiles will likewise discriminate stable from unstable conditions, and define near-surface shear, as well as provide a valuable input to boundary layer models.

The greatest concern we have for the descent phase results from the restriction against external deployment of the temperature sensor (for reasons of air bag safety). The sensor must sample atmosphere flowing through the lander rather than around it, at velocities well below the descent velocity. This slows sensor response time, e.g., to ~4 s if the internal velocity (yet to be established) is 1 m/s. For the entry phase, the major problem is correction of measured accelerations for angular inputs at off-center of gravity locations. For landed meteorology, the major concern is the design of the wind sensor to work sensitively at extremely low power levels in the low-density atmosphere and define wind directions. Problems of thermal contamination are also inevitably present.

N95- 16203

LANDING SITE CONSIDERATIONS FOR ATMOSPHERE STRUCTURE AND METEOROLOGY. A. Seiff[1], R. Haberle[2], and J. Murphy[1], [1]San Jose State University Foundation, Mail Stop 245-1, NASA Ames Research Center, Moffett Field CA. 94035, USA, [2]NASA Ames Research Center, Moffett Field CA 94035, USA.

The goal of the ASI/MET experiments is to extend our knowledge of Mars atmosphere structure and meteorology over that established by the Viking mission. The two *in situ* soundings of Mars atmosphere by Vikings 1 and 2 were highly similar, but radio occultations and infrared soundings have shown large variability in atmosphere structure on Mars with latitude, season, and terrain elevation [1,2]. It would be of great interest to obtain an *in situ* sounding showing strong contrast in thermal structure with the Viking profiles. These would be expected to occur in the winter season, in the southern hemisphere, or at polar latitudes. These options are ruled out by Pathfinder Mission constraints, which place the entry in low, northern latitudes in mid summer, with small seasonal difference from the two Viking landers, and small latitude difference from Viking 1. The Pathfinder arrival date and latitude correspond to a seasonally equivalent Earth date of August 15, compared to June 21 for Viking 1 and July 17 for Viking 2, not a striking difference. (In the Pathfinder arrival season, however, the seasonal pressure variation on Mars is essentially at minimum, corresponding to a pressure of 5.9 mbar at the mean radius [2]. This will lead to somewhat increased parachute descent velocities. Also, the arrival will coincide with the occurrence of transient normal mode oscillations previously observed by Viking in several consecutive Mars years [4].)

Within the Pathfinder constraints, the best possibilities for extending observations to other conditions are to (1) maximize latitude contrast with Viking 1 by moving toward the equator; (2) study the influence of prominent terrain features on structure and the general circulation; or (3) examine the effect of dark-albedo features on the overlying structure, since radiative equilibrium with the surface controls the temperature structure to first order [3]. Landing sites satisfying the above criteria are discussed below.

Near-equatorial sites, from 0° to 10°N latitude, are available in the region from 235°W to 150°W, with the eastern end in Elysium Planitia. This terrain is of mixed albedo, variegated light and dark. It would thus present a terrain contrast with Viking 1, in addition to a significant latitude difference. This region is south of Cerberus Rupes.

To study the influence of a prominent terrain feature, what better to choose than Olympus Mons? A site in Amazonis Planitia due west of Olympus at 150°W, 18°N has an elevation of –1.5 km. This terrain will certainly affect the atmospheric circulation below 20 km, and radiation effects from the inclined terrain could also influence the thermal structure. The descending terrain at this site will have a slope wind signature. It is an interesting site.

Another terrain influence possibility occurs in Isidis Planitia, directly east of Syrtis Major, which rises to an elevation of 4 km within a few hundred kilometers of a possible landing site at – 2 km, an ideal location for the study of slope winds as well as terrain influence.

Within Isidis farther from Syrtis Major, the primary goal for atmosphere structure would simply be to look for temporal change from 1976 and the effect of the small seasonal change. Centered at 270°W, there is a smooth, bland region with a large area below –2 km (>10° diameter) in which the terrain appears to be very similar to that in Chryse on the USGS maps. Other sites apparently similar to Chryse lie east of Chryse Planitia extending as far as 20°W longitude. A generally interesting target in this region is the upper region of Ares Vallis, which looks like a broad, dark-albedo flood plain, and therefore presents a difference. The Tui Valles region at about 13°N and 33°W also has some interesting characteristics. It is at the required low elevation, and is a valley centered on a river channel in a region of albedo contrasts.

Two members of the Science Advisory Team who worked extensively on analysis of Viking data favored continuation of the Viking 1 dataset as close as possible to the Viking 1 landing site. This would no doubt be valuable. However, it can be argued that the exploration of other sites is more likely to lead to major advancements in understanding of Mars meteorology.

To satisfy the third objective, a site within the unnamed but prominent dark-albedo feature about 350 km wide, which sweeps across Elysium Planitia from northeast to southwest, is suggested. At 15°N, where the center of this feature is at 245°W, terrain elevation is –1 km. The width of this feature nearly matches the horizontal region sampled by the structure experiment, so that sampling entirely within the vertical region overlying this feature is possible.

Assigning priorities to these options, we suggest, from the standpoint of atmosphere structure, the following sites: (1) Amazonis Planitia, 18°N, 150°W, elevation –1.5 km; (2) Isidis Planitia, 13°N, 278°W, elevation –2 km; (3) Ares Vallis, 16°N, 32°W, elevation –2 km; (4) Cerberus Rupes region in Elysium Planitia, 5°N, 190° to 197°W, elevation –2 km; (5) dark feature in Elysium Planitia, 15°N, 246°W, elevation –2 km.

By and large, site selection factors for atmosphere structure, to define the effects of latitude, terrain, and soil temperature, are also important to landed meteorology. Viking established that slope winds are dominant in summer, and their study would be continued at sites 1, 2, and 3. To further examine the pressure fluctuations associated with traveling baroclinic disturbances, seen at the two Viking sites, a site at midlatitudes is preferred [4]. The five sites we list are not optimum from this standpoint, but are well suited to monitoring such tropical phenomena as thermal tides, Kelvin waves, normal modes, and Hadley circulations.

Winds at several landing sites have been examined using the NASA Ames GCM [5]. Ten-day average winds at the two sites near the large terrain obstacles are ~20 m/s with extremes of 5 and 35 m/s, much larger than mean winds at the two Viking sites. Certainly, a key objective of the Pathfinder experiment will be to see if these predicted winds are verified by measurements. If so, it will establish the validity of the GCM not only for understanding Mars circulation, but also as a tool for future mission design.

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SURFACE SCIENCE CAPABILITIES FROM IMP SPECTRAL IMAGING.

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The Imager for Mars Pathfinder (IMP) originally had a single 12-position filter wheel for one of its two "eyes." Originally eight, and then nine, of these filters were optimized for surface science, and three narrow-band filters for atmospheric science. Because of some design revisions we will now have filter wheels on both sides. The wheels for right and left eyes are identical, 12 filter positions each, and rigidly linked to the same rotation shaft. There are now 13 surface filters, in addition to 5 for atmospheric observations. Refer to Table 1 for details of all the filter positions. Figure 1 shows approximate gaussian bandpasses for the 13 surface filters.

Geologic Science: The geology or surface filters are targeted for specific science objectives, and are therefore not necessarily uniform in bandwidth or spacing. A major capability of the geology bandpasses is to differentiate (and in many cases identify) most types of crystalline ferric oxide and oxyhydroxide from each other and from poorly crystalline or nanophase ferric oxides such as found in Mars-analog palagonites [1–4]. This provides knowledge of phases indicative of different environments and modes of alteration. With high signal/noise we can also study some subtle differences due to mixtures and coatings of weathered minerals. An equally important capability is to characterize unaltered crustal material (dark materials). In most cases we can estimate pyroxene Fe^{2+} "1-μm" band positions well enough to estimate the composition and mineralogy. Most spectrally observed dark regions on Mars show pyroxene bands centered from about 0.92 to 0.98 μm [5,6]. Where Fe^{2+} band minima occur slightly longward of 1.0, however, such as for very high Ca pyroxenes as well as for olivine, we are limited by the silicon detector spectral range. If we observe any dark materials with IMP that do not display a "1-μm" band, our interpretations will have to rely on inferences based on the shape and slope of the spectrum shortward of 1.0 μm.

The original set of eight geology filters was augmented to nine last fall with the addition of a 0.48-μm filter. This improved discrimination, particularly among crystalline hematite (αFe_2O_3), crystalline goethite ($\alpha FeOOH$), and nanophase or poorly crystalline ferric oxide. This distinction is important for interpreting alteration histories, and is also a significant benefit for the magnetic properties experiment. These nine bandpasses did a good job, but still left some spectral gaps. With the current set of 13 bandpasses we have extended the short wavelength coverage to 0.40 μm, filled the most significant spectral gaps, and provided an extra channel in the important Fe^{2+} and Fe^{3+} region between 0.89 and 1.0 μm. While still not a complete spectrometer, IMP is quite powerful for determining surface mineralogy, considerably more so than Viking.

The geology filters are arranged from the violet to 0.75 μm in one eye, and from 0.75 μm to the infrared in the other. This is to avoid the risk of choppiness or jitter in spectral data that can occur when measurements from different detectors are interleaved. (Both Galileo NIMS and Phobos2 ISM have had such problems.) Because IMP has a small number of relatively broad bandpasses, it is especially important that we can trust our calibration of contiguous channels.

Overlap between the two eyes is provided at 0.75 μm, a region where Mars-like materials generally lack absorption bands and have high reflectance. This is also a region of good signal/noise and high spectral contrast among surface materials, and so will be used for obtaining stereo and nominal monochrome images.

TABLE 1. Arrangement of IMP bandpasses in the two filter wheels.

Left Eye Center (μm)	Left Eye FWHM (A)	Filter Position	Right Eye Center (μm)	Right Eye FWHM (A)	
0.450	50	1	0.450	50	
0.890	50	2	0.890	50	Atmospheric
0.925	50	3	0.925	50	Science
0.935	50	4	0.935	50	
0.985	50	5	0.985	50	
0.75	200	6	0.75	200	Stereo
0.80	200	7	0.67	200	
0.86	300	8	0.60	200	
0.895	300	9	0.53	300	Geologic
0.93	350	10	0.48	300	Science
0.965	350	11	0.44	350	
0.99*	400	12	0.40	400	

* Actual filter center = 1.00 μm.

Condensates: IMP is also sensitive to condensates on the surface. There are striking differences in both albedo and color between frost and martian soils and rocks, making IMP sensitive to even thin or patchy condensate deposits. This is true for both H_2O and CO_2 frosts. Shortward of 1 μm the strongest H_2O ice band is an overtone centered near 0.95 μm. This band can vary in depth from as much as 10% for coarse-grained frost (400–2000 μm) to as little as 2% for fine-grained frost (50 μm) [7]. This water ice band is broad enough that for an optically thick frost layer it should be detectable

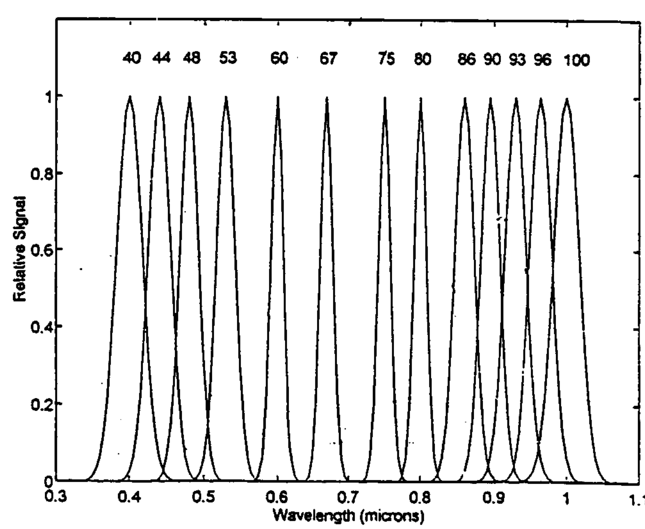

Fig. 1. The 13 surface science bandpasses shown as normalized gaussians. Actual sensitivity of each bandpass will depend on peak filter transmission, solar spectrum, and CCD responsivity.

and well defined by the five bandpasses from 0.86 to 1.0 µm. For an optically thin frost layer the 0.95-µm band can be difficult to see, depending on the substrate, even though the effect on visual slope and albedo is still large [8].

True Color Imaging: Accurate visual color rendition is important to the mission, for public distribution as well as science. Human color vision is a complicated and apparently not fully understood topic. After extensive research we have concluded that there is no single set of three bandpasses that is accepted as "best" at reproducing the colors that most people see most of the time. (MIPS at JPL has apparently reached a similar conclusion.) One common published system uses primaries of 436, 546, and 700 nm [e.g., 9], while another standardizes on 444, 526, and 645 nm [10]. We propose to use the IMP bandpasses at 440, 530, and 670 nm for standard "true color" imaging.

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GOLDSTONE RADAR CONTRIBUTIONS TO MARS PATHFINDER LANDING SAFETY. M. A. Slade and R. F. Jurgens, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109-8099, USA.

Goldstone radar can provide topography "profiles," statistical surface roughness, and radar images within a few degrees of the sub-Earth point. Goldstone/Very Large Array (VLA) bistatic radar observations can image the whole disk of Mars with integration times on the order of 10 min before pixel smearing occurs. Data from all these radar techniques can be useful for observing the local surface conditions relating to landing safety issues for Mars Pathfinder. Topographic profiles will be presented from the 1978 opposition (subradar latitude ~10°N), and the 1980–1982 oppositions (subradar latitudes ~20°–22°N) at 13 cm wavelength with a radar "footprint" of ~8 km (longitude) by 80 km (latitude). The 1992–1993 opposition (subradar latitudes ~4°–10°N) has both Goldstone/VLA images and topographic profiles at 3.5 cm wavelength (many of the latter have yet to be reduced).

During the 1995 opposition, additional opportunities exist for obtaining the data types described above at latitudes between 17°N to 22°N (see Fig. 1). Upgrades to the radar system at Goldstone since 1982 will permit higher accuracy for the same distance with a reduced footprint size at 3.5 cm. Since the Arecibo radar will still be in the midst of their upgrade for this upcoming opposition (which starts ~November 1994, with closest approach in February 1995), the Goldstone radar will be the only source of refined radar landing site information before the Mars Pathfinder landing.

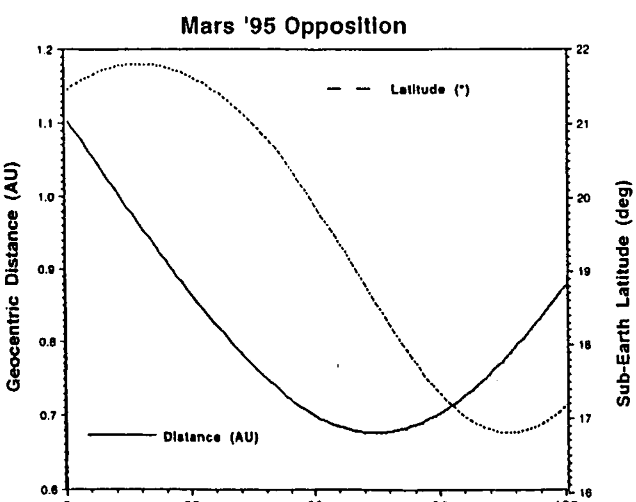

Fig. 1.

N95-16206

IMAGER FOR MARS PATHFINDER (IMP). P. H. Smith, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA.

The IMP camera is a near-surface remote sensing experiment with many capabilities beyond those normally associated with an imager. The camera is fully pointable in both elevation and azimuth with a protected, stowed position looking straight down. Stereo separation is provided with two (left and right) optical paths; each path has a 12-position filter wheel. The two light paths converge onto a single CCD detector that divides its 512 × 256 active pixels evenly between them. The CCD is a frame transfer device that can transfer a frame in 0.5 ms, avoiding the need for a shutter. Because the detector has a high quantum efficiency (QE) and our filters are relatively broad (40 nm FWHM), the camera optics are stopped down to f/18, giving a large depth of field; objects between 0.6 m and infinity are in focus, no active focusing is available. A jack-in-the-box mast elevates the camera about 75 cm above its stowed position on top of the lander electronics housing; the camera is fully functional in its stowed position so that pictures taken of the same object in each position can be compared to give accurate ranging information. The camera is designed, built, and tested at Martin Marietta. Laboratory testing of flightlike CCDs has been done at the Max-Planck-Institut für Aeronomie in Lindau, Germany, under the direction of co-investigator Dr. H. Uwe Keller, who is providing the focal plane array, the pre-amp board, and the CCD readout electronics with a 12-bit ADC. The important specifications for the IMP camera from the point of view of the scientists using the camera are given in Table 1. For comparison the same quantities are also provided from the Viking camera system.

Science Objectives: The primary function of the camera, strongly tied to mission success, is to take a color panorama of the surrounding terrain. IMP requires approximately 120 images to give a complete downward hemisphere from the deployed position. The local horizon would be about 3 km away on a flat plain, so that one can hope to have some information over a 28 km² area. At the horizon a pixel covers 3 m, but the resolution improves at closer distances; just outside the lander edge a pixel is 1.6 mm. Therefore, IMP provides the geologist, and everyone else, a view of the local morphology with millimeter- to meter-scale resolution over a broad area. Accurate ranging to local features is obtained with the stereo separation; at a distance of 5 m we can locate a rock to 1–2 cm by cross-correlating edge features. In addition to the general morphology of the locale, IMP has a large complement of specially chosen filters to aid in both the identification of the mineral types and their degree of weathering. Dr. Robert Singer will present both the filters and the scientific goals for this part of the IMP experiment in his talk.

The IMP team plans to study the atmosphere in several ways. Our baseline filter set includes three solar filters for viewing the solar disk. One of these filters is specially designed to be centered on the deepest lobe of the 935-nm water absorption band; an adjoining continuum filter provides calibration reference. The ratio of the two filters is obtained many times during the course of the day, especially when the Sun is low in the sky and the absorptive path is longest. Although the ratio is estimated to be only 0.98–0.99 for nominal water vapor values, we have gone to great pains to minimize systematic errors, and it is anticipated that the water vapor mixing ratio can be obtained to within 20%.

An additional solar filter at 425 nm has been added for studying the optical depth of the atmospheric dust. The wavelength baseline when combined with the 925-nm continuum filter is a factor of 2; sizes can be accurately obtained for dust particles less than 1.4 μm in diameter by comparing the ratio of optical depths in the two colors to Mie scattering models. The nonsolar filters can also be used for studying the scattering of sunlight from the sky. In this way, the phase function of the dust can be determined and the sizes of larger particles can be estimated. These experiments can be continued into the night by observing Phobos. Other experiments to learn about the atmospheric dust can be easily imagined.

Not only can IMP observe the dust in the sky, we can trap the magnetic portion of that dust onto a series of magnetic targets of varying strength. Dr. Jens Martin Knudsen of the University of Copenhagen in Denmark has developed a special set of targets for the Pathfinder Mission and has shown in the laboratory the usefulness of imaging these targets with the IMP spectral filters to identify which magnetic mineral he has captured. In addition to the spectral information, the magnetic strength of the material can also be determined by seeing which targets have trapped the dust. We currently plan for two sets of targets at different heights: close to the surface and about 0.5 m above the surface.

A final aspect of IMP related to atmospheric studies is the windsock experiment. Dr. Ronald Greeley of Arizona State University is developing and testing small telltales to be place at varying heights between the surface and 0.5 m on one of the antennae. By imaging these targets, both the direction and velocity of the wind can be estimated. Calibration is being done at the Ames Martian Wind Tunnel, where pressure and wind speeds can be simulated; of course, the gravity must be scaled. By including wind socks at several heights the local aerodynamic roughness of the terrain can be determined and the winds can then be accurately extrapolated above the lander site. Viking landers had wind measurements at 1.6 m above the surface only; extrapolation to other heights was very uncertain.

TABLE 1.

Parameter	IMP	Viking
IFOV (1 pixel)	0.057° (1 mrad)	B&W: 0.04° Color: 0.12°
Frame size	14.4° × 14.4°	line scan
Depth of field	0.6 m - inf	1.7 m - inf
Exposure time	0.5 ms - 32 s	0.4 ms or 25 ms
Pointing	–65° < elevation < +90° All azimuth angles	–60° < elevation < +32° 2.5° < AZ < +342.5°
Stereo	15 cm horizontal 76 cm vertical	80 cm horizontal limited field
Height above surface	1.4 m	1.3 m
Bits per pixel	12	6
Filters	12 per eye	6
Filter bandpass	40 nm typ	100 nm
Camera step size	1.125° both EL and AZ	
Pointing repeatibility	0.09° at any step position	

N95-16207

MELAS CHASMA: A MARS PATHFINDER VIEW OF VALLES MARINERIS. A. H. Treiman and S. Murchie, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113, USA.

A Mars Pathfinder landing site in Melas Chasma (Valles Marineris) would yield significant science return, but is outside present mission constraints. In Melas Chasma, Mars Pathfinder could investigate minimally altered basaltic material, sedimentary deposits, chemical weathering, tectonic features, the highland crust, equatorial weather, and Valles mists. Critical issues include (1) nature and origin of the Valles interior layered deposits, important for understanding water as a sedimentary and chemical agent, and for the past existence of environments favorable for life; (2) compositions of little-altered basaltic sands, important for understanding magma genesis and weathering on Mars, and the martian meteorites; and (3) structure and composition of the highland crust, important for understanding Mars' early history. Data from Melas Chasma would provide ground truth calibration of remote sensing datasets, including Phobos ISM.

Mission Constraints I: In the first workshop circular, the landing site was to be "roughly between the equator and 30°N" with a "landing . . . uncertainty of roughly 150 km." In the final circular, the landing site is restricted to "0°N and 30°N . . . within a 100-km × 200-km ellipse along a N74E axis around the targeted site . . ." No hazard-free nominal site in Melas Chasma satisfies these later criteria. However, a hazard-free restricted site to 85 × 170 km at the same orientation can be accommodated (Fig. 1).

Site. The proposed landing site is at 9.75S 72.75W in Melas Chasma, the widest portion of Valles Marineris [1–3]. The restricted site (Fig. 1) is a flat, smooth surface, –2 to +1/2 km in elevation, mapped as younger massive material [1,2]. This surface is probably composed of basaltic sand, very slightly hydrated and oxidized. A thermal inertia of 8–10 × 10^{-3} cal $cm^{-2}s^{-1/2}K^{-1}$ [4] and block abundances of 5–10% [5] suggest sand with scattered blocks (fewer than at VL1) and little dust. A surface of slightly altered basalt or basaltic glass [6] is suggested by its dark (albedo 0.18–0.2) and slightly reddish color [4,7], its abundance of high-Ca pyroxene [8], and the presence of H_2O but little structural OH [7].

North and east in the restricted site are rough floor material and landslide material [1], the smooth distal tongues of landslides. In the nominal site, but not the restricted site, are mesas of layered material, probably volcanic or lacustrine sediments [1,9]. Mesa elevations are to 2.5 km, and some are bounded by cliffs.

Surface. Imagery of the landing surface will help elucidate recent surface-atmosphere interactions (wind) and past geological processes in Valles Marineris (sedimentary or volcanic deposition, erosion by wind and water). Characterization of the landing surface will provide ground-truth calibration for remotely sensed data from Viking color and IRTM, Phobos 2 ISM, and Earth-based spectroscopy and radar.

Sand, rocks, and dust should be accessible. The sand has little adhering dust [6], so IMP and APXS analyses of sand will include little dust component. Data on the sand, if basaltic, will help explain martian magma genesis and volcanic processes, provide tests of the origins of "martian" meteorites (via element abundance ratios [10]); and provide clues to aqueous alteration processes (especially from IMP spectra). Rocks on the landing surface probably represent local types, including basalt, sediment (layered material), and highland material from Chasma walls. Chemical and spectral data on rocks will be important in elucidating the geologic history of the Valles Marineris area, and will be relevant to all sedimentary, highlands, and volcanic terrains on Mars. There will likely be local concentrations of dust for analysis.

Scene. The IMP will have spectacular views of Chasma walls to the north (~5.5° vertical angle, 101 IMP pixels, 60 m/pixel) and mesas of layered material to the southwest (~1.5° vertical angle). Spectra from IMP will help reveal the mineralogies and compositions of highland crust (in Chasma walls), Lunae/Syria Planum resurfacing units, layering at tops of the Chasma wall, and the sedimentary layered material. IMP and synthetic stereo imagery will help clarify structures, material properties, and slope processes of the Chasma walls; tectonic structures in and around Melas; and stratigraphic, depositional, and exobiological implications of layered Valles fill.

Atmosphere. Meteorological data from Melas Chasma would be the first from an equatorial site, but local effects could be significant. Valles mists could be studied directly, and the Chasma wall and mesas could provide some calibration for airmass optical depths as a function of elevation, at least to the wall heights.

Mission Constraints II: To investigate Melas Chasma requires landing at 10°S, entailing decreases of ~10–15% photovoltaic power (vs. 15°N), and ~1 hr/day line-of-sight with Earth (vs. 0°N) [11]. To maintain safety, a landing ellipse with an aspect ratio of 2:1 and elongation on N74E must be < ~170 × 85 km. Ellipses of 100 × 200 km aligned between east-west and ~S30°E can be accommodated in Melas Chasma with no elevation above about 1 km.

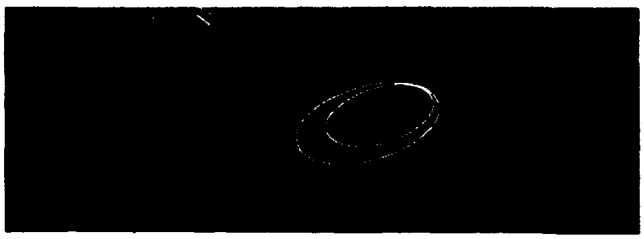

Fig. 1. Nominal and restricted landing ellipses (100 × 200 km and 75 × 150 km) proposed for Melas Chasma. Scene is 8 to 12S, 67.5–80W; ellipses centered near 9.75S, 72.75W.

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CLIMATOLOGICAL TARGETS FOR MARS PATHFINDER.

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Major Climatological Questions: Did Mars have a wet, warm climate early in its history? There is evidence that water flowed across the martian surface during the Noachian [1], and a hydrologic cycle was probably required [2]. However, surface temperatures early in martian history are predicted to have been too low for liquid water [3]. An atmospheric greenhouse, with CO_2 as the major constituent, has been postulated as a mechanism to raise surface temperatures. The subsequent fate of that CO_2 remains a puzzle; 2–5 bar would have been required, equivalent to a global layer of calcite 46–115 m thick. Although bulk carbonates have recently been reported in martian meteorites [4], it is important to search for *in situ* martian carbonates.

Did the discharge of martian outflow channels produced a large ocean in the northern plains, and Hesperian and Amazonian periods of clement climate? It has been hypothesized [5] that return of CO_2 to the atmosphere could have occurred during the creation of the outflow channels, and that subsequent higher surface temperatures could have permitted a global hydrologic cycle that was responsible for formation of a vast Austral ice sheet. The outflow would have formed a northern ocean that would eventually have reprecipitated the CO_2 into carbonates, thereby ending the warm, wet periods.

Is chemical weathering proceeding at present on Mars? The reactive nature of regolith materials suggests either that reactive oxidants are present in the soil [6], or, more likely, that heterogeneous chemistry is taking place between surface materials and photochemically produced oxidizing compounds in the atmosphere [7].

Target Considerations: The ability to look into the past means the ability to look down the sedimentary sequence. The ideal landing site is one in which sedimentary units are exposed. Ideally, a mixture of clastic and chemical sediments will be present; decimeter-scale coherent igneous rocks would provide the opportunity to examine chemical weathering processes. A near-shore deposit, where local channels show evidence of having dissected units of a variety of ages, would be ideal.

We search for depressions within the allowable latitude and elevation domain, into which channels or valleys clearly flow, and which show no obvious signs of subsequent deposition, such as wrinkle ridges, or the high-albedo/low-thermal-inertia signatures of thick dust deposits.

Target materials include carbonates, nitrates, sulfates, halides, phosphates, clays, and Fe-oxides. Much of the original CO_2 inventory was expected to be locked up in carbonates somewhere in the martian regolith. Although small amounts of carbonate have been detected in airborne dust [8], no significant *in situ* deposits or coherent carbonate rocks have been identified. Nitrates are important because Ni is an element of major biological significance and has not been identified in the martian soil. Moreover, some models of the Viking Labeled Release Experiment [9] require significant nitrate deposits. The presence of sulphates, particularly in the absence of carbonates and nitrates, would constitute support for the hypothesis [10] that reactions between S-rich volcanic aerosols and precipitates may have displaced CO_2 and NO_x back into the atmosphere. Halides are not predicted to form under any circumstances [11], so indications that they exist would be an important constraint on martian geochemistry.

Available Measurements and Strategies: The APXS imager may be able to identify depositional environments; if trenching can be done with the tires, even to a very limited depth, additional information may be gained. Small-scale stratigraphy can be very revealing. During Marsokhod rover tests in the Mohave in March 1994, the presence of well-rounded, high-sphericity pebbles at 15 cm was conclusive evidence of flooding. Resolution of 1 mm should reveal evidence of fluvial transport, if any, in clastic sediments.

Measurements of atmophilic elements in sediments may shed light on the climatic conditions that existed during their deposition. Coherent rocks of any probable evaporite could probably be identified with a combination of APXS and IMP imagery. Conversely, if evaporites are present only in the fines, unique identification is problematic, although APXS data may detect constituent elements. Mass balance calculations and geochemical considerations [12] may permit identification of evaporites. Examination of any crust should be a high priority, using both APXS and IMP data.

An important test for contemporaneous heterogeneous chemistry can be carried out with any rock larger than the saltation mean free path length. Weathering reactions should produce a rind, which mantles underlying material from subsequent alteration until accumulated unit-cell mismatches and physical abrasion cause spallation. If heterogeneous weathering is occurring, the windward and leeward sides of rocks may exhibit compositional gradients in their surfaces, detectable by the APXS. Comparison of the two sides of any large rock should be considered a high priority.

Target Area: Four areas fit within the elevation and latitude constraints: Chryse, Elysium, Amazonis, and Isidis. There is geomorphic evidence that all have supported standing water. In some sense, it would be difficult to pick a landing site that had no hope of teaching us about the climatic history of Mars.

The southeast Elysium Basin (3°N, 184.5°W) provides an optimal target in which a variety of materials may be accessible in a near-shore environment [13]. The albedo of the region is moderately low, and the thermal inertia is indicative of moderate rock coverage or some consolidation of fines, arguing that the site has not been covered with eolian dust deposits.

The orientation of the landing ellipse is parallel to the inferred shoreline, which is the circumglobal highland-lowland scarp. The probability of landing in a near-shore paleoenvironment, in which small but coherent fragments of highland materials might be deposited, is increased where the paleoshore lies along the long axis of the landing ellipse.

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