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MARS PATHFINDER LANDING SITE WORKSHOP II: CHARACTERISTICS OF THE ARES VALLIS REGION AND FIELD TRIPS IN THE CHANNELED SCABLAND, WASHINGTON

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MARS PATHFINDER LANDING SITE WORKSHOP II: CHARACTERISTICS OF THE ARES VALLIS REGION AND FIELD TRIPS TO THE CHANNELED SCABLAND, WASHINGTON

Edited by

M. P. Golombek, K. S. Edgett, and J. W. Rice Jr.

Held at
Spokane, Washington

September 24–30, 1995

Sponsored by
Arizona State University
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Cover: Regional mosaic showing the Mars Pathfinder landing site (100 km × 200 km landing ellipse shown). The mosaic shows large catastrophic outflow channels debouching into Chryse Planitia. Ares Vallis flowed to the northwest (from the southeast) across the landing site. Tiu Valles is just to the west of Ares Vallis and may also have flowed across the landing area. The landing site itself is a very smooth depositional surface, where the flood waters deposited the sediments carved from the channels. Landing at this location should allow analysis of a wide variety of rock types deposited by the flood. These catastrophic outflow channels on Mars are much larger analogs to the Channeled Scabland in Washington state.

Introduction

Mars Pathfinder, our next mission to arrive at Mars, will place a single lander on the surface of Mars on July 4, 1997, following a December 1996 launch. As a result of the very successful first Mars Pathfinder Landing Site Workshop held April 18–19, 1994, at the Lunar and Planetary Institute, the project has selected the Ares Vallis outflow channel in Chryse Planitia as the landing site. This location is where a large catastrophic outflow channel debouches into the northern lowlands. Landing on the material deposited by the flood (a so-called "grab bag" site) provides the opportunity to analyze a variety of different rocks that make up the martian crust (ancient Noachian highlands as well as Hesperian ridged plains). On September 24–30, 1995, a second workshop and series of field trips, entitled Mars Pathfinder Landing Site Workshop II: Characteristics of the Ares Vallis Region and Field Trips in the Channeled Scabland, Washington, were held in Spokane and Moses Lake, Washington.

The purpose of the workshop was to provide a focus for learning as much as possible about the Ares Vallis region on Mars before landing there. The rationale is that the more that can be learned about the general area prior to landing, the better scientists will be able interpret the observations made by the lander and rover and place them in the proper geologic context. The field trip included overflights and surface investigations of the Channeled Scabland (an Earth analog for the martian catastrophic outflow channels), focusing on areas particularly analogous to Ares Vallis and the landing site. The overflights were essential for placing the enormous erosional and depositional features of the Channeled Scabland into proper three-dimensional context. The field trips were a joint educational outreach activity involving K–12 science educators, competitively selected from Washington and Idaho, Mars Pathfinder scientists and engineers, and interested scientists from the Mars scientific community. The workshop was convened by M. Golombek of the Jet Propulsion Laboratory, who authored the "Mission Description" (pp. 1–8) found in Part 1 of this technical report. The field trip was convened by K. Edgett and J. Rice of Arizona State University and led by V. Baker of the University of Arizona.

Part 1 of this technical report includes a description of the Mars Pathfinder mission, abstracts accepted for presentation at the workshop, an introduction to the Channeled Scabland, and field trip guides for the overflight and two field trips. Part 2 includes the program for the workshop, summaries of the workshop technical sessions, a summary of the field trips and ensuing discussions, late abstracts of workshop presentations, reports on the education and public outreach activities carried out by the educators, and a list of the workshop and field trip participants.

Program

Thursday, September 28, 1995

7:30–8:30 a.m. Registration and Continental Breakfast

8:30–8:35 a.m. Welcome and Introduction
M. P. Golombek

SESSION I: THE MARS PATHFINDER MISSION, PROJECT, AND LANDING SITE

Chair: A. Treiman

8:35–10:30 a.m.

The Mars Pathfinder Mission
M. P. Golombek

Status of the Mars Pathfinder Project
A. J. Spear

Engineering Constraints on Pathfinder Landing
R. Cook

Mars Pathfinder Landing Site Selection
M. P. Golombek

SESSION II: REGIONAL GEOLOGY OF CHRYSE PLANITIA

Chair: V. Baker

10:45 a.m.–12:00 noon

Regional Geology and Sedimentary Stratigraphy of Chryse Planitia, Mars
K. L. Tanaka

The Geologic Mapping of the Ares Vallis Region
J. W. Rice Jr.

SESSION II: REGIONAL GEOLOGY OF CHRYSE PLANITIA (continued)

Chair: V. Baker

1:30–2:00 p.m.

Geologic Mapping Traverse of the Highland-to-Lowland Transition in an Area Adjacent to the Mars Pathfinder Region
L. S. Crumpler

SESSION III: CHRYSE FLOODING

Chair: R. Kuzmin

2:00–3:30 p.m.

Facies on Mars: A Model for the Chryse Basin Outflow Sediments Based on Analog Studies of Icelandic Sandar and the Ephrata Fan of the Channeled Scabland, Washington
J. W. Rice Jr. and K. S. Edgett

Catastrophic Paleoflooding at the Pathfinder Landing Site: Ares Vallis, Mars
G. Komatsu and V. R. Baker

Estimates of the Maximum and Minimum Flow Velocities of the Circum-Chryse Outflow Channels
R. A. Craddock and K. L. Tanaka

SESSION IV: LANDING ELLIPSE GEOLOGY, SEDIMENTOLOGY, AND EXOPALEONTOLOGY

Chair: K. Tanaka

3:30–5:00 p.m.

Mars Pathfinder: Geology of the Landing Site Ellipse
R. O. Kuzmin and R. Greeley

Viking Stereo of the Ares Vallis Site: Sedimentological Implications
T. J. Parker

An Exopaleontological Framework for the Mars Pathfinder Landing Site
J. Farmer

SESSION V: POSTERS

Chair: M. Golombek

5:00–5:30 p.m.

Morphologic Map of Ares Vallis
F. Costard

Preliminary Cartographic Analysis of the Pathfinder Landing Site Using Viking Orbiter Images
T. C. Duxbury

Viking IRTM Observations of the Anticipated Mars Pathfinder Landing Site at Ares Vallis
K. S. Edgett

Viking IRTM High Resolution (2–5 km) Observations of Ares Vallis and the Mars Pathfinder Landing Site Region
K. S. Edgett and J. R. Zimbelman

Characteristics of the Mars Pathfinder Landing Site
M. P. Golombek, T. J. Parker, H. J. Moore, M. A. Slade, R. F. Jurgens, and D. L. Mitchell

Topographic Map of the Ares Tiu Landing Site from Viking Orbiter Data
E. Howingon-Kraus, R. L. Kirk, B. Redding, and L. A. Soderblom

Possibility of Highly Contrasting Rock Types at Martian Highland/Lowland Contact
G. G. Kochemasov

5:30–6:30 p.m. Reception (Field Trip I Overflight Video Film Review)

Friday, September 29, 1995

SESSION VI: WHAT WILL PATHFINDER FIND?
Chair: R. Craddock

8:30 a.m.–12:00 noon

Potential Source Rocks of Sedimentary Deposits at the Pathfinder Landing Site
K. L. Tanaka

A Sojourner's Prospectus: Provenance of Flood-transported Clasts at the Mars Pathfinder Landing Site
J. W. Rice Jr. and K. S. Edgett

Hardpan and Other Diagenetic "Rock" in the Catchment of Ares Vallis and Surrounding Areas
A. H. Treiman

Ground Ice at the Mars Pathfinder Landing Site
M. T. Mellon

What Will Pathfinder See and Do on Mars?
H. J. Moore

After the Flood: A Preview of Eolian Features at the Mars Pathfinder Landing Site in Ares Vallis
K. S. Edgett

A Targeting Strategy for Ensuring a Hillside View at Ares Vallis
P. H. Smith

SESSION VII: HAZARDS—ROCKS AND ROUGHNESS

Chair: R. Simpson

1:30–4:00 p.m.

Size-Frequency Distributions of Rocks on Mars
M. Golombek and D. Rapp

Radar Scattering Characteristics of Ares Vallis and Environs from Arecibo Observations
J. K. Harmon and B. A. Campbell

Dual-Polarization Continuous Wave (CW) Observations from the Ares Vallis Site and Environs
M. A. Slade, D. L. Mitchell, and R. F. Jurgens

Assessment of Pathfinder Landing Site with Goldstone Radar Ranging and Goldstone-VLA Dual-Polarization Imaging
A. F. C. Haldemann, D. O. Muhleman, R. F. Jurgens, and M. A. Slade

Spatial Statistical Analysis of the Ares Vallis Region from Viking Orbiter and Worst-Case Scenario for Subpixel-Scale Roughness
M. K. Shepard, E. A. Guinness, and R. E. Arvidson

4:00–4:30 p.m. General Discussion

4:30–5:00 p.m Introduction to the Lake Missoula Breakout Field Trip
V. Baker

ADJOURN

Contents

Summary of Technical Sessions

—edited by M. P. Golombek

INTRODUCTION

The workshop agenda was organized to give the participants an introduction to the mission, followed by the regional geology of Chryse Planitia and its flooding; landing ellipse geology, sedimentology and exopaleontology; what Pathfinder is likely to find; and hazards from rocks and roughness. Each individual session was summarized by a different attendee and edited for continuity by the senior editor.

SESSION 1: THE MARS PATHFINDER MISSION, PROJECT, AND LANDING SITE

Summary by Nadine G. Barlow

Session 1 was an overview of the Mars Pathfinder mission and the landing site selection process. M. Golombek started off the session by reviewing the mission itself, including the launch and trajectory, instruments, goals, and science objectives of the mission. The questions following the presentation dealt primarily with the concerns about landing and determining the location of the lander/rover. A. Treiman questioned whether the direction of the prevailing winds had been taken into account during descent since part of the descent includes use of a parachute. Golombek replied that atmospheric scientists had been consulted with regard to what type of horizontal winds could be expected at the landing site. The consensus is that the horizontal winds are a random variable but peak at about 20 m/s. In addition, the rockets are still firing when the parachute is cut loose, so that it and the backcover will be taken some distance away from the lander itself and entanglement upon landing should not be a problem.

J. Moore wondered how well the location of the Mars Pathfinder lander could be determined after landing using only the orbital information from Viking. Golombek noted that the landing ellipse is 100 × 200 km in size and that the project expects to be able to determine where the lander sets down within 10–15 km by tracking the entry of the spacecraft into the upper atmosphere. Tracking of the lander signal on the surface should narrow down this uncertainty further. The looming question at the present time is how good is the Mars control or cartographic net—the Mars Pathfinder Project asked both T. Duxbury and the USGS Flagstaff (L. Soderblom and R. Kirk) to reanalyze the control net over the Pathfinder landing site in Ares Valles. The result is that the variation in the absolute positions of the control points have been reduced to less than 1 km in latitude and longitude and less than 50 m in elevation. R. Kuzmin asked a related question in terms of how well the rover location could be determined. The IMP on the lander will be used to keep the rover in sight at all times. In addition, stereo from the camera on the rover will provide additional constraints on where the rover is located and what hazards are within the field of view.

In response to H. Moore's question about whether a full-size mockup of Mars Pathfinder exists, it was noted that an engineering model of both the lander and rover are being constructed in a sandbox at JPL. This mockup is mainly for testing prior to landing, but may be reconfigured with the actual site after landing to assist in any problems that may develop during operations.

T. Spear then discussed the status of the Mars Pathfinder Project. The spacecraft testing is moving along on schedule and there is a good likelihood that Mars Pathfinder will come in under budget. Currently the spacecraft is at JPL, where the software is being loaded and the entire system is undergoing testing. Educational outreach is a prime goal of this project, so videos, a CD-ROM, and a contest among schools to include a plaque or essay on the spacecraft are ongoing activities. Treiman asked how one could obtain copies of the video and/or CD-ROM and was told to contact the JPL Public Affairs Office to make a request. G. Wetherill noted that JPL has a reputation for producing expensive products due to overhead and management and wondered how this project could be coming in under budget. The main cost savings is coming by taking only two years for development rather than the usual five. Spear emphasized that the cost savings is not reducing reliability or increasing risk, and no shortcuts with regard to testing of the equipment and instruments are occurring.

R. Cook described the engineering constraints on the Pathfinder landing site and how those constraints were derived. The preference was for a landing site in the Chryse region since good data from the Viking 1 lander exists for that area. R. Simpson asked if there was any way to know if the landing is successful if the spacecraft fails. Cook replied that some data about spacecraft operations will be returned during descent, but that it would be uncertain if failure was due to the landing system or the result of a surface feature. D. Shirley noted that the mission is called "Pathfinder" because it is the first of a series of upcoming spacecraft to Mars over the next 10 years, so this mission is mainly designed to determine if the engineering techniques work. Golombek seconded Shirley's comments by noting that the engineering requirements requested a "safe" landing site to design to, but that it is very difficult to determine the location of the "safest" site on Mars due to the data that currently exist. Also, Mars Pathfinder wants a location with rocks given that a major portion of the science investigation will be to determine the composition of those rocks. Golombek's comments led into his final presentation about how the Ares Valles site was selected. This selection process is described in detail in the technical report following the first Mars Pathfinder Landing Site Workshop (LPI Tech. Rpt. 94-04) and in the background material for this workshop (LPI Tech. Rpt. 95-01, Part 1).

SESSION II: REGIONAL GEOLOGY OF CHRYSE PLANITIA

Summary by T. Parker

In introducing his talk on regional geology and stratigraphy of Chryse Planitia, K. Tanaka stressed the importance of having had most of the workshop participants on both the overflights and field trips into the Channeled Scabland prior to the meeting. He felt that the overflight gave an excellent regional preview to the site-specific examples visited on the ground. Cross-sections viewed in road cuts were similarly important to understanding the depositional histories of large-scale floods. He also reminded us that the entire Channeled Scabland flood was probably comparable in scale to some of the smaller outflow channels in the Chryse region.

Based on new crater counts and new geomorphic interpretations, Tanaka reconstructed the geologic history of the circum-Chryse region, including identification of multiple channeling/sediment deposition and volcanic/tectonic episodes (a geologic map, by Rotto and Tanaka, of the Chryse Planitia region should be published soon). He indicated that there were four major periods of channeling from the late Noachian through the Amazonian. A surprise result, based on the new crater counts, was that some of the Chryse interior units, such as the ridged plains in the vicinity of the Maja Valles fan, turned out to date to the late Noachian. Kasei Valles showed ages similar to Lunae Planum, also dating to the Late Noachian, although the latest flooding was as recent as Early to Middle Amazonian.

Crater counts by Tanaka and M. Robinson appear to have corroborated the Late Hesperian to Early Amazonian ages assigned previously to the Ares/Tiu/Simud Valles floods. Mesas of earlier, Noachian and Hesperian flood deposits lie to the northwest of the landing site (recognizable as eroded layered mesas), and to the east in Oxia Colles (plains surfaces between the Oxia mesas). Of particular interest to this project, Tanaka stressed the point that there is no "butte-and-basin" topography analog in the Chryse Basin in the landing site, suggesting a depositional rather than erosional surface. This observation reflected a growing consensus among the workshop participants that the Pathfinder landing site comprises plains channel sediments. Tanaka saw no clear cross-cutting of either Ares or Tiu Valles deposits by the other, but inferred that deposits from Tiu Vallis embayed the mouth of Ares Vallis.

J. Rice described preliminary geologic mapping that he is conducting at the 1:500,000 scale of the MTM20032 quadrangle, which includes the Pathfinder landing ellipse. Focusing on the vicinity of the landing ellipse, he made a number of interesting points. Wrinkle ridges are rare (but present) in and around the landing site. Most appear to have been reactivated structures previously eroded/buried by the flood. Flow-parallel ridges and grooves are found in several places within the landing ellipse, but are subdued, not sharp, possibly suggesting a deposit rather than a stripped surface. The "scabby terrain" west of the landing ellipse was described (and received a great deal of attention throughout the meeting). Rice indicated that it could be fluvial (true scabland), eolian (deflation), or similar to terrestrial thermokarst areas. Rice (and several audience members) interpreted splotchy albedo variations in the area as low shields common in the southern Chryse region. There was considerable discussion of this interpretation and whether these were real features in the images or mosaic artifacts, and it was suggested that comparisons with the individual, less-processed images be made to verify the nature of these features. Rice suggested that the fields of small "secondary" craters may actually indicate airbursts scattering the impactors over a large area. Kuzmin disagreed, however, and offered a candidate primary crater to the south of the map area.

L. Crumpler described a highland-lowland traverse in an area adjacent to the Pathfinder landing site. Intercrater plains within the highlands are likely due to younger resurfacing. Consideration of rock distributions at the Viking 2 landing site in comparison to fracture densities in lava flows led him to conclude that the Viking Lander 2 site is a fractured lava surface, as opposed to an ejecta surface. He believed that the Pathfinder landing site will be very similar to the Viking lander 1 site, which he interpreted as being a fluvial surface.

SESSION III: CHRYSE FLOODING

Summary by K. Tanaka

This session began with a description by Rice and K. Edgett of a facies model for sedimentation at the Pathfinder landing site, based on catastrophic flood deposits on Earth. They concluded that both the Viking 1 and Pathfinder landing sites occur on mid-fan facies material, in which intermediate-size clasts have been deposited. H. Moore asked why the rocks at Viking Lander 1 are not as rounded as might be expected; Edgett responded that rounding processes are not clearly known even on Earth. Rice added that rounding is a function of flood duration, and T. Parker mentioned that rounding can also be a function of transport distance. Interest was also shown in the dark albedo partly covering the northeastern part of the Pathfinder landing ellipse. Edgett indicated that dark material can be seen near the ellipse, and R. Singer suggested that the landing site be moved toward the dark area so that dark materials can be examined by Pathfinder.

G. Komatsu next provided estimates of hydraulic parameters for a catastrophic flood event through Ares Vallis. These estimates are critically dependent on channel slope, and Simpson questioned the accuracy of the Mars digital topographic model used in the calculations. Komatsu responded that the absolute topography is problematic but that the local relative topography seems to be reliable.

Another approach to estimates of martian outflow channel hydraulics, which included both maximum and minimum flood conditions, was presented by R. Craddock. The minimum flood conditions are based on estimates of clast size based on Viking thermal inertia data. R. Sullivan suggested that a boundary-layer model used for atmospheres could be applied to derive a vertical velocity profile. K. Herkenhoff wondered how east-west radar topographic profiles could be used to define north-trending channel gradients, and Craddock replied that multiple radar tracks at different latitudes were used. Spear and Treiman expressed their concerns regarding the limitations of model estimates and observational constraints available to define potential hazards at the Pathfinder landing site.

SESSION IV: LANDING ELLIPSE GEOLOGY, SEDIMENTOLOGY, AND EXOPALEONTOLOGY

Summary by J. Crisp

Kuzmin presented work by himself and R. Greeley on the geology of the landing site ellipse. He showed high-resolution Viking images of several streamlined islands to the southwest of the ellipse that had eight distinct terraces on them. In the center of the ellipse, there are smooth areas and areas with many secondary craters, a few longitudinal grooves, and a few streamlined islands. There appears to be resurfacing of highland material to the east. In stereo, you can see a shallow rolling surface. Material from both the Ares and Tiu channels was deposited in the ellipse. There is evidence of erosion of former delta deposits in the streamlined terraced islands, and multistage flooding from both Ares and Tiu channels. The outflow from these channels continued much further north, beyond the ellipse. There is a 50-km-diameter crater between Tiu Vallis and Simud Vallis that is fresh, and approximately 500 km away to the south, which could be the source of secondary craters in the ellipse. The source areas of Tiu and Ares Valles are Hesperian (ridged plains) and Noachian (highlands) in age. Kuzmin cited evidence for an eolian origin of the etched terrain to the west of the ellipse. The last stage of flooding was lower Amazonian, according to Tanaka.

Kuzmin also described the landing sites chosen for the Russian Mars '96 mission. The main sites currently selected for the September 10, 1997, landing of small stations are: 41.31°N, 153.55°W and 32.48°N, 169.32°W; with an extra site at 3.65°N, 193°W. However, the landing ellipses are much larger than the one for Pathfinder, extending approximately 20° in latitude and longitude. The Mars '96 penetrators will land one month after the small stations land, and there are several options for where these will be sent.

Parker handed out three-dimensional red/blue glasses to the audience, and presented a slide show with many Viking (40 m/pixel) and some terrestrial stereo images. Examples of features in the landing site ellipse were shown for primary impact craters, secondary craters, streamlined islands, longitudinal grooves, "scabland" or etched plains, pancakelike shields, dikelike structures, knobs or buttes tens to a few hundred meters high, and undulating plains with ripplelike low-amplitude long-wavelength features parallel to flow (probably not current ripples). The landing site geology is probably predominantly the result of fluvial processes. However, other processes could have altered the surface after flooding, such as eolian reworking or burial, permafrost modification, lacustrine or marine deposition, desiccation, or burial by volcanic plains. Stereo images of an Earth example of flooding were shown for the Saint Francis Dam in southern California. When this dam broke, the discharge was 8–9 orders of magnitude lower than that estimated for Ares Tiu flooding, yet over 1 km downstream from the dam, 50-m cement pieces of the dam were deposited! Nonhorizontal bedding in one of the knobs in the landing ellipse suggest that it may have been an allocthonous block rafted by a flood.

J. Farmer discussed an exopaleontological framework for the landing site. The requirements for life are liquid water, nutrients, and an energy source. There is probably no extant life on the surface, but there could be life in the subsurface. It will be easier to look for fossil life on Mars. An ideal exopaleontological landing site would be a thermal spring, stromatolites, lake deposit, or a hydrothermal deposit. Preservation of organic materials or replacement minerals would be favored by a low-permeability host rock, closed chemical system, shallow burial, and low temperatures. Hydrothermal environments might be identified by outflow channels on volcano flanks, or outflow channels originating from thermokarst regions. The Pathfinder landing site outflow channels originate in chaotic terrain that may be thermokarst, and may be a good target for fossil life. Even if the rocks at the landing site turn out not to be from thermokarst, a determination of the mineralogy of the soil and rocks will be of great help in targeting future missions to search for fossil life on Mars.

SESSION VI: WHAT WILL PATHFINDER FIND?

Summary by K. Herkenhoff

Tanaka discussed the results of his recent geologic studies of Chryse Planitia, including new crater counting that indicates that both the Viking Lander 1 and primary Mars Pathfinder landing sites are on Late Hesperian/ Early Amazonian debris flows. He suggested that clasts at the Viking 1 site may have been ejected from a nearby crater, and showed images of bedrock exposures that indicate that the soil at Viking 1 is rather thin. He proposed the following geologic history of the Simud/Tiu Valles outflow system: Ejecta from the Chryse

Basin became water-saturated, then Marsquakes liquefied the ejecta, causing debris flows into the basin. The chaotic source regions at the heads of Simud and Tiu Valles are typical of debris flows. Tanaka showed evidence that the flows ponded, then backed up the channels in Ares below the landing site. He did not agree with interpretations of some ridges as glacial features, preferring a compressional tectonic origin (wrinkle ridges). He showed side-scan sonar images of submarine debris flows on Earth, suggesting that Chryse may have been full of water, allowing similar features to form on Mars. Crater counts indicate that the martian highlands are about 4 b.y. old; some of these old materials may have been deposited at the landing site. Tanaka argued that eolian stripping of the scabby terrain requires a paucity of large clasts, or a lag deposit will form and armor the surface against further erosion. He showed a histogram of knob sizes greater than 150 m and a power-law fit that he used to extrapolate to smaller block sizes. This extrapolation underestimated the abundance of clasts at the Viking 1 site by a factor of 100, but Tanaka suggested that they may represent local ejecta. Remote sensing data and analysis of the SNC meteorites indicate that basalts are present on Mars, but their compositional diversity is unknown. Finally, Tanaka suggested that the knobs may have been rafted in debris flows into the landing site area.

J. Moore noted that Tanaka's extrapolation to small block sizes does not agree with the thermal inertia data, which indicate higher block abundances. Rice argued that the presence of knobs within the channels suggests that the flood could not carry them into the landing site, and Tanaka responded that knobs may be abundant at the landing site but not resolved in the images. Golombek noted that a power law could not fit their counts of blocks, and asked if Tanaka's crater counts were averaged over different geologic units, and Tanaka responded that they were. V. Gulick asked if Tanaka found evidence for levees, and the answer was no.

Rice and Edgett listed the potential rock types at the primary Pathfinder landing site: volcanic, plutonic, impact breccias, sandstone, shale, carbonates, hardpan, and meteorite fragments. Large clasts are expected to have been derived from local sources, as observed at the Ephrata Fan during the field trip. More variety is expected in the small clasts, as observed in the dune fields south of the Ephrata Fan. Other mechanisms for moving large clasts include ice rafting and debris flows onto ice-covered lakes. Bank collapse onto ice rafts may preserve stratigraphy, but is unlikely. Rice and Edgett showed terrestrial examples of these processes, including boulders in the Willamette Valley, Oregon, that were rafted in ice during the Missoula floods. Undercutting of ice by rivers results in rafting, as does deposition of sediment on ice. Examples from Alaska and Antarctica were shown.

Shirley asked how the mineralogy of the sand in the dune fields near Moses Lake was determined, and the response was that the mineralogy was analyzed using a petrographic microscope in a laboratory. Treiman asked how small a rock can be analyzed by the APXS, and the answer was 5 cm.

Treiman motivated his presentation by stating that the martian highlands make up about two-thirds of the martian crust and that constraints on their composition will be important in unraveling Mars' early history. He showed images of layering in the walls of Valles Marineris. Layering is present throughout the canyon system but only near the tops of the walls. Layering is seen in both Hesperian and Noachian units, even under impact craters. These observations suggest that the layers are not primary depositional features, but were formed in place (diagenetic). Treiman showed photos of terrestrial analogs: hardpan. Layering is seen in the walls of valleys in the Chryse region, and Treiman interpreted the benches on streamlined islands near the primary Pathfinder landing site as having been caused by layering in the wall rock rather than fluvial erosion and deposition. Finally, he suggested that the layering in the large block shown by Parker is due to the presence of a hardpan layer.

Rice asked what the thickness of the terrestrial hardpans is. The answer was a few meters. Shirley asked what the martian hardpan is likely composed of, and the response was that they were mostly made up of carbonates or other salts, cements, or clays. Water is required to form such hardpans. Gulick suggested that the layers may have been formed by hydrothermal mineral deposits. Treiman responded that hydrothermal activity must have been laterally extensive to form such widespread layering. Gulick countered that there is evidence that volcanism is widespread on Mars, but Treiman was not convinced that this hypothesis is viable. Edgett noted that layering is found all over Mars, in support of Treiman's hypothesis. Kuzmin asked about thickness variations in the layers. The response was that there are some layer thickness variations, but the thickness of the whole sequence is rather consistent. It was suggested that the layers may be caused by ground ice, but it was not felt that deposition from vapor was possible. Sullivan asked why the layering was thought to be due to strength rather than albedo variations; the answer was that the lack of observed layering on the lower slopes of Valles Marineris may be due to a talus cover.

M. Mellon asserted that ground ice on Earth results in polygonal features regardless of soil type. Ground ice is unstable at the surface of Mars, so that a porous surface layer is required to permit formation of ground ice below the surface. Variations in Mars' obliquity and orbit affect ground ice stability, the frost point, and atmospheric water abundance. Mellon showed results of his modeling of ground ice stability, in which the choice of soil thermal and diffusive properties does not critically affect the results. His modeling indicates that ground ice has not been stable at the primary Pathfinder landing site for the last 500,000 years, but is more stable at higher latitudes. Ice wedging causes topographic features on Earth, so polygons should also occur on Mars despite higher tensile strength at lower temperatures. Mellon showed polygonal features on Mars, including possible polygons at the Viking Lander 2 site. These observations are consistent with his modeling. Polygons may be seen at the Pathfinder landing site, but more modeling is needed to support this prediction. The relatively thin soil at the Viking Lander 1 site may have prevented polygons from forming there. A lack of polygons at the Pathfinder site may indicate either unfavorable geologic conditions or problems with the theory.

Treiman asked if blocks can be lifted to the surface of Mars, as seen on Earth, but the response was that sorted stone circles on Earth are formed by frost heaving and require freezing and thawing of water. Liquid water is not likely to be stable on Mars, so frost heaving probably is not occurring there. D. Muhleman asked how the atmospheric water abundance is calculated. Answer: The calculation is based on the present water abundance and models of sublimation at the poles. Water is assumed to be always available at the poles. V. Baker noted that ice wedging on Earth requires lots of water and asked if Mellon thought that enough water is present on Mars. Mellon's response was that water transport into cracks needs to be investigated. Sand falling into cracks may also cause wedging.

H. Moore began his presentation by asserting that there are three kinds of Mars scientists: those who look down from their "ivory orbiters," groundbased observers, and "realists like us." Moore compared the Viking lander and IMP cameras, pointing out that both are mounted on fixed platforms. The Viking sampling arm had access to a limited area, while the Pathfinder rover will be able to traverse an area of at least 314 m^2. The rover will be able to "kiss" rocks; Moore felt that this capability is essential to the success of the Pathfinder mission. He compared Viking and Pathfinder instruments and their capabilities. The view from the rover cameras of Mars Hill in Death Valley shows that much can be learned and seen from rover-based images. The martian surface is heterogeneous, as indicated by the Viking Lander 1 panorama and site map. Therefore, mobility can increase the scientific yield of the Pathfinder mission significantly. Moore showed bright surfaces that resulted from tamping by the Viking 1 sampling arm, indicating particle sizes less than 50 μm in the drift material. The rover tracks may similarly yield the best estimate of grain sizes at the Pathfinder landing site. Moore compared the drift material to kitchen flour and the crusty material to the loess seen on the field trip. Crusts and clods at the Viking sites could easily be disaggregated, and are probably cemented by the same material. The blocky material is the strongest and has the highest Cl and S content. Disruption of the soil by the rover can yield material properties. It was difficult to move rocks at the Viking Lander 2 site, and may also be difficult at the Pathfinder landing site. Small landslides were observed at the Viking 1 site, but their causes remain unknown. The Pathfinder rover will be able to create landslides and image them. The Viking landers were unable to make good XRF measurements of rocks because they were covered with dust. The IMP must be used to search for clean areas on rocks. Conical piles of soil at the Viking 1 site were only changed by winds during a dust storm. The Pathfinder rover can also build piles to do a similar experiment.

J. Moore asked about the resolution of the rover cameras. Answer: At minimum, 6-cm focus distance, about 0.7-mm/pixel resolution from the rear rover camera. C. Stoker asked about the depth of penetration of APXS measurements. Answer: About 100 μm. It may be possible to measure the bulk density of soils using the APXS. Thermal inertia data must be interpreted carefully, as the Viking lander images show a complex mixture of materials.

Edgett discussed eolian features at the primary Pathfinder landing site. Windborne ash and silt are present in the Missoula flood deposits, and sand has been reworked into dunes. Eolian features are prominent at the Viking lander sites: Drifts with possible ripples and layering are seen at the Viking 1 site, and erosional scour and drifts are also present at the Viking 2 site. As described by H. Moore, soil in piles was moved during a storm at the Viking 1 site. Surface properties appear to vary from east to west at the primary Pathfinder landing site, based on color/albedo and thermal properties. Wind streaks in the area indicate winds blowing from the north-northeast, so that sand may be moving into the landing ellipse. Dark material is associated with crater clusters, and may be composed of sand ejected by the impacts. Edgett favored the eolian deflation hypothesis for the formation of the etched terrain. Mars Pathfinder has advantages over the Viking landers for studying eolian features: IMP spectral data and rover mobility will allow the composition of the drifts and physical properties of the fines to be determined. The cameras on the rovers will be able to resolve pits in rocks that may be eroded by saltating particles. Edgett predicted that no dunes will be found at the Pathfinder landing site, because none are seen in Viking Orbiter images of the area. However, drifts are likely, especially in the northeast part of the ellipse. The Pathfinder landing site may be similar to the Viking 1 site with more dark drifts.

Shirley asked what atmospheric density is needed to produce the observed eolian features. Answer: The dunes appear to be active today, but the process is slow. Bright dust would cover the dark dunes if they were not recently active. H. Moore pointed out the dark crater rims may be due to trapping of drift material by blocky ejecta. S. Metzger asked what wind speed was measured during the Viking 1 dust storm. H. Moore responded that the anemometer was broken, but the wind speed was estimated to be about 40 m/s at the height of the meteorology boom. Drifts with cross-laminations are made of dust, but other darker material at the Viking 1 site may be sand. The microbalance on the rover may be able to determine particle sizes.

P. Smith showed that there are many interesting features in the vicinity of the primary Pathfinder landing site, but none of them occur within the landing ellipse. He suggested that the ellipse be moved slightly to increase the chances of seeing interesting features with the IMP. He reviewed the characteristics of the IMP: 1 mrad/pixel resolution, 1.5 m above the surface. Assuming a spherical Mars, the distance to the horizon is 2.6/h km, where the height h is in meters. For the IMP, the horizon will be 3.2 km away and the resolution at that distance will be 3.2 m/pixel. If a feature is 200 m high, the top will be visible if it is 37 km away. Such a feature would have to be even closer if it is to be studied. Smith argued that 5 m/pixel resolution is required to learn much about a feature, so that Pathfinder must be within 5 km of topographic features. He showed the IMP filter effective wavelengths relative to Mars spectra and the 1-μm pyroxene band. The goal is to look for compositional variations and classify various rocks. Smith has submitted a proposal to obtain HST images of the Mars Pathfinder landing site at similar wavelengths to study regional variations and place IMP observations in a regional context. His experience on the field trip was that big rocks are few and far between, and that most of the surface is "boring gravel." Most of the useful geologic information (stratigraphy) is found in stream-carved channels, so Pathfinder should land near or on a streamlined island to maximize the chances of seeing the stratigraphy. Such views would excite the public. In any case, the lack of visible features in Viking Orbiter images does not assure that the site is safe. Landing in a group of islands may be just as safe, and will allow the lander to be located precisely using triangulation.

Golombek said that the islands were avoided in the site selection process because the slopes may be large enough to be unsafe for landing. The tails of the streamlined islands are locally derived depositional features and probably very coarse (and therefore unsafe). Treiman agreed that the Pathfinder landing site is boring and saw this as part of a NASA trend toward conservatism. One of the teachers asked if large slopes will be a problem for the Pathfinder altimeter, but the response was that gentle slopes would not present a problem. Farmer noted that the trend has been to develop smaller, less-capable rovers when rovers with greater mobility are needed. Shirley pointed out that the next (Mars Surveyor) lander is smaller and less capable than Pathfinder. Funding is limited, so larger rovers are not likely to be developed in the near future. Craddock wondered if it may be possible to see some large features from the Pathfinder landing site, since crater rims appear to be visible in Viking Lander 1 images. The answer was that there is less than a 40% chance of seeing one of the knobs within the landing ellipse, and the islands will not be visible. Treiman asked if better knowledge of martian atmospheric structure will help future navigation and targeting. Cook responded that the problem is not lack of knowledge about the atmospheric structure, because the size of the landing ellipse is mainly due to uncertainties in the ephemeris. Metzger felt that the public will not be excited by lander views of distant features, but by animations of the terrain. Smith did not share this opinion.

SESSION VII: HAZARDS—ROCKS AND ROUGHNESS

Summary by R. Craddock

At the time of the workshop the decision to land at Ares Vallis was awaiting final approval. Originally this area was chosen as the Viking A1, or principal landing site, based upon Mariner spacecraft data. However, this site was rejected because Viking Orbiter data showed evidence for intense fluvial dissection, wind stripping, and possible volcanic features and principally because Earth-based radar data had low reflectivity values. These data, however, were limited and taken as Mars was approaching superior conjunction so the signal to noise was low. Since the mid 1970s large improvements in the capability of Earth-based radar instruments have been made, and the Pathfinder mission has the heritage of Viking image and thermal data to build upon. Because the scientific return is dependent on not only the spacecraft landing safely but where it lands as well, the information presented at this session was arguably some of the most valuable of the workshop.

Rocks on the martian surface represent a commodity for the scientific instruments onboard Pathfinder. On the other hand, large, angular rocks could destroy or severely damage the spacecraft during landing. In an effort to assess the size distribution of rocks in the landing ellipse, Golombek and Rapp reviewed the available information for rock populations in the Viking landing sites. Because comminution of material usually produces more smaller particles than larger ones, a simple power-law function has typically been used to describe rock populations. However, Golombek showed that when the cumulative fraction of area covered by rock is plotted against rock diameter on a log-log plot, the rocks visible from the Viking landers fall on a convex-shaped curve best described by an exponential function. The most significant difference between the two functions is that the power law overestimates the number of large rocks on a surface. Comparing the Viking lander data with the rock populations created by a number of terrestrial geologic processes shows size distributions that follow similar relations. The importance of these data is not necessarily in determining processes responsible for creating the rock populations observed by the Viking landers but in providing confidence that the populations of large rocks in the Pathfinder landing ellipse will not be as great as would ordinarily be predicted by a simple power-law function. From these data, Viking thermal inertia measurements, and models of 10-cm-diameter rock coverage, Golombek and Rapp also developed equations that predict the rock population of any area on Mars. The Pathfinder spacecraft is designed to accommodate landing on a boulder with a maximum height of 50 cm. The modeled rock abundance at the Pathfinder landing site is approximately 20%, which from their equations suggests that less than 1% of the surface is covered by a rock 50 cm high or greater. Spear suggested that a risk analysis be prepared based on the data presented by Golombek. H. Moore stated that bedrock materials typically have thermal inertias twice those modeled by Christensen for rocks, which would tend to overestimate the amount of fines present. As Singer quietly pointed out, however, the higher thermal inertia values from outcrops actually means that the percentage of dangerous rocks would be smaller.

J. Harmon and B. Campbell presented results from quasispecular radar measurements made at Arecibo. These data suggest that the Pathfinder landing site is lower in elevation than the Viking 1 landing site by ~200 m. The maximum relief of the Pathfinder landing site was also determined to be on the order of 150 m. From data taken near the Pathfinder landing ellipse, it also appears that the RMS slopes are 7.2° with an assumed reflectivity of 0.068, which is higher than the martian average but typical of Chryse Planitia in general. Harmon also presented depolarized reflectivity maps from 1990 observations that included not only the Chryse region but several other potential backup landing sites as well. These data are useful in that they give information about roughness at scales less than those influencing RMS slope values. There was some indication that at the decimeter scale, the Viking Lander 1 site is rougher than the Mars Pathfinder landing site. In general Harmon stated that there does not appear to be anything unusually rough within the landing ellipse.

M. Slade and co-workers presented dual-polarization 3.5-cm continuous wave observations made by the Goldstone Observatory during the 1995 opposition. A total of nine transmit-receive cycles were performed within the Mars Pathfinder landing ellipse. When the opposite circular (OC) polarized returns are decomposed into both a quasispecular and diffuse echo, the quasispecular component is modeled with a Hagfors law. This yields a Hagfors roughness parameter, C, which is in turn used to determine the RMS slope of the surface. Simply stated, the Goldstone data suggest that the Mars Pathfinder landing site is "fine" with RMS slopes of ~6°. The continuous-wave observations also agree well with those made by the Arecibo Observatory. B. Campbell asked whether any penetration of the radar signal could be affecting the spread in the data. Slade responded that this was unlikely because it should show up in the diffuse component if it was.

Additional Goldstone Observatory measurements were presented by A. Haldemann and co-workers. These investigators have been using the Goldstone Deep Space Network antenna in altimetry mode, collecting data at 3.5-cm wavelengths. Five radar tracks within or near the landing ellipse were collected in the winter of 1994–1995, when Mars was at a distance of approximately 0.6 AU. These data indicate that the lowest elevation within the Mars Pathfinder landing ellipse is about 300 m below the elevation of the Viking Lander 1 site. A Hagfors roughness parameter fitted to these data is higher than that of the Viking lander 1 site, which suggests lower RMS slopes (4°–5° average). Haldemann added that while remote sensing data is being used to determine the surface characteristics of the Mars Pathfinder landing site, actually landing on the surface will probably tell us a lot about how robust any of these methods are.

The final presentation of the workshop was made by M. Shepard and co-workers. They applied a rather ingenious terrestrial technique for estimating the amount of subpixel-scale roughness to the highest-resolution Viking Orbiter images acquired within the Mars Pathfinder landing ellipse. Essentially the reflectance within a single pixel of any given image is a function of the surface composition, topography, and shadows cast by the topography. Assuming that the composition of the surface is homogeneous, the number of topographic elements smaller than the pixel size (e.g., rocks) can be estimated from the variance in reflectance between pixels. Ideally the Sun angle of the image should be about 45° or greater to maximize the length—and therefore the contribution—of shadows within a pixel. The higher the resolution, the smaller the surface element can be distinguished. The highest-resolution images covering the Mars Pathfinder landing ellipse are approximately 40 m/pixel, although the amount of dust within these images is large enough to reduce the contrast between shadows and the surrounding illuminated surface. Comparing these data, however, with similar images taken over the Viking 1 landing site suggests that in the worst case the Mars Pathfinder landing site is less rocky than what was seen at VL1. In summary, a variety of techniques were used to assess the potential hazards within the proposed Mars Pathfinder landing site.

Essentially what investigators suggested was that this site was probably physically similar to the Viking 1 landing site but with slightly lower RMS slopes, and it is also a few hundred meters lower in elevation. There is every indication that the probability of encountering a "Pathfinder-killer" boulder is less than 1%; however, there also appears to be a high probability that the spacecraft will see many smaller, safer rocks to analyze once on the surface.

DISCUSSION SESSION

Golombek did not see anything presented that would render the primary landing site unsuitable. It has about as many rocks as the Viking 2 landing site, and is less dusty than Viking 1. H. Moore did not see any reason that the Pathfinder site should be any more hazardous than the Viking lander sites, and pointed out that success is never guaranteed. A question was raised regarding the heterogeneity of proximal rocky areas on the Ephrata Fan and the potential for similar surfaces at the Pathfinder landing site. Baker pointed out that at analogous distances on the Ephrata Fan, the rock distribution is homogeneous and the rapid falloff in size relative to distance from the channel mouth should produce a similarly homogeneous surface at the Ares Vallis landing site. Cook said that it will be possible to retarget Pathfinder to another site if there is a dust storm in Chryse, including sites at different latitudes if necessary. Major dust storms are thought to be unlikely in the northern summer, but a contingency plan is needed. H. Moore stated that minimizing rock abundance in selecting a landing site would compromise the rover mission and science objectives. APXS measurements of dark areas are desired, as they may be composed of unweathered materials.

Golombek noted that all abstracts submitted for the workshop were accepted. A special issue of JGR describing the instruments and science objectives as well as the landing site is being planned. H. Moore requested that the Viking "safe site," Tritonis Lacus, be studied again. Spear said that the project engineers are more confident now after some successful tests, and that they may feel even better in a few months after the drop tests.

Summary of Field Work in the Channeled Scabland

—*K. S. Edgett and J. W. Rice Jr.*

INTRODUCTION

The field trips in the Channeled Scabland region were designed to bring together Mars scientists, Mars Pathfinder engineers and key project personnel, and a select group of K–12 educators. The purpose of the field trips was to investigate landforms and geologic features on Earth that are the best analogs to those present in or near the Mars Pathfinder landing ellipse in Ares Vallis.

The benefits of this field excursion far exceeded our initial expectations. Seeing catastrophic flood features in the field, particularly sites identified as analogous to the Ares Vallis landing ellipse (e.g., Rice and Edgett, 1995; Golombek and Rapp, 1995), had an enormous impact on the engineering and management personnel responsible for the landing and safety of Mars Pathfinder and its microrover, Sojourner. The scientific benefit will carry well into the Mars Pathfinder Primary Mission. The field trip provided an opportunity for Mars scientists to calibrate "minds and eyeballs" to the variety of landforms produced by catastrophic flooding, and how these features look on the ground as compared with their appearance from the above. The K–12 education and public outreach aspects of the field trips were perhaps the biggest surprise of all. The value of the interaction between K–12 educators and the science and engineering people has already resulted in interesting activities, events, and opportunities for children, parents, and teachers across Washington and Idaho, as well as outside the region. Portions of the field trips were filmed for future television usage, and stories about the field work appeared in many newspapers throughout Washington in late September and early October 1995 (see Appendix A).

This summary is divided into four sections. The first describes the aircraft overflights; the second is a summary of Field Trip I in the Channeled Scabland. Together, the overflights and first field trip formed a framework and context for discussion that was carried by the participants throughout the Ares Vallis workshop and second field trip. The third section summarizes discussions that took place between the participants on the evening of September 26, 1995, after the overflights and most of Field Trip I had been completed. The discussions underlined the value of the field trips in terms of planning and evaluating the Ares Vallis landing site for Mars Pathfinder. The discussions also began to reveal the educational value and the interaction and professional relationships that had begun to develop between the scientists, engineers, and K–12 educators. Finally, the fourth section discusses the events of Field Trip II, particularly the valuable contributions made by a guest field guide, R. Breckenridge of the Idaho Geological Survey.

FIELD TRIP I—AIRCRAFT OVERFLIGHT, SEPTEMBER 25 AND 26, 1995

The field trips included an aircraft overflight of the terrain, to place the Channeled Scabland in context with surrounding terrain. The overflight was critical to understanding that the Scabland features are carved by immense floods; the scale of landforms produced by the floods is difficult to contemplate from the ground without the overflights.

The field trip participants were divided into two groups; 19 people flew on the morning of September 25, 1995, and an additional 19 flew on September 26, 1995. Early morning flights were scheduled to provide low Sun to maximize topographic contrast, particularly for viewing subtle features such as giant current ripples and longitudinal grooves.

From the air, the groups saw many of the features that were visited later on the ground, such as streamlined islands, giant current ripples, the Dry Falls, Ephrata Fan, and Moses Lake sand dune field. The group also saw features not visited on the ground trip, such as the Palouse Falls and the Crab Creek channel near Odessa, Washington. V. Baker served as aerial "tour guide," describing the geologic history and fluvial features of the Channeled Scabland as each morning's group flew over the region.

The aircraft followed the route shown in the field trip guide (see Part 1 of this technical report). The eastern loop was flown first. The flights took off from Grant County Airport near Moses Lake, Washington. The departure of the overflight on September 25 was delayed for nearly an hour, owing to an engine glitch. After the engine was fixed, the overflight proceeded without any problems. Most participants remarked that the flight was very smooth and turbulence-free. Most were also impressed with large windows on the Twin Otter aircraft, provided by arrangement through Columbia Pacific Aviation, Inc. The second, western loop on each day of overflights was covered following a brief rest stop back at the Grant County Airport. On both mornings, the weather was generally clear and excellent for viewing and photographing the Channeled Scabland terrain.

FIELD TRIP I—THE CHANNELED SCABLAND OF WASHINGTON, SEPTEMBER 24–27, 1995

Introduction: Field Trip I was based out of Moses Lake, Washington. The main purpose of this phase of field work was to investigate the key landforms and geologic features of the Channeled Scabland, particularly those relevant to understanding Ares Vallis and the Mars Pathfinder landing ellipse centered on 19.5°N, 32.8°W. The field trip was led and narrated by V. Baker and coordinated by K. Edgett and J. Rice.

The field trip party was transported by chartered bus. The size of the group was limited by the number of seats on the bus. A total of 47 people were on the bus (including the driver). Two film crews (two people each) met the participants at each site to capture the events for future television usage (see "Summary of Education and Public Outreach" in this volume).

September 24—Day 0: Most of the field trip participants were met by the bus in Spokane, Washington, on Sunday afternoon, September 24. Participants received their first introduction to the Channeled Scabland during the drive along Interstate 90 from Spokane to Moses Lake. Along this route, some streamlined islands and butte-and-basin terrain can be seen from the highway. The bus arrived in Moses Lake near dusk.

The evening of September 24, at the hotel in Moses Lake, Washington, all the field trip participants gathered for an introductory session and dinner. M. Kisson and J. Rankin of the Ice Age Floods Institute, an organization that promotes education about the Missoula Flood region, joined the group for dinner. The Ice Age Floods Institute shared information with the group and also had available Channeled Scabland curriculum material and special T-shirts commemorating the Mars Pathfinder field trips (Fig. 1). The program for the evening of September 24 included an introduction to the Mars Pathfinder mission by M. Golombek and an introduction to the Channeled Scabland and Missoula Flood controversy by Baker.

Fig. 1. Mars Pathfinder Channeled Scabland commemorative T-shirt, designed by J. Rankin of the Ice Age Floods Institute, Ritzville, Washington. T-shirt is modeled here by J. Wellman of the Mars Pathfinder project. View is looking over the Dry Falls of the Lower Grand Coulee. Photo by K. Edgett, September 25, 1995.

September 25—Day 1: The field trip scheduled for Day 1 was designed to simulate a trip down the lower reaches of Ares Vallis, out into the landing site area and beyond. The plan, as detailed in the field trip guide, was to begin at Dry Falls, drive down the Lower Grand Coulee, and out into Quincy Basin. Participants would examine the nature of the flood sediments deposited in the Quincy Basin as potential analogs to the Ares Vallis landing site on Mars. On the morning of September 25, half the field trip participants gathered at the hotel in Moses Lake at 10 a.m., only to find their departure delayed by an hour because the aircraft overflight ran behind schedule.

The Day 1 field trip got underway at 11:00 a.m. In order to keep to the tight schedule, the trip leaders (Edgett, Rice, Baker) decided not to visit Stop 2 at Deep Lake. This stop was originally scheduled only as a place to eat lunch. Instead, the group spent extra time at the scenic Stop 1 (Dry Falls Interpretive Center). The extra time at Stop 1 allowed visitors to eat lunch, view the Dry Falls terrain, and see the videotapes and displays available in the Visitor Center. The group was joined at Dry Falls by T. Sowa and his photographic assistant from the Spokane *Spokesman-Review* newspaper, who went on to publish a story about the field work on September 27.

After the stop at Dry Falls, the group took a slow bus trip down through the Lower Grand Coulee on S.R. 17. Along the way, they observed the hanging valleys in the canyon walls, giant gravel bars (eddy bars) that block other channels along the eastern wall of the coulee, and the scour-formed lakes such as Lenore and Soap. A brief photographic stop was made near Lake Lenore Caves, then the group went on to Stop 3, the Ephrata Fan Road Cut (the second stop of the day). This stop was of interest because it showed some of the variety of clast sizes deposited in the Ephrata Fan, thought to be analogous to the sedimentary deposits that might occur in or near the Ares Vallis landing ellipse. At this stop, the group also encountered some local wildlife, a rattlesnake that had been run over by one of the film crews' vehicles. M. Harder collected the rattle, and the group observed that rattlesnakes are not expected to be a hazard at the Mars Pathfinder landing site.

The third stop of the day, Stop 4 in the guidebook, was the Monsters of Rock site. This stop was designed to show the most hazardous, rockiest site on the Ephrata Fan. This fact was not clearly communicated, however, and the Mars Pathfinder engineering team was quite disturbed by what they saw (indeed, their observations led to a change in the Day 2 field trip, as described below). This site has the giant, house-sized boulder (18 m × 11 m × 8 m in size) depicted in the field guide. The site was also seen as a great opportunity for H. Eisen to deploy an eight-wheeled prototype of Mars Pathfinder's microrover (Fig. 2). After some repairs were made on the microrover, it was found to easily drive over boulders more than twice its height.

Fig. 2. Eight-wheeled prototype of Mars Pathfinder's microrover. H. Eisen brought the rover to the Scabland for field testing. This site is near the Monster Rock. Note the relative lack of vegetation; this was caused by a brush fire that occurred some time between June and September 1995. Shown here, from left to right: R. Manning, G. Komatsu, and K. Magee. Photo by K. Edgett, September 25, 1995.

The Monsters Rock site had one rather fortuitous circumstance. Sometime between our field reconnaissance in June 1995 and the field trip in September 1995, there had been a brush fire that burned off nearly all the grass and shrubs that otherwise surround the boulders at this location. The lack of vegetation made the site appear more Mars-like than it had in June 1995, and afforded an excellent surface for testing the microrover prototype. In addition to exploring the potential hazards at the site, Golombek reviewed the measurements of rock population and dimensions that were made in June 1995 on the Ephrata Fan (see Golombek and Rapp, 1995). At this site, some participants encountered a live rattlesnake; others avoided its location.

Following the stop at Monsters of Rock, the group followed the field trip guide southward over the Ephrata Fan. Looking out the bus windows, Baker and Golombek pointed out the extremely heterogeneous nature of rock cover on the fan, noting that sites near Monsters of Rock had coarse bouldery lags that are otherwise rare over most of the fan's surface. The transition from boulders/cobbles to gravel and sand was noted as the group headed south on Dodson Road and came upon the potato, hay, and corn farms of the Quincy Basin area. The bus was detoured briefly off of Dodson Road by construction, but picked up the road again where it passes over Interstate 90.

The field trip participants then proceeded to the basaltic sand dune near the side of Dodson Road (Stop 5 in the field guide). At the dune site, Edgett led the discussion, pointing out that the Moses Lake dune field is one of the largest known basaltic dune fields on Earth, and that it might be similar in composition to dunes on Mars. Based on Viking Orbiter observations, it seems that a small amount of dark, mafic sand might be present at the Mars Pathfinder landing site, although it will probably not occur in the form of dunes (Edgett, 1995).

After the dune site, the field trip guide said that the group should continue south, then east across the O'Sullivan Dam and back to Moses Lake. However, because no more stops were scheduled, the group decided to head back along the shortest and most direct route to the hotel (back up Dodson Road to Interstate 90). Even though the group left one hour late in the morning, they arrived back at the hotel on time (6:00 p.m.).

September 26—Day 2: The second day of field work began upon the return of the second overflight group to the hotel around 10:00 a.m. Prior to their arrival, Golombek and Edgett discussed with the Mars Pathfinder engineering team some of their concerns about what they saw at the Monsters of Rock site on the previous day. There was considerable discomfort with the size, roundness, and percentage of boulders covering the surface at that site. Golombek and Edgett realized that somehow the point that the Monster Rock site represented the worst the Ephrata Fan had to offer was missed by many field trip participants. As a result, we decided to alter the field trip plan for Day 2 in order to visit another rocky site on the Ephrata Fan and emphasize the heterogeneous nature of the boulder/rock distribution on the surface of this deposit.

To revisit the Ephrata Fan, we decided to eliminate Stop 2, the giant current ripple field at Malaga, Washington. We learned two weeks previously that the site in Malaga had been altered by construction and landscaping equipment sometime between June and September 1995. The site was identified as the future home of the Chelan County Fire District 1 fire station and training facility. The purpose of the Malaga stop was to allow participants an opportunity to walk on giant current ripples, and determine whether such features would be recognizable if Mars Pathfinder landed on similar features. We realized that many of the Field Trip I participants would also be on Field Trip II, in which people would have an opportunity to get into the Spirit Lake, Idaho, giant ripple field. We also realized that altering our field plan in order to reexamine the Ephrata Fan surfaces was much more relevant and important to the goal of safely landing Mars Pathfinder in Ares Vallis. The Mars Pathfinder engineering personnel were very excited by the prospect of returning to another portion of the Ephrata Fan.

Thus, the first stop on Day 2 was a site on the east side of S.R. 17 about 0.6 miles (1 km) north of the intersection with Hatchery Road (T21N, R27E, S17NE). This site is about 1 mile (1.6 km) northwest of the Monsters of Rock stop that was visited on the previous day. The boulders at this site were mostly less than 40 cm high and well-rounded. Fewer boulders and rocks were present than at the Monster Rock site; in fact, Golombek commented that the site had about the same or less surface covered by rock than the Viking 1 lander site on Mars. Discussion at this site revolved around airbag landing safety. The rocks appeared relatively round (due to flood transport), alleviating some concerns that the Ares Vallis site might be littered with rocks with many sharp edges that could rip the airbags. The size and distribution of rocks, being similar to the Viking 1 site, was also not a concern. Eisen and H. Moore spent some time discussing the trafficability of the microrover, but their discussion was focused mainly on the silty soils found between the rocks. Most of the soil at this site is airfall—glacial silt plus volcanic ash (Mount St. Helens' 1980 ash was the most recent); these soils are similar to the fine "drift material" described by Moore et al. (1987) at the Viking 1 site.

All participants were impressed at the first stop on Day 2 that there is such a diversity of rock sizes and surface distribution over very short distances on the Ephrata Fan. They were amazed that the Monster Rock site was less than 2 km away, and that other locations within 2 km had no rock cover at all (as revealed by field work by Golombek, Rice, and Edgett in June 1995). The flexibility that allowed us to eliminate a stop and add this vital return to the Ephrata Fan also turned into an excellent learning experience for the K–12 educators who participated in the field work. It became very obvious that this stop was the most important event of the field trip, because the engineers had grown very concerned about the safety of landing on a flood deposit, until they had an opportunity to see and discuss this site and the heterogeneous distribution of rocks and boulders on the Ephrata Fan. This one stop did more to alleviate lingering concerns about the potential hazards of landing at the Ares Vallis site than any other stop visited during the week.

The second stop on Day 2 was the site identified in the field guide as Stop 1 (West Bar Giant Current Ripples and Slackwater Deposits). This site offers an impressive overlook from which to view the West Bar giant current ripples. Most participants had also seen the ripples during the overflights, and thus were able to put them in context with the regional view afforded by the perspective of the aircraft vs. the ground. Participants also examined the slackwater deposits and Mount St. Helens Set "S" Ash (~13,000 years old). Baker explained that the Set "S" ash helps fix the age of the Missoula Floods. The group ate lunch at this location.

Upon leaving the second stop, we proceeded down into the Columbia Gorge on S.R. 28 so that participants could see where the mouth of Moses Coulee enters the Columbia River area. The bus then turned around and headed toward Stop 3 (the Potholes Cataract). In terms of the original field guide, all items indicated for Day 2 between mile 49.0 and 83.0 (i.e., Malaga ripples) were not visited. The Potholes Cataract stop offered a nice view and an opportunity to contemplate the immense power of the Missoula Floods.

After the Potholes Cataract site, the trip proceeded according to plan, stopping next at Stop 4 (Pillow Lavas and Palagonite). J. Crisp led discussion at this site, explaining to the group what types of materials constitute palagonite and the fact that such materials might be found on Mars. The palagonite and associated pillow lava structures offered a great opportunity for photography and sample collecting, plus discussion of the Columbia Plateau basalts. The Mars Pathfinder imager (IMP) should be capable of examining palagonite, if present. R. Sullivan also noted at the site the quartz-rich climbing sand dunes that are found in the area. These dunes, he said, are climbing at a very steep angle, up and out of the Columbia River gorge. Baker explained that the sand had come from the river sediment, but no new sand had been supplied since a dam had been built in the area, flooding much of the lower portions of the valley.

The fifth stop offered a view of the Corfu Landslide. Baker explained how the multiple slides developed as a result of undercutting by Missoula Floods combined with seismic events. On the trip over to the viewing area, Golombek discussed the structure of the two anticlinal ridges, Frenchmen Hills to the north and Saddle Mountains to the south. These ridges are considered to be analogs to the wrinkle ridges found on Mars and the Moon. On the trip back to Moses Lake, the bus drove up over the eastern end of the Frenchmen Hills ridge and across the O'Sullivan Dam. This portion of the trip allowed participants to see the Drumheller Channels, which were carved by the Missoula Floods. These channels cut through the Frenchmen Hills anticline, revealing their interior structure. T. Parker noted that there is a small wrinkle ridge in the Ares Vallis landing ellipse.

September 27—Day 3: The purpose of the third day's field trip was to investigate certain key Missoula Flood features that had not been seen on the previous days, particularly streamlined islands and true "scabland" terrain. Streamlined islands are present near and within the Ares Vallis landing ellipse. If such an island is visible from the Mars Pathfinder lander, as strongly desired by Smith (1995), what could it tell us about the flood history or geology of the region? One way to find out is to see streamlined islands up close.

There were no overflights on Day 3, so the bus departed Moses Lake at 8:30 a.m. The weather was cooler than it had been the first two days, and it rained most of the morning. The group followed the roadlog in the field guide without any alterations. At the first stop, the Marengo Railroad Cut, the group was joined by M. Harder's family. The Harders own the property on which the railroad cut is located, and the extended Harder family holds much of the land in the Cheney-Palouse Scabland region. We were all very thankful that the Harder family allowed us to visit sites on their property, and were all the more excited to have them join us in the field and discuss some of the things they have observed over the years working in the Scabland terrain. At the Marengo cut, Baker explained how the streamlined islands preserve sediments (repeated layers of flood gravel, eolian loess, and calcic paleosols) that indicate multiple giant floods occurred over an extended period of time.

The second stop on Day 3 (also the last stop of Field Trip I) provided an opportunity to climb up onto a small streamlined island. Most of the group chose to hike up the steep slope (carved by floodwaters) of the 37-m-high island. M. Harder explained that the island is visited and examined each year by kids from her school in Ritzville. Discussions that ensued on top of the island centered around the fact that this site was very helpful for visualizing the depth and power of the Missoula Floods. This was a particularly useful revelation for the non-geologists in the group. Baker explained that the flood waters had come up to and slightly overtopped this small island. Standing on top of the island, participants could also see the expanse of the Cheney-Palouse Scabland and identify other islands, bars, and current ripples in the giant "streambed" below. This site was an excellent reference point relative to the overflights that had taken place on the previous two days. It was important to the Mars Pathfinder engineers because, again, it underlined the power of the Missoula Floods, floods that were much smaller than those that carved Ares Vallis and the streamlined islands seen in and near the landing ellipse.

After Stop 2, the group proceeded by bus back to Spokane, Washington, to prepare for the Landing Site workshop, which was to take place September 28–29. Near mile 95.0 (see field guide), Edgett noted that one of the flood-scour lakes to the left (west) of S.R. 23 is named Fourth of July Lake. He noted that this lake should serve as a reminder that Mars Pathfinder is scheduled to land in a similar terrain on July 4, 1997. The group arrived in Spokane shortly before 3:00 p.m.

FIELD TRIP I DISCUSSION SESSION, SEPTEMBER 26, 1995

Field Trip I participants met for a group dinner at 7:00 p.m. on Day 2, September 26. The purpose of this dinner was to provide a forum for discussion about the results of the field work up to that point. The session lasted until 10:00 p.m. Three main topics were discussed: (1) engineering and Mars Pathfinder Project issues (e.g., landing safety), (2) general questions and answers about Mars Pathfinder, and (3) education outreach and impressions of the 13 educators after spending 2.5 days with the Mars science and engineering personnel. This summary captures the essence of these discussions, although not every person who spoke up is mentioned here.

Mars Pathfinder Project Discussion: The Channeled Scabland field trips were designed in part to get key Mars Pathfinder engineering and management people out to a real Mars-analog terrain. The first two days of field work emphasized the magnitude and scale of catastrophic flood features, and the nature of erosional and depositional landforms in terrain thought to be similar to the Ares Vallis region. In particular, the group focused attention on the Ephrata Fan, a broad deposit of boulders, cobbles, gravel, and sand deposited in the Quincy Basin. The surface of this fan was considered to be the best Channeled Scabland analog to the Ares Vallis landing site.

R. Cook began the discussion by noting that in planning for Mars Pathfinder's landing, project personnel have to deal with conflicting problems and priorities. Collectively, we want the mission to do good science, and this has to be weighed against potential hazards at the landing site and Mars Pathfinder's inherent engineering capabilities. Based on what Cook saw and evaluated during the field trips, he said that "there is a fairly high likelihood that we can handle [the Ares Vallis site on] Mars if the Channeled Scabland is a good analog." Cook identified one concern that hadn't been considered before—the apparent heterogeneity of the rock cover on the Ephrata Fan. On these field trips, he realized that the "rock abundances" that are derived from Viking IRTM data (e.g., Christensen, 1986) represent averages, but within a given area, the distribution of rocks on a surface can vary considerably. This observation had become most apparent at the first stop on Day 2, when the group returned to the Ephrata Fan and learned that within 2 km of the Monsters Rock site, there were other surfaces with few rocks and other surfaces with Viking-like rock cover.

T. Rivellini was asked to address the question of Mars Pathfinder's airbag landing. Rivellini said the "Monster Rock site is terrifying," but considered the Ephrata Fan site examined on Day 2 to be "a lot nicer." The critical issue for airbags is whether there are sharp, "pointy" surfaces on rocks that might grab, catch, or tear the airbags. Another issue is the size of rocks; something the size of the 18-m Monster Rock is too big for the airbags to handle, although Rivellini thought that if the landing velocity is very slow, a landing at that site could be done. Golombek and Baker reiterated that the Monster Rock is the biggest rock on the entire Ephrata Fan, and that few other rocks come close to it in size. Rice noted that the Monsters Rock site is the "worst-case scenario" for a landing in similar martian terrain. Indeed, most of the Ephrata Fan surface has few rocks exposed at the surface. Rivellini was happy to see that catastrophic flood-transported rocks are a lot rounder than he expected, and certainly more round than the rocks that are being used in airbag drop-tests for Mars Pathfinder.

R. Manning felt that the field trip was useful in part because of the observation of heterogeneous rock cover on the Ephrata Fan surface. He said that much testing of various landing scenarios for Mars Pathfinder had been underway, and the heterogeneous rock cover would be a useful addition to landing site hazard assessment. Like Rivellini, he was relieved that the flood-transported rocks were more rounded than he expected.

A question was raised about the scaling of rock sizes from

Earth to Mars. If the Ephrata Fan is about 10 times smaller than the Ares Vallis sedimentary deposits, would the rocks at the Ares site be 10 times larger than those observed in the field in Washington? Baker responded that the rocks we saw on the Ephrata Fan would probably be similar in size to what should be expected at Ares Vallis. Baker said that even though the flood channels and deposits on Mars are larger than in the Channeled Scabland, "the laws of physics say that the reduction of rock sizes will be about the same." In general, the size of the rocks exposed on the Ephrata Fan is governed by the internal fracture surfaces found in the Columbia Basalts, which were eroded by the floods. Baker noted, for example, that basalts on Mars should generally have similar-scale planes of weakness, and thus would break up about the same way as the rocks in the Channeled Scabland. There should not be too many boulders that are larger than the Monster Rock, and most rocks at the Ares Vallis landing site should be relatively small (perhaps on scales similar to those observed at the Viking landing sites). Baker also noted that with the reduced martian gravity, particle settling velocities will be different than on Earth. Cook said that on the Ephrata Fan, and presumably on Mars, clast size will drop off rapidly away from the channel mouth. He also commented that the Ephrata Fan suggests the heterogeneity of boulder distributions should drop off with distance from the channel mouth.

Eisen was asked to discuss microrover issues in the context of what he saw in the Channeled Scabland field areas. His first comment was that after the second visit to the Ephrata Fan (first stop on Day 2), he would "sleep well tonight." He said there was nothing he saw in the field that the Sojourner microrover could not handle in terms of control and navigation. One thing he liked was that the rocks on the Ephrata Fan were well rounded and well buried, or fixed to the ground, by eolian silts. One concern to the microrover team would be rocks that are loose and can be moved or rolled. For rover navigation, it is better if the rocks are embedded in the soil, as were the rocks seen on the Ephrata Fan. Eisen also commented on the immense value of having the opportunity to spend time talking with the Mars scientists in the field. Looking at Mars analog surfaces and discussing soil properties and rover trafficability with experts such as H. Moore was an invaluable part of the field experience for Eisen.

Manning felt that the Mars Pathfinder team had reached consensus on the issue of topographic effects on the landing. One issue is the ability of the onboard radar to detect the surface and estimate distance to that surface in time for the landing rockets to fire. A surface with many topographic variations, such as Dry Falls, would be a problem, especially if the spacecraft detected the surface above the falls, fired its braking rockets, but then drifted over the edge of the falls and down toward a surface that is lower than previously detected. Manning was pleased to learn that the Dry Falls/Grand Coulee areas are not analogous to sites within the Ares Vallis landing ellipse. Another issue that had been discussed among the Mars Pathfinder team was how long the airbags stay inflated for bounces that occur after initial impact. A flat surface, again, is better, and surfaces like Dry Falls or the butte-and-basin topography of much of the Scabland would be more difficult than the kinds of surfaces seen on the Ephrata Fan. Finally, a third issue discussed was airbag retraction and petal (solar panel) deployment; Manning saw no problems for these based on his field observations. Ramp deployment for the microrover also seemed not to be a problem, even in the rockiest site examined on the Ephrata Fan. Cook noted that the trip down the Lower Grand Coulee from Dry Falls was helpful because otherwise it would have been difficult to understand the context of where all the flood debris on the Ephrata Fan had come from. All were impressed by the immense scale of the Missoula Flood features, and the fact that the outflow channels on Mars are considerably larger.

General Question and Answer Period: Following the discussion among Mars Pathfinder's management and engineering personnel, the floor was opened up to general questions from the scientists and the thirteen K–12 educators. The first question came from C. Flanagan, who asked about the radius of exploration for the microrover, and who decides what the rover will do and observe. Wellman identified himself as the key manager. Rover traverses would be planned on the basis of the scientists' goals and objectives. Cook said that before Mars Pathfinder lands, they will take a prototype rover and the landing site geologists out to sites in the Mojave Desert and Death Valley to gain experience in planning rover operations. D. Shirley noted that during the primary mission, the rover is not planned to go more than 10 m from the lander. She also said that the rover can go no more than about 0.5 km away from the lander because of the radio communication link between the two. Noting that most of the Ephrata Fan surface has few rocks, S. Metzger expressed hope that Mars Pathfinder's site is not boring, that there will be many things, such as rocks, to examine within the 10-m rover radius.

S. Klug asked why an airbag landing system was chosen over retrorockets, and whether this impacted the landing site selection process. Rivellini said that the airbag system costs less than a rocket system. Neither landing system would impact the size of the landing ellipse, because it is a mainly a function of the spacecraft trajectory from Earth and the properties of the martian atmosphere at the time of the landing.

In terms of dealing with students and the public, F. O'Rourke asked for reasons why we should explore Mars. The responses were general; for example, H. Moore noted that the "man on the street" cares mainly about the sense of exploration and the opportunities to see new things. R. Craddock added that exploring other planets helps us solve problems here on Earth, and helps us to better understand, scientifically, our home planet.

L. Fayette added to the exploration discussion, saying that as a result of her selection to participate in the Mars Pathfinder field trips and workshops, she knew of "at least 250 8th grade students" who are "darn excited about all this." She asked if the data from Mars Pathfinder and other missions would be available to students. The answer was "yes," indeed, Mars Pathfinder images and other data will be available through the Internet (among other potential sources). H. Moore noted that in terms of education and planetary spacecraft, "our engineers build great things that are mostly successful," and that this fact can be a great model for enhancing education of young people. The question and answer session was lively. The final question was from Sullivan, who asked whether Mars Pathfinder's airbags would be able to retract properly if the spacecraft landed on the worst case we saw on the Ephrata Fan (Monster Rock site). Rivellini said this is "not a problem."

Education Outreach and Teacher Impressions: The final discussion topic for the evening was related to the K–12 education outreach aspects of the field trips. Educators were asked to share their impressions of the field trip, the science and engineering teams, and other concerns.

A. Haldemann opened the session with a comment that children he met seemed interested in space exploration, but many who had seen the 1995 motion picture, *Apollo 13*, did not realize that the film was based on a true story. Speaking from experience in middle and high school classrooms, J. Gallagher noted that "kids today" want instant gratification; they don't want to have to work hard to get something.

Cook said that he was impressed with the field trips because as a group we had found a way to pass on to children the enthusiasm of the people involved with Mars Pathfinder. He felt it was important that the K–12 educators had been able to come on the field trips and see some aspects of real teamwork and real mission planning take place.

J. Dodds noted the importance of continuing the contacts and the process of educating the educators that had gone on during the field trips. Klug considered the events up to that point to have been very useful in "making the scientists human." She considered that it would be useful if Mars Pathfinder would produce a videotape showing the people at work on the project, solving problems. M. Murray felt that the Mars Pathfinder field trips in the Channeled Scabland represented a good model for the way NASA "should do" education and public outreach. As the session wrapped up, it was agreed that the educators would like to remain in contact with the engineers and scientists (via Internet, at least) long after the field trips are over and Mars Pathfinder lands on the Red Planet.

FIELD TRIP II—LAKE MISSOULA BREAK-OUT, WASHINGTON AND IDAHO, SEPTEMBER 30, 1995

Field Trip II was based out of Spokane, Washington, on September 30, 1995. The trip had two main purposes: For participants who had not been on Field Trip I, it was an opportunity to see a portion of the Channeled Scabland, including landforms relevant to the Ares Vallis landing site. For people who had participated in Field Trip I, it was an opportunity to see the area where the Missoula Floods first broke out and poured across eastern Washington. The trip also offered the only opportunity to visit a giant current ripple site from the ground (recall that the Malaga ripple field was not visited in Field Trip I, as had originally been planned). The field trip began with an introduction and review of the Missoula Flood landforms and historic controversy presented by Baker the evening before the trip.

The field trip bus departed the hotel in Spokane at 8:00 a.m. About 42 people were present, including 10 who had not been on the first field trip. The bus went from the hotel directly to Stop 1 at the Lake Missoula break-out area at the south end of Lake Pend Oreille, in Farragut State Park, Idaho. The bus driver took a somewhat faster route to the park than the one outlined in the roadlog. As on Field Trip I, Baker was the trip leader; Edgett and Rice acted as trip coordinators.

At Lake Pend Oreille, the group was joined by R. Breckenridge of the Idaho Geological Survey. Breckenridge is a local expert on the Missoula Floods and Channeled Scabland (e.g., Breckenridge, 1989), and his most recent work has been on the nature of the ice dams that repeatedly formed and then released Lake Missoula to form the Scabland terrain (Breckenridge and Stanford, 1995). It was an honor to be joined by Breckenridge in the field. Both Baker and Breckenridge discussed the nature of Lake Missoula and how glacial ice lobes had blocked off the Clark Fork River to cause the formation of Lake Missoula. Breckenridge brought a series of illustrations put together using field data and digital elevation models to show how the lake formed, the correspondence between shoreline features and lake levels, etc. He also had a fascinating photograph of shore lines near Clark Fork, Idaho, that had been revealed on a hillslope following a forest fire in the 1930s. Breckenridge and Stanford (1995) found that their ice dam model put Lake Missoula's high stand near 1260 m, with the dam itself being about 1400 m high. Other ice dams were smaller and the lake levels lower. The field trip participants were fascinated by the magnitude and power the Missoula floods must have had. Breckenridge brought a mosaic of satellite images of the Lake Pend Oreille and Rathdrum Prairie area, to illustrate the size of the flood channel and nature of deposits left behind by the floods (Fig. 3). Breckenridge stayed with the group through the rest of the day.

The next stop was the only visit the group was able to make to see giant current ripples from the ground. Giant current ripples, some with clasts measuring larger than 0.5 m, were seen from the aircraft overflights and at the West Bar overlook site on Field Trip I. The interest in visiting giant current ripples on the ground stemmed from the desire to understand what such features look like, in the event that Mars Pathfinder should land on such ripples. Giant current ripples are not easy to recognize from the ground without the aid of airphotos. The group went to Stop 2, the Spirit Lake Giant Current Ripples. Clasts in these ripples surprised most participants

Fig. 3. R. Breckenridge (left) and V. Baker describe how the Missoula Floods originated at Lake Pend Oreille by repeated failure of glacial ice dams. The mosaic of satellite images (center) depicts the break-out area (under Baker's hand) and the Rathdrum Prairie area (brighter surface running diagonal across the mosaic). Photo taken at the Spirit Lake ripple site, September 30, 1995, by K. Edgett.

Fig. 4. Engineers, scientists, and K–12 educators together examine the Rock Coulee site. From left to right, people whose faces are clearly visible: H. Eisen, R. Cook, J. Gallagher, T. Spear, T. Campbell, R. Breckenridge, V. Baker, J. Rice, V. Gulick, R. Craddock, and L. Selvig. Photo by K. Edgett, September 30, 1995.

because they were not basalts, but mostly crystalline rocks from the mountains to the east. The magnitude of ripple crests and troughs (see field guide) impressed most participants.

The third stop was up on a hill (at Quinimose Estates) overlooking the Rathdrum Prairie and Spokane Valley. Baker and Breckenridge explained how the Missoula Floodwaters had poured through the valley, and how scientists had figured out the depth and velocity of such floods by examining erratic boulders emplaced on surrounding hillslopes. Again the group was impressed by the incredible size, power, and depth of the Missoula Floods, and the fact that these floods were not large compared with those that carved Ares and Tiu Valles on Mars. The group ate lunch at this scenic overlook site, although the air was cold and it rained during much of the lunch period. On the trip to this site, we noted in the original field trip guide that the road at mile 104.5 is now paved, not gravel.

After leaving the overlook site, the group drove "downstream" through the Spokane Valley, emerging southwest of the city along Interstate 90 at an area where the first streamlined hills and scour-pit lakes occur. Then the group left Interstate 90 at Sprague, Washington, and drove down into classic butte-and-basin scabland terrain. For participants who missed Field Trip I, this was their opportunity to see scabland and streamlined islands similar to what might be found on Mars.

The group went on to Stop 4 (Rock Coulee near Hole-in-the-Ground). Here, the group walked down into the coulee for a good view (Fig. 4). The canyon was impressive, particularly for the participants who did not go on Field Trip I and and thus did not see the Lower Grand Coulee. Rock Coulee provided another excellent example of the power of the Missoula Floods.

The final stop in the field guide, Stop 5 (Latah Creek Site), was listed as optional. Because of time constraints and rainy weather, the bus only stopped briefly at this site so participants could see the outcrop from the highway. Baker explained how the sediments at this site had been used to prove the case for multiple Missoula Floods (see field guide), while some participants got out of the bus to obtain photographs. The bus soon departed, and the field trip ended at 5:00 p.m.

REFERENCES

Breckenridge R. M., ed. (1989) *Glacial Lake Missoula and the Channeled Scabland, Field Trip Guidebook T310 for the 28th International Geological Congress.* American Geophysical Union, Washington, DC. 72 pp.

Breckenridge R. M. and Stanford L. R. (1995) Glacial Lake Missoula/Clark Fork ice dam—A digital model. *Geological Society of America Abstracts with Programs, 27 (4).*

Christensen P. R. (1986) The spatial distribution of rocks on Mars. *Icarus, 68,* 217-238.

Edgett K. S. (1995) After the flood: A preview of eolian features at the Mars Pathfinder landing site in Ares Vallis. In *LPI Tech. Rept. 95-01, Part 1,* p. 12.

Golombek M. P. and Rapp D. (1995) Size-frequency distributions of rocks on Mars. In *LPI Tech. Rept. 95-01, Part 1,* pp. 13–14.

Moore H. J., Hutton R. E., Glow G. D., and Spitzer C. R. (1987) Physical properties of surface materials at the Viking landing sites on Mars. *U.S. Geol. Surv. Prof. Paper 1389.*

Rice J. W. Jr. and Edgett K. S. (1995) Facies on Mars: A model for the Chryse Basin outflow sediments based on analog studies of Icelandic sandar and the Ephrata Fan of the Channeled Scabland, Washington. In *LPI Tech. Rept. 95-01, Part 1,* pp. 24–25.

Smith P. H. (1995) A targeting strategy for ensuring a hillside view at Ares Vallis. In *LPI Tech. Rept. 95-01, Part 1,* pp. 27–28.

Summary of Education and Public Outreach

—*edited by K. S. Edgett and J. W. Rice Jr.*

INTRODUCTION

The Mars Pathfinder Landing Site Workshop II and Field Trips in the Channeled Scabland involved education and public outreach goals from the very beginning. Education enhancement and public involvement is a major goal of NASA programs such as Mars Pathfinder. The Mars Pathfinder landing, scheduled for July 4, 1997, offers great potential for inspiring a generation of students too young to remember the previous Mars landings in 1976.

This section details the education and public outreach efforts related to the Mars Pathfinder field trips that occurred prior to mid November 1995. Outreach efforts occurred before, during, and after the field trips and science workshop in September. The thirteen K–12 educators who participated in the field trips are planning to continue these efforts through at least the 1997 Mars landing.

SELECTION OF K–12 EDUCATOR PARTICIPANTS

Thirteen K–12 educators participated in the field trips and scientific workshops held in eastern Washington, September 24–30, 1995. Teacher J. Dodds (O'Leary Junior High School, Twin Falls, Idaho) served as an education advisor in organizing the field trips and education/public outreach project.

A letter was mailed in late February 1995 to several thousand K–12 educators on the mailing lists of the Washington and the Idaho Science Teachers Associations. The letter announced the opportunity for K–12 educators to participate in the Mars Pathfinder Channeled Scabland events. Teachers were told to propose how they would share the field trip experience with students, parents, and other teachers in their home community. The goal was to have the selected educators return home and immediately involve their community in Mars Pathfinder and Channeled Scabland education outreach. Possible activities might include things like town meetings, science fairs, field trips, and design of hands-on science activities that convey some aspect of Mars Pathfinder and/or the Channeled Scabland. Potential applicants were told they would have to cover some of the expenses of their trip, including travel, lodging, and meals. Applicants had to state their ability to cover these costs.

A total of 63 qualified applications were received by the end of March 1995. The proposals were evaluated by Dodds, K. Edgett, and J. Rice. Selections were based on the merit of each educator's proposed plan for sharing the Mars Pathfinder and Channeled Scabland experience. In addition to Dodds, eleven K–12 educators were selected in April, and a thirteenth educator, H. Cassidy, was added to the participation list in August because of her outstanding efforts to help with education and public outreach in Spokane, Washington, during the week of September 24–30, 1995. The education outreach projects undertaken are detailed in reports by the educators that are included in this volume. Educators who were not selected to participate in the field trips received Mars education material from the Arizona Mars K–12 Education Program directed by Edgett.

Most of the 13 educators found financial assistance from a number of sources, including their own savings, Eisenhower Title II funds provided through district or state sources, the Idaho Space Grant Consortium, and Idaho Science Teachers Association. Seven of the educators applied to receive graduate credit through K. Othberg at the University of Idaho (Moscow, Idaho) for their participation in the field trips, workshop, and follow-up educational activities. Dodds contacted Othberg and made all the relevant arrangements; she also helped other educators find additional funds to help them participate in the week's events.

Prior to the field trips and workshop, each of the 13 educators received educational material about Mars, Mars Pathfinder, and Mars Global Surveyor from the Arizona Mars K–12 Education Program directed by Edgett and from Golombek and the Mars Pathfinder Project. Materials included fact sheets, lithographs, newsletters (JPL's *The Martian Chronicle* and ASU's *TES News*), pins, decals, posters, and a slide set. The set of 18 slides was mailed to the educators in August 1995 by the Arizona Mars K–12 Education Program. The slide set was designed to explain the Mars Pathfinder mission and Channeled Scabland field trips by showing pictures of the lander, the microrover, Sojourner Truth, Landsat views of the Scabland, the Ares Vallis landing site, Mars Global Surveyor, a Viking lander image, and the Mars Surveyor 1998 spacecraft. Copies of this otherwise extremely limited edition slide set are on file at Arizona State University.

In October 1995, each of the 13 participants received a certificate signed by Edgett and Rice with the following text:

"Mars Scientists, Engineers, and Educators Working
Together for Children and Future
This is to certify that (Name) was a selected educator
participant in the Mars Pathfinder Landing Site
Workshop II and Field Trips in the Channeled
Scabland of Washington and Idaho
September 24–30, 1995
Sponsored by Arizona State University,
the Lunar and Planetary Institute,
the Jet Propulsion Laboratory, and
the National Aeronautics and Space Administration."

OTHER OUTREACH EFFORTS

Because only thirteen K–12 educators could participate in the field trips and workshop, we sought to extend the education and public outreach value of these activities through additional education and public outreach events in eastern Washington, and through the cooperation of print and television media.

Additional Outreach in Washington

With the assistance of Cassidy, we organized a teacher workshop in Spokane the evening of September 27 and a public open house the evening of September 28. Cassidy and Edgett are thrilled and very grateful to all the field trip and workshop participants who helped with these two events. These are described in more detail in the report by Cassidy and Edgett later in this volume.

Additional education outreach activities were carried out by Edgett during the week following the field trips and workshop in eastern Washington. On October 2, 1995, Edgett was a guest of teacher M. Harder at Ritzville High School. During the day, all of Ritzville's K–12 students had an opportunity to see a slide presentation about Mars Pathfinder and the Mars Surveyor program, examine a Mars globe, and ask questions about Mars.

On October 3, 1995, Edgett visited about 100 eighth-grade students at Cassidy's Chase Middle School in Spokane for 1 hour, then Edgett was a guest on a Young Astronauts STEP/Star television program. Hosted by teacher D. Howe and broadcast from Spokane, Washington, the Young Astronauts television program airs live via satellite every Tuesday and Thursday at 11 a.m. Pacific time. The program, designed for grades 4–6, is broadcast to about 100 subscribing schools or school districts around the U.S., with particularly large groups in Alaska, New York, Texas, and Washington. The show on October 3 focused on Mars, Mars Pathfinder, and the Channeled Scabland. Edgett fielded questions phoned-in live by student viewers, plus did a demonstration, using balloons, of the scale size and distances of Earth, Moon, and Mars. As of mid November, an effort is underway to have the show rebroadcast on NASA Select TV, in order to increase the student audience reached by the special Mars/Scabland episode.

Television and Print Media

Another means to educate and inform the public is to use television, newspapers, and magazines. We utilized this forum to extend our outreach throughout Washington, Idaho, and beyond. We also established a World-Wide Web page on the Internet that provides information about the Mars Pathfinder excursion to the Scabland (see Appendix B).

Television footage of Field Trip I (September 24–27) was obtained by representatives of KAET-TV, a PBS affiliate from Tempe, Arizona, and by the Jet Propulsion Laboratory's Public Information Office (JPL PIO). The KAET footage will be used in a broadcast to Arizona residents in January 1996. Both the footage from KAET and JPL PIO is available for use in future television productions about Mars Pathfinder and/or the Channeled Scabland. One example of how the footage might be used was outlined by S. Belanger of Oregon Public Broadcasting. Belanger attended the Mars Pathfinder Landing Site Workshop II in order to meet the Mars scientists, engineers, and educators, for involvement in a possible future PBS television production about Mars exploration that she is seeking to produce.

Print media were also involved in public and education outreach. For example, Edgett wrote articles about the Mars Pathfinder mission and Channeled Scabland for *Kids* newspaper, a publication that was distributed to 30,000 children in the Spokane, Washington, area in September (see Cassidy and Edgett, this volume). The Arizona State University News Bureau put out two press releases during the year (May 18 and September 18, 1995), and sent S. Koppes to participate and later write about the events in Washington. JPL PIO put out a press release on September 29, 1995, that included comments from Golombek about the results of Field Trip I. The Planetary Society sent K. Magee in part to write an article for their magazine, *The Planetary Report*; this article is scheduled to appear in early 1996 (Magee also demonstrated The Planetary Society's "Red Rover" education project for teachers and kids in Spokane September 27 and 28). Some of the newspaper articles that appeared as of mid November 1995 are listed in Appendix A. These include articles from small-town newspapers in Washington and Idaho, large city newspapers in Washington, and a national publication, *Space News*. Additional articles are likely to appear over the next several months, particularly as a result of the local education outreach efforts each of the 13 educators have initiated in their communities.

REPORTS FROM WASHINGTON AND IDAHO K–12 EDUCATORS

This section includes reports submitted by each of the K–12 educators who participated in the Mars Pathfinder Channeled Scabland events in September 1995. Each educator was asked to submit their report by October 27, 1995. Thus, some of the outreach activities and events described below had not occurred as of the deadline. One report was not received as of mid November 1995, so only 12 educator reports are included here. To some of these reports, we have added an "Editors' Note" afterward to provide updated information current as of mid November 1995.

The 13 educators who participated in the Mars Pathfinder events are an excellent resource for other teachers in Washington, Idaho, and the U.S. Many of the Idaho teachers got together and presented Mars education material at the Idaho Science Teachers Association conference October 5–6, 1995;

many of the Washington teachers did likewise November 3–4 at the Washington Science Teachers Association meeting. Educators from around the western U.S. were treated to similar presentations and information at the National Science Teachers Association Area Convention in Salt Lake City, Utah, October 19–21, 1995. Relevant presentations at the NSTA meeting in Salt Lake City were given by Campbell, Dodds, Edgett, and Gallagher.

EDUCATOR REPORTS

LANDING MARS PATHFINDER IN THE CLASSROOM: THE EDUCATIONAL BENEFITS OF ATTENDING THE MARS PATHFINDER LANDING SITE WORKSHOP II. T. C. Campbell, Capital High School and T. C. Bird Planetarium, 8055 Goddard Road, Boise ID 83704, USA.

The week that I spent at the Mars Pathfinder Landing Site Workshop was one of the most exciting, enlightening, and beneficial times of my life.

Astronomy and space exploration are topics that excite students. They are "hooks" that get students of all abilities involved and lead to success in many other areas of their curriculum. The information that I received at the workshop and the ideas I generated as a result of the workshop will excite and enthrall my students, as they did me, about our current space program.

I am fortunate as a teacher to work with many of the most able and brightest students in our district. These are the young men and women who will be engineers, scientists, and teachers in the near future. Meeting and watching the Pathfinder engineers and scientists interact and problem solve has given me a new and renewed enthusiasm for helping to prepare my students for their chosen careers. Teaching is a rewarding and exciting profession. I enjoy helping students to learn and succeed. I found that the Pathfinder engineers and scientists were excited about and committed to their professions as I am to mine. I really enjoyed being able to talk and socialize with these people.

I was amazed to learn how young the Pathfinder people are. If these people are in charge of our future space exploration program, it could not be in better hands.

The information gained from the workshop is invaluable. My astronomy class has been introduced to the Mars Exploration Program and will continue to monitor any new developments throughout the year.

Mars Pathfinder has become a major topic in all my planetarium presentations. By the end of the school year over 25,000 students and teachers will have visited the planetarium and been exposed to the current state of Mars exploration.

The four Idaho teachers who attended the Pathfinder workshop presented two sessions at the Idaho State Science Teachers Conference. We also brought the prototype rover from JPL to the conference to inform and excite Idaho teachers. Two of us presented Pathfinder at the astronomy "share-a-thon" at the National Science Teachers Regional Conference in Salt Lake City, Utah, October 19–21.

I have included Pathfinder as a part of all the educator workshops that I present throughout Idaho. I have developed a new workshop around Pathfinder and have and will present at least three of these "Space Exploration–Pathfinder" workshops within the next four months. Sheri Klug and I have submitted a proposal through Boise State University for Idaho State Eisenhower funding. The project, called Project SEARCH (Space Exploration Activities for Raising Children's Horizons), will involve 40 teachers from 10 area schools in an extensive one-week summer workshop. The workshop will stress hands-on activities and computer programs for teaching astronomy and space exploration. The Pathfinder and Planetary Society "Red Rover" project will be the foundation for this workshop. After the summer, the involved teachers will continue to meet once a month for updates throughout the school year.

I have also designed a Mars Exploration T-shirt for Idaho educators. I will provide T-shirts at workshops to keep Idaho teachers and their students involved.

I would like to thank everyone involved with the Pathfinder workshop for including the educators. I hope that what we do with our students and fellow teachers will help to repay your consideration. I hope that you will continue to include us as a part of the project and offer other educators the same type of opportunities that you've given us.

EDUCATION OUTREACH EVENTS IN SPOKANE, WASHINGTON, DURING THE WEEK OF THE MARS PATHFINDER WORKSHOP. H. H. Cassidy[1] and K. S. Edgett[2], [1]Chase Middle School, East 4747 37th Avenue, Spokane WA 99223, USA, [2]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287-1404, USA.

The gathering of Mars Pathfinder engineers, Mars scientists, and selected K–12 educators in Spokane, Washington, for the Mars Pathfinder Landing Site Workshop II in September 1995 presented an incredible and unique opportunity for education and public outreach for the Spokane community. We thus involved the workshop participants in several outreach efforts: a K–12 educator workshop, a public open-house event, and a special publication for parents and children. In addition, the Washington Science Teachers Conference November 3–4, 1995, is planned to include a special Mars session presented by the Washington educators who participated in the week's events.

Spokane Mars Exploration K–12 Educator Workshop: On September 27, 1995, 30 educators representing the Spokane public schools attended a three-hour Mars Exploration Workshop at Salk Middle School in Spokane, Washington. The workshop was presented by K. Edgett of the Arizona Mars K–12 Education Program with the assistance of several Mars Pathfinder project personnel and scientists and many of the K–12 educators from Washington and Idaho who participated in the Mars Pathfinder field trips.

The presenters demonstrated how to use the Mars missions to capture interest in science in students, and emphasized the interdisciplinary nature of space exploration. Topics included the Mars Pathfinder and Mars Global Surveyor missions, information about the planet Mars, the similarities between Mars and the Channeled Scabland region of eastern Washington, and the future of space exploration. Teachers were introduced to a variety of hands-on activities associated with Mars exploration, as well as a wide range of resources available from NASA, JPL, The Planetary Society, the Ice Age Floods Institute, and other educational materials, including the Challenger Center's "Mars City Alpha" and The Planetary Society's "Red Rover" project.

The Mars Educator Workshop provided a core of Spokane educators with the tools and inspiration that will affect hundreds of children in Spokane classrooms. As these teachers share resources and activities with others educators in their schools, the impact of this workshop will spread.

Spokane "Mars Night" Open House: A public "Mars Night" open house held at Chase Middle School in Spokane, Washington, on September 28, 1995, attracted a capacity crowd of 700 children, parents, and community members who came to learn more about NASA's Mars Exploration Program. The two-hour program consisted of a slide show and question and answer session led by K. Edgett (ASU), M. Golombek (JPL), and D. Shirley (JPL), followed by numerous hands-on activities, demonstrations, and one-on-one conversations with scientists and educators.

After the introductory slides and questions, members of the audience visited a wide variety of exhibits, participated in activities, and attended demonstrations. A favorite activity was the Mars Pathfinder microrover demonstration by H. Eisen of JPL. One eighth-grade student commented, "My favorite part of Mars Night was when they had the rover running over a bunch of kids. It's really fascinating to think that a machine just like that will soon be walking on Mars!" Another student wrote, "I loved the station with the rover. I was surprised at how versatile the rover really is—that it climbs over people with no problem at all!" R. Manning and R. Cook of JPL fascinated the audience with airbag samples and test videos. "Thank you for coming to our school and teaching us about how the airbag works. I think the airbag is very cool. I can't believe that the piece of rope can hold about 800 pounds!" wrote another student. T. Parker, also from JPL, presented a popular three-dimensional Mars slide show. J. Crisp from JPL and A. Treiman from LPI monitored a station with meteorites, Moon rocks, and microscopes. A student commented, "The meteorite you showed us through the microscope looked cool. The rocks looked different from the ones on Earth. What you showed and told me about Mars helped me learn a lot." Another commented, "It's cool to see something that's not from Earth. Maybe someday we'll get rocks from Mars." J. Rice from ASU explained the geological mapping and the Ares Vallis landing site. One excited student wrote in a thank-you letter, "I used the names of the geological points on your Mars globe to name geological points on my own Mars map. I enjoyed looking at the next destination of mankind."

Technology demonstrations included a link-up to a "Red Rover" site in Utah, by K. Magee of the Planetary Society, and Internet and CD-ROM explorations in the school media resource center. Other space-related activities such as soda straw rockets, "Mystery Planet" problem-solving activities, building models of Mars Pathfinder, and a demonstration using a laser to estimate the distance from Earth to Mars, were led by Mars Pathfinder personnel and Idaho and Washington educators who were participants in the Mars Pathfinder field trips.

The "Mars Night" Open House provided Spokane children and their parents with a unique opportunity to learn firsthand of NASA's Mars Exploration Program and to personally interact with scientists and educators who have dedicated their careers to scientific inquiry and space exploration. Many perceptions were changed, as demonstrated by this comment from an eighth-grade student, "You (the scientists) were great speakers! Before, I thought all scientists wore white jackets and were very old, but I guess that wasn't true. Now I know that not all scientists are 'mad scientists.' Thank you for all you have done." Many students were inspired by the idea of space exploration: "The concept of going to Mars is pretty exciting. The slides of Mars were so graphic and real that at times I felt like I was traveling to Mars. The prospect of traveling to Mars is so exciting!" Another student wrote, "You made learning fun, not only for the youngest of children, but for the oldest of adults."

As a result of the "Mars Night" Open House, Spokane now enjoys a network of parents, children, and teachers who understand a little more about Mars exploration and what scientists do; they have discovered scientists and engineers to be entertaining and interesting people who love their work and constantly strive to meet new challenges. When Mars Pathfinder is launched in December 1996 and lands on Mars on July 4, 1997, hundreds of children and adults in Spokane will be watching and feeling connected to this next step in space exploration. They will remember the Mars scientists and engineers who spent an evening at their school sharing their expertise, enthusiasm, and curiosity about the planets.

***Kids* Newspaper, September 1995:** The September 1995 issue of *Kids* newspaper, published in Spokane, Washington, was distributed to approximately 30,000 school children and their families in the Spokane area and featured several articles written by K. Edgett. "Mars Pathfinding in Eastern Washington," or "The Martians are Coming to the Spokane Area for a Preview," is a three-page article comparing Mars to Eastern Washington and describing the activities of the Mars scientists and educators in Spokane during the week of September 24–30. "Exploring Mars From Eastern Washington" shares information for parents who are interested in exploring the Channeled Scablands area with their children and comparing it to Ares Vallis, Mars. Suggestions for Mars exploration on the Internet and for recent books and articles on Mars were also provided for parents interested in helping their children get ready for Mars Pathfinder's mission.

Washington Science Teachers Association Conference: On November 4, 1995, the Mars Pathfinder Field Trip Educators from Washington will present a workshop on Mars exploration for about 40 attendees at the Washington Science Teacher's Association Annual Conference in Pullman, Washington. Educators planning to participate in this presentation are H. Cassidy, L. Fayette, J. Gallagher, M. Harder, M. Murray, K. Olive, and M. Olson. The workshop will combine hands-on activities, slide presentations, demonstrations, and identification of instructional resources available to educators. The emphasis will be on the interdisciplinary nature of space exploration and is designed to use the Mars missions to inspire an expanded understanding and enthusiasm for science. Finally, the Washington Mars Pathfinder Educators will share experiences from their participation in the Mars Pathfinder field trips and workshop.

EDUCATION OUTREACH EVENTS FOLLOWING THE MARS PATHFINDER WORKSHOP AND FIELD TRIP. J. Dodds, O'Leary Junior High School, 2350 Elizabeth Blvd., Twin Falls ID 83301, USA.

The week of September 24, 1995, involved Mars Pathfinder scientists and engineers plus educators from Washington and Idaho examining the Channeled Scabland area of eastern Washington, a site that is analogous to the Pathfinder landing site at Ares Vallis. Participants experienced an aircraft overflight and ground field trips in eastern Washington and northern Idaho led by experienced geologists, technical reports given by the Mars Pathfinder project scientists and engineers, and professional interaction that fostered the continuation of the educational aspect of this week. This is a report of the educational outreach initiated since the September workshop.

Within a week after returning from Spokane, the Idaho Science Teachers Association fall conference convened in Boise. While in Spokane, it was arranged with the conference chair to amend a session and add a presentation by a JPL rover engineer, K. Jewett. The rover team at JPL was very helpful in allowing one of their engineers to participate in the conference for several days. Jewett was in the exhibit area with the rover simulator when he was not presenting a session. In another session the Idaho educators who attend the Spokane workshop gave a joint presentation involving the geology of the two sites and the specifics of the Pathfinder project. Slides and viewgraphs obtained from K. Edgett, M. Golombek, and T. Parker were used, as well as paper models of the Pathfinder and rover.

The following week, on October 13, a Star Party was held at our school to celebrate the completion of our Newtonian telescopes that were made by our students. Members of the Magic Valley Astronomical Association were prepared to give presentations inside involving what objects were available for viewing and information about telescopes, as well as helping outside with the use of telescopes. This was a great opportunity to also talk about the Mars Pathfinder mission. This Star Party will be followed by others throughout the school year.

The National Science Teachers Association held their regional conference in Salt Lake City, Utah, on October 19–21. In addition to Edgett's presentation and others from JPL, J. Gallagher, T. Campbell, and I found a great opportunity to share our experience and information about Mars Pathfinder at the Space Educators Share-a-Thon. This event was scheduled late and allowed for impromptu presentations. We also participated in the National Earth Science Teachers Association Share-a-Thon at the same conference. In both sessions, a paper models of the Pathfinder and rover were passed out and explained. Information was also included about the analogy of the geology of the Channeled Scabland area with Ares Vallis.

A Space Exploration Workshop is planned for Twin Falls, October 26–28, 1995. This is a 15-hour teachers' workshop that will be held after school and on Saturday. A focus during this workshop will be Mars missions, especially Pathfinder. Most of the participants in the workshop are elementary teachers. This workshop is primarily taught by Campbell and funded through the Title II Eisenhower funds.

When our district teachers receive money from the Eisenhower funds to travel to conferences or workshops, there is an expectation to share what they have learned. On November 14, 1995, our district will have a science and math share-a-thon involving teachers K–12. Each teacher will have 20 minutes to present their activity to a group of teachers, then everyone will rotate to another presentation. There will be six sessions during the evening and I will not only share information concerning the Pathfinder mission but will also alternate with an activity comparing the Bonneville and Missoula Floods.

Communication with former NEWMAST (NASA Educational Workshops for Mathematics, Science, and Technology Teachers) participants has continued since we all had our experience at NASA Ames Research Center in 1994. Many of us were interested in Mars and have had many exchanges about projects in our classroom. The Mars Pathfinder workshop and field trip will be a great addition to the dialog about Mars and it is a different way to increase the educational outreach. Teachers in this Internet group are from all over the country.

I also have been asked to share this project with another e-mail group, Access Excellence (AE). Teachers who have been selected to be AE Fellows the past several years are high-school biology teachers. There are several hundred teachers in this group, but anyone who has membership to America On Line can access the AE forum. The interdisciplinary approach in science teaching can incorporate aspects of Earth science in biology.

Additional plans for the school year include presentations at Rotary and Magic Valley Astronomical Association meetings. Another community project will occur in the spring, when our district implements science and math night at the mall. If JPL's scheduled testing of the rover allows, we will have a rover and engineer at the shopping mall. K. Edgett and J. Rice will visit our school and talk with students about Mars exploration and conduct a short teacher inservice. At this time the students should be finished with constructing their Marscape and their motorized rover. The "Red Rover" project is sponsored by The Planetary Society and is in its second year. If accepted as a beta site for "Red Rover," students will also be able to drive another rover via the computer. Students will experience time-delay in relaying messages, teamwork, and the excitement of space exploration.

My Earth science students will expand a program started last year. When our district purchased a Starlab, the ninth-grade Earth science students learned the mechanics of how to set up and take down the inflatable planetarium as well as how to give a program for the elementary schools. This year the students will include presentations and activities involving space exploration, specifically the Mars Pathfinder.

Other aspects of educational outreach involve teacher workshops during the summer and continued presentations at conferences, such as the NSTA Conference in Phoenix next fall.

One week in September has resulted in activities that will involve teachers, students, and community members all over the country. The Mars Pathfinder project scientists and engineers from the Jet Propulsion Laboratory, NASA Ames Research Center, Arizona State University, University of Arizona, Lunar and Planetary Institute, and U.S. Geological Survey have been very generous and excited to share information with the educators who had the privilege of exploring the Channeled Scabland of eastern Washington.

Editors' Note: On November 10, 1995, J. Dodds reported: "I am giving a presentation for the local astronomical society in December . . . these folks are really excited about what we did in Washington. Yesterday and today were parent-teacher conferences [at O'Leary Junior High School]. So many parents had compliments about what we are doing in class; kids are talking about the Mars Pathfinder and other missions at home! Wow! I hope you realize how exciting the field trip experience was and continues to be."

MARS PATHFINDER LANDING SITE WORKSHOP II: POST-WORKSHOP/POST-FIELD TRIP EDUCATION OUTREACH REPORT. L. Fayette, Toppenish Middle School, 104 Goldendale Avenue, Toppenish WA 98948, USA.

Immediate Follow-up Activities: Shortly after returning from the Pathfinder workshop, several activities ensued that allowed me to share the Mars Pathfinder mission with the public. Another educator participant, K. Olive, and I were interviewed on a morning radio talk show by Jim Breadlove of AM980 KUTI in Yakima, Washington. The regional newspaper, *Yakima Herald-Republic*, published an article about the workshop, and our local newspaper, the *Toppenish Review*, interviewed me to do a story. Informally, I have shared the experience with my students, colleagues, administrators, and school board members. In November, the Washington educator participants will share the Pathfinder mission and our plans for making it connect to our classrooms with our colleagues statewide at the Washington Science Teachers Association annual conference at Washington State University.

Future Activities: Our middle school has been involved in a partnership with the Department of Energy through Pacific Northwest Lab-Battelle (PNL) for five years. This OPTIONS program connects the resources, scientists, and engineers of PNL with our science teachers and students to enhance the science educational experience. The focus is to develop curriculum that is multidisciplinary and interdisciplinary in nature. In my eighth-grade Earth science arena, four scientists (R. Fruland, P. Molton, O. Olivares, J. Wise) have been collaborating with me in developing a space-based, thematic curriculum. These same scientists will also spend time as mentors in the classroom and on line as the project develops.

This curriculum project will allow connections to be made among the science disciplines of geology, soil science, plant biology, astronomy, chemistry, and physics. Cross-curriculum integration with math, technology, art, literature, English, and history will be inherent in the project. The students will be using community resources in support of their efforts. A parent group will be organized to work in the classroom, provide transportation for students who need to get supplies or go to resource sites, and organize the logistics of the culmination activities.

The basic design of this several-week project is that the students will work in teams like scientists, engineers, architects, artists, etc., do in the real world to produce a final product. For this project, the final product will be the development of lunar settlements. Each team member will be responsible for developing 1 of 10 components (Architectural Design, Transportation, Life Support, Lunar Science and Exploration, Government and Administration, Resource Utilization, Social and Health Services, Commercial Services, Communication Systems, Energy). The goal is to give the students the opportunity to be creative and to use higher-level thinking skills as they learn to produce a high-quality end product in a cooperative format as real-world professionals do.

Mars Pathfinder Mission Connection: 1. At the mock professional conference, students will use the format that was followed at the Pathfinder conference in Spokane as their guide. A team of parents will be the conference organizers. It will be held at the beautiful Yakima Nation Cultural Center conference center in Toppenish. Community leaders, parents, Heritage college personnel, Battelle personnel, members of the media (local and regional newspapers and T.V. stations) will all be invited to listen to the students present their projects at this formal gathering.

2. An evening public open-house night will be organized for the community, parents, and families to come to the conference center, to see the settlement models, rover scenarios, and other displays that the students have created. The elementary classrooms will be invited to view the projects and ask questions during the day.

3. During the school year, the eighth-grade curriculum has a solar system component. This year the Mars Pathfinder mission will be written into the study of Mars. The students will make a display showing the Earth and Mars and the spacecraft in flight, in descent, and on the planet's surface, along with mission information. The display will go into the school's display case and into one of the downtown storefront windows to advertise the open house.

4. The Lunar Settlement curriculum project has Transportation and Lunar Sciences components that will have a Mars exploration aspect.

a. Mars exploration. One of the justifications for building bases on the Moon will be to further explore the solar system, with Mars being the first step. The Moon will be a testbed for designing, building, and testing telerobotic vehicles for lunar and Mars exploration. In the classroom, the students will build two erector-set vehicles from instructions, then create two vehicles as their models for their settlement project.

The next step in performing hands-on activities in this component will be to use the "real" telerobotic rover (see Fig. 1). This is a working model of a rover, designed by R. Fruland, that the students will guide from behind a barrier through a simulated Viking I landing site set up in the classroom. An advanced exercise will be to use stereoscopic views with two cameras attached to the rover to map the rocks. H. Moore of USGS has provided the maps, photos, and instructions for this activity.

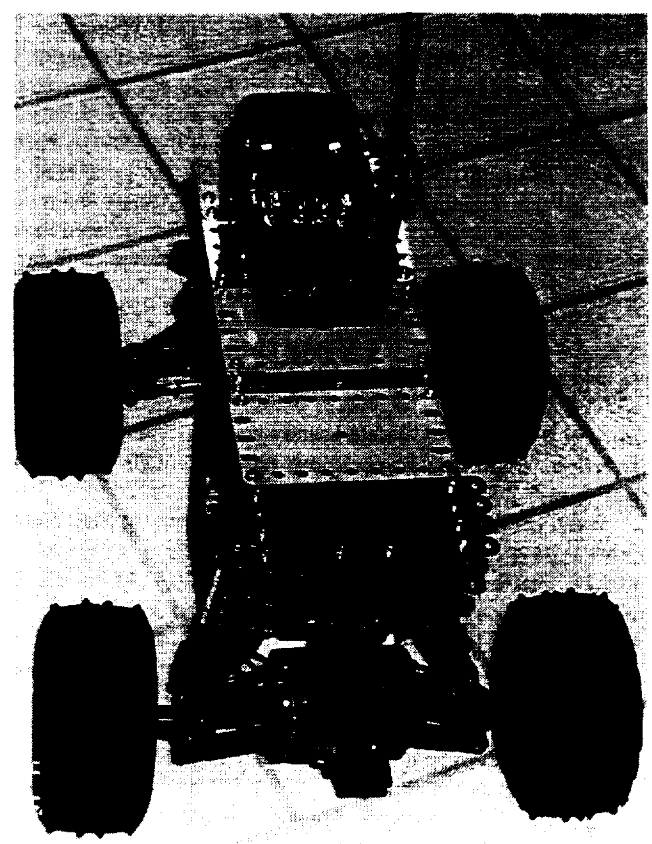

Fig. 1. Rear view of telerobotic mini-rover designed by R. Fruland. Rovers such as this are used by students at Toppenish Middle School.

b. Sample return mission. Using the Pathfinder mission as a model, vehicles will be sent to Mars to explore, as explained in the above scenario. In the second phase of exploration, soil and rock samples will be returned, including samples containing microbial life. The Moon bases will be ideal sites to create highly controlled sterile environments to receive and test these samples. Genesis, or terraforming, experiments will take place in the lunar labs, providing ultimate control during the addition of nutrients, microbes, and higher life forms like insects. Learning how to approach terraforming on Mars would be potentially easier on the Moon than on the Earth.

Conclusions: A significant amount of information that was learned at the Pathfinder workshop will be incorporated into a developing curriculum project that will involve our eighth-grade students during February and March 1996. The public will be reached by parent involvement, community resource connections, and open-house invitations to the public, and the media coverage of their final product presentations. It should be exciting!

MARS PATHFINDER EDUCATION OUTREACH IN PORT ANGELES, WASHINGTON.

J. Gallagher, Port Angeles High School, 304 East Park, Port Angeles WA 98362, USA.

The best way to learn something is to actually do it, and the best way to evaluate the learning is to teach it to others. This simple philosophy of education fit well with the experiences of Idaho and Washington teachers during the workshop. We worked side-by-side with the scientists and engineers as they conducted research, performed experiments, solved problems, and debated different aspects of the Mars Pathfinder mission. For one week, we experienced the challenge and excitement of working on a team dedicated to the success of planetary exploration. Our task is to convey this experience to our students, our local community, and the larger community of teachers nationwide.

The experience of working with the Mars Pathfinder project team and associated members of scientists was a truly incredible one. As teachers, we try to convey to our students the excitement of being part of a team, working toward a common cause, meeting challenges, and discovering new and exciting things. We have now experienced that ourselves! I returned from this workshop and made Mars the topic of conversation among many of my students and fellow faculty members, often without my initiating the subject. Everyone wanted to know about this new mission to Mars—few had even heard of it before. This breached other topics, such as: Whatever happened to the last mission (Mars Observer)? Are we planning other missions to Mars? When are we sending people to Mars? What are we doing to study the other planets? It seemed that everyone had heard about where I was for the week and wanted to know more. For an educator, having people thinking and questioning is a great reward.

My education from this week of real-life science has become an integral part of my Astronomy/Geology class since I have returned. My class concluded its study of local geology with a look at the Channeled Scabland features, discussing the last glacial period and the Missoula Floods. We then began our study of planetary geology with a look at the similar features on Mars. This was the first time I have done this in class and it was a great way to start looking at things. Students had an Earth-based analogy for the features on another planet. We will continue looking for other similarities as we study Mars and the rest of the planets.

My students are currently preparing presentations to conclude their next section of Mars studies. They studied maps of Mars topography and used the activities "If Mars had Seas, Where Would They Be?," and "Where Will You Build a Research Station on Mars?" from The Planetary Society's MARSLINK curriculum, to plan research missions to Mars, deciding what they wished to study and why. Using "Mars Landing Site Selection" activities from the Arizona Mars K–12 Education Program's "1995–1996 Education Supplement and Guide," we then looked at the criteria for choosing a landing site for Mars Pathfinder and chose landing sites based on the criteria and the proposed studies the students wished to pursue. Student teams will make final presentations on their sites and then we will look at the reasons for choosing the Ares Vallis site.

I have recently begun the educational outreach portion of the workshop. I presented at the National Science Teachers Association (NSTA) Western Regional Conference in Salt Lake City, Utah, October 19–21, 1995. Approximately 150 elementary and secondary teachers attended an Earth Science "Share-a-Thon" at which I summarized the Mars Pathfinder mission objectives, schedule, and spacecraft and rover design. Each of the teachers received designs for making paper models of the Mars Pathfinder spacecraft and rover devised by C. Diarra (Jet Propulsion Laboratory). At the same conference, I made a similar presentation to approximately 50 educators associated with NASA's educational programs.

I will be presenting a two-hour workshop, along with other Washington Pathfinder workshop participants, at the annual Washington Science Teachers Association (WSTA) conference in Pullman, Washington, November 3–4, 1995. We will give an overview of the Mars Pathfinder mission using viewgraphs provided by M. Golombek. Each participant will receive materials to build paper models of the spacecraft and rover, and will build these models in teams. We will build a full-scale, two-dimensional construction paper model of the spacecraft as a large group.

"Mars Night" will take place December 5, 1995, at the Vern Burton Center in Port Angeles, Washington. This two-hour event will be modeled after our open house in Spokane during the Pathfinder workshop. Open to the general public, but targeting families of elementary and middle-school students, I will introduce Mars Pathfinder and Mars to our Port Angeles community. Local teachers and high-school students, trained during several of my scheduled inservices, will conduct Mars-related activities in small breakout sessions, and we will have opportunities to drive The Planetary Society's "Red Rover" model by computer network with Logan, Utah.

I look forward to more opportunities to be involved with Mars Pathfinder in the future. I will be making proposals for presentations at future NSTA and WSTA conferences, especially upcoming ones in Phoenix, Port Angeles, and Seattle. I will be an active participant in future Mars Pathfinder outreach programs, including plans for such programs in Death Valley and those coordinated for launch and landing of Mars Pathfinder.

CONNECTIONS BETWEEN OUR BACKYARD AND MARS.

M. Harder, Ritzville High School, Wellsandt Road, Ritzville WA 99169, USA.

Immediately following the completion of our workshop, K. Edgett gave students in the Ritzville School District a brief introduction to the Mars mission and the connections to phenomenal features that can be found in our own back yard. Students were full of questions and enthusiasm for the information that I have shared with them and their teachers upon my return from this tremendous experience.

Our entire staff has shown a great interest in materials that I have been able to provide, so they can involve their students with not only the Channeled Scabland, but also information that allows us to bring students into the realm of science and space exploration. At this time we have completed one mini-session together, where I included background information on how this project came to take place in our area, and showed slides that we have received, as well as slides I took that included locations of sites of interest to everyone in our community.

The most exciting project was with a group of consumer math students who, because of hands-on experience, were able to make real connections between math, science, and engineering when we drew an assortment of models to scale, and finished up with a life-size creation of the Mars Pathfinder and the Sojourner microrover. I have enjoyed seeing the younger students marvel at this replica and listen to the conversations that began with the understanding that this is something we could touch, imagine, and understand. Here we live in a unique area where scientists and engineers from all across the world came to explore and help all of us understand the outer reaches of space, truly the unknown, and form hypotheses that will be used all over the world.

As I work with junior-high students, I have a new insight to the formation of hypotheses and collecting data. Students are using Mars Pathfinder Fact Sheets and and are creating their own data logs. This has truly become a project that is being used across the curriculum.

As I receive materials and information, I make copies and materials available to staff members and plan our second mini-session to explore ideas to integrate these ideas across the curriculum for all grades. The first-graders are using information for beginning writing projects, the eighth-grade class prepares to create a landing site in their classroom, and the junior-high students practice problem-solving situations.

Our annual field trip to the Scabland will now have an additional element, the landing site selection. Problem-solving techniques and rationale for each site will be included and given by the high-school and junior-high students. Our initial field trip will examine each site for uniqueness and the theories that surround its formation. Our final field trip will be to present information on an appropriate landing site and demonstrate the samples that will be gathered at the site should it be selected. Long after the Pathfinder makes its initial landing and continues to collect data, we too will have our data to continue to collect and form new questions to answer. The exchange of information and possibilities for our students and public are widespread; without this experience coming to our backyard, we would have never made such connections.

Early next month I will participate with the other teachers from Washington in the Washington Science Teachers Association Conference, where we will again present a mini-session and use the model built by students to show the actual size of the lander and Sojourner rover. Presentations similar to our first mini-session will be presented to our local historical group and Chamber of Commerce in the coming months.

It is difficult to put into words the tremendous amount of information that I have returned with. My hope is not only to share these facts and theories but also to convey the inner workings and the pride that I observed in all the participants of this endeavor. I hope that the students learn not only about the knowledge it takes to create products but also the dreams that it takes to be successful. An experience like this truly allows dreams to be created. As a teacher in a rural area where there is a lack of technology to instantly "hook up" our students to the current information, I look forward to making connections with many of the participants in a time-delayed fashion.

UNLOCKING THE CHALLENGES IN OUR FUTURE BY IGNITING INTEREST IN OUR EDUCATORS AND STUDENTS USING SPACE-RELATED EDUCATION: FOCUS ON THE MARS PATHFINDER MISSION. S. L. Klug, Canyon Owyhee School Service Agency, Marsing Middle School, P.O. Box 340, Marsing ID 83639, USA.

As an educator in rural Idaho, I have unfortunately found that high-tech subjects such as space exploration and spacecraft design seem light years away from our student's everyday lives. Lack of resources, lack of technology, and sometimes lack of vision of what the future might hold can be formidable obstacles to overcome when we attempt to expand our student's horizons beyond our terrestrial home.

As an educational participant in the Mars Pathfinder Landing Site Workshop II, I discovered the incredible benefits that a partnership between scientists, engineers, and educators can reap for our scientists of the future. Last September, in preparation for the July 1997 Pathfinder landing on Mars, the Mars science specialists, engineers, and selected educators from Idaho and Washington convened in eastern Washington for two purposes: (1) to study the analogies of the Channeled Scabland area and the catastrophic flood plain of the Ares Vallis region on Mars and (2) to provide a forum for direct interaction between educators and the Mars scientific community.

As a participant, I found the information generated by our two field trips, the overflight of the area, and the technical abstract presentations extremely stimulating. Many times, as educators, we lose touch with the ongoing discoveries and research projects taking place. Our time is consumed by routine tasks of daily lessons, grading papers, classroom management, etc. We tend to forget the invigoration of field exploration and working together to glean and connect information that will help us solve unknown problems of the future. For me, however, it was the latter purpose, the interaction between the diverse participants, that proved to be the most memorable and energizing.

The workshop was an excellent example of the linkage between the educator's role of preparing our students for careers in scientific fields and the scientist's responsibility to stay connected with the educators. This connection is needed in order to help provide educators with a realistic, scientific vision of where our students are headed. As the different groups interacted, the relationship between our ideas and methods of teaching, contrasted with what actual skills a scientist and/or engineer really needs to be successful, was indeed evident and enlightening. My personal methodology and teaching techniques were somewhat challenged, somewhat validated, and indelibly impacted by my experience at this workshop.

Upon my return, I immediately had numerous opportunities to share my experiences. I, along with other Pathfinder education colleagues, conducted two Pathfinder workshops at the state meeting of the Idaho Science Teachers Association and made a special presentation to the astronomy class at Boise State University. Our group presentations were greatly enhanced by the loan of a mini-rover, similar to the rover on the Pathfinder Mission, and a rover project engineer from the Jet Propulsion Laboratory. My personal multimedia presentations included several senior citizens groups from different communities, an education class at Boise State University, my afterschool Horizons program at three elementary schools, and a Saturday, school-sponsored, family-oriented geology field trip.

In all my presentation experiences, several common factors stood out: (1) There was a universal interest in the space program: past, present, and future. This was true regardless of age. (2) There was a universal interest in more space related education. (3) There is a desire to have a closer, more personal connection to ongoing space projects. (4) Educators, especially elementary educators, do not realize the enormous impact they can have on their student's future in science-related careers. The Mars Pathfinder workshop gave me many insights as to how powerful space education can and should be in our schools and communities. I learned that space-related topics can be successfully taught across the curriculum, encompassing art, history, mathematics, health, science, etc. Second, there is current, cutting-edge information available from many space-related agencies, not to mention the vast sources of information on the Internet. Idaho is also quite fortunate to have a series of ongoing, hands-on, astronomy/space-related workshops and a summer astronomy camp conducted by T. Campbell (a Mars Pathfinder workshop participant). Finally, one of the most interesting items I learned while interacting with many of the scientists and engineers was that most became interested in their career fields while still in grade school! Not many of the educators I talked with had any inkling that future planetary geologists, astrophysicists, or exobiologists might be present in their classroom each day.

The end of the workshop will in no way mark the end of my endeavor in pursuing space education. I have many presentations to yet to come. I have co-authored a science grant to provide a space exploration/astronomy/computer summer camp for educators in southwest Idaho for the coming year. Again, the opportunities are endless. In closing, I feel an urgency to understand the necessity of space education and implore our future generations to look at the possibilities and promise that space exploration holds for the future. When educators can connect in a personal way with the scientific community, as we did on the Pathfinder workshop, the possibilities for realistic education are boundless. Obstacles seem to disappear as opportunities to explore uncharted areas open before us. My wish for educators at all levels is for them to experience firsthand the possibilities and excitement of our expanding future in space. It is a great time to be an educator, especially in rural Idaho!

Editors' Note: On November 8, 1995, S. Klug reported, "We did a family field trip to an area showing the Bonneville Flood deposits with one of my schools. We had a graduate student on loan from the University of Idaho. It went really well. We prepped the trip with an introduction on Mars Pathfinder and catastrophic floods. I plan to run the same trip in the spring with my other two schools."

A REPORT ON POST-FIELD-TRIP ACTIVITIES FOLLOWING THE MARS PATHFINDER LANDING SITE WORKSHOP II AND FIELD TRIPS IN THE CHANNELED SCABLAND, WASHINGTON: BRINGING MARS DOWN TO EARTH.

M. A. Murray, Alki Middle School, 1800 Northwest Bliss Road, Vancouver WA 98965, USA.

Introduction: An opportunity for theme-based, experiential learning will be provided to hundreds of students by linking study of the Channeled Scabland of Washington to Ares Vallis on Mars. My participation in the field trips and workshop [1] provided an opportunity to develop meaningful science programs in my community. As a result, students of all ages, parents, and teachers will be introduced to related planetary science through field trips, labs, simulation activities, and week-long camps planned through 1997.

Related Activities: I taught a workshop based on related Mars science to Vancouver-area teachers featuring hands-on activities intended to be used in their classrooms on October 26. Held at Discovery Middle School in Vancouver, the event was sponsored by Washington State University, Educational Service District 112, and the Vancouver School District #37.

I designed a new science camp experience for Vancouver students to debut in February 1996. It is organized around Mars Pathfinder and its rover "Sojourner." On four consecutive Saturdays, students aged 9–11 will work in teams alongside high-school "Principal Investigators" to complete selected Pathfinder mission goals. Middle-school students will serve as assistants in this multiaged program. This project will be evaluated for inclusion in a new K–12 integrated science curriculum under development in the Vancouver schools.

Students in my lab at Alki Middle School in Vancouver will research, design, test, and evaluate conceptual models of robotic spacecraft and rovers beginning in January 1996. A symposium will be held later in the school year to present papers and demonstrate prototypes. Design criteria must meet NASA's Discovery Program as nearly as possible. Mars is the students' intended target, with numerous simulated landing sites under discussion, including Ares Vallis.

During the summer of 1996, students from around the region will participate in a new camp entitled "Mars Adventure," sponsored by the Oregon Museum of Science and Industry (OMSI). I designed the camp to follow in the footsteps of scientists, engineers, and educators who flew, drove, and hiked through the great Washington Channeled Scabland in September of this year. Returning to the Portland museum, students will participate in a simulated Mars mission as a culminating event.

Conclusion: Through the planned activities described here, students of all ages, teachers, parents, and community members will become involved in the excitement of science, linking our home planet to the exotic world of Mars. The field trip to the Channeled Scabland opened a number of doors for me personally and professionally that I have shared and will continue to make available locally and regionally to others. The serendipitous effects of involving classroom science teachers in the field trips and workshops in September will continue to provide learning opportunities to our communities for years to come. For our children, Mars will have been "brought down to Earth" through their meaningful involvement in these programs.

References: [1] Golombek M. P. et al., eds. (1995) *LPI Tech. Rpt. 95-01, Part 1.*

MARS TAKES OVER CLASSROOM AT WILSON MIDDLE SCHOOL!

K. Olive, Wilson Middle School, 902 South 44th, Yakima WA 98908, USA.

It has been very busy since I returned from the Pathfinder Workshop II: L. Fayette and I were on a local radio talk show at station KUTI AM; on Monday, October 2, the *Yakima Herald-Republic* ran an article about the workshop; and on Wednesday, October 4, KIMA Television came to my classroom and interviewed me and some of my students regarding the Pathfinder workshop. I have conducted 4 parent/student astronomy nights in my classroom where the average number of people attending was 62. Mars was the topic of one of these parent/student nights. We did one activity where we used NIH for the Macintosh to measure the size of one of the river channels on Mars. The activity was designed by W. Johnson of the Joint Education Initiative. Teams of parents and students measured the length and width of a river channel and an island in one of the channels. They were able to tell what direction the water flowed and then compared the size and shape of the channels to the Channeled Scabland of Washington by using the topographic maps from *The Washington Gazetteer*. My slides of the workshop have not been developed yet, so I could not use them at that time. I did show the video footage and we talked about the similarities between the two areas.

Right now I am working on a huge public awareness project for at least 4000 students. I am on the coordinating committee to bring the region's fifth through ninth grades into Yakima's Sundome for an assembly where I will prepare a slide show of space and space projects. The Mars Pathfinder slides will be part of this presentation. After the slide show, Astronaut B. Dunbar will speak on U.S.-Russian cooperation in space flight. We are trying to get a separate session for girls of the area that morning.

During the large assembly I will answer a number of questions that will be sent out to all of the schools in attendance. One of the questions is "Who is the rover of the Mars Pathfinder Mission named after?" I will explain the name and let them know that it was named by a student in their own age group. I am sending out to all schools the NASA/NSTA Space Science Student Involvement Program application. At the assembly I will be encouraging everyone to participate in this program. One of the categories is "Mars Scientific Experiment Proposal."

I have completely restructured one of my classes to study Mars all year long and use Mars as a tool to compare to Earth. This class will be giving Astronaut Dunbar a "Breakfast on Mars" the morning of her presentations. This class is creating a newsletter that is being sent to all their parents to keep them updated on the progress of the class. I held a parent meeting to discuss the restructuring of the class and the implications of using Mars as our tool for comparison to Earth. Eighteen of 28 parents came to the meeting and were excited about the "new" class. We are currently measuring the amount of CO_2 in our atmosphere with Gastec Analyzer Gas Diffusion Tubes and Gas Sampler Tubes. Students are measuring the cumulative effects of CO_2 buildup in the classroom over the length of a day and then they measure the amount from 1000 cc of air using the Gas Sampler Tube. All our data will then be compared to the atmosphere of Mars.

I am currently training this class to use the program NIH so we can do image processing of digital images of Mars and compare them to digital images I took with an Apple Quick Take Camera on the overflight of the Channeled Scabland.

We are currently building a 5" refractor telescope to go along with our 2-8" and 13" reflector telescopes. We will have more telescope nights where we look for Mars and continue some of the activities we have started.

My students are in contact with B. Cooper, the rover driver, and we are beginning to start designing a rover of our own.

I really want to thank you for the opportunity to be a part of this project. I hope we can become a resource to our individual regions and each other.

Editors' Note: On November 7, 1995, K. Olive reported, "Tomorrow is the Bonnie Dunbar program. We start with 'A Breakfast on Mars' in my classroom and then go to a girls-only presentation, [followed by] an area-wide program where we have almost 4000 reserved seats for students. We are handing out teacher packets of curriculum and other things. It is going to be a great day!" Olive also noted, "I did a couple more vacuum/bell jar Mars demonstrations. I put a balloon in there [with atmosphere at martian pressures] and it swelled up and popped. Did the same with a marshmallow."

THE SEATTLE COUNTRY DAY SCHOOL MARS ENGINEERING CONTEST: HABITS OF MIND FOR THE TWENTY-FIRST CENTURY. M. B. Olson, Seattle Country Day School, 2619 4th Ave. N., Seattle WA 98109, USA.

Seattle Country Day School (SCDS) stages an engineering contest extravaganza the day before Thanksgiving each year. We believe this experience promotes the habits of mind that prepare people to lead fulfilling and responsible lives in our technologically advancing world. Our engineering contest is a natural outgrowth of our daily science educational process, which entails three steps: First, students confront their current understanding of the physical world. They predict events, try things, and have the opportunity to make mistakes. Second, they encounter an array of sequenced lessons that enlarge their base of experience. Finally, they have opportunity to generalize new understanding to novel and remote situations.

Our science contest provides a crosslinked network of activities that capture student interest in science and technology. Both students and parents become intrigued by the design challenges of the technological theme for the year, and students learn values, attitudes, and skills of mechanical construction, data collection, and graphical analysis.

SCDS science activities are designed to use junk. We want students to become familiar with the materials that make up their household environment and to be ingenious in nonstandard uses of these materials to solve tasks. We choose a single theme for our contest each year and then allow students to create subcategories as they experiment with variables. Students begin by constructing small devices in daily science classes so every student in the middle school has at least one completed contraption to enter in the celebration. As students become familiar with the concepts, they embellish and modify design criteria. Any given individual may create three or four rigs to enter in the grand finale. Team size matters: Pairs are ideal, because teams of four or five may allow gender or learning style differences to show up, as the science-shy watch while the mechanically able student does the tinkering. We try to manage competition so that everyone remains challenged yet everyone wins.

This year's engineering contest theme is "Bogie Suspension Systems." Bogies were used in logging and steam technologies in the early days of our country. Bogies (a term from logging skid devices) and front "truck" wheel assemblies were designed to swivel to conform to curves in the tracks. The bogie idea has been applied to the space age. When engineers at Jet Propulsion Lab were given the task of designing a series of small rovers to land on Mars, they incorporated the bogie suspension idea in their plans by crafting rocker-bogie levers to support the wheels. This design produced the high level of rover mobility needed to navigate the boulder-strewn martian landscape.

Ingenious Students—Ingenious Rovers: An Educational Activity that Develops Informed Citizenry: Did you ever wonder why it takes 18 months to assemble, test, and get ready to launch a rover to Mars? Indeed, this is considered a fast-track approach to the development of space vehicles. On October 17, 1995, the 144 middle-school students at SCDS began to find out. Each individual student was faced with the challenge of designing a small rover and then revising it each day according to new criteria. The sequence of activities began with making a balloon-powered rover move. Students revealed their mechanical misconceptions by taping the axle to the chassis or by letting the axle ride directly on the chassis. A major breakthrough in understanding came when someone discovered that drinking straws could be used as bearings to reduce friction as wheels turned. The second design challenge required the rover to be powered by rubber bands. Once again, misconceptions were revealed as most students failed to comprehend the need to uncover the axle so rubber bands could be attached to drive it. Once the bearings were revised, the task was to make a lightweight chassis strong enough to withstand the tension of a wound-up rubber band. The third design criteria of the month-long project was to create a bogie suspension system that could flex around a curved track. Using blueprints from old steam trains and wooden toy trains, students crafted flexible suspension systems. Next we considered whether solar or battery power would be more appropriate for use on Mars. In fact, a solar panel with battery back-up design was selected for the Pathfinder mission to demonstrate solar panel performance in the dim martian sunlight. Having little Sun in Seattle, we opted for experimenting with battery power. We redesigned our rigs again to be driven by small electric motors and found that three D-cell batteries would allow a pair of motors to drive two wheels nicely.

In November, the design criteria will change to powering 5" lawn mower wheels with a battery-powered motor attached to a gear box. Using house gutter spikes and ferules for axles and bearings, our prototype is able to move on a single D-cell battery. Gutter straps, plumber's tape, and various sizes of house wire will be transformed into a flexible rover chassis.

After learning to drive our rovers over rock-sized boxes, we will be ready for our grand finale. The morning of November 22, 1995, we will gather in the gym with more than 200 fine-tuned rigs. Cargo nets at the gym ceiling will release a catastrophic flood of boulder-sized boxes to create an analog to the Channeled Scabland of eastern Washington and Ares Vallis of Mars. Our rovers will then demonstrate their engineering capabilities as they scramble over the flood debris. We will pit our ingenuity in rover design against a real Pathfinder prototype rover built at Jet Propulsion Laboratory and navigated in our celebration by C. Diarra. The technical understanding developed by crafting and revising rover designs will lead every student to appreciate the cleverness brought to fruition in the JPL Sojourner rover. In this way we will come to understand how the ingenious development of the Pathfinder rover was done quickly and efficiently in just 18 months.

MARS ACTIVITIES AND RESEARCH FOR STUDENTS. F. O'Rourke, Cedar Wood Elementary School, 3414 168th Street SE, Bothell WA 98012, USA.

For more than 3000 years, Mars has captured the imagination of all. It has also been the subject of intensive scientific study. NASA began exploration of Mars with the Mariner 4 mission in 1964–1965, and will continue on July 4, 1997, when the Mars Pathfinder spacecraft will touch down on the Red Planet at the mouth of a giant flood channel, Ares Vallis, giving me the opportunity to simulate the process with interdisciplinary curriculum. The students will participate in a mission from start to finish. Students will develop an invigorated interest in language, math, science, and technology while they experience firsthand the thrill, challenge, and unique adventure of simulated space travel.

Program Design: Pathfinder is a total hands-on activity. Students will construct the martian surface, design a model of their own Pathfinder spacecraft, study all the aspects of planning and then simulate a mission, provide news coverage of the mission, perform experiments while on the mission, gather data from the mission, and provide a debriefing after the mission.

September/October: Students study Mars and its geographical characteristics. A focus will be on composition of rocks and soils (as in the real mission). The recreation of Mars is made with paper mache.

October/November: Students design and engineer Pathfinder landing systems and rover vehicles using K'Nex (K'Nex construction materials have been on the toy market for about four years; they are like plastic Tinker Toys, and the astronauts have been using them for communication training). In each step of the mission, students will be creating hypercard stacks and multimedia presentations to showcase their studies. The computer presentations will then be on display during the mission for everyone to view. The use of a video spicket card will allow students to record and keep record of trials and errors in creation of vehicles and then enter them into the computer as a part of their hypercard stack. It is through this programming of hypercards that students are reaching a level of learning that surpasses anything we could give them in a book. They must use logic, planning, analytical thinking, and cooperative learning to complete the stacks.

December/January: Design a method of protection for their vehicle, as it will be dropped from a 25-foot ladder onto the student-made surface of Mars.

February: *Mission day.* The community, parents, and other students will be invited to watch as students drop their vehicles from a ladder, then have to control the vehicle to make a soil and rock collection. Guests will be given the opportunity to predict which designs will be successful. All project methods will be analyzed and data collected and recorded on the best designs.

Evaluation. The evaluation of this project will be informal assessment observations of the students' work, plus their participation in both large and small groups. Student journals will be used to reveal their thinking and their development of knowledge, skills, and attitudes. Self-reports will be used to assess students prior knowledge of a subject, concept, or process. Computer-based assessment utilizes student-designed interaction.

Extensions. Sharing information is what I do with not only students and colleagues but the general public and community. On November 2, I will be speaking to the Everett business community, by invitation of Everett Foundation; sharing my interactive week on "Mars" will be the topic. In addition, Viacom Cable, Boeing, University of Washington, City University, and Western University have all asked me to speak on the Pathfinder field trip at various public functions.

On November 17, I will be giving a joint presentation with former astronaut Buzz Aldrin for all the elementary students in the Everett School District. I will be discussing Pathfinder and future missions to Mars.

Daily, I send in-school e-mails to the staff with a Mars tip of the day, a fact about the mission, or related information.

In-services offered for my school and district staff give other teachers the opportunity to create a weekly "Monday Mars Madness," during which we as a school offer some type of fun and creative Mars activity. The day is filled with activities that stimulate and activate imagination.

Presently I am working with J. Tillman and A. Bruchner at the University of Washington, creating teaching modules based on the next missions to Mars. All these units will be published on the World-Wide Web.

Martian Driver's License: My students have created the first driver's license for the planet Mars. With the help of State Representative D. Schmit, the children have discussed the issues involved with "licensing" and the reasons behind a license. Representative Schmit is seeking Washington state's House and Senate approval plus the signature of our governor on the license. The driver's license will be sent to B. Cooper (at JPL) so he doesn't receive a ticket for driving on Mars without a license! In addition, my students will create a landing license for the Russian lander. Working with the Russian consulate in Seattle, we hope to find an elementary school in Russia to work with us in the creation via the Internet and present the license to workshop participant R. Kuzmin.

Rover License Plate: The students have also created a license plate for Sojourner. The license plate will be sent to H. Eisen (at JPL) for safekeeping.

With K'Nex, my students and I are working to develop rover toys for publication. To make sure student vehicles fit within engineering principals, the children will have the assistance of Eisen and his team of designers along with local Boeing engineers.

Upcoming Planned Presentations: Upcoming presentations that are currently planned include in-services for local school districts, a presentation at the Washington Science Teachers Association (WSTA) meeting, a presentation at the Seattle Science Center, the NCCE computer conference, University of Washington student-teacher in-service, City University technology classes, and a technology conference in April 1996.

In 1993 I was selected to participate in Science Grasp, sponsored by UpJohn Chemical Company. All the teachers in the U.S., Canada, and England are in touch through first-class e-mail, which has given me the opportunity to share information and resources with these teachers.

To date, the information gained from the Pathfinder field trip has stimulated excitement and the search for more knowledge. Students, staff, and community members alike have renewed interest and feel they have been personally touched by the upcoming mission.

"Much education today is monumentally ineffective. All too often we are giving young people cut flowers when we should be teaching them to grow their own plants." —John W. Gardner, Secretary of Health Welfare and Education under President Lyndon B. Johnson [1].

This field trip gave me the tools, resources, and support to help my students grow their own learning.

References: [1] Gardner J. W. (1984) In *The World Book Complete*, p. 305, World Book Encyclopedia, Inc., Chicago.

Editors' Note: Notice the acronym (MARS) built into F. O'Rourke's title. Also, O'Rourke sent updates several times after her report was submitted. On October 31, 1995, she reported, "I've ended up doing a lot more talks, etc., since the paper was written. So much more has come this way, and the community can't get enough. The driver's license has really taken off and turned into a big project in itself. It was invited to be on display at the Smithsonian! My students and their parents are just going nuts over this. 'Thank you' is so little compared to what you have given my kids and the community!"

On November 3, 1995, O'Rourke sent another update. "The week of November 27 the Governor and Representative Dave Schmidt, the director of Washington State Transportation, and the Secretary of State will all come to Cedar Wood. We are also trying to get Brian Cooper here. If Brian comes, we will have him take a driver's test with a remote control car, on a student-created surface of Mars. All the students at Cedar Wood have helped make the surface. All the kids designed driver's licenses, and then we chose the one we wanted to use as official. Bob Craddock set up the [opportunity to] display [the license] at the Smithsonian. Some classrooms are designing a license plate for the rover, and others are doing road signs for the planet. All will be on display the day the Governor comes. I have Boeing engineers in my classroom once a week, teaching the basics of engineering so the kids can build their own rovers. When we begin to build the rovers, Howard Eisen will give advice over e-mail. Yesterday I gave a talk to 250 local businessmen and women on Pathfinder. They are very excited about the classroom activities and want more presentations around town. Our community is loving everything they can get their hands on. The parents at are school are doing fund-raising so that we can get the supplies we need."

Another update was submitted on November 10, 1995. "Washington Governor Lowry is coming November 28 to our school. He will sign the driver's license and give it the seal of approval. Brian Cooper is coming [from JPL]. I'll do a full school assembly, and then give the driver's test, have Lowry sign the license, and present it to Brian. Our community is so excited. There will be a lot of 'P.R.' Also a news article will break next week. Buzz Aldrin will be here on November 17, and I will get to attend, but not make a joint presentation with him. I [also] want you to know that Joy Crisp [of JPL] has been sending my kids lessons. They love getting her packages. She has truly been of help and guidance. Other news—I just received two Mars grants for solar-powered cars, computer upgrading, and a parent has sent out letters to local businesses asking for computer equipment for the student rover."

OUTREACH TO THE TEACHERS AND STUDENTS OF IDAHO AS A RESULT OF THE MARS PATHFINDER LANDING SITE WORKSHOP II IN EASTERN WASHINGTON. L. K. Selvig, Centennial High School, 12400 West McMillian Road, Boise ID 83713, USA.

The Idaho Science Teachers conference was held on October 5–6, 1995, in Boise, Idaho. During those two days, materials, activities, and knowledge were shared with over 200 teachers in the state. The appearance of the Mars rover model from JPL was used as an attention grabber. The rover's presence at the convention center enticed many teachers to learn more about the Mars Pathfinder mission. The major goal of the presenters at the Boise conference was to inform. Materials such as posters, scale-model instructions, and other handouts, specific to the mission, were provided to the participating teachers at the Boise conference.

Four of the 12 teachers that were selected to attend the Mars Pathfinder Landing Site Workshop in Washington state were involved in presenting a different aspect of the mission. With the use of slides, videos, three-dimensional images, viewgraphs, the rover model, and personal experience, the knowledge and understanding of the Mars Pathfinder mission was relayed to those in attendance in Boise. T. Campbell, using viewgraphs, gave an overall perspective on the mission. J. Dodds used slides to present the geologic setting and analogy of the Channeled Scabland region of eastern Washington to the Ares Vallis region on Mars. S. Klug explained and demonstrated the landing mechanism (airbags) of the Pathfinder lander. I used three-dimensional images to acquaint the participants with the geomorphology of the landing site [1]. All the materials and items used in the presentations were very graciously provided by different scientists involved in the Pathfinder II workshop. M. Golombek (JPL) provided the viewgraphs, T. Rivellini and R. Manning (JPL) provided the videos and airbag materials, and T. Parker (JPL) provided the three-dimensional images. The slides that were used were those provided to the teachers by K. Edgett (ASU).

Because of this workshop in Boise, many teachers who had no idea that this mission was happening went away with new ideas and materials for their classrooms. Teachers were looking forward to relaying the information to their students about new and future missions of NASA and JPL. One teacher commented that, "Mars has always been a mysterious planet for students, and soon we will be driving a little car on its surface—how exciting!"

Additional outreach programs have and will come about in the form of student activities, sharing of information with students and parents, and in the future, building of a remote-controlled rover mock-up. In my Earth science class, the three-dimensional images have already been used in a lesson involving topographic mapping. Students had been studying mapping techniques and were able to make profiles of the three-dimensional images. Using the scale given by Parker, students then figured the size of some of the landforms shown in the images. The students never thought of this project as being "schoolwork" because they were using "real images" of the surface of Mars [1]. The students especially liked using the three-dimensional glasses.

Activities designed to supplement the school curriculum based on Mars-related information is one of my goals. It is hoped that an aspect of the Mars Pathfinder mission will be included in *every* unit that is being taught. The unit on minerals and rocks could be supplemented with the knowledge and workings of the alpha proton X-ray spectrometer (APXS) [2]. Surface erosion and river systems may be supplemented with activities that require students to compare and interpret drainage patterns on Earth and Mars. An activity is in the process of being put together that will ask the students to determine the source of a specific rock type from sand samples in a river outflow channel [3]. The students will have a specific number of tries in which they use acquired knowledge and outside information about rock types to analytically determine the location of the rocks' original source. This activity will be analogous to the information and techniques that will be used to interpret the materials at the landing site on Chryse Planitia in the outflow area of Ares Vallis [3,4].

Another goal is to have students build a rover mock-up that is controlled remotely with a signal delay. The rover will be designed to utilize a security video camera. The video signal will be sent to a monitor to allow the driver to maneuver the rover through a designed martian surface. This idea was inspired by L. Fayette [5]. Her model was displayed in Moses Lake, Washington, during the first part of the Pathfinder workshop. Through partnerships from within the community, the materials and engineering skills necessary for such an endeavor will be acquired. The definitive conclusion is to have all three high schools in our district compete with each other.

References: [1] Duxbury T. C., this volume. [2] Golombek M. P. et al., eds. (1995) *LPI Tech. Rpt. 95-01, Part 1.* [3] Rice J. W. Jr. and Edgett K. S. (1995) in *LPI Tech. Rept. 95-01, Part 1*, pp. 25–26. [4] Tanaka K. L., this volume. [5] Fayette L., this volume.

EDITORS' CONCLUSIONS ABOUT THE OUTREACH EFFORT

The combination of field work, science, engineering, education, and public outreach proved to be a great success. The enthusiasm and energy of the 13 educators who participated was contagious. Indeed, many of the scientists and engineers remarked afterward that they felt energized and revitalized by their interactions with the educators and the Spokane residents, mostly children, that they met during the week. Many participants felt that the educators' contribution to the process of evaluating the Ares Vallis landing site and preparing for the Mars Pathfinder mission was as important as any of the science and engineering considerations that were addressed.

We believe that the efforts made to combine field work, engineering, science, education, and public outreach should serve as a model for future scientific workshops. The engineers and scientists developed new professional relationships with the educators and with each other. The exchange of ideas and information continues more than a month after the field trips and workshop ended. We have been gratified to learn that the impact of the Mars Pathfinder excursion to the Channeled Scabland will continue long after September 1995. In October, teacher M. Harder commented that "this has touched so many people in ways we'll never fully appreciate." Cedar Wood Elementary teacher F. O'Rourke echoed this statement in November, saying, "you guys have changed the lives of so many, many [people] you will never even know." When Mars Pathfinder lands in Ares Vallis on July 4, 1997, we believe that the multiple goals of engineering, science, and education will translate into a fantastic and exciting mission.

Appendixes

APPENDIX A: NEWSPAPER ARTICLES ABOUT THE MARS PATHFINDER LANDING SITE EVENTS IN WASHINGTON

by K. S. Edgett

Because only thirteen K–12 educators could participate in the Field Trips and Mars Pathfinder Workshop, we sought to extend the education and public outreach value of these activities through the cooperation of print media. Here we list the newspaper articles that appeared and were collected by participants of the field trips and workshops, as of mid November 1995. We suspect that more articles appeared (e.g., in other cities throughout Washington) than are listed here, and that more will appear as the result of K–12 and public outreach efforts underway by the 13 educators and some of the science and engineering personnel. Articles are listed in chronological order, and copies of them can be obtained from K. Edgett upon request.

"Mars 'field trip' planned for K–12 schoolteachers," by Steve Koppes, Arizona State University *Insight*, Tempe, Arizona, May 19, 1995.

"Charting the Steps of Pathfinder: Scientists Study Washington's Mars-like Scablands," *Mars Underground News*, The Planetary Society, Pasadena, California, Second Quarter, 1995.

"Mars Pathfinding in Eastern Washington," by Ken Edgett, *Kids* newspaper, Spokane, Washington, September 1995.

"Exploring Mars from Eastern Washington," by Ken Edgett, *Kids* newspaper, Spokane, Washington, September 1995.

"Owyhee County Teacher Selected for Space Workshop," by Jamie Hodges, *The Owyhee Avalanche*, Homedale, Idaho, September 6, 1995.

"NASA Investigates Moses Lake's Terrain," by Michael Sear, *Columbia Basin Herald*, Moses Lake, Washington, September 20, 1995.

"Scientists' Mars Invasion Begins in Washington," by Steve Koppes, Arizona State University *Insight*, Tempe, Arizona, September 22, 1995.

"Mars on a Budget: Scientists Tour Eastern Washington to get a Feel for the Red Planet," by Tom Sowa, *The Spokesman-Review*, Spokane, Washington, September 27, 1995.

"Mars Pathfinder Scientists: Channeled Scablands Topic of Study," *Ritzville Adams County Journal*, Ritzville, Washington, September 28, 1995.

"NASA Using Basin as Stand-in for Mars: Scablands are Training Site for 1997 Space Mission," *Wenatchee World*, Wenatchee, Washington, circa September 29, 1995.

"Columbia Basin Terrain Doubles as Mars," *The Bellingham Herald*, Bellingham, Washington, October 2, 1995.

"Eastern Washington Doubles as Mars for Study by Scientists," by Wes Nelson, *Yakima Herald-Republic*, Yakima, Washington, October 2, 1995.

"Exploring Mars through Moses Lake," by Michael Sear, *Everett Herald*, Everett, Washington, October 6, 1995.

"Scientists Study Mars Landing Site in Wilds of Washington," by Diane Ainsworth, Jet Propulsion Laboratory *Universe*, Pasadena, California, October 6, 1995.

"Toppenish Science Teacher Gets Taste of Mars Near Moses Lake," *Toppenish Review*, Toppenish, Washington, October 11, 1995.

"Mars Team Treks to Scabland," *Space News*, Springfield, Virginia, October 9-14, 1995.

APPENDIX B: KEY MARS PATHFINDER EDUCATION RESOURCES

by K. S. Edgett

This list represents but a fraction of the Mars Education resources available to K–12 educators. Here we focus on resources directly relevant to Mars Pathfinder and the Channeled Scabland.

Recent Magazine Articles

"To Boldly Go . . . " D. F. Robertson, *Astronomy*, December 1994.

"A Parachute and Set of Airbags," *Astronomy*, January 1995.

"Mars Pathfinder on Track," *Sky & Telescope*, April 1995.

"The Floods that Carved the West," M. Parfit, *Smithsonian*, April 1995 (about Missoula Floods).

"To Mars by Way of the School House," K. Edgett, *Mercury*, July–August 1995.

"Building a Bridge to Mars," W. H. Boyer, *Final Frontier*, August 1995.

"A Mock-up Martian Rover . . . " *Astronomy*, September 1995.

"Bringing the Mars Landing Down to Earth: Mars Pathfinder will Reach the Red Planet on 4 July 1997," K. Edgett, *Ad Astra*, September–October 1995.

"Jack Farmer, Exopaleontologist," B. Edgar, *Discover*, October 1995.

Mars Pathfinder CD-ROM

SpaceGuide: Tour of the Mars Pathfinder Project, by Kurt Gramoll, Georgia Tech, 1995. Educational CD-ROM about Mars Pathfinder mission, available from Dr. Cheick Diarra, Mars Education Outreach Program, Mail Stop 180-401, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena CA 91109.

Missoula Floods Video Tape

The Great Floods: Cataclysms of the Ice Age, is a 13.5-minute VHS videotape produced by Washington State University and the National Park Service that documents the formation of the Channeled Scabland. Includes animated sequences showing the extent of the Missoula Floods. For ordering information, contact Coulee Dam National Recreational Area, Attn: Northwest Interpretive Association, 1008 Crest Drive, Coulee Dam WA 99116.

World-Wide Web Sites

The following World-Wide Web (WWW) addresses are good as of mid November 1995. There is also a WWW site with information and photographs about the Mars Pathfinder Landing Site Workshop II and Field Trips in the Channeled Scabland, located at:

http://esther.la.asu.edu/asu_tes/TES_Editor/PATHFINDER/SCABLANDS/scablands_menu.html

Mars Pathfinder Home Page at JPL:
http://mpfwww.jpl.nasa.gov/

Imager for Mars Pathfinder (IMP) at University of Arizona:
http://www.lpl.arizona.edu/imp.html

The Martian Chronicle Newsletter (JPL):
http://www.jpl.nasa.gov/mars

Arizona Mars K–12 Education Program, Arizona State University:
http://esther.la.asu.edu/asu_tes/

TES NEWS Newsletter (Arizona State University):
http://esther.la.asu.edu/asu_tes/tesnews_info.html

Live from Earth and Mars (K–12), University of Washington:
http://www.atmos.washington.edu/k12/index.html

Center for Mars Exploration, NASA Ames Research Center:
http://cmex-www.arc.nasa.gov/

Related Curriculum Sources and Guides

Channeled Scabland Curriculum Guide: Information and classroom activities about geology, biology, and history of the Scabland region of Washington. Contact: Ice Age Floods Institute, P.O. Box 122, Ritzville WA 99169, USA.

Red Rover, Red Rover Project: Students construct, test, and operate microrovers on simulated martian terrain. Students connect via computer/modem to other Red Rover sites around the world, and utilize rovers at the remote sites. Contact: The Planetary Society (Attn: Red Rover), 65 N. Catalina Ave., Pasadena CA 91106-2301, USA.

Mars City Alpha Kit: Students use team work, gather facts, form hypotheses, design, and construct an international Mars colony. Grades 5–8. Contact: The Challenger Center for Space Science Education, 1029 North Royal St., Suite 300, Alexandria VA 22314, USA.

Earth and Planetary Science Education Resource Catalog: Comprehensive list of educational materials and information, compiled by the Lunar and Planetary Institute, Houston, Texas, published in *Earth in Space*, September 1995. Available from American Geophysical Union, 2000 Florida Ave., NW, Washington DC 20009, USA. It is also available electronically via the LPI's WWW home page, at:
http://cass.jsc.nasa.gov/lpi.html

Late Workshop Abstracts

GLACIAL LAKE MISSOULA/CLARK FORK ICE DAM—A DIGITAL MODEL. R. M. Breckenridge and L. R. Stanford, Idaho Geological Survey, University of Idaho, Moscow ID 83844, USA.

Glacial Lake Missoula and the associated catastrophic Spokane Floods have long been attributed to the action of a ice-lobe dam of the Clark Fork river near Clark Fork, Idaho. While many workers have studied the effects of the floods both downstream and in the lake basin, little field research has been conducted in the ice dam area. New surficial geologic mapping in the Clark Fork Valley and Pend Oreille Lake area provides evidence for the operation of the ice dam, including the extent and thickness of the lobe and the corresponding water levels in Lake Missoula. We have incorporated maps of the glacial and lacustrine deposits into a reconstruction of the ice dam environment.

We constructed digital elevation models (DEMs) depicting the physiographic terrain in four phases. The land surface was generated from USGS 3-arcsecond elevation data. The glacial ice surface was reconstructed by entering known and interpolated data points at the ice margin. The Pend Oreille Lake bottom surface was digitized from published bathymetric data. Strandlines in the Clark Fork Valley were used to generate the Lake Missoula perimeter. Areas of the land surface were replaced digitally with the ice and lake surfaces. Surface data points were then gridded for subsequent analysis or visual rendering.

Use of the three-dimensional digital model to reconstruct the ice dam enabled us to extrapolate the ice boundary between field observations, and also allowed us to recognize and correct those contacts on the planimetric map that were inconsistent with glacier dynamics. This method allowed us to infer the proper height of the ice dam and depth of lake water consistent with the depositional

LOCATION MAP

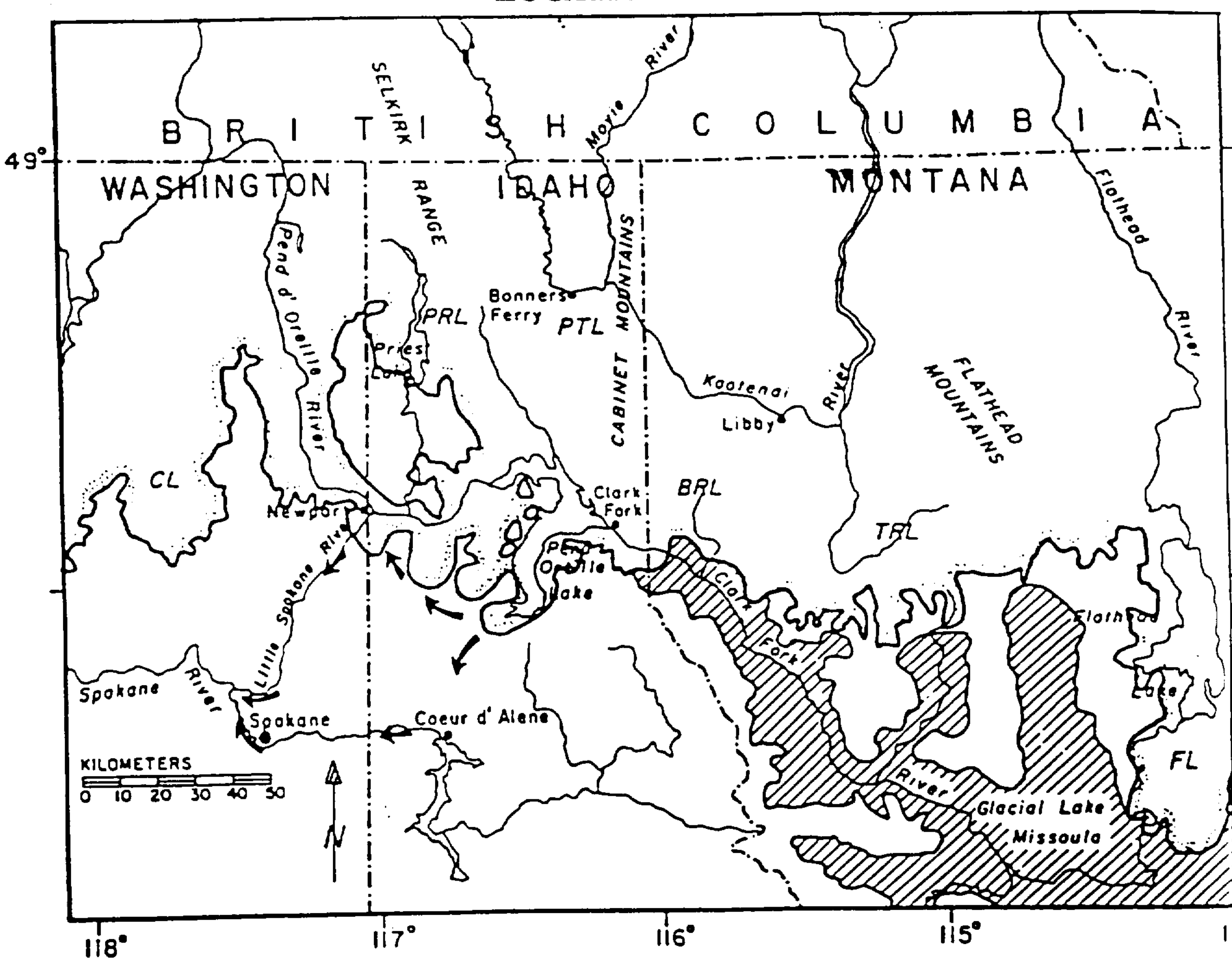

Fig. 1. Location map of the ice dam and surrounding area showing the Cordilleran ice margin (stippled); Glacial Lake Missoula (cross-hatch); and major flood outburst routes (arrows). BRL = Bull River Lobe; L = Flathead Lobe; PTL = Purcell Trench Lobe; PRL = Priest River Lobe; TRL = Thompson River Lobe.

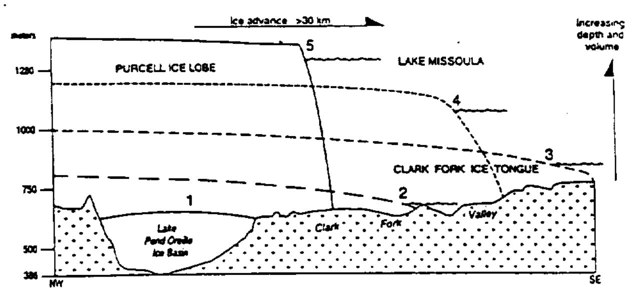

Fig. 2.

environment of flood deposits (eddy bars and giant current ripples) and glacial deposits (kame terraces and proglacial deltas).

The ice dam model shows a high stand of Lake Missoula near 1260 m blocked by a >1400-m-high ice dam at the mouth of the Clark Fork Valley that resulted in the most recent catastrophic flood. Then glacial ice readvanced tens of kilometers up the valley but the ice dam was lower and the lake dumped less water. The latest Lake Missoula may have emptied through an ice marginal channel rather than by catastrophic breakup of the ice dam.

Conclusions: We interpret the geologic evidence to suggest an idealized cycle of damming and lake filling as follows: (1) Ice advances or readvances down the Purcell Trench and fills the Lake Pend Oreille ice basin. (2) Upon filling the ice basin, a tongue of the lobe spills into the Clark Fork Valley and forms a dam of the Clark Fork River. (3) The ice rapidly advances as much as 30 km up the valley, displacing a shallow but deepening lake. (4) As the lake fills, the terminus is eroded by calving, buoyant ice, and ablation. Even though the Purcell Trench Lobe is advancing, the Clark Fork tongue becomes thicker but shorter. (5) The cycle reaches a penultimate stage. The maximum level of the lake is restrained by a high but short ice dam precariously near the mouthh of the Clark Fork Valley. At this critical stage any rise in lake level results in failure of the dam or overflow.

Each cycle could be interrupted or reversed depending on the mass balance of the ice as well as the budget of the glacial lake. Thus smaller floods could occur more frequently with less vigorous and smaller ice advances. In fact, our geologic record shows that after the last penultimate failure, the cycle only reached stage 3 and either stagnated or drained quiescently.

Future Work: We find our data consistent with a repetitive flood model and plan to compare the field results with paleohydraulic studies of Vic Baker and others, and glacial dynamic studies like those of Clarke and Mathews.

ENGINEERING CONSTRAINTS ON THE MARS PATHFINDER LANDING SITE. R. A. Cook, Jet Propulsion Laboratory, Pasadena CA 91109, USA.

The landing site selection process for Mars Pathfinder must factor in the programmatic objectives of the mission, the science and technology investigations, and the flight system and rover capabilities. Mars Pathfinder is primarily an engineering demonstration mission, so the key mission requirement is to successfully land on the surface of Mars. Safe landing depends on both the capabilities of the lander and the characteristics of the landing site. The flight system capabilities were largely driven by the resources available to the project (cost, schedule, etc.) and are essentially fixed. As a result, these capabilities represent hard engineering constraints on the landing site. This abstract gives a brief summary of these constraints and the engineering issues relating to site selection. Sites that satisfy all these constraints are only minimally acceptable from a safety perspective, however. Within these constraints, the site selection process must balance safety concerns with the other scientific and technological objectives of the mission.

The idea of a singular landing site (i.e., a fixed point on Mars) is a useful abstraction, but does not reflect reality. Navigation errors and entry trajectory variations cause a landing site footprint that covers a finite area. This footprint is a probabilistic construct, i.e., the size depends on the desired confidence level. Navigation analysis performed by the project indicates that the 3-σ landing footprint is an ellipse with a 300-km major axis and a 100-km minor axis. This ellipse is aligned along the approach trajectory with a heading angle of 16°WSW. All landing site engineering constraints must be satisfied over this entire ellipse. Considerable conservatism exists in the navigation analysis, however, so the requirement could be relaxed to use a 2-σ ellipse (200 km × 67 km). Given conservative assumptions, this ellipse represents a 90% confidence limit.

The Entry, Descent, and Landing (EDL) system (aeroshell, parachute, etc.) is strongly dependent on the altitude of the landing site. The minimum deploy altitude of the parachute is about 5.5 km. A total of 60 s is needed between parachute deploy and landing to deploy the heat shield, separate the lander from the backshell, acquire radar data, and deploy the airbags. During this time, the lander drops about 5 km. As a result, the worst-case landing site altitude should be below 0.5 km and the mean altitude must be below –0.5 km (given a ±1 km variation). This requirement has been relaxed to a mean altitude <0 km because it is unlikely to have a worst-case low parachute deploy and high-altitude site. Note that it is also important to understand the relationship between altitude and surface pressure. These altitudes are referenced to the 6.1-mbar pressure level, but the tie between topographic height and base atmospheric pressure is not perfectly known.

The latitude of the landing site drives the performance of the lander and rover thermal control and power systems. Because both the lander and rover are solar powered, they depend on the tilt of the solar arrays relative to the Sun. If the landing site is not at the subsolar latitude (15°N on July 4, 1997), the power impact can be significant. Thermal control is also adversely affected by higher latitudes because the daily solar insolation is lower. Detailed analysis by the rover team (the rover has a smaller array and less thermal mass than the lander) indicates that variations up to ±5° in latitude are acceptable without adversely impacting the mission.

Terrain slopes at the landing site affect the performance of the EDL system, the power output of the solar arrays, and the trafficability of the rover. A radar altimeter is used during terminal descent to sense the height of the lander above the ground. Significant local slopes (>25°) over relatively short wavelengths (100 m) could spoof the radar and increase the resulting landing velocity. Lander tilts caused by slopes decreases the solar array output in a manner exactly analogous to changing the latitude. As a result, the slope of the landing site at the scale of the lander should be less than 15°. The rover is less dependent on local slopes because it is mobile (i.e., it can turn to face the Sun rather than away from it). If the local slopes get large enough, however, the rover cannot be deployed or move around the surface easily; this only occurs at slopes larger than 30°, however.

The final landing site concern is rock size/frequency distribution. The ability of the airbag system to successfully cushion the impact depends on both the impact velocity vector (speed and direction) and the size and shape of the rocks. The airbags have been designed to withstand larger-than-expected impact speeds (up to 28 m/s) onto rock fields similar to Viking 2. The minimum stroke capability of the airbags is 0.5 m, which should protect it against rocks up to 0.5 m in height. Abrasion is a key concern, however, which means that landing on rocks may cause material failures unrelated to the stroke capability. The project has performed an extensive test program to investigate the airbag design. Tests were performed using large rocks (which are relatively unlikely even at VL-2) and moderate impact velocities (up to 16 m/s) and average rocks (20–30 cm height) with high impact velocities (26–28 m/s). Some of the later tests involved both fixed and movable rocks and seemed to show some dependence on the difference. All tests were successful, so the project feels that it has a viable airbag design that can withstand rock fields with significant numbers of moderate-sized rocks and a few large rocks. Additional tests are planned, however, to characterize the system performance if the lander bounces several times (which is likely). The rock distribution also affects the navigability and trafficability of the rover. The rover has extensive onboard navigation capabilities that allow it to traverse autonomously and avoid hazards. These autonomous capabilities degrade if there are large number of closely spaced rocks. The rover generally likes to avoid situations where it cannot turn around in place. A rock field similar to VL-1 would allow the rover to easily traverse without violating this turnaround rule. The VL-2 rock distribution represents the upper limit on rock frequency, which would not excessively limit the rover's autonomous capabilities.

PRELIMINARY CARTOGRAPHIC ANALYSIS OF THE PATHFINDER LANDING SITE USING VIKING ORBITER IMAGES. T. C. Duxbury, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

An initial stereo photogrammetric analysis of Viking Orbiter 1 (VO-1) images within the central portion of the expected Pathfinder landing ellipse was performed. These images were taken on Revolution (REV) 4 and included four overlapping images looking forward from nadir about 16° and four additional overlapping images of the same site looking backward from nadir about 16°. The attitude of VO-1 had been maneuvered off the normal Sun-Canopus three-axis stabilized configuration to align thefootprints of the images along the orbit groundtrack.

During both of these sequences, camera pointing has held fixed relative to the spacecraft, enabling the twin orbiter cameras to lay down strips of images with overlap between the twin cameras and overlap along the direction of orbital motion. The camera design (focal lengths, fields-of-view, readout rates, etc.) and mounting alignments were chosen specifically to enable such imaging sequences.

Maneuvering the attitude of the spacecraft had the advantage of providing the optimal footprints of the orbital images to build up the overlapping strip of images, but had the disadvantage, for stereo photogrammetry, of providing less-accurate camera pointing information. In the normal Sun-Canopus three-axis attitude configuration, Sun sensors and the Canopus tracker measure the spacecraft attitude to an accuracy of 0.3° (1 σ). Reconstructing the attitude of the spacecraft when maneuvered off the Sun and Canopus relied upon the inertial gyro angular rate readouts, which gave a reduced pointing accuracy of about 0.5° (1 σ).

One major reason for redoing the cartography of the Pathfinder site or any other site on Mars is that recent work (Dr. David Smith of NASA Goddard Space Flight Center and colleagues and Dr. Alex Konopliv of the Jet Propulsion Laboratory) significantly improved the Mars gravitational field and orbits. Processing very long arcs of Mariner 9, VO-1, and VO-2 radio tracking Doppler data has produced new orbits having precisions of about 100 m along-track and cross-track and 50 m in radius. This represents an order of magnitude or more improvement over the old orbits.

The cartographic processing included (1) obtaining the timetag, camera pointing, and orbit information of the eight overlapping, stereo images; (2) establishing a control network of 152 surface features within an area of 32.8°–34.2°W longitude and 18.2°–20.2°N latitude; (3) measuring the reseau locations in each of the eight images; (4) measuring the image locations of the control points in all images; (5) producing initial values of the control point coordinates; (6) performing the stereo photogrammetric data reduction by using the measured image coordinates of the control points as observations and estimating the control point locations, camera alignments, platform pointing, and orbit corrections; (7) interpolating the control network positions to produce a digital elevation model (DEM) within the image coverage; and (8) registering and map projecting the eight images to the DEM to produce a controlled photomosaic in the form of a gridded digital image model (DIM).

The VO-1 images were obtained from the CD-ROM dataset produced by the Planetary Data System (PDS). The timetags of these images were expressed in Julian Ephemeris Date with a truncation/roundoff error of up to 0.2 s. The camera pointing was given as inertial angles of unknown heritage relative to the Earth Mean Equator and Equinox of B1950 system. These timetag and pointing data were replaced by data obtained from computer printouts of the original Supplemental Experimenter Data Records (SEDRs) archived at the JPL Regional Planetary Image Facility (RPIF). SEDR timetags weregiven to a millisecond. The pointing data was taken in the form of scan platform clock, cone, and twist angles relative to the spacecraft, derived from the original telemetered spacecraft attitude and platform pointing data.

The spacecraft positions were obtained from Navigation Ancillary Information Facility (NAIF) SPICE SPK Kernels, which contained the precision orbit solutions produced by Dr. Alex Konopliv of the Jet Propulsion Laboratory. The Mars spin axis, prime meridian, and mean ellipsoidal surface were obtained from the SPICE PcK Kernel, which is based on the 1994 published recommendations of the IAU (Davies et al.). This approach of timetags, platform pointing, new orbits, and the latest IAU standards allowed all processing to be performed in the Earth Mean Equator and Vernal Equinox of J2000 system.

Reseau image locations were automatically measured by convolving a simple two-dimensional digital filter having the shape of a reseau with the images. The measured reseau locations, accurate to about 0.3 pixels (1 σ), were used to construct a geometric model between image space and object space independently for each image. The VO cameras used vidicon tubes for producing images that exhibited the normal beam-bending local distortion of up to 2 pixels in position between dark and bright image areas. The reseau measurements give the ability to remove the global effects of beam readout distortions but are too sparse to remove local beam-bending distortions acting over small areas. This beam bending limits the planimetric accuracy of the images to a few tenths of a pixel (1 σ), unlike the CCDs, whose image plane distortions are an order of magnitude or more smaller.

Initial control point image location measurements were made manually using computer-assisted overlays to an accuracy of 0.8 pixels (1 σ), near the limiting accuracy of the Viking Orbiter images. The initial Mars-fixed coordinates of each control point were determined by averaging the calculated surface intercept locations for each measurement of a given control point, including the effects of image distortions, camera alignments, platform pointing, spacecraft position, and the mean Mars surface. Two to six measurements of the same control point were used.

Many different data reduction schemes were used in performing the stereo photogrammetric processing. Control point measurement uncertainties varied from 0.3 to 2.0 pixels (1 σ). *A priori* camera-pointing uncertainties varied from 0.1° to 0.5° (1 σ). *A priori* orbit position uncertainties varied from 0 to 100 m (1 σ).

It was determined that camera-pointing uncertainty controls the calculation of the control-point absolute positions on Mars. These positions varied up to 5 km in latitude and longitude and 200 m in elevation based upon the *a priori* pointing uncertainty. The relative control point locations were controlled by the image location measurement accuracies. The orbit uncertainties were small and had little effect on the results. The control point locations exhibited a systematic position offset of about 10 km west-southwest of their positions given on the USGS map product MTM20032/I-2311.

The nominal case for discussing results assumes measurement uncertainties of 1 pixel (1 σ), camera-pointing uncertainties of 0.5° (1 σ), and no orbit errors. This case gave measurement residuals of 0.8 pixels (1 σ), fixed-pointing corrections of about 0.6° to the first set of four images and 0.5° to the second set of four images, and a mean elevation of this area of about −1.0 km with respect to a spheroid having an equatorial radius of 3393.4 km and a polar radius of 3375.8 km. The absolute elevation uncertainties of the control points were about 0.4 km; however, the relative elevation uncertainties were about 30 m.

This work will be significantly improved by (1) including additional, near-nadir looking images taken on REV 4 as well as other near-nadir and off-nadir images taken of the area on REVs 3, 6, and 13; (2) using an automated digital correlation technique to measure the control point image locations; and (3) comparing/sharing results with USGS and RAND.

The additional images will have a significant impact on reducing the effects of camera-pointing uncertainty because of the square root of N effect as well as the fact that some of these new images were taken when the spacecraft was in its more accurate Sun-Canopus attitude. The variation in absolute positions of control points should be reduced to less than 1 km in latitude and longitude and less than 50 m in elevation. The use of an automatic image location measurement technique should reduce the measurement errors from 0.8 pixels to 0.3 pixels, the limiting accuracy of the vidicon tubes. The increased measurement accuracy and additional stereo measurements of the control points (up to 12 measurements per point) will also increase the control point location accuracy.

Acknowledgments: I wish to thank Dr. T. Parker (JPL), who helped in obtaining the digital images, and Dr. M. Golombek (JPL) for discussions of this problem. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

VIKING IRTM HIGH-RESOLUTION (2–5 km) OBSERVATIONS OF ARES VALLIS AND THE MARS PATHFINDER LANDING SITE REGION. K. S. Edgett[1] and J. R. Zimbelman[2], [1]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287-1404, USA, [2]Center for Earth and Planetary Studies, MRC-315, National Air and Space Museum, Smithsonian Institution, Washington DC 20560, USA.

Introduction: Investigation of the highest-ground-resolution Viking Infrared Thermal Mapper (IRTM) observations was undertaken in a systematic manner beginning in the mid 1980s [1–3]. The high-resolution observations provide narrow ground tracks (tens of kilometers) that cover a few percent of the planet's surface. Relative to the moderate-resolution Viking IRTM thermal inertia mapping [4,5], the high-resolution observations have proven useful for investigating the physical properties of individual martian surface features, such as the volcanos [6–8], wind streaks [9], channels [3,10], and dark intracrater deposits [11]. The only other data available for better than 30-km-resolution mapping of surface thermophysical properties are the Phobos 2 Termoskan images [12,13], from which only one thermal inertia map has been presented so far [14]. The Termoskan observations do not include the region of northern Ares Vallis, where Mars Pathfinder is slated to land in July 1997. Some of the high-resolution Viking orbiter IRTM observations do, however, provide insight as to the nature of sedimentary debris in Ares Vallis and the physical properties of materials near the 100-km × 200-km landing ellipse.

Data: The highest-resolution IRTM data used for single-point thermal inertia mapping are constrained to those observations with slant range <1500 km, emission angle <60°, and local times between 19 H and 5 H for nighttime observations, and between 10 H to 14 H for daytime observations [1]. The highest-resolution tracks are manually shifted relative to the Mars latitude-longitude grid to account for timing errors introduced by gravitational perturbation of the spacecraft orbit. Only four high-resolution IRTM ground tracks meeting all constraints were found to pass near Ares Vallis [3]. The data were obtained by the Viking 2 orbiter during daylight hours on orbits 567 (sequence 9), 529 (sequence 4), 531 (sequence 1), and 569 (sequence 5). None of these high-resolution ground tracks pass through the Mars Pathfinder landing ellipse, nor do any other IRTM tracks with slant ranges 1500–2500 km [15]. Thermal inertias described here were computed using the standard Kieffer (1977) thermal model and are reported both in units of J m^{-2} $s^{-0.5}$ K^{-1} (and 10^{-3} cal cm^{-2} $s^{-0.5}$ K^{-1} in parentheses). Owing to dust suspended in the atmosphere, the thermal inertias reported here might be high by about 60–80 (1.4–1.9) units [16], but this does not affect our interpretations or the relative comparison between high-resolution and moderate-resolution observations of the Ares Vallis region. To account for first-order atmospheric effects on high-resolution daytime observations, the thermal inertias initially computed were compared with Mars Consortium thermal inertias [4] and adjusted accordingly [see 3].

Results: Two of the four high-resolution ground tracks pass within 150 km of the western end of the landing ellipse (Viking 2, orbit 567-9 and 529-4). Comparison of the thermal inertias obtained along these ~3-km-resolution ground tracks with the ~30-km-resolution thermal inertia map of Christensen and Malin [5] shows that the results are about the same. This means that the thermophysical properties seen at the 30-km scale within the landing ellipse [see 15] can be generally assumed to indicate the thermal inertias that might be obtained if a higher resolution was available. In other words, at the 3-km scale of the high-resolution IRTM ground tracks, there does not appear to be any large variation of thermal inertia near the mouths of Ares and Tiu Valles; indicating that the moderate-resolution thermal inertias and rock abundances computed for the region by Christensen [5,17,18] are probably applicable to at least the 3-km scale in the region.

Another observation worthy of discussion is that made by Henry and Zimbelman [3] regarding the apparent change in thermal inertia "downstream" from the upper to lower reaches of Ares Vallis. They noted that the high-resolution track from Viking 2 orbit 531-1, which crosses Ares Vallis at about 18°W, 1°–4°N, shows higher thermal inertias on the channel floor than are seen further "downstream" where two additional tracks (from Viking 2 orbits 531-1 and 569-5) cross near 26°–28°W, 11°–12°N. The "upstream" crossing of the valley shows thermal inertias on the valley floor of about 460–600 (11.0–14.0), whereas the crossings further "downstream" have thermal inertias around 300–460 (7.0–11.0). These relatively high channel floor thermal inertias do not appear to coincide with any low-albedo features (e.g., sand deposits), and thus are interpreted to indicate a downstream change in original flood-sediment clast size from larger to smaller rocks. However, as Christensen and Kieffer [18] note, moderate-resolution thermal inertia mapping indicates that the thermal inertia of the Ares Vallis floor then begins to increase northward of the last two high-resolution tracks described by Henry and Zimbelman. The increase might be the result of eolian reworking and exposure of rocks and sand [e.g., 10,18], or to a change in erosion and deposition of clast size in the initial Ares Vallis floods.

Conclusions: No high-resolution (2–5 km) Viking IRTM observations were made of the region enclosed by the Mars Pathfinder landing ellipse. However, high-resolution observations made by the Viking 2 IRTM in 1978 that pass within 150 km of the landing ellipse show no significant variation relative to the lower-resolution (~30 km) thermal inertia map of Christensen [5]. It is therefore reasonable to assume that within the landing ellipse, the thermal inertias seen in the moderate-resolution mapping [e.g., 15] can be extended down to about the 3-km scale. The apparent "downstream" decrease in channel floor clast size reported by Henry and Zimbelman [3] might not be directly relevant to the Mars Pathfinder landing site, but it is interesting to note that the channel floor thermal inertias increase northward from the region examined by Henry and Zimbelman, perhaps as a result of eolian reworking or a change in flow conditions in the original Ares Vallis floods.

References: [1] Zimbelman J. R. and Leshin L. A. (1987) *Proc. LPSC 17th*, in *JGR, 92*, E588–E596. [2] Zimbelman J. R. et al. (1987) *LPS XVIII*, 1128–1129. [3] Henry L. Y. and Zimbelman J. R. (1988) *LPS XIX*, 479–480. [4] Palluconi F. D. and Kieffer H. H. (1981) *Icarus, 45*, 415–426. [5] Christensen P. R. and Malin M. C. (1988) *LPS XIX*, 180–181. [6] Zimbelman J. R. (1984) Ph.D. dissertation, Arizona State Univ., Tempe, Arizona. [7] Mouginis-Mark P. J. et al. (1988) *Bull. Volcanol., 50*, 361–379. [8] Robinson M. S. et al. (1993) *Icarus, 104*, 301–323. [9] Zimbelman J. R. (1986) *Icarus, 66*, 83–93. [10] Craddock R. A. (1987) M.S. thesis, Arizona State Univ., Tempe, Arizona. [11] Edgett K. S. and Christensen P. R. (1994) *JGR, 99*, 1997–2018. [12] Selivanov A. S. et al. (1989) *Nature, 341*, 593–595. [13] Betts B. H. et al. (1995) *JGR, 100*, 5285–5296. [14] Kuzmin R. O. et al. (1995) *LPS XXVI*, 815–816. [15] Edgett K. S. (1995) in *LPI Tech. Rpt. 95-01, Part 1*, pp. 12–13. [16] Hayashi J. N. et al. (1995) *JGR, 100*, 5277–5284. [17] Christensen P. R. (1986) *Icarus, 68*, 217–238. [18] Christensen P. R. and Kieffer H. H. (1979) *JGR, 84*, 8233–8238.

EXOPALEONTOLOGICAL FRAMEWORK FOR THE PATHFINDER LANDING SITE.

J. D. Farmer, NASA Ames Research Center, Moffett Field CA 94053, USA.

Introduction: The Ares and Tiu outflow channels originate from highly fractured, elongate to circular chaotic terranes. These areas consist of irregularly broken and jumbled blocks probably formed by collapse as subsurface ice was removed by melting and outflooding. On a regional scale, the channels are broadly anastomosing networks that include a variety of large-scale bed forms. Features of the martian outflow channels compare favorably to similar terranes on Earth formed by catastrophic flooding, such as the channeled scablands of eastern Washington [1,2]. The immense erosive capability of such outflows is capable of transporting and depositing vast quantities of sedimentary material [3], and the location of the Pathfinder landing site near the mouth of the Ares channel mouth will likely provide access to a wide variety of lithologies derived from source areas upstream [4]. Potential source terranes include heavily cratered, Noachian-aged volcanic and sedimentary units and reworked Hesperian-aged channel deposits [5].

Thermal Spring Deposits as Targets for Exopaleontology: Masursky et al. [6] suggest a thermokarst origin for the chaotic terranes associated with many martian outflow channels. Outfloods of water could have occurred by the melting of water ice stored in the regolith. The favored mechanism is heating by shallow intrusives. Under such circumstances, it is likely that epithermal and subaerial hydrothermal systems would develop and persist for some time prior to and following major outflooding events [7]. Thermal systems are thought to have played a key role in the origin and early evolution of life on Earth, and today support diverse microbial communities represented by a large number of chemotrophic and phototrophic bacteria and cyanobacteria. The early fossil record Earth is dominated by stromatolites (biosedimentary structures produced by microbial communities), associated permineralized microfossils and organic matter, and biologicallymediated sedimentary microfabrics. The best preservation of these materials is observed where rapid mineralization entombed organisms before they could be decomposed by microbial recycling [8]. Thermal springs frequently exhibit high rates of mineralization, driven by outgassing and declining temperature. Surficial hydrothermal deposits are therefore given a high priority for Mars exopaleontology because they have been shown to capture and retain a wide range of biological information, primarily as microbial stromatolites and biogenic microfabrics [9,10].

Fluid Inclusions and the Volatile Record of Mars: During crystallization, thermal spring minerals also incorporate inclusions of liquid and volatile phases present in the environment at the time of formation. For stable minerals, such as silica, primary volatiles may be retained for billions of years and are not only prime targets for fossils and biomolecular compounds, but also for prebiotic organic compounds and volatiles. This is especially important for exopaleontology because the prebiotic chemical record, which has been lost on Earth by crustal recycling, may still be preserved on Mars.

Hydrothermal Systems and Chaos: Aram Chaos and related features within the terranes that fed the Ares and Tui outflows could have formed above focused subsurface heat sources, possibly shallow igneous intrusives. Near-surface heat sources associated with such features could have interacted with ground ice, driving hydrothermal systems for some time prior to and following outflooding events. Potentially fossiliferous deposits associated with surface springs, or epithermal systems in the shallow subsurface, could have been delivered to channels and swept downstream during outfloods, coming to rest near the Pathfinder landing site [7].

Mineralogical Targets for Future Exploration: A key question for future missions is whether aqueous mineral deposits of the type outlined above are actually present on the martian surface. Despite elemental analyses obtained from the two Viking landers, the mineralogical variation of the martian surface is largely unknown. There is a basic need for future missions to go beyond simple elemental analyses, to include information on mineral structures. Infrared spectroscopy from orbit, and especially hyperspectral, high-spatial-resolution near-IR, is a favored method for mineralogical mapping on Earth [11–13] and could provide information fundamental for successfully planning future landed missions to Mars aimed at exploring for an ancient biosphere.

References: [1] Baker V. et al. (1992) in *Mars* (H. Kieffer et al., eds.), pp. 493–522, Univ. Arizona, Tucson. [2] Baker V. (1982) *The Channels of Mars*, Univ. Texas, Austin. [3] Komar P. (1979) *Icarus, 37*, 156–181. [4] Golumbek M. (1994) *LPI Tech. Rpt. 94-04*. [5] Tanaka K. and Scott D. (1986) *Atlas of Mars, 1:15,000,000 Series, Western Region*, M15M, 0/90G, I-1802-A. [6] Masursky H. (1986) *NASA TM-88383*, pp. 459–461. [7] Farmer J. et al. (1995) *LPS XXVI*, 393–394. [8] Farmer J. and Des Marais D. (1994) *LPS XXVI*, 367–368. [9] Walter M. and Des Marais D. (1993) *Icarus, 10*, 129–143. [10] Farmer J. and Des Marais D. (1994) in *Microbial Mats: Structure, Development and Environmental Significance* (L. Stal and P. Caumette, eds.), pp. 61–68, NATO ASI Seies, Springer-Verlag. [11] Abrams et al. (1977) *Geology, 5*, 713–718. [12] Kruse F. et al. (1993) *Remote Sensing of Environment, 26*, 309–336. [13] Kruse F. and Taranik D. (1989) *Proc. IGARSS '89, 12th Canadian Symposium on Remote Sensing, 2*, 952–956.

HIGH-RESOLUTION TOPOGRAPHIC MAP OF THE ARES TIU LANDING SITE FROM VIKING ORBITER DATA.

E. Howington-Kraus, R. L. Kirk, B. Redding, and L. A. Soderblom, U.S. Geological Survey, Flagstaff AZ 86001, USA.

Introduction: The Ares Tiu landing site selected for Mars Pathfinder was also a candidate Viking landing site, and hence was imaged extensively early in the Viking Orbiter mission, with near-optimal illumination and observation geometries for assessing relief. On orbit 4, Viking Orbiter 1 (VO1) obtained convergent sequences of images covering ~80% of the Pathfinder landing error ellipse four times: with ~25° and ~10° emission angles from both the up- and down-track directions. The high-emission-angle sequences provide an excellent parallax/height ratio of about 0.8 for stereo mapping, while the lower-emission angles are well suited for photoclinometric mapping. All images have resolutions of ~40 m and incidence angles in excess of 60°, providing excellent contrast. Partially overlapping coverage is provided by frames from other early VO1 orbits with similar observational parameters, strengthening the local geometric control and extending monoscopic coverage over the landing error ellipse; a single medium-resolution image from orbit 827 contains the entire region and futher strenghtens control. We are compiling a high-resolution photogrammetric/photoclinometric topographic map (and digital terrain model) of the landing site using 56 VO1 images (Table 1).

Control: We have collected 112 pass points between the images in Table 1 to form a local, relative control network. Connection of this local control network to an absolute, global control system is problematic. Other sources of control information (including both control-point networks and controlled data products) available include the following:

Horizontal control. (1) A local mosaic of the landing site region at 1:250K scale, compiled for the Pathfinder project by the USGS, Flagstaff, in 1994. This mosaic is tied to our global mosaicked digital image model (MDIM) of Mars [1], which in turn was constructed by using the MC91 control net [2] with some readjustments; (2) one control point from the MC91 network, coordinates of which differ from the feature placement in the above mosaic by 5.5 km (resolution of images used in this global net is only ~1 km); (3) three points from the RAND control network [3], which show a systematic displacement of 13.6 km from features in the mosaic, believed to be the result of inclusion of Viking Lander 1 in [3] but not in an earlier RAND net from which MC91 was derived.

Vertical control. (1) The 1:2M-scale contour map of quadrangle MC-11NW (unpublished), which shows little relief in the region of interest, with sporadic contours of –2 km relative to the adopted 6.1 mbar datum; (2) the control point from [2] cited above, with an elevation of –1.5 km, inconsistent with the topographic map despite the fact that this map was compiled with input from the MC91 control network; (3) three radar profiles across the landing ellipse, recently obtained by Martin Slade and Ray Jurgens, processed by Jurgens and Albert Haldeman, who provided us with the data [4]. All profiles are lower than the above data (–2.5 to –6.5 km). Two of the profiles are very similar and show appropriately small east-west slopes (<1°) but are offset, indicating a northward slope of –3°. The third indicates a northward slope of +30° and up to 3 km local relief. We conclude that there remain systematic errors in the processing of these data and are not using the profiles until these errors are understood.

We are taking a pragmatic approach, using the landing-site mosaic (i.e., the MDIM) for horizontal control (thus generating co-registered datasets for landing-site studies), and tying a few local control points to the –2-km elevation taken from the 1:2M map. We are supplying coordinates of our pass-points to Tom Duxbury for analysis [5] in the hope that he can shed light on the extent to which the *a priori* pointing of our images can constrain the absolute position and elevation of the net. We anticipate that changes in the control will result in horizontal and vertical translations of the data but not to significant distortions.

Cartographic Products: Cartographic products in our local relative coordinate system will be delivered by the end of October

TABLE 1. Images selected for topographic modeling.

PICNO	Lat	Lon	Inc	Emiss	Res (m)	Remarks
003A37	19.26	34.32	63.40	5.57	38	Strengthen
003A38	18.95	34.05	63.77	4.19	38	control
003A39	19.82	33.23	64.22	6.52	38	network
003A40	19.51	32.94	64.60	5.28	38	
003A41	20.40	32.14	65.05	8.22	38	
003A42	20.09	31.86	65.39	7.19	38	
003A53	18.77	33.03	65.12	10.29	38	Photoclinometry
003A54	18.48	32.66	65.55	10.48	38	(fill out landing
003A55	19.40	31.89	65.94	7.57	38	ellipse)
003A56	19.10	31.56	66.36	7.84	38	
004A20	18.67	35.08	62.23	23.06	43	Stereo sequence
004A21	18.25	34.45	62.96	23.00	42	"left" images
004A22	19.01	34.61	62.56	23.64	43	
004A23	18.58	33.97	63.30	23.58	42	
004A24	19.34	34.15	62.91	24.22	43	
004A25	18.92	33.48	63.65	24.16	42	
004A26	19.68	33.66	63.26	24.80	43	
004A27	19.26	33.02	64.00	24.78	43	
004A28	20.03	33.16	63.58	25.43	43	
004A29	19.59	32.52	64.31	25.39	43	
004A30	20.35	32.71	63.92	25.97	43	
004A31	19.92	32.04	64.66	25.95	43	
004A32	20.69	32.21	64.29	26.56	43	
004A50	20.40	31.46	65.48	14.37	39	Photoclinometry
004A63	18.70	35.10	63.13	12.02	38	
004A64	18.35	34.47	63.83	11.25	38	
004A65	19.04	34.59	63.53	11.42	38	
004A66	18.69	33.97	64.23	10.65	38	
004A67	19.38	34.10	63.91	10.80	38	
004A68	19.03	33.45	64.60	10.00	38	
004A69	19.72	33.60	64.27	10.23	38	
004A70	19.37	32.97	64.97	9.36	38	
004A71	20.06	33.08	64.60	9.61	38	
004A72	19.70	32.46	65.30	8.76	38	
004A73	20.40	32.60	64.98	9.02	38	
004A74	20.05	31.94	65.67	8.09	38	
004A75	20.73	32.08	65.35	8.43	38	
004A79	18.04	34.95	63.85	25.65	40	Stereo sequence
004A80	18.77	35.12	63.48	25.53	40	"right" images
004A81	18.40	34.44	64.21	25.02	40	
004A82	19.14	34.59	63.90	24.87	40	
004A83	18.77	33.94	64.63	24.36	40	
004A84	19.49	34.05	64.29	24.19	40	
004A85	19.12	33.40	65.02	23.68	40	
004A86	19.84	33.55	64.67	23.57	40	
004A87	19.47	32.88	65.40	23.06	40	
004A88	20.19	33.01	65.02	22.90	40	
004A89	19.82	32.36	65.74	22.39	39	
004A90	20.53	32.49	65.40	22.29	39	
004A91	20.16	31.82	66.14	21.72	39	
004A92	20.87	31.97	65.80	21.62	39	
006A25	20.34	33.58	63.17	24.90	40	Extend control
006A27	20.67	33.09	63.53	25.49	40	network
006A85	20.33	33.45	64.60	23.67	40	
006A87	20.66	32.97	64.97	23.10	40	
827A23	20.60	31.70	71.97	30.05	244	

1995. These will include the following: (1) Contour map compiled on our analytic stereoplotter, controlled to the image mosaic at 1 :250K scale. Based on the parallax/height ratio and resolution of the images, the expected vertical precision is ~10 m, supporting a contour interval of 50 m. (2) Digital terrain model derived from the contour map by interpolation. Digital scale (1/2048° or ~30 m/pixel) and bounds to match the image mosaic, though only part of this region will be filled. (3) Digital terrain model enhanced by merging above data with results of two-dimensional photoclinometry [4]. To reduce computation time to create this dataset, the images will be 2 × 2 averaged; the resulting DTM will show features as small as ~80 m. (4) A brief report on processing, incuding control point coordinates, residuals, dificulties encountered, etc. In particular, all assumptions made in setting up a local network will be documented to allow for future conversion to a revised absolute coordinate system.

References: [1] Batson R. M. and Eliason E. M. (1995) *Photogram. Eng. Remote Sens.*, in press. [2] Wu S. S. C. and Schafer F. J. (1984) in *Tech. Papers of the 50th Annual Meeting of Am. Soc. of Photogramm., 2,* 456–463. [3] Davies M. E. and Katayama F. Y. (1983) *JGR, 88,* 7403–7404. [4] Jurgens R. and Haldeman A., personal communication. [5] Duxbury T., this volume. [6] Kirk R. L. (1987) Unpublished Ph.D. thesis, pp. 165–257, California Institute of Technology, Pasadena.

GEOLOGIC HISTORY OF CHRYSE BASIN, MARS.

K. L. Tanaka, U.S. Geological Survey, Flagstaff AZ 86001, USA.

A complex sequence of erosional, depositional, and structural events that make up the geologic history of Chryse Basin has been deciphered by photogeologic methods, including geologic/geomorphic mapping at 1:5,000,000 scale [1], crater counts (Table 1), and geomorphologic analysis. Apparently, four distinct periods of outflow-channel formation and associated basin sedimentation occurred from Late Noachian to Middle Amazonian time, interspersed by local emplacement of volcanic flows, structural deformation, and mass wasting.

Late Noachian: Mawrth Vallis, perhaps the earliest outflow channel on Mars, as well as other minor channels, locally dissected highland rocks. Within Chryse Basin, marginal highland rocks succumbed to mass wasting, forming mosaics of mesas separated by grooves and isolated knobs (many of which are preserved on local topographic highs such as crater rims and wrinkle ridges). Next, volcanism emplaced ridged plains material (unit Hr [1]) in southwestern Chryse Basin.

Early Hesperian: A thick sequence of lava flows (ridged plains material) buried Lunae Planum and southern Tempe Terra. Floods then dissected northern Lunae Planum, resulting in degraded and sculptured plateaus (units Hrd and Hchs) and the broad, higher floor of Kasei Valles (unit Hchh). Perhaps at about the same time, precursory Simud, Tiu, and Ares Valles were cut through both highland rocks as well as ridged plains material in southern Chryse Planitia.

Late Hesperian and Early Amazonian: A second major episode of outflow channeling carved Simud, Tiu, Ares, and Maja Valles; two depositional phases separated by dissection occurred in Chryse Planitia. The first depositional phase resulted in as much as a few hundred meters of sediment in Chryse Planitia (where degraded impact-crater rims appear partly buried); this material is mapped as higher channel floor (unit Hchh) among the distributaries of Simud, Tiu, and Ares Valles, as knobby plains material (unit Hck) in eastern Chryse Planitia, and as channel bars (symbol b) having serrated edges (which distinguishes them from those carved in highland rocks). These extensive remnants of the deposit indicate that it may have covered much of Chryse Basin. In Chryse Planitia and part of Ares Vallis, the deposit appears degraded into circular pits and complex depressions that may result from thermokarst action [2]. In northern Chryse Planitia, the deposit includes low knobs that are remnants of the Late Noachian knob-forming event (many occur associated with impact crater rims); additionally, some knobs may have become detached and transported by debris flows. Such knobs are absent in the deposit in southern Chryse Planitia.

This depositional phase was followed by dissection that reached a slightly lower base level and cut through the earlier flood deposit by at least several tens of meters across Chryse Planitia (judging from the height of channel bars made up of the earlier deposit relative to the heights of nearby wrinkle ridges and impact craters and from the depth of dissection of unit Hck by Ares Vallis). Dissection was followed by deposition of a thin debris flow deposit (making up much of unit Hchl) in southern Chryse Planitia, which probably flowed out from Simud and Tiu Valles and filled shallow channel distributaries in southern Chryse Planitia (including parts of Ares Vallis). Locally, a smooth scarp can be observed bounding the debris flow. The flow also includes low knobs that may be blocks of material rafted by the flow. In higher-resolution images, the flow locally appears complexly degraded (perhaps due to thermokarst and eolian processes). In the terminal areas of Simud, Tiu, and Ares Valles, the debris flow is buried by what appears to be another debris-flow unit that flowed south. Because that flow direction is counter to the general topography, it may be that the upper debris-flow unit is part of the same flow as the lower unit and represents back flow. In other words, momentum of the original debris-flow surge produced a thick, high sea of debris in northern Chryse Basin; this viscous deposit then flowed backward as it leveled out. This upper unit, mapped as complex plains material (unit AHcc), includes fractures and peculiar ridges and valleys. The fractures probably formed by rapid desiccation of a thick, wet deposit [3]. The ridges and valleys have proposed fluvioglacial origins [4]; however, they are restricted to the deposit and appear associated with wrinkle ridges in places and may be formed by compression during shifting of the debris flow while it was still somewhat viscous. In Acidalia Planitia, the deposit likely makes up mantled and grooved plains materials (units Hvm and AHcg) where total sediment thickness likely exceeds 500 m based on the complete burial of ancient degraded impact crater rims [5] and on the formation of polygonal grooves presumably due to compaction [3]. Below Maja Valles, wrinkle ridges are carved and then appear subdued (perhaps due to partial burial).

Early to Late Amazonian: Lobate lava flows from Tharsis (unit At_4) partly buried northwestern Kasei Valles, then a final outburst carved the inner, lowest channels of Kasei Valles (unit AHchl). The deposit from this event is not clearly seen in Chryse Planitia, indicating that the deposit is very thin.

TABLE 1. Crater densities of basin units in Chryse and Acidalia Planitiae, Mars (after units of [1]; note that relative ages differ slightly in a few cases from those assigned to map units).

Map unit	Area of count (km²)	Cum. no. craters per 10^6 km² > 2 km	Cum. no. craters per 10^6 km² >5 km	Relative age*
AHchl (Kasei Valles)	198,170	313 ± 40	30 ± 12	MA
AHcc	514,440	280 ± 23	60 ± 11	LH/EA
AHcg	242,330	347 ± 38	62 ± 16	LH/EA
Hvm	161,650	291 ± 42	62 ± 20	LH/EA
Hck	356,490	351 ± 31	70 ± 14	LH/EA
AHchl (Maja Valles)	185,930	457 ± 50	75 ± 20	LH/EA
AHcs	276,340	326 ± 34	76 ± 17	LH/EA
Hchl (Simud/Tiu/Ares)	410,070	285 ± 26	83 ± 14	LH/EA
AHcr	236,100	356 ± 39	93 ± 20	LH/EA
HNck	124,280	612 ± 70	113 ± 30	N/LH
Hr (Lunae Planum)	1,013,400	610 ± 25	145 ± 12	EH
Hchh (Kasei Valles)	266,570	465 ± 42	146 ± 23	EH
Hchs, Hrd (Kasei Valles)	156,090	602 ± 62	160 ± 32	EH
Hr (Chryse Planitia)	230,240	747 ± 57	230 ± 32	LN/EH
HNr (near Mawrth Valles)	70,641	1274 ± 134	424 ± 78	MN/LN
Ares highlands	697,630	—	538 ± 28	MN

*Based on crater-density stratigraphy of [6]; N = Noachian, H = Hesperian, A = Amazonian, E = Early, M = Middle, L = Late.

References: [1] Rotto S. and Tanaka K. L. (1995) *USGS Map I-2441*, in press. [2] Aguirre-Puente J. et al. (1994) *JGR, 99*, 5657–5667. [3] McGill G. E. and Hills L. S. (1992) *JGR, 97*, 2633–2647. [4] Kargel J. S. et al. (1995) *JGR, 100*, 5351–5368. [5] Roth L. E. et al. (1989) *Icarus, 79*, 289–310. [6] Tanaka K. L. (1986) *Proc. LPSC 17th*, in *JGR, 91*, E139–E158.

POTENTIAL ROCK CLASTS AT THE MARS PATHFINDER LANDING SITE. K. L. Tanaka, U.S. Geological Survey, Flagstaff AZ 86001, USA.

Numerous clues and lines of reasoning provide a meaningful basis to predict the plausible types and characteristics of rocks that Mars Pathfinder will encounter in Chryse Planitia. Here I will discuss (1) what was seen at the nearby Viking 1 landing site (VL1), which has a somewhat similar geologic setting to that of the Mars Pathfinder landing site (MPLS); (2) the Viking orbiter images of the MPLS; and (3) the age and possible composition and size distribution of rock clasts.

Rock Characteristics at VL1: At VL1, a wide array of probable silicate rock fragments from small pebble size to boulders 3 m across litter the landscape surrounding the lander [1–3]. These rocks have angular shapes, pitted or smooth surfaces, and high density and strength (as inferred from lander experiments); some appear massive, whereas others have layered structure. Many of the rocks may be ejecta from two impact craters about 130 and 180 m in diameter <100 m from VL1 [2]. The ejected clasts may be derived from a sedimentary breccia, such as a debris-flow deposit, or from bedrock, such as a lava flow. In the VL1 scene, an ~4-m-wide rocky surface cut by fractures and a prominent veinlike ridge may be bedrock [3]. Thus, rock clasts at VL1 may have local provenance as well as derivation from highland rocks cut by Maja Valles [4]. VL1 is within Late Noachian ridged plains material [5] modified by Late Hesperian to Early Amazonian resurfacing by scouring and perhaps deposition of Maja Valles [4] (Early to Middle Amazonian flooding of Kasei Valles [5] may also have reached the area).

Local Geology of MPLS: MPLS consists of a generally smooth channel plain in the region of the junction between Simud/Tiu Valles and Ares Vallis. This area includes many sculptured bar forms that collectively define distributary channels that shallow to the north and merge into plains. The lowest channels of both Simud/Tiu and Ares Valles appear to have a common base level. Highest-resolution images (~40 m/pixel) of the MPLS area show many small impact craters in the 100- to 300-m size range. A few larger craters are present, and ones smaller than ~100 m cannot be resolved. Many of the craters are grouped into elongate swarms that may be groups of secondaries or primary impacts formed by a fragmented bolide. In addition, knobs hundreds of meters across rise above the channel floor; the largest is about 1 km across. The knobs are sparsely distributed and generally are several kilometers apart; most do not appear aligned with one another or associated with any obvious topographic highs. Debris aprons can be observed around the taller knobs.

Several roughly teardrop-shaped bars occur within 40–100 km of MPLS; most of the bars appear terraced into 2–5 levels. The lower terraces generally have smooth outlines that appear sculptured by the outflow channel activity, whereas some of the uppermost terraces have scalloped outlines that may be modified by mass wasting. A few of the taller isolated knobs also appear terraced. Inspection of high-resolution images surrounding MPLS shows a few barely discernible scarps along some channel margins. The overall geomorphology surrounding MPLS can be interpreted in terms of alternating channel downcutting and fill by debris flows. The final channel event deposited a massive debris flow emanating from Simud/Tiu Valles across its and Ares Vallis' lower distributary [5].

Debris flows are noted for their very poorly sorted grain-size distributions, which are virtually identical with impact ejecta [6]. Boulders as large as 3 m across have been transported on Earth by mudflows [7]. Because of Mars' lower gravity (which means less density contrast between the debris flow matrix and the boulders) and the immense volume and thickness of the Chryse debris flows relative to their terrestrial counterparts, potentially much larger boulders may have been transported to MPLS by debris flows. Measurement of knob lengths at MPLS (Viking images 4A42, 44, and 46) indicate that they follow a power-law distribution, which is consistent with debris flows on Earth [6]. However, this distribution extrapolated to smaller rock sizes suggests that only one boulder larger than 90 cm should occur per 10^3 m^2 and one rock >10 cm per 9 m^2. In comparision, the 10-cm-size rock density is a hundredfold greater at VL1 [8].

Ages and Type of Rocks at MPLS: Most of the rocks cut by Simud, Tiu, and Ares Valles are Noachian in age. Highland surfaces cut by Ares Valles have an average crater density consistent with a Middle Noachian age [5], which provides a minimum average age of ~4 Ga for the dissected rocks. More potential for Hesperian material (~3–4 Ga) arises from the source rocks of Simud and Tiu Valles, although the majority of the rocks should still be Noachian.

Possible compositions of martian highland rocks can only be crudely inferred. Spectral studies indicate that basalt should be the most abundant rock type [e.g., 9]. This interpretation is consistent with compositions of the SNC meteorites [10]. In particular, the recently studied meteorite ALH 84001 is thought to be a martian highland plutonic rock (orthopyroxenite cumulate) that may be from an intrusive body. Thus, the martian highlands may include ancient basaltic volcanic rocks and their plutonic parent rocks. In addition, some rocks should be brecciated, recrystallized, and mixed by impact shock and heating, which is commonly observed in lunar highland rock samples [e.g., 11].

References: [1] U.S. Geological Survey (1982) *USGS Map I-1366.* [2] Moore H. J. et al. (1987) *USGS Prof. Pap. 1389.* [3] Christensen P. R. and Moore H. J. (1992) in *Mars* (H. H. Kieffer et al., eds.), pp. 686–729, Univ. Arizona, Tucson. [4] Rotto S. and Tanaka K. L. (1995) *USGS Map I-2441,* in press. [5] Tanaka K. L., this volume. [6] MacKinnon D. J. and Tanaka K. L. (1989) *JGR, 94,* 17,359–17,370. [7] Bull W. B. (1964) *USGS Prof. Pap. 437-A.* [8] Wu S. S. C. (1979) *JGR, 84,* 7955–7959. [9] Soderblom L. A. (1992) in *Mars* (H. H. Kieffer et al., eds.), pp. 557–593, Univ. Arizona, Tucson. [10] McSween H. Y. (1994) *Meteoritics, 29,* 757–779. [11] Wilhelms D. E. (1987) *USGS Prof. Pap. 1348.*

List of Workshop and Field Trip Participants

Victor R. Baker
Department of Geosciences
University of Arizona
Tucson AZ 85721
Phone: 520-621-6003
Fax: 520-621-2672
E-mail: baker@pirl.lpl.arizona.edu

Nadine G. Barlow
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston TX 77058
Phone: 713-280-9021
Fax: 713-486-2162
E-mail: barlow@lpi.jsc.nasa.gov

Sharlene Belanger
Oregon Public Broadcasting
7140 SW MacAdam Avenue
Portland OR 97219
Phone: 503-293-1980

Cory Borst
Jet Propulsion Laboratory
2826 Adams Street
La Crescenta CA 91214
Phone: 818-354-9382

Roy M. Breckenridge
University of Idaho
Idaho Geological Survey
Moscow ID 83844

Bruce Campbell
National Air and Space Museum
MRC 315
Smithsonian Institution
Washington DC 20560
Phone: 202-357-1424
Fax: 202-786-2566
E-mail: campbell@ceps.nasm.edu

Thomas C. Campbell
Capital High School
5011 Outlook Avenue
Boise ID 83703
Phone: 208-322-3875
Fax: 208-322-3736
E-mail: o0100901@idptv.idbsu.edu

Heather H. Cassidy
Chase Middle School
South 4402 Eastern Road
Spokane WA 99223
Phone: 509-358-4633
Fax: 509-358-4639
E-mail: heatherc@comtch.iea.com

Richard Cook
Mail Stop 230-235
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-393-7820
Fax: 818-393-1227
E-mail: richard@brahe.jpl.nasa.gov

Brian K. Cooper
Mail Stop 107-102
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-6298
Fax: 818-354-8172
E-mail: cooper@robotics.jpl.nasa.gov

Robert A. Craddock
CEPS/NASM Room 3775
MRC 315
Smithsonian Institution
Washington DC 20560
Phone: 202-357-1457
Fax: 202-786-2566
E-mail: craddock@ceps.nasm.edu

Joy Crisp
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-9036
Fax: 818-393-0071
E-mail: joy@glassy.jpl.nasa.gov

Larry Crumpler
Department of Geological Sciences
Box 1846
Brown University
Providence RI 02912
Phone: 401-863-3825
Fax: 401-863-3978
E-mail: larry-crumpler@brown.edu

Jo Dodds
O'Leary Junior High School
4036-A Canyon Ridge Drive
Twin Falls ID 83301
Phone: 208-733-2155
E-mail: dodd0100@spacelink.msfc.nasa.gov

Kenneth S. Edgett
Department of Geology
Box 871404
Arizona State University
Tempe AZ 85287-1404
Phone: 602-965-0204
Fax: 602-965-1787
E-mail: edgett@esther.la.asu.edu

Julie Edwards
University of Michigan
9386 Schellenberger Road
Manchester MI 48158-8524
Phone: 313-936-2611
Fax: 317-764-4556
E-mail: jedwards@umich.edu

Howard J. Eisen
Mail Stop 158-224
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-9360
Fax: 818-393-1227
E-mail: howard.j.eisen@jpl.nasa.gov

Jack D. Farmer
Mail Stop 239-4
NASA Ames Research Center
Moffett Field CA 94035
Phone: 415-604-5748
Fax: 415-604-1088
E-mail: jack_farmer@qmgate.arc.nasa.gov

Louise Fayette
Toppenish Middle School
4781 Lombard Loop Rd.
Zillah WA 98953
Phone: 509-865-1396
Fax: 509-865-7503
E-mail: lfayette@destiny.esd105.wednet.edu

Chris M. Flanagan
Centennial Middle School
2716 South Post Street
Spokane WA 99203-1878
Phone: 509-922-5482
Fax: 509-891-9520
E-mail: flanagan@on-ramp.ior.com

John Gallagher
Port Angeles High School
304 East Park
Port Angeles WA 98362
Phone: 360-452-7602
Fax: 360-452-0256
E-mail: jgalla@orca.esd114.wednet.edu

Matthew Golombek
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-351-3883
Fax: 818-393-1227
E-mail: mgolombek@jpl.nasa.gov

Virginia Gulick
Mail Stop 245-3
Space Science Division
NASA Ames Research Center
Moffett Field CA 94035
Phone: 415-604-0781
Fax: 415-604-6779
E-mail: gulick@barsoom.arc.nasa.gov

Albert Haldemann
Mail Stop 170-25
California Institute of Technology
Pasadena CA 91125
Phone: 818-395-6477
Fax: 818-585-1917
E-mail: albert@earthl.gps.caltech.edu

Maureen Harder
Ritzville High School
Rt. 101, Box 312A
Ritzville WA 99169
Phone: 509-659-1720

John K. Harmon
NAIC/Arecibo Observatory
Box 995
Arecibo PR 00613
Phone: 809-878-2612
Fax: 809-878-1861
E-mail: harmon@naic.edu

Ken Herkenhoff
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109-8099
Phone: 818-354-3539
Fax: 818-354-0966
E-mail: Ken.E.Herkenhoff@jpl.nasa.gov

Nancy W. Hinman
Department of Geology
University of Montana
Missoula MT 59812
Phone: 406-243-5277
Fax: 406-243-4028
E-mail: nhiunman@selway.umt.edu

Raymond Jurgens
Mail Stop 238-420
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-4974
Fax: 818-354-6825
E-mail: jurgens@planets.jpl.nasa.gov

Jacqueline H. Kim
Mail Stop 230-235
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-393-0780
Fax: 818-393-1227
E-mail: jackie@saturnv.jpl.nasa.gov

Mikki Kisson
Ice Age Floods Institute
P.O. Box 122
Ritzville WA 99169

Sheri Klug
Marsing Middle School
5200 Southeast First Avenue
New Plymouth ID 83655
Phone: 208-896-4753
Fax: 208-896-4790
E-mail: c63adm01@idptv.idbsu.edu

Goro Komatsu
Lunar and Planetary Laboratory
Department of Planetary Sciences
University of Arizona
Tucson AZ 85721
Phone: 520-621-4861
Fax: 520-621-4933
E-mail: goro@pirl.lpl.arizona.edu

Steve Koppes
New Bureau
Box 871803
Arizona State University
Tempe AZ 85287-1803
Phone: 602-965-3502
Fax: 602-965-2159

Ruslan O. Kuzmin
Geochemistry and Analytical Chemistry
Vernadsky Institute
Kosygin St. 19
Moscow 117975
RUSSIA
Phone: 7 095 938 2054
E-mail: abasilevski@glas.apc.org

Kari Magee
The Planetary Society
65 North Catalina Avenue
Pasadena CA 91106-2301
Phone: 818-793-5100
Fax: 818-793-5520
E-mail: tps.km@genie.geis.com

Rob Manning
Mail Stop 230-200
Jet Propulsion Labortory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-393-7815
Fax: 818-393-5020
E-mail: robert.m.manning@jpl.nasa.gov

Skip McNevin
Public Information Office
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-9382
E-mail: e.mcnevin@jpl.nasa.gov

Mike Mellon
Mail Stop 245-3
NASA Ames Research Center
Moffett Field CA 94035
Phone: 415-604-0315
Fax: 415-604-6779
E-mail: mellon@barsoom.arc.nasa.gov

Stephen Metzger
University Nevada, Desert Research Institute
Quaternary Sciences Center
7010 Dandini Boulevard
Reno NV 89512
Phone: 702-673-7300
Fax: 702-673-7557
E-mail: metzger@scs.unr.edu

Henry J. Moore
U.S. Geological Survey
Mail Stop 975
345 Middlefield Road
Menlo Park CA 94025
Phone: 415-329-5175
Fax: 415-329-4936
E-mail: moore@astmnl.wr.usgs.gov

Jeff M. Moore
NASA Ames Research Center
SETI Institute
Mail Stop 245-3
Moffett Field CA 94035
Phone: 415-604-5529
Fax: 415-604-6779
E-mail: jmoore@gal.arc.nasa.gov

Duane Muhleman
Mail Stop 170-25
California Institute of Technology
Pasadena CA 91125
Phone: 818-356-6186
Fax: 818-585-1917
E-mail: dom@venus1.gps.caltech.edu

Michael A. Murray
Alki Middle School
2600 Northeast Minnehaha #A7
Vancouver WA 98665
Phone: 360-737-7348
Fax: 360-737-7353
E-mail: kerrim@clark.edu

David M. Nelson
Department of Geology
Box 871404
Arizona State University
Tempe AZ 85287-1404
Phone: 602-965-7029
Fax: 602-965-8102
E-mail: nelson@asuws2.la.asu.edu

Keith Olive
Wilson Middle School
2908 West Chestnut
Yakima WA 98902
Phone: 509-454-5848
Fax: 509-454-5848
E-mail: olivek@destiny.esd105.wednet.edu

Meredith B. Olson
Seattle Country Day Middle School
4262 Northeast 125
Seattle WA 98125
Phone: 206-284-6220
Fax: 206-283-4251
E-mail: molson@bush.edu

Fran O'Rourke
Cedar Wood Elementary
2908 122 Street Southwest
Everett WA 98204
Phone: 206-338-5165
Fax: 206-338-5167
E-mail: hart1200@spacelink.msfc.nasa.gov

Tim Parker
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-2451
Fax: 818-354-0966
E-mail: parker@sloppy.span.jpl.nasa.gov

John Rankin
Ice Age Floods Institute
P.O. Box 122
Ritzville WA 99169

Robert J. Reid
Lunar and Planetary Laboratory
University of Arizona
Tucson AZ 85721
Phone: 520-621-1479
Fax: 520-621-4933
E-mail: breid@lpl.arizona.edu

Jim Rice
Arizona State University
Department of Geography
Tempe AZ 85287
Phone: 602-965-1790
Fax: 602-965-8313
E-mail: asjwr@asuvm.inre.asu.edu

Tom Rivellini
Mail Stop 158-224
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-5919

Linda Selvig
Centennial High School
4130 Particia Lane
Boise ID 83704
Phone: 208-939-1404
Fax: 208-939-1420
E-mail: lselvig@nobska.idbsu.edu

Mike Shepard
Department of Geography and Earth Science
Bloomsburg University
Bloomsburg PA 17815
Phone: 717-389-4568
Fax: 717-389-3028
E-mail: shepard@planetx.bloomu.edu

Donna Shirley
Mail Stop 180-401L
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-MARS
Fax: 818-393-6800
E-mail: dshirley@ccmail.jpl.nasa.gov

Dick Simpson
Durand Building, Room 232
Stanford University
Stanford CA 94305-4055
Phone: 415-723-3525
Fax: 415-723-9251
E-mail: rsimpson@magellan.stanford.edu

Robert B. Singer
Lunar and Planetary Laboratory
Space Sciences Building #92
University of Arizona
Tucson AZ 85721
Phone: 520-621-4824
Fax: 520-621-4933
E-mail: singer@pirl.lpl.arizona.edu

Martin Slade
Mail Stop 238-420
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109-8099
Phone: 818-354-2765
Fax: 818-354-6825
E-mail: marty@radarsun.jpl.nasa.gov

Peter Smith
Lunar and Planetary Laboratory
University of Arizona
Tucson AZ 85721
Phone: 520-621-2725
Fax: 520-621-2994
E-mail: psmith@lpl.arizona.edu

Tony Spear
Mail Stop 230-235
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-393-7868
Fax: 818-393-1227
E-mail: anthony.j.spear@jpl.nasa.gov

Pam Stevenson
KAET-TV
Arizona State University
Box 871405
Tempe AZ 85287-1405
Phone: 602-965-5155

Carol Stoker
Mail Stop 245-3
NASA Ames Research Center
Moffett Field CA 94035
Phone: 415-604-6490
Fax: 415-604-6779
E-mail: carol_stoker@qmgate.arc.nasa.gov

Robert Sullivan
Department of Geology
Box 871404
Arizona State University
Tempe AZ 85287-1404
Phone: 602-965-7029
Fax: 602-965-8102
E-mail: sullivan@asu.edu

Kenneth Tanaka
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff AZ 86001
Phone: 520-556-7208
Fax: 520-556-7014
E-mail: ktanaka@iflag2.wr.usgs.gov

Richard Torruellas
KAET-TV
Arizona State University
Box 871405
Tempe AZ 85287-1405
Phone: 602-965-5155

Allan Treiman
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston TX 77058
Phone: 713-486-2117
Fax: 713-486-2162
E-mail: treiman@lpi.jsc.nasa.gov

John Wellman
Mail Stop 230-235
Jet Propulsion Laboratory
4800 Oak Drove Drive
Pasadena CA 91109
Phone: 818-393-7861
Fax: 818-393-1227
E-mail: john.wellman@jpl.nasa.gov

George W. Wetherill
Department of Terrestrial Magnetism
Carnegie Institution
5241 Broad Branch Road Northwest
Washington DC 20015
Phone: 202-686-4370 ext. 4375
Fax: 202-364-8726
E-mail: wetherill@eros.ciw.edu

Aimee Whalen
Mail Stop 230-235
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109
Phone: 818-354-2432
Fax: 818-393-6800
E-mail: Aimee.L.Whalen@jpl.nasa.gov