Report on the 4th 2003 Mars Exploration Rover Landing Site Selection Workshop

Held at the Embassy Suites, 201 Huntington Drive, Arcadia/Pasadena, California
January 8^{th}-10^{th}, 2003

January 8^{th}, Wednesday

Introduction

9:00 a.m.	Welcome, Overview of the Landing Site Selection Process and Workshop Goals John Grant (Co-Chair, Landing Site Steering Committee)
9:15 a.m.	Mars Exploration Program Jim Garvin, Mars Program Scientist
9:30 a.m.	Landing Site Selection and the Athena Science Payload Steve Squyres
9:45 a.m.	History of Ellipse Changes since 3^{rd} Workshop Matt Golombek (Co-Chair, Landing Site Steering Committee)
10:15-10:30 a.m.	Coffee Break
10:30 a.m.	Engineering Constraints, Factors, Process in Selecting the MER Landing Sites Mark Adler, Project Landing Site Engineer
11:30 a.m.	EDL System Updates Rob Manning , JPL

Summary of Introductory Presentations (provided by J. Grant):

John Grant:

Presented overview of landing site process
- Community input critical to success
- Described expected outcomes
  - Tables of Testable Hypotheses to be filled out at workshop
  - Quad Charts for NASA Headquarters (presented by J. Garvin)

Jim Garvin:

Repeated that science community input is critical to the success of the process
Requested identification of representative images for each of the remaining sites
Request assistance in developing Quad Charts for each of the sites that will be shown to E. Weiler
- Includes site name, expected science impact if we go there, advantages and disadvantages of the site, and what could be accomplished at the site.

Cathy Weitz ended by showing an example of a Quad Chart template with sample entries

Steve Squyres:

Presented examples of data collected using flight hardware
Emphasized the comprehensive calibration that will ensure high quality data
Spoke to comprehensive nature of Athena instrument suite and expected data
Specific to landing site selection activities:
- All activities must be documented completely

All of the details must be known to team, project, and Headquarters
Need a set of testable hypotheses to help define initial operations
Community can provide hypotheses used to plan initial science operations

Matt Golombek:

Gave update on the process of defining ellipses
- Began with where we left off at third workshop
  - Used science to select 6 sites assessed at 3rd workshop
  - Winds and other concerns eliminated Melas, Eos, Athabasca

Changes since third workshop
- Athabasca demoted to back-up, then deleted due to radar signature and trafficability concerns
- Isidis promoted to prime site
- Revisited process to identify "wind safe" sites
- Identified multiple potential sites
  - Chose EP78B2

Due to low rock abundance
- Acceptable winds, smoothest at all scales
- Farther south sites have more power

Remaining sites now Meridiani, Gusev, Isidis, Elysium
Name change of Hematite now referred to as Meridiani Planum
Elysium name provisionally maintained

Mark Adler:

Started by reminding that we are one year from landing!
Provided summary of the process to date with interplay of science and engineering
Described current phase as the endgame leading to landing site selection in April
Moved on to summarize EDL events
Described mission success drivers that include how fast landers impact surface, what it impacts on the surface, how many bounces the landers make, and how long the rovers will survive after landing.
Summarized how various parameters could impact the mission success and how each has been mitigated
Reviewed the DIMES instrument and ongoing testing (which has not been approved for use)
Showed numerous examples of "bounce-down" for a 2 X 4 km area in Gusev
Discussed very preliminary mission success rankings based on work to date:

Landing Site:	Rock Abundance (%)	Shear (MPF ratio)	Horiz wind (m/s)	Turb/vert (m/s)
Meridiani	5	0.4	4	1-2
Elysium	5	0.3	4	Higher
Gusev	8	0.9	7	Higher
Isidis	14	0.7	9	Higher

Which of the sites may be best suited to meeting mission success?
No definitive answer yet, but depends on assumptions regarding relative science value of sites (e.g., if Meridiani is greater value than Elysium, Gusev greater than Elysium, and Gusev greater than Isidis)

Bottom line: not yet sure if Meridiani and Gusev are safe enough, but feel that Meridiani, Gusev, and Elysium are likely safe enough. Not clear if Isidis is safe enough, but Gusev would be higher science value than Isidis based on community input to date.

Described that a lot of contingencies are built into the process (e.g., defer TCM-1 for MER-A until after MER-B launch). May also be significant fuel left for retargeting of landing site after TCM-1 and well into cruise.

Question was also posed: if there is only one rover, due to failure, where would we go? Meridiani versus Gusev? Adler would like the landing site community to provide input and decide.

Squyres pointed out that this was done at the third workshop and that changes are unlikely at this point unless there is significant new data showing new interpretations are likely and/or that previous interpretations were flawed.

Rob Manning:

Provided a review of EDL accomplishments to date: 40 –50 drop tests made, new bladder layer in air bags greatly helps mitigate problems encountered earlier.

Data shows that the landing system can handle 20 m/sec tangential and 12-15 m/sec normal velocity at impact.
Parachutes have been redesigned and improved based on earlier test results.
DIMES tests are ongoing, but instrument is not yet approved for flight and operation
EDL flight software is being tested.
EDL work remaining includes:
Final parachute lot acceptance
EDL system tests
Completion of descent-rate limiter qualification
One additional radar flight speed drop test
Summary: EDL is robust and is not a threat to MER Development

12:00-1:00 p.m. Lunch

1:00 p.m. Analysis of Nighttime Temperatures at the Landing Sites
N. Bridges and T. Martin, JPL

1:30 p.m. Discussion

Science of the Landing Sites

2:00 p.m. Analysis of THEMIS Data for Meridiani, Isidis, and Elysium Sites
Phil Christensen and THEMIS Science Team

Summary of Introductory Talks (cont'd) (provided by K. Tanaka):

Nathan Bridges and Terry Martin:

Near-surface temperatures at the MER landing sites affect mission lifetime. Lowest temperatures at 1 m above the surface occur during pre-dawn hours. Worst-case temperatures have been estimated for Sol 1 at each site using a 1-D model by J. Murphy (NMSU). This model is based on Viking and Mars Pathfinder lander measurements and has input parameters including thermal inertia, albedo, elevation, dust abundance, season, and time of day. The MER mission is concerned with temperatures falling below -97°C (176 K). The analysis included TES-derived albedo and thermal inertia provided by the TES team. Thermal inertia has the greatest influence on results.

Results indicate the following probabilities for landing at sites <-97°C for each ellipse in increasing order: Isidis, 0%; Gusev, 3%; Elysium, 7%; Meridiani, 8%. Squyres emphasized need to analyze data for Sol 90 at each site. Christensen suggested that temperatures likely would not decrease by more than a few degrees, but that could be important; also, temperatures could be 10-15° warmer near rocks and 3-5° variations may occur within TES pixels. Kass indicated that advection (wind chill) has been factored into the -97° temperature limit. Correction made after the meeting: Nathan Bridges checked, and found out that the modeling was done for Sol 90, not Sol 1.

Other effects on temperature could include ponding of cold air in topographic lows such as craters and warmer air descending from higher, nearby topography. THEMIS nighttime IR data and mesoscale atmospheric models may help improve future analysis.

Phil Christensen and THEMIS Science Team:

Christensen reviewed the THEMIS day (DIR) and night (NIR) infrared (100 m resolution) and VIS (18 m resolution) multispectral data for the MER sites. Dust cover generally obscures determination of mineralogy, but thermophysical properties are nicely portrayed in the IR data. Bedrock is ~20 K warmer than dust at night. Squyres questioned whether the bedrock could be duricrust; Christensen indicated that the thermal inertias indicate very dense rock. NIR data show warm, rocky slopes are common. Also, warm, blocky slide material in Melas Chasma contrasts with the cool plateau surface in NIR. Athabasca region also shows lots of rocky material in IR data.

The Gusev ellipse shows thermophysical and albedo variations, with a 15 K temperature range. In detail, some morphologic units have distinct thermophysical properties. The Isidis ellipse shows uniform thermophysical properties, with slight variations in plains north of the ellipse. The THEMIS Team suggests a geologic history involving fluvial dissection of ancient highlands, infilling of intermontane basins, wind erosion to form etched, high thermal-inertia units, infilling of Isidis basin with smooth and ridged volcanic plains, and finally, deposition of sand and dust deposits. The Team has produced a map of the units associated with this history. The DIR, which now has been collected for 40% of the planet, does a better job at resolving morphology than comparable the Viking MDIM. Other non-volcanic interpretations for the origin of the Isidis ellipse material were noted by Crumpler. Christensen cited as possible evidence of volcanism collapse pits and ridges along the margins of the lowland materials that may represent high lava stands. North of the ellipse, rows of knobs that in some cases have summit pits may be pseudocraters, volcanic cones, or glacial moraines, among other possible explanations. The margin of the units forms a subtle ridge in MOLA data. The Elysium ellipse shows 15-20 K of variability in NIR data.

The Meridiani site has extensive THEMIS and MOC coverage. TES mapping of hematite abundance has been registered to the image data. High DIR thermal contrasts of >25 K occur among the units. Crater rays can be traced for hundreds of kilometers. Hematite abundance mapping correlates extremely well with morphologic mapping using THEMIS VIS and IR data. Thickness of hematite unit not yet studied but may be meters to tens of meters. Crater ejecta generally appears to superpose the hematite layer.

THEMIS multispectral data in some cases can show compositional variations, including an olivine-rich basalt layer within Valles Marineris. However, THEMIS was designed to detect silicate, carbonate, sulfate, and other mineralogies but not hematite. MiniTES will be capable of detecting hematite. Meridiani ellipse displays 8-10 K of temperature variation. Squyres: What does the hematite have to do with water? Christensen: Aram Chaos may be an important clue because it contains a layer of hematite in a closed basin and thus could have a lacustrine origin or may be goethite that was baked into hematite. It could also be a cement, but clearly not wind deposited. Parker: Appears in MOC that hematite might embay crater rays. Christensen: The rays detected in THEMIS are subtle and may be without secondaries. Gentry: What is probability of finding hematite with rover considering TES pixel size? Christensen and others: The sharp correlation of TES hematite signature and smooth unit morphology suggests that hematite likely distributed throughout. Carr: MOC images show two units throughout, with bright unit locally. Squyres: The rover might spend a week or so investigating the hematite unit, then go to nearby outcrop of bright unit.

3:00-3:15 p.m. Coffee

3:15 p.m. Crater Counts at the Landing Sites: Implications for Surface Materials
Martha Gilmore and Ken Tanaka

3:45 p.m. Characterization of Hematite Deposits and Associated Units
Frank Seelos, Washington University

4:15 p.m. Possible Relationships Between Hematite and Large Impact Basin
Horton Newsom

4:45 p.m. Discussion

Summary of Gusev Crater talks (compiled by Jack Farmer):

Marty Gilmore and Ken Tanaka:

The USGS PIGWAD crater data base was used to estimate the age of units at the Meridiani site. These results suggest that the hematite-bearing unit is Noachian in age and has been exposed during the Amazonian. The hematite-bearing unit is a medium-low albedo unit which overlies a light-colored (higher albedo) unit. This light unit is presently being exhumed and is visible as crater rims, ridges and other higher relief features that stick up through the hematite unit.

Phil Christensen:

THEMIS is a 9-band, multispectral infrared spectrometer with uncooled bolometer presently mapping from orbit on the Odyssey spacecraft. The spectrometer maps 32 km swaths. Comparison of THEMIS day-night images have revealed in amazing detail the thermal properties of surface materials at the Meridiani site. TES images overlain on THEMIS provides a basis for understand the distribution of the hematite-bearing unit (mapped spectrally by TES at 3 km/pixel) in relationship to thermophysical and albedo units mapped at much higher spatial resolution by THEMIS (~100 m/pixel).

Rocks retain heat at night and are cooler during the daytime, relative to fines, which are cooler at nighttime and warmer during the daytime. The observed thermal contrast is large (25 degC difference between rock units). The marked differences in thermal inertia reveal many important details about the state of surface materials not apparent in visible images. For example, crater ejecta rays not apparent in daytime images show up in vivid detail in nighttime mosaics. The range of rock abundances for the area is estimated between 2 and 15%. In contrast to previous ideas, there appear to be large areas of exposed rock (i.e., outcrops do not appear to be dust covered).

Hematite at the site is concentrated on mesa-like features. As noted above, it maps as a darker unit, overlying a light-colored unit. There is an excellent correlation of hematite occurrence mapped by TES and this mappable darker unit. MOLA shows that the hematite surfaces are essentially flat. However, the 18-meter visible image shows clear evidence for a stratigraphy at the site. THEMIS data suggest that the hematite deposit is not a loose windblown deposit that mantles the surface (i.e. as a surface lag), but is instead an indurated unit that is being actively eroded and reworked locally from a thin, hematite-bearing horizon that is on the order of tens of meters thick. The hematite present could be a cement, but is not a loose material. The likelihood of encountering the hematite bearing material within the landing ellipse appears to be excellent, although the major scientific goal is to discover associated materials that may provide definitive evidence for the activity of water.

Within the landing ellipse, THEMIS data do not show much spectral contrast, suggesting that the area is relatively uniform compositionally. However, the spectral regions covered by THEMIS (and similarly, the mini-TES) do not include the active intervals for oxides. In addition, the low spectral resolution of THEMIS may be contributing to this apparent compositional uniformity for other mineral groups. THEMIS data do show the ellipse to be more or less uniform in terms of thermophysical properties. However, even though it appears to be thermophysically uniform, it is not a parking lot, with temperatures ranging from 8-10 degK over the ellipse. Superimposed younger craters are revealed in THEMIS nighttime images as cool (dark) ejecta rays sitting on the hematite unit. While the Meridiani landing ellipse appears safe, ejecta rays from adjacent impact craters indicate that material has been deposited within the ellipse. The good news is that ejecta from the underlying units has been redistributed into the ellipse over a distance of ~three times the crater diameter and should be accessible by the rover.

Frank Seelos presentation (incomplete):

A rover access model (RandoMER) was used to better understand the mobility capabilities of MER at the landing site. The modified random diffusion model estimated a mean step size of 11.5 m after 52 iterations.

Horton Newsom:

Several alternative hypotheses have been proposed for the origin of the specular hematite deposit. These include deposition from an oxygenated, standing body of water (i.e., lake), hydrothermal alteration of pre-existing volcanic units (e.g. air fall tuffs), low temperature aqueous weathering of mafic volcanics, and high temperature, non-aqueous oxidation of basalt. The majority of these hypotheses require the active involvement of water, although the latter does not.

Regional context mapping of the Meridiani site has revealed that the site falls on the margin of a large arcuate features interpreted to be a very old, large (800 km diameter) multi-ring impact crater. MOLA data were used to confirm the existence of a central high separated with an annular ring crest and basin. Channel networks within this terrane are controlled by the topography of the ring structure. The proposed landing site at Merdiani is positioned along the outer annulus, in one of three basins that were connected to a large channel network that dissected a southern watershed the size of the state of Texas. THEMIS and MOC data suggest that Iani chaos to the north also received surface and groundwater flow from these basins. Epithermal neutron data is consistent with a concentration of hydrated minerals in all of these basins.

5:30 p.m. Adjourn

<u>January 9th, Thursday</u>
Science of the Landing Sites (cont.)

8:30 a.m. Eolian History at Meridiani and Gusev
Ron Greeley, ASU

9:00 a.m. Synthesis of the Testable Hypotheses for Gusev
Nathalie Cabrol, NASA Ames

9:30 a.m. Testing Hypotheses in Gusev Crater using the Athena Payload
B. Sutter, J. Moore, N. Cabrol, and A. Zent

9:45 a.m. THEMIS Thermophysical and Spectrascopic Properties of Gusev
J. Moersch, H. McSeeen, University of Tennessee

10:15-10:30 a.m. Coffee

<u>Summary of early Gusev Crater talks (compiled by George McGill):</u>

<u>Greeley:</u>

Surface albedo landform features at these sites were used to test GCM's and mesoscale wind models. For Gusev, there is a large-scale correlation between dark albedo patterns and the GCM, but local features relate to mesoscale models predicating inward-oriented night winds and outward-oriented day winds. For Meridiani Planum, there is no correlation between albedo features and the GCM, but dunes do correlate with summer winds. The mesoscale model predicts vertical cells of winds at Meridiani in the afternoon.

<u>Cabrol:</u>

It was pointed out that, because of the diversity of materials and their properties at Gusev, the site provides an opportunity to calibrate orbital TES data. Six hypotheses were discussed, and for each the relative instruments and measurements were listed:

GRS Hydrogen abundance is due to near-surface ice or to hydrated minerals
Sediments in Gusev are of global provenance
A lake or lakes once existed in Gusev, either long-lived or ephemeral
Ma'adim is a fluvial channel
Deposits in Gusev are volcanic, being derived from Apollinaris Patera
Deposits in Gusev are related to glaciation.

<u>Sutter:</u>

Five different types of hypotheses were presented (lacustrine, eolian, fluvial, volcanic, and glacial), but only the first two of these were discussed. The specific properties diagnostic of eolian and lacustrine processes were listed and discussed. These included definition of characteristic grain-sizes, round, sorting, and bedding (or absence of bedding).

<u>Milan and Moersch:</u>

Independent unit maps were prepared using thermophysical properties and morphologic data in images. The two maps defined 8 units, most of which were correlatable between the two maps (some of which did not). All units are probably Hesperian based on crater counts. Results of the mapping are consistent with a fluvial/lacustrine model, but do not prove it. A principal component analysis of multispectral THEMIS data demonstrates that two components dominate the site: basalt and dust. Low albedo areas are dominantly basalt, whereas high albedo areas are dominantly dust.

10:30 a.m. Fluvial/Lacustrine Analysis of the Gusev Site Based on THEMIS, MOC, and MOLA
Jim Rice, ASU

10:45 a.m. Geologic Units in Gusev Crater
Ross Irwin, NASM CEPS

11:00 a.m. MER Science Goals and Testable Hypotheses at the Isidis Site
Larry Crumpler, NMMNH, and Jeff Moore, NASA Ames

11:30 a.m. Geologic Setting of the Isidis Site
George McGill, UMASS

11:45 a.m. Scientific Hypotheses Addressable at the Elysium Site
Jim Rice, ASU, Mike Carr, USGS

12:15-1:15 p.m. Lunch

1:15 p.m. Geology of the "Elysium" Site
K. Tanaka, J. Skinner, M. Carr, M. Gilmore, and T. Hare

1:45 p.m. Beyond the Hematite: Additional Motivation to Land in Meridiani
Wendy Calvin, University of Nevada

Summary of later Gusev, Isidis, Elysium, and Calvin Meridiani talks (compiled by Ginny Gulick):

Jim Rice:

Jim Rice summarized his observations using THEMIS and MOC images and MOLA topographic data. He noted that there are several units in the Gusev area. Smooth material is retreating, layering is everywhere. Not sure whether the dark streaks are erosional or depositional. Jim thinks the dark streaks are actually deposits, because they embay obstacles. Crater floors have dark mantles while crater ridges are always bright. Older knobby material is embayed and knob morphology is scattered throughout Gusev. Jim doesn't think the knobs and mesas are delta deposits. Instead, he interprets the knobby landform to be exhumed and similar to knobs in the fretted terrain. He interprets "Rumpled" material as lava or debris flows.

Summary of extended discussion by Steve Ruff (not a listed presentation):

Steve has identified two distinct materials: lobate and etched material. These two units are spectrally distinct from each other. The floor of Thyra crater located on the eastern side of the landing ellipse within Gusev crater has spectral properties suggestive of "dust". There is high temperature, low albedo material located on the southern rim of Thyra.

Lobate material is located in four different regions south of Thyra. This material may be slightly different material than dust.

Etched material contains two components: 100μm and 1-2cm dusty material over both. Steve thinks that the sandy material is being deposited onto the higher albedo material.

Ross Irwin:

The stratigraphy with Gusev Crater consists of four distinct units:

1) Duricrust or cap layer in low-inertia material that probably consists of fine sediments. Ross interprets this unit as possible duricrust or dust devil deposits.
2) Low thermal inertia layer that fills the interior of craters has been impact gardened and etched. Ross interprets these materials as possible varves, pyroclastic or other airfall deposits.
3) High thermal inertia layers are located within ejecta and etched terrain; high TI is caused by material differences not by illumination.

4) 1km deep Ma'adim deposit located beneath these surface units

Jeff Moersch:

Jeff summarized his viewpoint on Gusev:
-high thermal inertia material on top
-top 100 microns is dust
-high thermal inertia strips is basaltic in composition

Larry Crumpler and Ken Tanaka:

The regional geology of the Isidis site was reviewed. Libya Montes, Isidis rim contains the oldest stratigraphic unit on Mars and potentially provides a long-term record of fluvial activity and about the earliest and wettest periods. The ellipse region contains high valley network density that provides information on the regional sedimentation. Highland material is being deposited into the landing ellipse area by the valley networks. Therefore, the sedimentation record within the ellipse reflects ancient water flow processes with a low energy fluvial environment, not catastrophic processes. These sediments contain rocks and fines and detritus from fluvial and mass wasting processes. Using the MOC image data, four distinct units/features were within the ellipse: 1) craters and tables, 2) streak, 3) channels, and 4) contact ridges. A number of hypotheses that could potentially be tested were summarized including the composition of the highland rocks, erosion by fluvial activity, presence of spring deposits, and the character of the HL-pediments.

Jeff Moore:

The southern rim of Isidis basin has been extensively modified by fluvial and mass wasting processes during the Noachian to early Hesperian.
2 terrain units dominate in the ellipse region:
1) putative Libya Montes-derived alluvium
2) younger thumbprint terrain

MOLA topography indicates several indistinct ramps sloping down into the southern edge of the ellipse. Jeff interprets these ramps as possible alluvial fan material. If ramps are alluvium then might be able to sample them. Most of the ellipse is located in this material. North of the ellipse is a unit associated with "thumbprint" terrain that superposes and forms a sharp contact with the "fan" material. This material appears similar to material located in the Beagle landing ellipse.

Mike Carr:

Mike summarized key science issues surrounding the Elysium site.
What is bench material?
What underlies it?
Ancient cratered terrain underlies the bench, but do northern plains materials also underlie the bench material at a depth of a few hundred meters or less?
What is the bench material?
Hypothesis 1: Interbedded volcanic plains and interbedded units
Pro: looks like parts of ridged plains, pancake structures like structures
Con: no visible flows, no major volcanic sources
Hypothesis #2: Sediments deposited in northern ocean
Pro: bench materials are layered and appear to lap onto adjacent uplands.
Con: evidence for ocean is not compelling
Hypothesis #3: Alluvium/colluvium derived from adjacent highlands
Pro: located close to steep highland front
Con: no evidence for fluvial activity very low slope would be difficult to transport material across bench (~500m) by mass wasting processes(e.g., solifluction)
Hypothesis#4:Wind deposits analogous to Medusae Fossae formation
Little to support this hypothesis as there is little evidence for wind erosion here.

Mike thinks that unit is reworked highland material transported probably across bench by fluvial processes.
Questions:
Ross Irwin asked: Can it fit in with materials of resistant horizons?
Mike Carr.: It is not consistent with deflation processes.
Tim Parker: What would produce the scarp at the end of the bench?
Mike Carr.: The scarp is inconsistent with shoreline hypothesis because the hollows are local.
Jim Rice: The hollows don't glow at night…
Jeff Moersch: That's unusual to have a steep slope hollow that doesn't have higher temperatures at night.

Ken Tanaka:

The MER Elysium site regional geology consists of a degraded highland boundary, with a series of eroded units and plains materials that is underlain by the Vastitas Borealis formation. Landforms seen within the landing ellipse consist of wrinkle ridges, craters, knobs, and irregular depressions. There are two large wrinkle ridges and numerous subtle ridge forms. Four craters are larger than 1 km in diameter. Knobs likely have multiple origins forming wrinkle ridge arches, crater rims, outliers of older materials and possible mud and/or silicate volcanoes. Irregular depressions are located in the center and east end of the ellipse and are possibly related to collapse.

Pancake domes with small knobs are interpreted by Ken as mud volcanoes

Large knobs and depressions are pronounced in MOLA data but not in images.

Classic flow features are not seen in the ellipse just flow margins. With MOLA topographic data, one can see depressions going into the ellipse area.

Question: Mike Carr: Why do you think collapse occurs only at margins? M.C. thinks it's caused by deflation.

K.T.: Why are the collapse regions seen to be structurally controlled? We can ask the same question for deflation.

Is there evidence for fluvial processes in the ellipse?

K.T.: There are degraded series and eroded units and plains materials.

Summary of geologic history:

LN/EH: Highland boundary zone degradation:

Collapse may have been due to mass wasting processes, volcanic intrusion, volcanic resurfacing.

EH/LH: Tectonic compaction indicative of mechanical discontinuities at 2 km depth.

Marine sediments?

LH/EA Local collapse? Mud/silicates, volcanic activity.

LA: Local dune formation in craters and along scarps.

The Elysium site offers several advantages: 1) The potential to sample both Noachian highland dissected rocks and Hesperian lowland sediments. 2) The opportunity to assess highland/lowland boundary geology. 3) The potential to sample possible mud volcanism and spring discharge deposits. 4) The opportunity to study a relatively simple geologic setting at least as it appears from the regional scale. 5) The site offers well-defined, testable hypothesis. The problem with the Elysium site is that it may be primarily volcanic in origin.

Wendy Calvin:

Spectral data from the Meridiani site was further evaluated to determine whether this region ever contained appreciable amounts of water. Early Mariner 6 data show some low albedo regions being more hydrated and there is a correlation between classic low albedo regions and drainage density. Mariner 6 spectral data indicate that there is a strong correlation of hydration and hematite in Aram Chaos and in Meridiani. Results using apparent absorbance Mariner data suggest 2% additional water by weight at hematite sites. Because the average is inferred to be only 1-2%, this is a significant local increase in water bound in minerals.

2:15 p.m. Science Discussion

3:15 – 3:30 p.m. Coffee

Site Safety Presentations

3:30 p.m. Plans for EDL Simulations and Sensitivities
Wayne Lee, JPL

4:45 p.m. Meter-Scale Slopes from MOC Photoclinometry
R. Beyer and A. McEwen, University of Arizona

5:15 p.m. Topographic Mapping and Slope Analyses
R. Kirk, USGS Flagstaff

Site Safety Presentations (provided by A. Haldemann):

Wayne Lee:

(These notes complement the presentation materials)
Will construct a sensitivity analysis to generate a range of "pass" (successful landing) percentages.
Will report on types of failure.
Simulation has 4 stages: (i) cruise jettison, (ii) hypersonic flight, (iii) terminal descent, and (iv) terrain interaction.
Each run includes 500 to 2000 trials.
Terrain "pass" criteria:0.5 to 0.7 m rocks generate failure; this is a conservative assumption, and no difference is assumed between good and bad rocks.
Will check if failures are due to conservative assumptions.
Atmosphere inputs:
The Kass-Schofield model range includes the MarsGRAM mean, which is lower than that of K-S. We believe K-S more because is based on measurements from TES.
The mesoscale wind model is included via a dispersed set of wind vector columns for each site.
Terrain inputs:

"Statistically representative" digital terrain maps are chosen based on hazard zone maps, and we run separate statistics for each zone in the ellipse.

Rock interactions are NOT correlated with terrain features and/or slopes. We use "bad" rock estimates. Bad rock effects depend on lander orientation which is accounted for/simulated.

Will examine variations on the sensitivity matrix.

Will be ready to run at the end of January. Results are due mid-March for the landing site peer review.

Ross Beyer:

Does point photoclinometry.
The slopes generated are upper bounds.
Does 100 m averaging and reports/maps the rms deviations.
At each landing ellipse:
1. the slope upper limits are good.
2. slope information highlights morphology changes.
3. slope images may be useful for traverse planning.

Randy Kirk:

Description of technique and a list of error assessments are presented.
The Elysium stereo DEM is rugged, but is still low compared to all the ellipses.

5:45 p.m. End of Day Two

January 10th, Friday
Site Safety (cont'd)

8:30 a.m.	Hazard Maps of the Landing Sites Tim Parker, JPL
9:00 p.m.	Terrestrial Interferometric Radar Observations of Terra Meridiani and Isidis K. Larson, A. Haldemann, R. Jurgens, R. Arvidson, M. Slade
9:30 a.m.	Boulder Counts in the Gusev Ellipse R. Schroeder and M. Golombek
9:45 a.m.	Probability of Impacting and Accessing Rocks at the MER Landing Sites M. Golombek, A. Haldemann, E. DiMaggio, R. Schroeder, and J. Matijevic, JPL
10:15 a.m.	Athena Science Team Perspective on MER Landing Sites Steve Squyres

Summary of Safety Talks (cont'd) (compiled by M. Shepard):

Tim Parker:

Overview of geomorphic/hazard maps of the Meridiani Planum, Gusev, Isidis, and Elysium landing sites. Discussion for all sites centered on various interpretations of units. Gusev coverage is extensive, with 60-70% MOC coverage and most of the remainder filled in by Themis. It also appears to have approximately 5 different hazard units – the largest variety of all sites. Meridiani Planum has ~50% MOC coverage and ~80% MOC plus Themis. Isidis has approximately 90% Themis/MOC coverage. Elysium is the least covered landing site with ~20% MOC and ~50% Themis/MOC total coverage. All hazard units identified will be used to select representative digital elevation models (DEMs) from R. Kirk's work as inputs into the Entry/Descent/Landing (EDL) simulations.

Larson et al. (presented by A. Haldemann):

Presentation of latest radar imaging of Mars (2001 opposition) which utilized four different receiver stations and MOLA topography to remove the N-S ambiguity inherent in radar imaging of Mars. Only data from two stations have been linked to date. The Meridiani track went through the landing ellipse and shows a correlation of radar albedo with known locations of hematite. The Isidis tracks went south of the landing ellipse and into the highlands.

Schroeder and Golombek:

Authors conducted a search for boulder fields in and around the landing ellipses. Seven boulder fields were found in the landing ellipse within Gusev crater, six within the Isidis ellipse, one within the Elysium ellipse, and none within the Meridiani Planum ellipse. All boulder fields appear to be associated with old degraded craters. Boulder sizes ranged from ~2m to 10m. Areal coverage of boulder fields in Gusev is ~1.4%; convolving in the targeting probability, the probability of the MER lander encountering a boulder field in Gusev (during landing) is very small (<1%).

Golombek et al.:

The authors used IRTM estimates of rock abundance at each landing site and model size-frequency distribution curves (based on observations at terrestrial and Martian sites) to estimate the probability of encountering rocks of various sizes during landing and roving.

For landing, airbag tests suggest no failures for encounters with rocks <0.5m in size, but failure rates increase for rock sizes >0.7m. At all landing sites, the probability of encountering a rock of this size within the first few bounces is at the 1% level or smaller. Rocks >5m in size are not considered a hazard since they effectively present a planar surface to the airbags. Boulder fields have a cumulative probability of impact at the 1% level (or less) for all landing sites. Smaller triangular rocks are believed to be a hazard by causing a failure of the inner bladder on impact. They are estimated to be encountered <2% of the time within the first two bounces (the most critical) at all landing sites. In sum, improvements to the airbag system coupled with estimates of rock abundance suggest rocks will not prove to be a significant hazard for landing at any of the sites.

For roving, the authors estimated probabilities for encountering rocks >0.1m to analyze with instruments on the IDD, and rocks >0.3m on which to use the RAT. Two ranges were estimated; within reach of the IDD and within three rover lengths drive away. For rocks of within reach of the IDD, they estimate >60% probability of encountering a rock >0.1m in size at all sites. For rocks within three rover lengths, they estimate a 35-99% probability of encountering a rock >0.3m at all sites (lowest at Meridiani, highest at Isidis). In sum, even at the sites with low rock abundance (e.g. Meridiani), there is a significant probability of encountering rocks within a short distance suitable for analysis

S. Squyres:

Outline of the procedure for landing site selection. A science recommendation is made by the MER team to the MER project based on the scientific community input. These recommendations are based solely on the science. The recommendations must include a single best science site in the event of a failure of one rover. The MER project folds in the engineering constraints and EDL analysis and makes a recommendation to NASA HQ where the final decision is made. The PI requests continued input from the science community for the next year, especially in formulating new site-specific hypotheses that can be tested by the rover immediately after landing.

10:45 a.m. Discussion

Summary of Discussion (compiled by J. Crisp):

J. Grant: Introduction to Discussion:

We would like to get these write-ups (lists of hypotheses to be tested) in a more polished form. Let's discuss what we have right now.

Ron Greeley: Gusev:

Imagine doing remote sensing of the Earth based on just three landing sites. MER ground truth information will be very helpful for improving our interpretations of the orbital data sets.

In the application of Athena science, we'll have to consider the different scales of observation (context, outcrop, hand specimen, and "laboratory") and the likely materials we'll find (fines, rocks, bedrock). What we get will be a function of where we land and rove. See Nathalie Cabrol's tables (Main hypotheses on the origin of the materials in the Gusev landing ellipse and possible results from Athena Instruments on different materials) for a higher level of detail.

What process is responsible for the material in the floor of the crater? First of all, there's the primary geology, which is greater than "skin deep." What was the primary process that formed this material? This same question would apply to a lot of areas on Mars. If we're wrong about the water hypothesis, it would reset our thinking about other areas on Mars, too. Hypotheses that should be considered for the primary geology process are:

- Aeolian, saltation (look for well-sorted, rounded grains < 4 mm, cross bedding)
- Aeolian, suspension (look for fine-grained dust)
- Volcanic, explosive (fine-grained, angular, glassy)

Note that ambiguities will arise among these 1st three hypotheses, above

- Paleolake, distal (fine-grained, thin beds, mud cracks, oscillation ripple marks)
- Fluvial (clastic, wider range of sizes, rounded grains, graded bedding, current ripples, imbrication)
- Volcanic, effusive (crystalline with vesicles, flow texture "cords")
- Impact ejecta (clastic, poorly sorted, angular, brecciated, shatter cones)

What processes were responsible for the surficial geology (the upper meter or so)? The dark streaks – are they exposed bedrock, lag "desert pavement" deposits (we'd expect granule to cobble size grains in a thin layer that you could dig through using the rover wheels) or a dark deposit of grains < 4 mm in size? The drift deposits – are they active dunes or remnants of a formerly more extensive fluvial or aeolian deposit?

There is the calibration of remote sensing, and ground truth, which includes removal of atmospheric effects, determination of compositions (checkerboard distribution versus intimate mixing), and estimation of thermophysical properties (dust, rock abundance, induration).

There's also the secondary or alteration processes, such as hydrothermal, aeolian, and chemical/physical weathering processes (details are TBD.)

Ron showed an example of an Analysis Tree, which is essentially "Geology 101." All of the branches were not filled out; it was meant just as an example of how specific Athena-determined indicators could be used to infer processes.

Textures and structures are really important for determining the primary processes (igneous, sedimentary, impact, etc.). Mineralogy and chemistry narrow down the specific characteristics of those primary processes. Mineralogy and chemistry are more important for the identification of secondary processes.

What are the science pros and cons of Gusev? Ron said that it can be done, but the list isn't ready yet.

The "attractiveness" of Gusev is its geomorphologic evidence at the Viking scale.

Dave Des Marais noted the difference in the kind of water evidence for the various landing site candidate. At Meridiani, it's mineral evidence. At Gusev, it's physical evidence. At Isidis, it's the timing…that the rocks may be from the early part of Mars' history.

Steve Ruff: What's the likelihood that the surface we'll land on represents the lakebed?

We know enough to suggest a stratigraphy in Gusev.

Dave Des Marais: Impact gardening process will help churn up lakebed sediments if they're buried. The craters should excavate to at least 1/10 their diameter. It's likely you'll have access to rocks from lake sediments if they're there, but you can't guarantee it. That particular "con" needs to include science judgment and include the extent to which it may be mitigated by impact gardening and expected rover traverse capability.

We may find impact blocks at Gusev. Just to the SW of Gusev, Kane Crater impacted into Noachian rocks. The rover might encounter rocks from that impact.

The MOC images of Gusev don't look like the Gale images. That's a "con." Steve Ruff: An observable that's disconcerting is that there's a suggestion that one of the last depositional events is this lobate material viscous flow material that doesn't look like a lake deposit. What if we land on that material?

Ross Irwin: The scale of many of the impact craters is 200 m and larger, which should garden up the deposits in Gusev. There's a fairly good chance to see rocks brought up from depth with the rover. To discriminate between aeolian and lacustrine deposition, we could look at the blocks, and identify the composition of the cementing material.

Send your comments on Gusev to Ron Greeley by email so that he can generate a more comprehensive list.

George McGill: Isidis:

George presented three main testable hypotheses and their key observation and measurement requirements: (1) Wet early Mars (rocks derived from Isidis rim), (2) Isidis basin was once the site of a body of standing water, and (3) Isidis is floored by basalt that embays the highlands.

If the Isidis site is lava flows (hypothesis #3), then there could be a lot of dangerous rocks at this site.

Evidence for #1 included rounded rocks, but someone noted that alluvial fans on Earth often contain angular rocks, and also secondary processes like frost shattering could produce some very angular rocks.

It was recommended that for each of the sites, we should start with the higher order hypotheses, and work down to more details. The more you can add to this 1 page sheet for Isidis, the better (on separate pages).

One particular con that should be noted: If it's basalt, then it doesn't have aqueous processes.

Pros: This site directly addresses the principle goals of the Mars Program, there are lots of rocks for the rover to study, it may allow us to obtain compositional information about highlands rocks, and it should provide a good view.

Alluvial processes have less to do with habitability than lacustrine or sites with longer-term water activity.

We need to add testable hypothesis for the more recent alluvial environment as well as the ancient environment that formed the highlands rocks.

The "Cons" for each site should include the scientific risk of being able to address the top 3 science objectives of the mission (aqueous processes, habitability, and the likelihood of preservation of evidence for aqueous processes and habitability).

A "pro": Even if it's basalt lava, impacts may give you access to things underneath that does involve water.

Make sure Larry Crumpler and Phil Christensen are involved in the updates to this list of hypotheses.

The atmospheric hypotheses are less important.

It would be much more useful to look directly at the sun with solar filters.

David Kass did produce a set of atmospheric hypotheses for all 4 sites.

These should be cycled through the atmospheric science Athena team members for their comments and additions.

Gentry Lee: The process for evaluating the sites with respect to atmospheric science has not been well addressed.

Let's not introduce that now. Let's only include it as a "Pro," if something significantly extra as a science bonus comes out of it for a particular landing site.

Could you aim Mini-TES at a nearby mountain and compare it to the rover's surface? No, it would be worse than orbital remote sensing.

A "smoking gun" observation that would nail this: If there's an abundance of rounded rocks, they've been shed from highlands. An absence of rounded rocks would dispute this.

If they're Noachian rocks with "goldfish" in them, how would you know they're Noachian?

<u>Mike Carr: Elysium:</u>

Mike thought the pros and cons referred to the hypotheses, not the site. He presented a 1-sheet write-up on each of 5 hypotheses for the origin of the materials in the Elysium site:

1) Volcanic
2) Marine sediments
3) Layered alluvium
4) Aeolian (Mike Carr thinks this is very unlikely)
5) Alluvium modified by mud volcanoes and springs [but identification of mud volcanoes is ambiguous, seepage at ridges is ambiguous]

The biggest problem is that the geologic model of the site is so uncertain, that it's difficult to strongly advocate this site with respect to the broad goals of MER. The models are too uncertain. It's hard to get enthusiastically behind this site. It's probably a mixture of stuff.

The nearest highland source is where? The nearby knobs could be the source.

At EVERY SITE we should consider hypotheses for all these processes: aeolian, volcanic, mass wasting, aqueous, and impact. Then we should look at which predominate.

Someone mentioned that it's not so much processes that deposited materials here, but the processes that stripped it, that may be of interest. Determining the stripping process can only be addressed with the rover cameras

<u>Frank Seelos/Ray Arvidson: Meridiani:</u>

Frank showed a spreadsheet listing testable hypotheses, key observations, and measurement requirements.

Hypotheses for the hematite deposit:

Formed in a subaqueous environment, hydrothermal system, surface coating, or nonaqueous oxidation

Should these be added to the list: Impact metamorphism, and contact metamorphism? If it was metamorphism, did it involve water so it was really more of a hydrothermal (metasomatic) process? Clastic or precipitate sedimentation?

Hypotheses for the light-toned material:

Is it a volcaniclastic formation, is it stratigraphically below the hematite-bearing layer, are the light-toned aeolian bedforms derived from the light-toned material. The light-toned aeolian bedforms…are they granule ripples?

Add to the list of hypotheses to test: Is the light-toned material sedimentary? Is it the light-toned material that contains the coarse-grained hematite?

Do you want 1st order and 2nd order hypotheses?

John Grant: We want as complete a story as possible, but a distinction between what's 1st and 2nd order.

The rings of bright material at Meridiani: are those tops of crater rims? If so, they're Noachian, which would give us a chance to sample possible wet early Mars, and this is a strong "pro" for this site (unless they're only subdued by burial, and still buried).

Dave Des Marais: The other speakers organized their lists according relate to processes. This list is based on two features (the hematite and light-toned material).

This is a mineralogical vs. morphological site, so it's not surprising that they organized them differently. The Gusev charts also apply to this site too, the same process hypotheses should be considered.

Dave Des Marais: Aqueous processes are in the science goals. Here, you're talking about features, so processes become 2nd order. These hypotheses should be re-organized in terms of processes.

How do we factor in the role of volcanic processes, etc.? Is that considered primary or secondary?

Ross Irwin: The same sorts of characteristics for the surface of Gusev apply here too. How did that material get there, and what is it? We should focus on the origin of the layer, that'll be more like the way the other sites were described.

Pros: Unique mineral signature, likelihood of sampling multiple units, first investigation of a low albedo surface, provides ground truth for orbital spectroscopy.

Cons: Low rock abundance (although that enhances trafficability); and possibly of landing on top of a horizontal layer-cake stratigraphy so you might not see much except the very top, although gardening will help; possibility that this site has nothing to do with aqueous processes.

General Discussion:

A question was raised about the effect of dust coatings on our ability to do spectroscopy with the rovers. We can't do ground truth if there's nothing we can truth. The scale of data from THEMIS is 100 m. The only site that's relatively dust-free is Meridiani. The other 3 candidate landing sites have a higher dust cover than Viking Landers 1 and 2.

If dust cover obscures what we see, it will hinder our ability to figure out the best places to send the rover. (1) Will we be able to do spectroscopy for in-situ investigation? Steve Squyres thinks this will not be a problem. Looking obliquely, you'll see the sides of rocks, and Mini-TES is pretty good at penetrating through 10 microns of dust. Matt Golombek noted that a lot of rock sides were heavily dust covered at Pathfinder, and it may be that the real "gems" in the field may not be apparent because they're dust covered. The Pathfinder site was the least dusty of the 3 we've been to so far. The sites under consideration here (Elysium, Isidis, and Gusev) are even dustier – they're more like Viking. (2) Will we be able to do good ground truth? The 3 dustier sites will be a problem. It will harder to do.

Wendy Calvin: We should estimate the thickness of aeolian coatings at the Viking Lander 1, 2, and Pathfinder landing sites. When you'll start obscuring rocks at x thickness, observed from a distance y, how do the landing sites compare? Trevor Graf at ASU is wrapping up his Master's thesis on this.

Is it harder to correlate orbital with ground truth at some of the sites? Is there an operational advantage of low-dustiness at some of the landing sites?

From orbit, the spatial resolution is 3 to 5 orders of magnitude larger than what we'll have on the ground. We may see more dust-free surfaces with the rover.

The tables that were presented today are not finished works. Please contribute to making them more complete over the coming week, by sending comments to the leads (Ron Greeley for Gusev, George McGill for Isidis, Mike Carr for Elysium, and Frank Seelos/Ray Arvidson for Meridiani).

Let's use a common format and try to fit in the template we've provided (testable hypotheses, key observations, and measurement requirements). An Excel spreadsheet would be fine.

List the 1st order, then the 2nd order hypotheses.

Describe the pros and cons for the site as a whole (pros and cons with respect to the science mission objectives, not with respect to each hypothesis).

The Analysis Tree that Ron showed was good. Could that be elaborated on?

For all the sites, there should be a set of hypotheses that address the origin of the unit you're sitting on.

12:30 p.m. End of Workshop – Adjourn

Tables of Testable Hypotheses Generated for each of the Landing Sites:

The Meridiani Site (Compiled by Ray Arvidson and Frank Seelos):

Topic	Hypotheses to be Evaluated	Key Observations	Key Measurement Requirements	Implications
Hematite Occurrence	*Is hematite present?	*Unequivocal evidence for the presence of hematite inferred from Athena observations	*Pancam multi-spectral and Mini-TES mosaics, combined with detailed observations of key deposits to derive and analyze reflectance and emission spectra *Mössbauer Spectra	*Validation of inferences from TES *Key ground truth for orbital observations in general since the site is thought to be unusual in mineralogical properties *Starting point for further data acquisition and hypothesis testing
Hematite Formation Mechanisms	*Did hematite form via aqueous processes and under what environmental conditions?	*Hematite occurrence detailed and determined to be due to platy outcrops, discrete specular grains, or as hematite particles embedded in volcanic glass or as coatings on lithic fragments of basaltic or other composition *Minerals formed with hematite defined and inferences derived as to whether the ensemble formed via low (lacustrine) or high temperature (hydrothermal) aqueous processes or via anhydrous oxidation (magmatic or ambient) *Local geologic setting defined, including grain size distributions and other textural parameters, presence of layering and primary sedimentary features, including how hematite-bearing deposits fit in	*Ensemble of Athena Observations	*The extent to which the deposits formed or where modified by aqueous processes *Environmental conditions associated with aqueous processes (lacustrine, hydrothermal) or perhaps anhydrous oxidation and associated environmental conditions *Implications for preservation of biosignatures through the development of coatings and other minerals that formed when hematite formed (e.g., silica deposits) *Implications for geochemical cycles of biological relevance
Geologic Setting Associated with Hematite-Bearing Materials	*Are hematite-bearing materials the top stratum of an extensive layered deposit draped over the ancient cratered terrain? *Did the layered deposits form via lacustrine, volcaniclastic, or other means?	*Exploration and characterization of the dark materials evident at the site as plains and dark dunes *Exploration and characterization of the bright substrate evident at the site as subdued crater rims, bright plains, and bright dunes *Search for and characterize crater ejecta from underlying cratered terrain crust *Use all data to develop stratigraphic column and test the model with continued observations	*Mobility to get to various locations and the ensemble of Athena observations to characterize the sites and materials *OMEGA hyperspectral observations (0.36 to 5.2 micrometers) to provide mineralogical inferences at few hundred meter scale (Acquisition will MER is operational)	*Fundamental to understanding if the landing site is located on the upper strata of a vast lacustrine (or marine) deposit or if the site on the top of a thick (hundreds of meters) volcaniclastic pile, with or without evidence for aqueous alteration processes *Implications for defining planetary habitability and the extent to which subsurface or surface habitats may have existed

REA 1/17/03

Pros: We have specific, well-defined hypotheses to test that relate to the geologic history and set of processes that have operated, with a focus on the extent to which aqueous processes have been involved. Athena Payload and MER mobility system very well matched to testing the hypotheses. Spectral signatures relative to rest of the planet and the low-albedo, dust free nature of the site make it a good site for ground truth calibration of orbital data.

Cons: may not be evidence for aqueous processes and the site does not have a lot of topography for exciting vistas.

The Gusev Crater Site (Compiled by Ron Greeley):

Topic	Hypotheses to be Evaluated	Key Observations	Key Measurement Requirements	Implications
Determine the origin of the primary materials filling Gusev Crater (requires rocks, bedrock) and evaluate role of water in shaping crater filling deposits	Wind-related deposits (global dust mantle vs. local saltation vs. volcanic, air-fall)	Very fine grains, massive homogenous beds vs. well sorted, rounded grains < 4 mm, cross bedding locally derived compositions vs. angular, massive, fine grained, glass shards, silicate compositions (e.g., from Ap. Patera)	Imaging, , RAT, spectroscopy (grain sizes below resolution; compositions not unique) Imaging spectroscopy (ambiguous; could be well-sorted sands of fluvial origin, but frosted likely aeolian	May constrain evolution of hydrologic cycle, implications for water inventory Any outcome can help evalauate changing role of processes through time Access to materials with good to fair preservation potential if lacustrine or fluvial
	Lacustrine (distal vs. proximal materials)	Thin, fine grained beds (rythmites), mud-cracks, ripples; authigenic aqueous minerals (e.g., carbonates, evaporite salts)	Imaging, RAT, spectroscopy	
	Fluvial	Clastic materials, rounded variably sized; graded or cross bedding, imbrication, variety of compositions (carbonates?)	Imaging, RAT, spectroscopy	
	Volcanic, effusive (i.e., lava flows)	Fine-grained crystalline rocks (phenocrysts, vesicles, corded textures or vesicle "trains")	Imaging, RAT, spectroscopy (flow features unlikely to be preserved/observed, and vesicle-like features can be non-volcanic)	
	Impact (i.e., ejecta deposits)	Clastics, brecciatted, poorly sorted variable sized, Noachian impact melt matrix compositions, schlieren, shatter cones; hydrothermal alteration)	Imaging, RAT, spectroscopy	
	Mass wasting (e.g., debris flows, solifluction)	Clastics, poorly sorted, sizes and shapes dependent upon source material; little if any internal bedding structure; compositions correlative with likely source area	Imaging, spectroscopy	
Determine the origin dark streaks (can have more than one origin)	Exposed bedrock (i.e., removal of bright dust from the surface;)	Bedrock surface is observed and it is darker than the surrounding area	Imaging, spectroscopy	Verification of first two hypotheses indicative of high-energy wind regime, whereas third indicates low energy regime) May identify access to bedrock or in situ indurated sediments
	Lag deposit (e.g., stone pavement)	Clastic materials darker or larger than dust And may form pavement)	Wheel trenching; imaging of surface and sub-surface materials	
	Deposit of dark material	Deposit of dark particles < 4 mm; composition correlates with source	Imaging, spectroscopy	
Determine the origin of drift deposits	Active wind-transported material (e.g., dunes or ripples)	Grains > 60 microns and coarsening-up indicate as ripples; grains fining-up indicate dune transport	Imaging	Determine whether drift represents wind-transported materials versus remnant of mantle (eolian, volcanic, fluvial, colluvial, other)
	Remnant of former mantle (sand, dust, fluvial, or mass-wasting)	Internal structure (e.g., cross-beds of former dunes vs. larger fluvial or mass-wasting clastics)	Imaging	
Determine possible secondary/alteration processes	Weathering in a wet environment	Clay minerals (pedogenic or as sulfates and salts if hydrothermal).	Spectroscopy	Determine weathering environment of Mars near-surface over time
	Alteration in a relative water-free environment	Crystalline minerals or mineroids associated with primary minerals	Imaging, spectroscopy	Constrain role of water in weathering
	Hydrothermal alteration	Porous carbonate deposits, siliceous sinter	Imaging, spectroscopy	Constrain modern hydrologic cycle

Pros:

1. Relatively clear geological models can be posed and tested, including that involving long-duration aqueous environments.

2. Depending on the outcome of "hypothesis testing," the results are directly relevant to the primary MER project goals

3. Results (e.g., a channel intersecting a flat-floored, large crater) can be applied to other areas of Mars and carry significant implications for the general geological evolution of the planet

4. Secondary objectives (origin of dark streaks, drifts) can also give insight to these features seen elsewhere on Mars

Cons:

1. Many of the hypotheses do not have definitive tests using the Athena payload

2. Most of the "primary geology" (modes of origin for the floor materials) are dependent on having access to the relevant materials; processes, such as solifluction, might have emplaced thick(m??) materials not related to the primary floor-filling; we will be dependent on small impact craters to have excavated the relevant materials and in our being able to differentiate among the potential sources of the ejecta materials.

3. Gusev is a geologically complex area with an interesting history that can be difficult to deconvolve; this would make for lively discussions!

The Isidis Basin Site (Compiled by George McGill):

Topic	Evaluated Hypotheses	Key Observations	Instruments	Implications
Early Mars was wetter than today	1) Ellipse in Isidis Basin lies within an ancient alluvial fan depositional environment	Detailed evaluations of rock shapes and surface morphology, e.g., rock shapes (roundness), juxtaposition of landforms (bar and swale), presence of weathering/alteration products (hydration minerals), fragment composition/petrology, textures (crystalline or clastic, veins)	PANCAM PANCAM, THEMIS, MOC MS, Mini-TES & RAT APXS, mTES & RAT MI & RAT (MI before and after RAT)	Noachian Rocks from Isidis rim present within landing ellipses. Transport from Isidis rim into basin involved streams and alluvial fans Mars had an active hydrologic system involving overland flow and active drainage networks. Place limits on climate evolution.
	2) Isidis Basin was once the site of a standing body of water ("lake")	Landforms (Benches or berms, cuspate forms Rock shape and structure (sorted, rounded, sediments) Rock type/Petrology (mature versus immature, major versus minor component composition, crystalline versus clastic) Statigraphy (any low angle truncations, accretion or forset beds, orientation relative to basin margin, continuity)	PANCAM, THEMIS, MOC PANCAM MI & RAT (MI before and after RAT) Mini-TES, MI, APXS	Shoreline features are present and indicate that either nearshore or pelagic deposits comprise near-surface materials and embay the highlands If near-shore, high energy environment, lower preservation potential If pelagic, low energy environment, higher preservation potential Mars had an active hydrologic system involving overland flow and active drainage networks. Place limits on water budget, cycling and climate
	3) Isidis Basin is floored by basalt that embays the highlands	Rock textures (grainsizes, glasses, phenocrysts) Rock structures (vesicles, jointing, banding) Morphology (typical of flows, aa, pahoehoe, tumuli) Stratigraphy Composition (major and minor minerals and elements	PANCAM, MI, RAT (MI before and after RAT) PANCAM, MI PANCAM, THEMIS, MOC RAT, MS, APXS, Mini-TES	Materials erupted in Isidis Basin and flowed to edge of basin Constrain timing and inventory of volcanics Does not resolve role played by water in evolution of site or early Mars conditions

Scientific Pros:
- Water and habitability involved with hypotheses 1 and 2
- Water, habitability, and preservation in Noachian tested by hypothesis 1
- Abundant rocks, which may be rounded and thus less dangerous to landing for hypotheses 1
- Obtain compositions of highland rocks for hypothesis 1
- Good view!

Scientific Cons:
- For hypothesis 3 the site does not address mission goals
- Habitability and preservation difficult in an alluvial fan environment (but water alteration in veins good for habit/pres)

The three hypotheses predict different assemblages of observables. Differences between these are discussed below.

1. Overview: For hypotheses 2 and 3, THEMIS images and possibly PANCAM images should suggest embayment of the Isidis rim massifs by the adjacent plains material. The only adequate data available as of mid-January, 2003 bearing on this issue are day and night THEMIS thermal images at 100m/pxl. One THEMIS VIS image at 18m/pxl includes a small area of Isidis massifs, but the embayment relationships on this image are ambiguous. Embayment relationships also are possible for hypothesis 1 if deposits due to a process younger than the formation of alluvial fans are present. Large rocks present within the landing ellipses most likely would be blocks excavated by small, young impact craters for hypotheses 2 and 3. For hypothesis 1, some large rocks would be emplaced by fluvial +/- mass wasting transport from the Isidis rim, and could be more rounded as a result. PANCAM could image fan morphologic characteristics such as shallow leveed channels and imbricated boulders if these have been preserved.

2. Rock Structures: Hypothesis 1 predicts that many (perhaps most) larger rocks within the landing ellipses were derived from the Isidis rim, and thus should be very ancient. With the exception of one meteorite sample, we do not know what the structures of Noachian highland rocks are. Considering the probable source, impact breccias and fractured rocks are likely. Hypothesis 2 predicts that the Isidis site is underlain by deposits of a "lake". Because the site is close to the shoreline, the lake deposits likely would include layers with differing grain size and sorting, with graded bedding also possible. Hypothesis 3 predicts basalt, and primary basaltic rocks could contain vesicles and flow banding. These various structures should be visible in PANCAM or MI images, depending on scale.

3. Rock textures: Basalt (hypothesis 3) has a crystalline texture with interlocking grains of feldspar and mafic minerals. Phenocrysts also might be present. Lake deposits (hypothesis 2) most likely would be clasitic sedimentary rocks without interlocking grain boundaries (an exception might be chemically precipitated evaporite minerals, but these should be identified by MINI-TES if they are present). Impact breccias (hypothesis 1) would be chaotic mixtures of angular fragments of different rocks at both PANCAM and MI scales.
   It is clear in the MOC and THEMIS VIS images that some dune and sand sheet material is present at the site. If this is sampled, it should be possible to identify it from its expected very well sorted, sand-sized texture.

4. Mineralogy and petrology: Bulk mineralogy from MINI-TES, iron mineralogy from MS, and elemental make-up from APXS should permit inference of basaltic composition. If textures are interlocking (primary igneous), a basaltic lava would be indicated (hypothesis 3); if textures are clastic, a sedimentary origin with basaltic provenance would be indicated. Alteration minerals (including hydrous ones if detectable) would be possible with all three hypotheses, but would seem more likely for hypothesis 1, by analogy with meteorite ALH84001. MIN-TES could identify evaporite minerals formed as a result of hypothesis 2, or occurring in veins likely to be present in Isidis rim rocks (hypothesis 1).

The Elysium "Wind Safe" Site (Compiled by Mike Carr):

Topic	Testable hypothesis	Key observation	Measurement requirement	Implications
Can geologic setting be deconvolved so as to identify where highlands material might be sampled (either in situ or subsequent to transport)?	1. Bench is a sequence of interbedded volcanic flows and pyroclastics overlying a Noachian basement	a) surface morphology - flows, outcrop textures, etc, (b) rock textures (massive, vesicular, friable, etc), (c) rock mineralogy	(a) PANCAM, (b) PANCAM, MI, RAT, c) MINITESS, MOS	Not able to sample Noahcian highlands materials or address most mission science objectives
	2. Bench is a marine terrace, comprised of layered marine sediments derived from highland front and overlying Noachian basement	a) presence of terraces, layered sediments, b) sedimentary fabrics- sorting, cement, ripples, rounding, etc. c) rock mineralogy - evaporites, cement, d) rock mineralogy - fractionation, sorting.	a) PANCAM, b) PANCAM, C) PANCAM, MI, RAT, d) APXS, MOS	Mars had a robust hydrologic system involving overland flow and oceans. Place limits on water budget, cycling and climate Possible access to materials with good preservation potential
	3. Bench consists of layered alluvium/coluvium derived from highland front and overlying Noachian basement.	a) surface morphology - channels, debris flows, layering, b) sedimentary fabrics and rock mineralogy as in 2 above.	a) PANCAM, b) PANCAM, MI, RAT, MINITESS, APXS, MOS	Might be able to sample reworked and transported Noachian highlands material (might be very difficult to identify), but little context. Difficult to address many mission objectives.
	4. Bench consists of layered alluvium/colluvium derived from highlands, overlying Noachian basement, and modified by mud volcanism and/or local groundwater seepages.	Same as 3 above except make observations on pancake like structures and indistinct flows observed in orbiter images.	Same as above	Might be able to sample reworked and transported Noachian highlands material (might be very difficult to identify), but little context. Access to widely scattered forms that may be mud volcanoes or springs might permit assessment of aspects of more modern hydrologic cycle, possible life.

Scientific pros: A) may provide opportunity to examine a former marine environment, B) Local knobs appear to be highland basement and bench most likely a degradation product of the highlands so highland rocks may be abundant. C) Bench material may have been emplaced by aqueous processes (fluvial, solifluciton, etc) so may provide an opportunity to study such processes.

Scientific cons: No satisfactory geologic model for the origin of the bench on which the landing site is located. Great uncertainty about what will be found and whether the findings will relate to the main goals of the Mars exploration program, the role of water and the prospects for life.