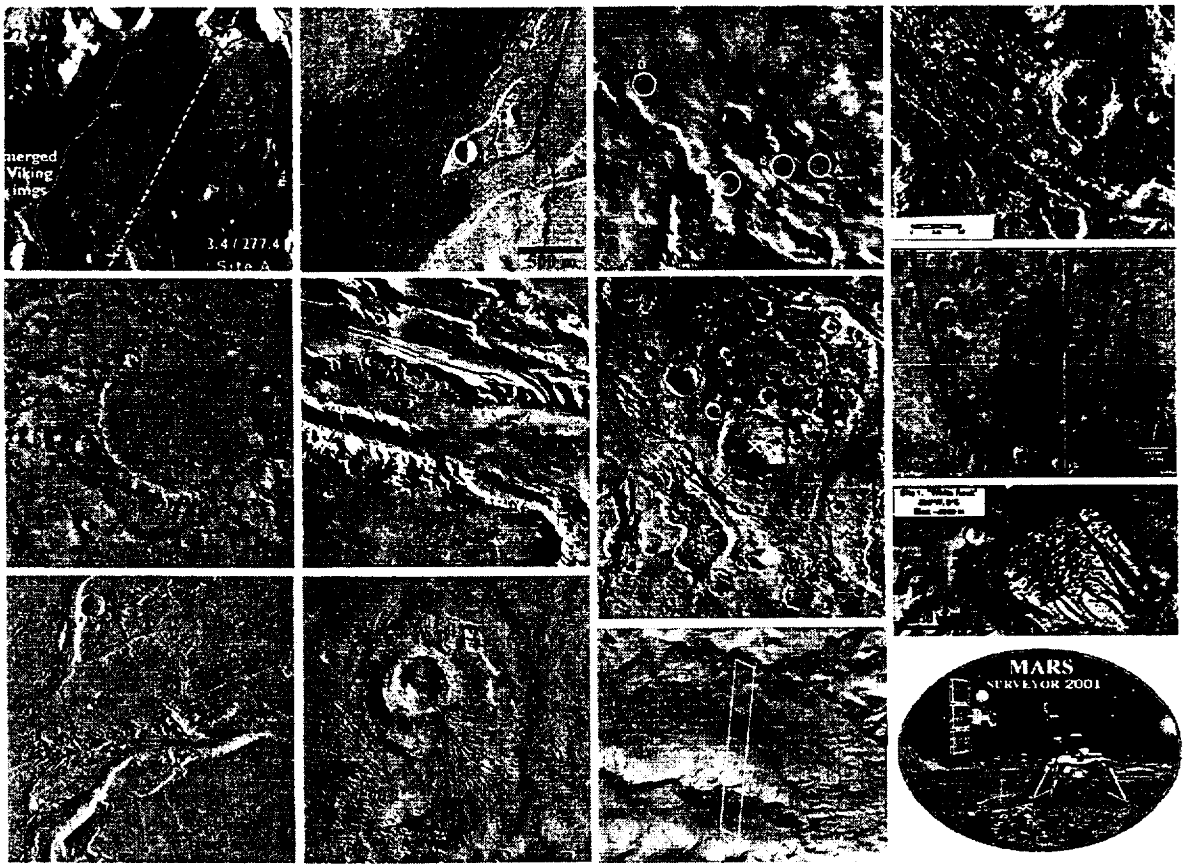
SECOND MARS SURVEYOR LANDING SITE WORKSHOP



STATE UNIVERSITY OF NEW YORK AT BUFFALO
BUFFALO, NEW YORK
JUNE 22 & 23, 1999

SECOND MARS SURVEYOR LANDING SITE WORKSHOP

Edited and Prepared by:
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Steve Saunders (JPL)
Geoff Briggs (Ames)
Matt Golombek (JPL)
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Workshop Organizer:
Virginia Gulick

Organizing Committee
Steve Saunders, Geoff Briggs, Matt Golombek

Held at
SUNY at Buffalo

June 22-23, 1999

SECOND MARS SURVEYOR LANDING SITE WORKSHOP PROGRAM

TUESDAY 21 JUNE: MORNING

MARS SURVEYOR PROJECT AND PROGRAM SCIENCE AND CONSTRAINTS

CHAIRS: J. Zimbleman/V. Gulick

8:45 **WELCOME AND INTRODUCTION**
G. Briggs/V. Gulick**

9:00 **MS'01 STATUS AND SITE SELECTION PROCESS UPDATE**
*S. Saunders**

9:20 **APEX LANDER SCIENCE**
*S. Squyres**

9:40 **LANDING SITE ENGINEERING CONSTRAINTS**
*D. Spencer**

10:00 **CONSTRAINTS AND APPROACH FOR SELECTING THE MARS SURVEYOR 2001 LANDING SITE**
M. Golombek, N. Bridges, M. Gilmore, A. Haldemann, T. Parker, R. Saunders, D. Spencer, J. Smith, and C. Weitz,*

10:20 **PRELIMINARY CONSTRAINTS FOR MARS SURVEYOR 2003 AND 2005 LANDING SITES**
*J. Crisp and M. Golombek**

10:35 **COFFEE BREAK**

MARS GLOBAL SURVEYOR RESULTS AND OTHER CONSIDERATIONS

11:00 **CHARACTERIZATION OF TERRAIN IN THE MARS SURVEYOR 2001 LANDING SITE LATITUDE AND ELEVATION REGION USING MAPPING PHASE MARS GLOBAL SURVEYOR MOC IMAGES.**
M. C. Malin, K. S. Edgett, and T. J. Parker*

11:20 **TES RESULTS AND CONSIDERATIONS FOR LANDING SITE SELECTION**
*P. Christensen**

11:35 **RECENT MOLA RESULTS AND IMPLICATIONS FOR SITE SELECTION**
*J. Head**

11:50 **GLOBAL DATABASE OF GSSR MARS DELAY-DOPPLER RADAR OBSERVATIONS: ANALYSIS FOR LANDING SITE CHARACTERIZATION AND ROVER TRAFFICABILITY.**
A. F. C. Haldemann, R. F. Jurgens, M. A. Slade, T. W. Thompson, and F. Rojas*

12:05 **LUNCH**

TUESDAY 21 JUNE: AFTERNOON

GENERAL CONSIDERATIONS AND LANDING SITE TOOLS

CHAIRS: Jim Rice and Marty Gilmore

1:45 **SITE SELECTION FOR THE MGS 2001 MISSION: AN ASTROBIOLOGICAL PERSPECTIVE.**
Jack Farmer, David Nelson, Ronald Greeley, Harold Klein, and Ruslan Kuzmin*

2:00 **THE VALUE OF CONTEXT IMAGES AT THE MARS SURVEYOR LANDING SITES: INSIGHTS FROM DEEP OCEAN EXPLORATION ON EARTH.**
M. H. Bulmer and T. K. Gregg*

2:15 **A VIRTUAL COLLABORATIVE ENVIRONMENT FOR MARS SURVEYOR LANDING SITE STUDIES+**
V.C. Gulick, G. A. Briggs*, D. G. Deardorff, K. P. Hand, and T. A. Sandstrom*

2:30 **WEB-BASED GIS SUPPORT FOR SELECTION OF THE MARS 2001 LANDER SITE.**
*T. M. Hare and K. L. Tanaka**

2:45 **TOPOGRAPHIC EVALUATION OF MARS 2001 CANDIDATE LANDING SITES: A MGS-VIKING SYNERGISTIC STUDY.**
J. M. Moore, P. M. Schenk, and A. D. Howard*

3:00 **BREAK AND POSTER SESSION**

POSTERS

CANDIDATE-LANDING SITES AND BACKUPS FOR THE MARS SURVEYOR PROGRAM IN THE SCHIAPARELLI. CRATER REGION
Nathalie A. Cabrol, Edmond. A. Grin, and Kevin Hand

POTENTIAL LANDING SITES FOR THE 2001 LANDER IN THE NOACHIAN HIGHLANDS AND IN VALLES MARINERIS.
N. Mangold, F. Costard, P. Masson and J.-P. Peulvast

VIKING HIGH-RESOLUTION TOPOGRAPHY AND MARS '01 SITE SELECTION: APPLICATION TO THE WHITE ROCK AREA.
K. L. Tanaka, Randolph L. Kirk, D. J. Mackinnon, and E. Howington-Kraus

CONCEPT MAPPING AS A SUPPORT FOR MARS LANDING SITE SELECTION
Nathalie A. Cabrol and Geoffrey A. Briggs

A VIRTUAL COLLABORATIVE ENVIRONMENT FOR MARS SURVEYOR LANDING SITE STUDIES
Virginia C. Gulick, Geoffrey A. Briggs, D. Glenn Deardorff, Kevin P. Hand, and Tim A. Sandstrom*

HIGHLAND CANDIDATE SITES (Longitudes 0-40°W+)

3:45 **A PROPOSED LANDING SITE FOR THE 2001 LANDER IN A HEMATITE-RICH REGION IN SINUS MERIDIANI**
Philip R. Christensen, Joshua Bandfield, Victoria Hamilton, and Steven Ruff*

4:00 **2001 SITE IN NORTH TERRA MERIDIANI: THE TES CONCENTRATION AREA**
*M. G. Chapman**

4:15 **SAMPLING THE OLD AND THE NEW: LANDING SITE PROPOSALS FOR THE DICHOTOMY BOUNDARY (6°S, 210°W) AND THE ARES VALLIS HEADLANDS (2°S, 18°W)**
*N.T. Bridges**

4:30 **POTENTIAL HIGHLANDS LANDING SITES FOR MARS SURVEYOR 2001.**
*Nadine G. Barlow**

4:45 **POTENTIAL LANDING SITES IN MARGARITIFER BASIN, MARGARITIFER SINUS, MARS.**
*John A. Grant**

WEDNESDAY 22 JUNE: MORNING

CANDIDATE SITES WITHIN VALLES MARINERIS AND MEMNONIA (Longitudes: 31-175°W)

CHAIRS: Nathan Bridges and Nadine Barlow

8:45 **GANGES CHASMA LANDING SITE: ACCESS TO SAND SHEETS, WALL ROCK AND LAYERED MESA MATERIAL**
*James W. Rice, Jr.**

9:00 **GANGES CHASMA SAND SHEET: SCIENCE AT A PROPOSED "SAFE" MARS LANDING SITE.**
*Ken. S. Edgett**

9:15 **THE CONFLUENCE OF GANGES AND EOS CHASMAS (5-12°S, 31-41°W): GEOLOGIC, HYDROLOGIC, AND EXOBIOLOGIC CONSIDERATIONS FOR A LANDING SITE AT THE EAST END OF VALLES MARINERIS.**
*S. M. Clifford and J. A. George**

9:30 **POTENTIAL 2001 LANDING SITES IN MELAS CHASMA, MARS.**
C. M. Weitz, B. K. Lucchitta, and M. G. Chapman*

9:45 **POTENTIAL MARS 2001 SITES COINCIDENT WITH MAGNETIC ANOMALIES.**
*M. S. Gilmore**

10:00 **NORTHERN MEMNONIA AREA: A POTENTIAL SITE FOR "MODERN" GROUND WATER.**
Ronald Greeley and Ruslan Kuzmin*

10:15 **COFFEE BREAK**

CANDIDATE SITES WITHIN AEOLIS, ELYSIUM AND TERRA CIMMERIA (Longitudes 185 – 241°W)

10:30 **CANDIDATE MARS SURVEYOR LANDING SITES NEAR APOLLINARIS PATERA**
*Virginia C. Gulick**

10:45 **THE MARS SURVEYOR PROGRAM, HUMAN EXPLORATION OBJECTIVES AND THE CASE FOR GUSEV CRATER, MARS**
Nathalie A. Cabrol, Edmond. A. Grin, and Kevin Hand*

11:00 **GEOLOGY AND LANDING SITES OF THE ELYSIUM BASIN-TERRA CIMMERIA REGION, MARS**
D.M. Nelson, J.D. Farmer, R. Greeley, H.P. Klein, R.O. Kuzmin*

11:30 **PROPOSED MARS SURVEYOR 2001 LANDING SITE AT "IBISHEAD PENINSULA", SOUTHERN ELYSIUM PLANITIA.**
T. J. Parker and J. W. Rice, Jr.*

11:45 **A HIGHLAND STRATEGY FOR THE MARS 2001 MISSION: NORTHWESTERN TERRA CIMMERIA.**
*R. A. De Hon**

12:00 **LUNCH**

WEDNESDAY 22 JUNE: AFTERNOON

HIGHLANDS CANDIDATE SITES WITHIN TERRA CIMMERIA, ISIDIS AND SINUS SABAEUS (Longitudes 246-348°W)

CHAIRS: Larry Crumpler and Cathy Weitz

1:30 **THE AMENTHES TROUGH, MARS: NOACHIAN FLUVIAL/MASS-WASTING SEDIMENTS FOR INVESTIGATION BY THE MARS 2001 LANDER.**
*K. L. Tanaka**

1:45 **A CANDIDATE LANDING SITE WITHIN A FLUVIALLY BREACHED CRATER IN THE SOUTHERN HIGHLANDS OF MARS**
James R. Zimbelman and James W. Rice, Jr*

2:00 **HIGHLAND VALLEY NETWORKS AND EPHEMERAL LAKE BASINS, LIBYA MONTES, SW ISIDIS BASIN MARGIN.**
*L. S. Crumpler**

2:15 **LYBIA MONTES: A SAFE, ANCIENT CRATERED TERRAIN, MARS SURVEYOR LANDING SITE AT THE ISIDIS BASIN RIM.**
A. F. C. Haldemann, R. C. Anderson, and W. Harbert*

2:30 **TWO CRATER PALEOLAKE SITES THAT MEET PRELIMINARY ENGINEERING CONSTRAINTS FOR THE ATHENA LANDER MISSION.**
R D. Forsythe and C. R. Blackwelder*

2:45 **COFFEE BREAK**

3:15 **SUMMARY AND DISCUSSIONS OF CANDIDATE LANDING SITES, COMMUNITY RECOMMENDATIONS OF CANDIDATE SITES BASED ON ENGINEERING AND SCIENCE**
MODERATORS: MIKE CARR & TBD

5:15 **SUBMISSION OF COMMUNITY RECOMMENDATIONS OF CANDIDATE LANDING SITES TO THE MS 2001 PROJECT**

*Speaker
+Both talk and poster

ABSTRACTS SUBMITTED FOR PRINT ONLY

LANDING SITE STUDIES USING HIGH RESOLUTION MGS CRATER COUNTS AND PHOBOS-2 TERMOSKAN DATA
William K. Hartmann, Daniel C. Berman, Bruce H. Betts.

STRATEGIES AND RECOMMENDED TARGETS FOR MARS SURVEYOR PROGRAM LANDING SITES.
James W. Rice

GANGES CHASMA: A POTENTIAL LANDING SITE
Ruslan Kuzmin and Ronald Greeley

AMENTHES RUPES AREA: A POTENTIAL SITE FOR ANCIENT FLUVIAL DEPOSITS.
Ruslan Kuzmin and Ronald Greeley

SHALBATANA VALLIS: A POTENTIAL SITE FOR ANCIENT GROUND WATER
Ronald Greeley and Ruslan Kuzmin

PALEOLAKE DEPOSITS IN CENTRAL VALLES MARINERIS: A UNIQUE OPPORTUNITY FOR 2001.
Bruce Murray

ESTIMATING SURFACE ROUGHNESS AT SCALES BELOW SENSOR RESOLUTION
Michael K. Shepard

MANGALA VALLES PALEOLAKE LANDING SITE.
K.L. Tanaka and M. G. Chapman

Candidate Landing Sites Proposed for the Second Mars Surveyor Landing Site Workshop, June 22-23, 1999 at SUNY-Buffalo, Buffalo, New York

#	Name	Latitude	Longitude	Proposer	Site Environment
1	Amenthes Boundary	2.5N	241.5W	N. Barlow	Ancient terrain / paleofluvial / lava flows
2	Amenthes Rupes	2.9S	249.5W	R. Greeley and R. Kuzmin	Paleofluvial / impact crater
3	Amenthes Trough	1.7S	246.4W	K. Tanaka	Highlands plain with variable geology
4	Apollinaris Chaos	11.1S	188.5W	D. Nelson, J. Farmer, R. Greeley, H. Klein, R. Kuzmin	Hydrothermal / paleolacustrine / outflow / lowlands
5	Apollinaris Patera 1	~8.5S	~187.5W	V. Gulick	Paleofluvial / long-lived hydrothermal / paleolake or ocean environment / Highlands-Lowlands boundary
6	Apollinaris Patera 2	~12S	~185.5W	V. Gulick	Paleofluvial_/_long-lived hydrothermal / paleolake or ocean environment / Highlands-Lowlands boundary
7	Apollinaris Patera 3	8.5 S	188	M. Bulmer and T. Gregg*	
8	Arabia Terra	12S to 3N	310W to 342W	J. Rice	
9	Ares Vallis Headlands	2S	18W	N. Bridges	
10	Candor Mensa	6.5S	73.5W	B. Murray	
11	Confluence Plain of Samara, Parana/Loire, and Margaritifer Valles 1	10.00S	21.79W	J. Grant	Paleofluvial environment
12	Confluence Plain of Samara, Parana/Loire, and Margaritifer Valles 2	10.85S	21.62W	J. Grant	Ancient fluvial environment
13	Dichotomy Boundary	6S	210W	N. Bridges	Highlands / lowlands

14	S. Elysium	2.5S	196.5W	T. Parker	Eroded highlands
15	Eos Chasma	10.5S	37.1W	S. Clifford and J. George	Paleofluvial environment
16	Escalante Crater Region	2N	240.5W	J. Moore, P. Schenk, A. Howard	
17	Evros Basin	10S	348W	R. Forsythe and R. Blackwelder	Paleolake / saltpan basin
18	Ganges Chasma 1	8.5S	43.9W	R. Greeley and R. Kuzmin	Paleofluvial / paleolake
19	Ganges Chasma 2	8.8S	42.5W	R. Greeley and R. Kuzmin	Paleofluvial / paleolake
20	Ganges Chasma 3A	7.9S	49.3W	J. Rice	Sand sheet
21	Ganges Chasma 3B	8.1S	48W	J. Rice	Sand sheet
22	Ganges Chasma 3C	7.4S	49.5W	J. Rice	Layered mesa
23	Ganges Chasma 4	6.5S	37W	S. Clifford and J. George	Paleofluvial environment
24	Ganges Sand Sheet	8.0S	49.3W	K. Edgett	Sand sheet deposit
25	Gusev Crater	14S	184W	N. Cabrol and E. Grin	Impact crater / paleolake basin
26	Hematite Deposit	~2N to 3S	353W to 5W	J. Moore and P. Schenk	Ancient highlands / paleolacustrine environment
27	Hematite Site 1	1.5S	6W	M. Chapman	Ancient fluvial / possible hydrothermal environment
28	Hematite Site 2	1N - 3S	0 to 8W	P. Christensen and the TES team	
29	Iani Chaos Region	5S	21W	N. Barlow	Ancient terrain / lava flows
30	Ibishead Peninsula, Elysium Basin	1.5-3.5S	195-198W	T. Parker and J. Rice	
31	Libya Montes/Isidis Planitia 1	3.77N	277.6W	L. Crumpler	Ancient fluvial environment / highlands-lowlands boundary

32	Libya Montes/Isidis Planitia 2	2N	276.5W	L. Crumpler	Ancient fluvial environment / highlands-lowlands boundary
33	Lybia Montes 1A	2.8N	273W	A. Haldemann, R. Anderson, W. Harbert	Reworked or altered ancient highland material
34	Lybia Montes 1B	3.0N	272.9W	A. Haldemann, R. Anderson, W. Harbert	Reworked or altered ancient highland material
35	Lybia Montes 1C	3.0N	272.0W	A. Haldemann, R. Anderson, W. Harbert	Reworked or altered ancient highland material
36	Lybia Montes 1D	3.1N	272.0W	A. Haldemann, R. Anderson, W. Harbert	Reworked or altered ancient highland material
37	Lybia Montes 2	2N	273W	N. Mangold, F. Costard, P. Masson, J.-P. Peulvast	Paleofluvial / ancient crustal environment
38	Magnetic Anomaly Site 1	8.29S	202.1W	M. Gilmore	Highland / lowlands, positive magnetic anomaly, paleofluvial environment
39	Magnetic Anomaly Site 2	13.2S	165.2W	M. Gilmore	Ancient terrain, paleofluvial environment
40	Mangala Valles	6.3S	153.2W	K. Tanaka	Paleolacustrine environment
41	Melas Chasma 1A	11.5S	71.0W	C. Weitz, B. Lucchitta, M. Chapman	
42	Melas Chasma 1B	11.5S	71.4 W	C. Weitz, B. Lucchitta, M. Chapman	
43	Melas Chasma 1C	11.6S	72.1W	C. Weitz, B. Lucchitta, M. Chapman	
44	Melas Chasma 1D	10.4S	73.2W	C. Weitz, B. Lucchitta, M. Chapman	
45	Melas Chasma 2	10S	73W	N. Mangold, F. Costard, P. Masson, J.-P. Peulvast	
46	Memnonia Valley	11.2S	178.2W	D. Nelson, J. Farmer, R. Greeley, H. Klein, R. Kuzmin	Paleofluvial / paleolacustrine

47	N. Memnonia 1	11.3S	174.2W	R. Greeley and R. Kuzmin	Paleofluvial / potential "modern" ground water site / transition highlands-lowlands zone
48	N. Memnonia 2	11.2S	187.2W	J. Farmer and D. Nelson	Paleofluvial / lacustrine
49	Meridiani	4.5S	5W	T. Parker	Dissected highlands
50	Palos Crater	2.5S	249.5W	J. Zimbleman	Paleolactrine / fluvial
51	Ravi Vallis	2.8S	40.8W	N. Barlow	Ancient terrain / outflow channel environment
52	Reuyl Crater 1	9.9S	192.8W	J. Farmer and D. Nelson	Paleofluvial / possible hydrothermal environment
53	Reuyl Crater 2	9.9S	192.8W	D. Nelson, J. Farmer, R. Greeley, H. Klein, R. Kuzmin	Paleolacustrine / possible hydrothermal environment
54	Schiaparelli Crater	2.5S	343W	N. Cabrol and E. Grin	Impact crater / paleolake basin
55	Shalbatana Vallis 1	0.2N	46.3W	R. Greeley and R. Kuzmin	Ancient ground water / outflow channel site
56	Shalbatana Vallis 2	0.7N	44.5W	R. Greeley and R. Kuzmin	Ancient ground water / outflow channel site
57	Sinus Sabaeus	9.12S	347.81W	N. Barlow	Ancient terrain / paleofluvial environment
58	Terra Meridiani, SW Schiaparelli	7S	346W	N. Mangold, F. Costard, P. Masson, J.-P. Peulvast	Paleofluvial / possible hydrothermal environment
59	Valles Marineris	4.1S	35.2W	S. Clifford and J. George	Outflow channel environment
60	Central Valles Marineris 1	9.7S	75.3W	B. Murray	
61	Central Valles Marineris 2	11S	73.5W	B. Murray	
62	White Rock Basin	7.8S	334.75W	R. Forsythe and R. Blackwelder	Paleolake / saltpan basin

* Site withdrawn

ABSTRACTS

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POTENTIAL HIGHLANDS LANDING SITES FOR MARS SURVEYOR 2001.

Nadine G. Barlow, Department of Physics, University of Central Florida, Orlando, FL 32816. ngb@physics.ucf.edu.

The original plan for the Mars Surveyor 2001 lander was to land in a location which may have been conducive to ancient martian life and use the sampling capabilities of the rover to collect materials which could contain biogenic evidence. However, the recent revisions to the mission architecture removes the sampling capabilities and thus changes the goal of this mission to exploring the landing location with a rover similar in design to Sojourner but carrying the more detailed Athena rover science instrumentation. Although identifying locations which may have been conducive to the existence of martian life is still a major emphasis of this mission, the lack of sampling capability means that this mission will be more focused on providing in-depth information about the landing area. The heavily cratered southern highlands will be a prime location for the Mars Surveyor 2001 lander for the following reasons: (1) the ancient age of this region provides the opportunity to investigate soil and rocks formed early in martian history, and (2) most models of Mars' geologic history indicate that conditions conducive to the existence of martian lifeforms were present only during the period when the highlands existed. Thus, a highlands landing site would provide a new perspective of martian geologic history, including information about sites which may have been able to support ancient life. This is a perspective lacking from current surface lander investigations due to their location on the younger northern plains.

The engineering constraints combined with the limited high-resolution Viking coverage have severely restricted the possible range of landing sites. Using the maps located on the MS01 Landing Site web page for elevation, rock abundance, thermal inertia, and Viking coverage, I have identified four highlands sites which could provide interesting environments for the study of ancient martian materials. These sites, in order of possible interest, are as follows: (1) Sinus Sabaeus (9.12°S 347.81°W): (2) Ravi Vallis region (2.8°S 40.8°W); (3) Amenthes Boundary area (2.5°N 241.5°W); and (4) Iani Chaos region (5°S 21°W). Table 1 provides information on the regions surrounding each of the proposed landing sites (55-km diameter circles centered on the proposed landing site).

Site 1: Sinus Sabaeus (9.12°S 347.81°W). This proposed landing site is located in the Terra Sabaea region south of the Schiaparelli impact basin (Figure 1). The region is mapped as Noachian aged dissected plains (Npld) [1] and contains numerous small valley network channels. The proposed landing site is in a smooth region near the confluence of many of these channels and may represent channel depositional material. Thus this site provides the opportunity to analyze possible fluvial deposits originating from the surrounding Noachian-aged terrain. A few small craters (<5-km diameter) are found in the landing site region but ejecta deposits are probably rare since few large fresh craters which could provide such ejecta are seen in the immediate area. Based on information from the web site maps, this region has an elevation of <1.5 km, a fine component thermal inertia value between 4 and 5, and approximately 5% rock abundance. Viking Orbiter imagery of this region includes resolutions between 32 and 42 m/px. The disadvantage to this site is its possible roughness. The high-resolution Viking imagery indicates that the landing site region (see Table 1 for boundaries) is dissected by a number of ridges and gullies, likely produced by the valley network channeling or other fluvial activity. In particular, the regions directly east and west of the proposed landing site (but within the landing ellipse) appear quite rough. A few small craters (<3-km-diameter) are found within the landing site region and the northeast boundary of the 55-km-diameter circle centered on the landing site crossed the fluidized ejecta blanket of an 8.3-km-diameter crater . Nevertheless, this site provides a good opportunity to study material emplaced by ancient fluvial activity and perhaps an area where water ponded for some period of time.

Site 2: Ravi Vallis region (2.8°S 40.8°W). Ravi Vallis is an outflow channel located west of Hydraotes Chaos. It is located on Noachian-aged subdued cratered unit (Npl2) [2] which are interpreted to be thin lava flows. A smaller structurally controlled channel is found south of Ravi Vallis. To the southeast of these channels is a smooth region. The proposed landing site is on this smooth region (Figure 2). This site would allow examination of possible ancient volcanic lava flows and possibly some fluvial deposits from the channels to the north, although this possibility seems small considering the direction of water flow. There are several small craters in the landing site region, many of which are elongated and oriented in a northwest-southeast direction. These are interpreted as secondary craters. The source of these secondaries is not clear from imagery of the area, but one possibility is the 113-km-diameter crater from which Shalbatana Vallis emanates. The evidence of secondary craters in this region suggests that material excavated from depth by impact craters is likely to be found in this region. In addition to the secondary craters, a 20-km-diameter crater with a fluidized ejecta blanket is located to the northeast of the landing site. The northeastern boundary of the landing site region abuts this ejecta blanket of this crater. This site has an elevation <1.5 km, has a fine component thermal inertia value between 6 and 8, and has an 8-10% rock abundance. Viking imagery with resolutions between 66 and 80 m/px have been identified for this site.

Site 3: Amenthes Boundary area (2.5°N 241.5°W). Site 3 is located in Noachian-aged dissected plains material [1] south of the highlands-plains dichotomy boundary (Figure 3). This area has numerous channels and ridges crossing it and is proposed to be ancient volcanic lava flows affected by fluvial erosion. The landing site is north of a highly eroded 64-km-diameter crater. High resolution Viking imagery suggests that some of the material near the landing site may be the old dissected ejecta blanket from this crater. A 12-km-diameter crater with a fresh fluidized ejecta blanket is located to the northeast of the proposed landing site. Thus this landing site provides the opportunity to examine possible old volcanic material as well as material excavated from depth by older and younger impact craters. The disadvantage of this site is that the dissection of the terrain and possible ejecta deposits may make this area too rough for a safe landing. This site has an elevation of about 1.5 km, a fine grained TI component of about 6, and 5-10% rock abundance. The best Viking imagery of this area has resolutions between 20 and 89m/px.

Site 4: Iani Chaos region (5°S 21°W). Site 4 is located on smooth material of the Xanthe Terra region mapped as Noachian-aged subdued crater unit (Npl2) by Scott and Tanaka [2]. The proposed landing site is located west of the Iani Chaos region (Figure 4). The area is interpreted an ancient thin volcanic lava flows. There several small (<1.5-km-diameter) impact craters within the 55-km-diameter circle centered on the landing site. Most large craters in this region are heavily eroded and any ejecta deposits emplaced by them are likely weathered beyond recognition. No obvious indication of fluvial activity is seen in this region. The primary information that could be obtained in this location would data on old volcanic lava flows and weathered volcanic material. The advantage of this site over the three previously described locations is the smoothness and low rock abundance of the landing site region. This area has an elevation of less than 1.5 km, a fine grained TI component between 6 and 8, and about a 5% rock abundance. The best Viking orbiter imagery of this area has resolutions of 32 m/px.

References: [1] Greeley R. and J. E. Guest (1987), *U.S.G.S. Mis. Invest. Series Map I-1802-B.* [2] Scott D. H. and K. L. Tanaka (1986), *U.S.G.S. Misc. Invest. Series Map I-1802-A.*

Figure 1: Proposed landing site in Sinus Sabaeus (Site 1).

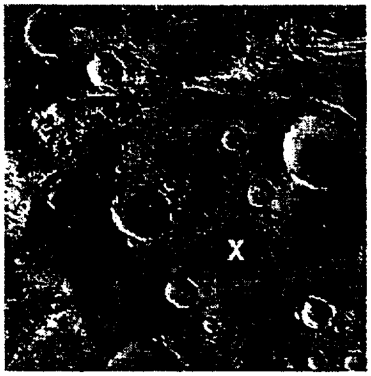

Figure 2: Proposed landing site in the Ravi Vallis area (Site 2).

Figure 3: Proposed landing site in the Amenthes Boundary area (Site 3)

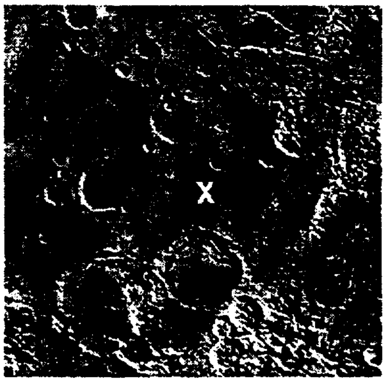

Figure 4: Proposed landing site in Iani Chaos region (Site 4).

TABLE 1: PROPOSED HIGHLANDS LANDING SITES

	Site 1	Site 2	Site 3	Site 4
	Sinus Sabaeus	Ravi Vallis Region	Amenthes Boundary	Iani Chaos
Center Latitude, Longitude	9.12S, 347.81W	2.8S, 40.8W	2.5N, 241.5W	5S, 21W
Corner Latitude, Longitude				
NW Corner	8.7S, 348.3W	2.4S, 41.12W	2.85N, 241.85W	4.55S, 21.2W
NE Corner	8.7S, 347.4W	2.5S, 40.3W	2.85N, 241.15W	4.82S, 20.5W
SW Corner	9.55S, 348.3W	3.1S, 41.2W	2.15N, 241.85W	5.2S, 21.45W
SE Corner	9.55S, 347.4W	3.2S, 40.5W	2.15N, 241.15W	5.5S, 20.75W
Elevation	1-2 km	1-2 km	1-2 km	1-2 km
Rock Abundance (%)	5%	8-10%	5-10%	5%
TI (fine grain component)	4-5	6-8	6	6-8
Type of Site	Highlands	Highlands	Highlands	Highlands
Stratigraphic Unit	Npld	Npl2	Npld	Npl2
Fluvial Activity	VN site/paleolake?	Outflow channel to N	Sheet floods?	None
Excavation?	Nearby craters	Secondary craters	On possible ejecta	Nearby craters
Image numbers/Resolution	436A58 32m/px	911A07 66m/px	721A16 20m/px	378B18 32m/px
	436A82 42m/px	014A13 69m/px	099A45 79m/px	
	436A84 42m/px	014A15 69m/px	099A25 84m/px	
		012A65 70m/px	099A05 89m/px	
		012A84 80m/px		
		012A86 80m/px		

Sampling the Old and the New: Landing Site Proposals for the Dichotomy Boundary (6°S, 210°W) and the Ares Vallis Headlands (2°S, 18°W)

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Introduction

One of the goals of the Mars Pathfinder mission was to sample a diversity of rocks deposited by the Ares and Tiu Vallis floods [1]. It was hoped that ancient highlands and younger lowlands material could be studied, as well as a diversity of rocks within these regions. Although Pathfinder found rocks that exhibited a number of textures and morphologies, several factors precluded the identification of a petrologic suite of rocks, if it was present. Namely among these were 1) The lack of geologic context for the rocks examined, 2) instrument limitations, and 3) pervasive dust and possible weathering rinds. Based on the Pathfinder experience and incorporating resent results from Mars Global Surveyor and previous missions, two landing sites are proposed that can potentially overcome this problem and offer samples of ancient and recent Martian rock. The first site is at the dichotomy boundary, where ancient highlands and more recent lowlands meet. The second site is at the Ares Vallis headlands, where some of the source materials for the Pathfinder landing site may have been derived. Both of these sites meet the remote sensing and elevation constraints of the 2001 Lander mission but exhibit significant slopes and potential hazards in places. However, a properly placed ellipse can alleviate much of the concern, thereby offering two exciting sites that otherwise would not be chosen.

Site 1: The Dichotomy Boundary (6S, 210W)

The crustal dichotomy is the major geologic and structural division between the southern highlands and northern lowlands. Its origin has been attributed to internal convection [2, 3], an impact basin [4], multiple impacts [5] and other hypotheses. Most workers agree that it is one of the most ancient preserved features of the Martian crust [6].

A landing site on relatively flat northern plains near inliers of highlands offers the exciting possibility of sampling and acquiring high resolution images of both units. As shown in Figure 1, a rover traverses could visit several knobs and mesas where ancestral highlands rocks and stratigraphy would be expected.

This region has overlapping Viking image coverage at 15 m pixel. The nearest high resolution MOC image is centered at 4.17°S, 206.03°W and reveals a fluted surface. The fine component thermal inertia, rock abundance, and elevation are within the 2001 landing constrains (Table 1).

Site 2: Ares Vallis Headlands (2°S, 18°W)

The headlands of Ares Vallis consists of jumbled blocks in Iani Chaos that may have formed from removal of artesian water or ice that fed the outflow channels [7, 8]. The mechanism by which this occurred is not known. Possible origins include magma/water interaction and overpressure on a confined aquifer [9]. By examining the geomorphology and geochemistry of this region, insight will be gained in the processes that formed the outflow channels. The types of rocks deposited at the Pathfinder landing site, a small percentage of which may have been derived from the headlands, can also be investigated.

Viking image coverage at up to 27 m/pixel is available. A MOC image, 8903, imaged the area at -2.17°, 14.65° and reveals an assortment of eroded knobs. Remote sensing properties and elevation are within the constraints of the 2001 mission (Table 1). Compared to Site 1, this location presents more hazards and is considered a less probable landing site locale.

Conclusions

Both of the sites contain hazards in the form of mesas and knobs. At the same time, they have acceptable remote sensing properties and exhibit very interesting geology. Although they may not be at the top of the list for the Mars 2001 mission, it is urged that they and similar locales at least be considered as possible alternate locations that can provide interesting science.

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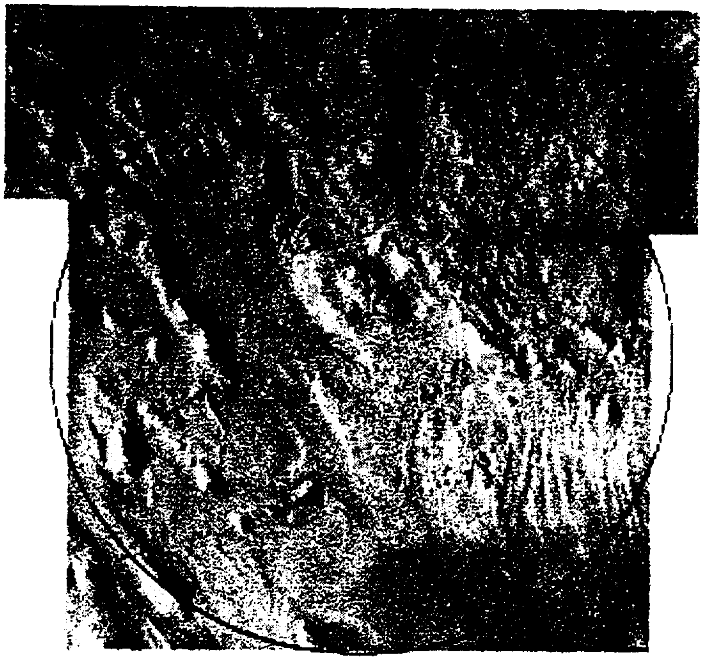

Figure 1: Possible landing site near the dichotomy boundary near 6°S, 210°W. 20 km landing circle, landing location (x), and potential rover traverse paths are shown. The rover traverses are probably the maximum that can be achieved with Marie Curie.

Table 1: Landing Site Data

Property	Site 1	Site 2
Location for Data	6.5°S, 210.5°W	2.5°S, 18.5°W
FC Inertia	5.7	8.7
Bulk Inertia	6.1	9.1
Albedo	0.27	0.19
% Rocks	5	8
Elevation	-0.172	-1.036

THE VALUE OF CONTEXT IMAGES AT THE MARS SURVEYOR LANDING SITES: INSIGHTS FROM DEEP OCEAN EXPLORATION ON EARTH.

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Exploration of the Martian surface with a rover is similar to investigation of Earth's oceans using remotely operated vehicles (ROVs) or deep submergence vehicles (DSVs). In the case of Mars, the techniques required to perform a robust scientific survey are similar to those that have been developed by the deep ocean research community. In both instances, scientists are challenged by having to choose and characterize a target site, identify favorable sites for detailed analysis and possible sample collection, only being able to maneuver within a few meters of the landing site and integrating data sets with a range of spatial resolutions that span 1-2 orders of magnitude (rover data versus satellite data, or submersible data versus bathymetric data). In the search for biologic communities at Earth's mid-ocean ridges, it is important to note that the vast majority of the terrain is completely barren of life: no microbes live in the thousands to hundreds of thousands of meters that separate the life-sustaining hydrothermal vent fields [1].

In attempts to better understanding the origin and emplacement of geologic and biologic features on the seafloor, techniques have been developed to select sites of special interest (target sites), by combining the low-resolution, high spatial-coverage data with medium-resolution, higher spatial-coverage data [2]. Once individual sites are selected, then a DSV or ROV is used to obtain high-resolution, low-spatial-coverage data. By integrating the different resolution data sets, the individual target sites can be placed into the larger context of the regional and global geologic system. Methods of exploration of the oceans are pertinent to the Mars Lander Missions because they highlight the importance and value of the acquisition of 'context' images.

Over 60% of Earth's mid-ocean ridge crests have been surveyed using multibeam bathymetry. The typical resolution of such data is 100 m in the vertical and 20 m in the horizontal. This data set is comparable to the Viking Orbiter images of Mars. Only 7% of Earth's seafloor has been imaged using side-scan sonar systems which are towed behind a surface ship at an altitude of ~20 m to 200 m above the seafloor. This data set provides textural information on the target surface. The resolution of these instruments varies from 50 m for GLORIA to 1 m across and 2-4 m in the vertical for the DSL-120. Higher resolution is provided by camera sleds such as ARGO II, which is towed at altitudes of ~3 - 15 m above the seafloor. Videos on these instrument platforms can provide continuous real-time video imagery via a fiber-optic tether. Still and video photographic and digital images are typically collected every ~10 - 15 seconds. The typical field of view of images from these cameras is 5 m. Added flexibility is provided when DSVs such as Alvin are used since they are capable of more autonomous exploration and can collect and return samples.

Lessons learned: Detailed site investigations of the ocean floor and of planetary surfaces share the common burdens of being both costly and time consuming, making appropriate site selection and the achievement of science goals vital. The methodology adopted to achieve these tasks and goals is to collect low-resolution but high aerial coverage data, and then to improve image resolution at the expense of aerial coverage as the list of possible sites is reduced. However, selecting the 'appropriate' or optimum resolution is a difficult problem, one dependent on many factors, not least of which is what the goal(s) of the exploration maybe.

On a recent survey of the Puna Ridge [3], the WHOI DSL-120 deep-towed vehicle was used to obtain side-scan sonar acoustic imagery, co-registered fine-scale bathymetry, and high resolution data along the crest of the Ridge and one region on its southeast flank. These data were used to plan the flight-path of the ARGO II sled. ARGO II photographic imagery from seven survey regions was used to provide geologic groundtruth, to understand the detailed morphology of the volcanic surfaces, and to select sites suitable for wax coring and dredging. Analysis of the DSL-120 data was complicated by the nature of the terrain and changes in elevation along the Ridge. ARGO II was configured with four still (two of which were for navigation only and had no recorded data stream) and two video cameras (as well as the necessary illumination), a forward and side-looking sonar, an altimeter as well as standard sensors for attitude, heading, pressure depth, acceleration and navigation. Cameras used where: 1) a color camera with a 4.8 mm lens positioned to be down-looking; 2) a Silicon Intensified Target (SIT) black and white camera with a 8.4 mm lens, mounted to be forward-looking; 3) a 35 mm still camera with a 28 mm lens synchronized to a

400 watt/second strobe, mounted to be down-looking; and 4) an Electronic Still Camera (ESC) with a 16 mm lens mounted adjacent to the 35 mm still camera. Due to the changing altitude of AGRO caused by ship motion on the tether, the field of view (FOV) was variable but at 5 m above the seafloor the horizontal FOV for the ESC was 4 m and the vertical FOV was 2.8 m. During 139.5 hours of explorations ARGO II covered 31.3 nautical miles, acquiring 29,320 images along with 125 hours of color and black and white video.

Using the data collected during this survey to achieve the science goals of understanding the formation and evolution of the Puna Ridge, a number of difficulties have arisen. It has not been easy to integrate the DSL-120 sonar data which covers a large aerial extent with the high-resolution low spatial photographic coverage from ARGO. The need has arisen for a 'context' image data set at a resolution in between that of the DSL-120 data and that from ARGO. This is not a problem that is easily addressed without another survey. A solution has been the design of a different instrument configuration which specifically incorporates the acquisition of context images. This is achieved by attaching an open framed, towed vehicle equipped with a SIT camera at a transition point from the main tow cable to main instrument sled. Typical altitudes for this second and smaller vehicle are between 20 and 30 m, providing context images of the seafloor being imaged by the main instrument sled at higher resolutions.

Mars Exploration: A similar desire for context images for target sites, arose in the analysis of data from the Mars Pathfinder Mission [4]. It proved to be difficult to integrate Viking Orbiter and lander images. Due to unforeseen problems with Mars Global Surveyor, results from the MOC are being released at a slower rate than originally planned. MOC data of the surface of Mars at the highest resolution has not been available for the Mars '98 lander, nor for the selection of the Mars '01 lander. However, the recent completion of the 100 m/pixel global image set provides a very useful addition to resources available to assist in the selection of suitable landing sites. Both the Mars '98 and '01 landers have descent imagers. Based on our experience in deep sea exploration, we believe that the images that will be acquired by these descent imagers will be of extremely high scientific value and allow for significantly improved integration of the orbital images with those from the landers.

The Descent Imagers on the Mars '98 and '01 missions, built by Malin Space Science Systems, will be similar [5]. The Mars Surveyor '98 Descent Imager MARDI will produce panchromatic wide-angle views (3.4° FOV) of the Martian surface beginning about 10 seconds after the lander's parachute has been deployed, at approximately 8 kilometers (5 miles) in altitude, until its landing. Image resolutions will span almost three orders of magnitude in scale, from roughly 8 m/pixel to 1 cm/pixel, while covering areas from 8 km to 10 m across. These images will be stored in the spacecraft DRAM for later transmission to earth. It is anticipated that the descent images will 1) provide both a local and regional setting for the '98 and '01 landers; 2) provide a link between the landing site and orbital data sets; and 3) serendipitously discover evidence of geomorphic processes at scales between those seen from orbit and those from the surface. Based on the value of context images in deep ocean research, we believe that the context images from MADRI will meet all three of these goals. However, the question of the 'appropriate' or optimum resolution for context images for the '01, '03 and '05 landers should continually be re-evaluated in light of the current state of knowledge of the most favored landing site.

Consideration: Given the value of context images, we propose that such images could be acquired by a science package on the lander itself and not just during descent through the atmosphere. In a basic configuration, a camera could be sent aloft from the lander by a balloon or small rocket (with cost, engineering and science implications). The time to launch such a package would be determined from the meteorological instruments that are part of each Mars Surveyor Landers science payload. At an added level of cost and complexity, a camera could be sent aloft that is tethered to the lander. If the tether were on a winch, a controller could determine the height at which images were acquired above the lander. Control of a winch offers the further possibility of multiple ascents and descents, allowing multiple spatial and temporal context images to be acquired.

Conclusion: The acquisition of context images during deep ocean exploration, that are intermediate in resolution between that of low-resolution, large-spatial area, and high-resolution, small-spatial area data, has resulted in significant gains in data integration and interpretation. Based on our experiences, we highlight the importance of acquiring 'context' images for the Mars Surveyor Landers. We advocate continual re-evaluation of optimum resolution of these 'context' images if they are to be acquired on a one-time only basis during lander descent. Further, we propose that consideration be given to a camera package that could be deployed from on-board the lander that could obtain multiple spatial and temporal 'context' images of the local and regional terrain around the lander site. Context images will significantly enhance the integration and interpretation of MOC images and MOLA data with lander images, and should be considered a priority task for lander science teams.

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CONCEPT MAPPING AS A SUPPORT FOR MARS LANDING-SITE SELECTION

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Introduction: The NASA Ames' Center for Mars Exploration (CMEX) serves to coordinate Mars programmatic research at ARC in the sciences, in information technology and in aero-assist and other technologies.

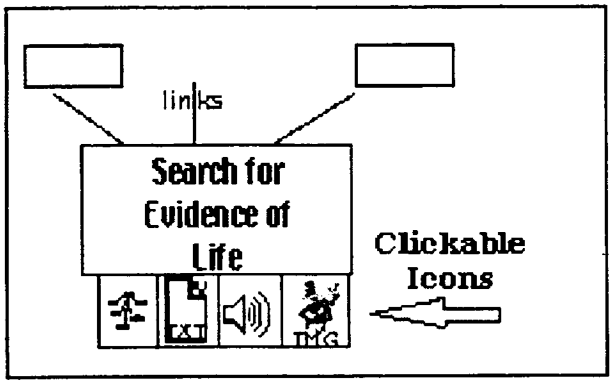
Most recently, CMEX has been working with the Institute for Human and Machine Cognition at the University of West Florida to develop a new kind of web browser based on the application of concept maps. These Cmaps, which are demonstrably effective in science teaching, can be used to provide a new kind of information navigation tool that can make web or CD based information more meaningful and more easily navigable. CMEX expects that its 1999 CD-ROM will have this new user interface.

CMEX is also engaged with the Mars Surveyor Project Office at JPL in developing an Internet-based source of materials to support the process of selecting landing sites for the next series of Mars landers. This activity -- identifying the most promising sites from which to return samples relevant to the search for evidence of life -- is one that is expected to engage the general public as well as the science community. To make the landing site data easily accessible and meaningful to the public, CMEX is planning to use the IHMC Cmap browser as its user interface.

What is a concept map? A concept map is a two-dimensional representation of a set of concepts constructed so that the inter-relationships among them are evident. The overall structure of a concept map constitutes a *hierarchical framework* for the concept included in it. All concepts at any levels in the hierarchy will tend to have similar degree of generality.

The Potential of "C-Maps": Concept maps are read from the top downwards as a series of linked propositions that, together, summarize a topic. Used as an information navigation tool, concept maps provide access to web-based information -- texts, images, audio, video, --.

The different icons associated with the concept boxes identify the nature of the information in question. By clicking on the icons, the reader will access texts and figures, images, videos, or deeper levels of concept map associated to the subject in question (see example in the figure).



Example of concept box associated with clickable icons that lead the reader to texts, images, videos, other concept map levels, etc. that will provide developed information on the subject described by the concept box.

Application to the Landing Site Selection: Concept maps can be used to present candidate-landing sites for the Surveyor Program and show how the proposed sites comply with the science objectives and the engineering constraints of the Surveyor Program. A first level map allows to make the reader acquainted with the most important criteria that demonstrate the importance of the proposed site. The links between boxes displaying the criteria should allow the reader to develop an idea about how these different criteria are related to each other, what are the strenghs and weaknesses, and the existing and missing data. In the end, the concept map will help the reader/reviewer to understand why it is important to take into consideration the site in question. In the future, it is expected that readers/reviewers could have access to "chat" links, where *pro* and *con* discussions concerning the proposed site will be possible. Finally, the concept mapping will provide a standard way to present the many sites proposed by the planetary science community with respecting the originality of each site and its potential. To demonstrate the potential of the "C-Maps", we propose to present the case of Gusev crater using this method.

CANDIDATE-LANDING SITES AND BACKUPS FOR THE MARS SURVEYOR PROGRAM IN THE SCHIAPARELLI. CRATER REGION

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Rationale: Our Survey area comprises the Sinus Sabeus NW quadrangle that includes most of the Schiaparelli crater and part of the Arabia SW region (3N to 15S Lat.) and (0 to 337.5W long.) and covers all regions that show a potential hydrogeological link with the Schiaparelli impact structure. This area is hereafter defined as the Schiaparelli Crater Region.

The Schiaparelli crater region is one of the most documented MOC targets. Up to now, MGS MOC camera took two dozens images at an average of 5m/pxl resolution that not only provide an exceptional insight on the local geology and morphology, but give also key-elements to assess landing safety criteria. In addition, the MOLA topographic profile No. 23 passes through part of the crater basin (Smith et al., 1998) allowing the adjustment of the elevation as previously known from the Viking mission (USGS I-2125, 1991). Beyond the Mars Polar Lander mission that will land next December, the future missions (2001 APEX, 2003, and 2005) are led by a series of science objectives and engineering constraints that must be considered in order to select landing sites that will fulfill the Surveyor Program's objectives. The search for a sound and safe candidate-site (without ending up with the usual "safe but boaring" or "fascinating but too risky" site) is usually limited by the data available to the investigator, by the data accuracy (*e.g.* poor image resolution, poor altimetry), and the by lack of crucial information for science and safety that can be derived from them. The Schiaparelli region provides an exception to this recurrent pattern.

We listed the preliminary constraints for landing site selection identified for the Surveyor '01 mission, in terms of safety requirements and data needed (after Golombek *et al.*, 1999) and compared them against the existing information and/or data already available for the Schiaparelli region. The engineering constraints of '03 and '05 are not designated yet but, since they are also related to atmospheric density and Lander designs, we will assume that these points will be comparable to '01. The main difference will reside in the rover design, the Rocky-7 class rover being bigger than Marie Curie ('01) will be able to overcome bigger obstacles.

We listed then the main objectives of the Surveyor Program and compared them with the potential offered by the Schiaparelli Crater Region to document them.

Within the survey area, the Schiaparelli impact crater is 2.5S/343.3W (USGS I-1376, MC-20 NW, 1981) and occupies a significant surface area. The crater has been proposed as a potential candidate-site in the past years (Rice, 1994, Barlow 1998, Zimbelman 1998, Edgett et al.,1998, Cabrol 1998). The purpose of this study is to show that, not only the Schiaparelli Crater would be a high-priority target, but that the region where it is located offer several very-high potential back-up sites, all within science and engineering constraints, that make this region probably the most promising candidate area so far.

Area 1: Schiaparelli Crater South and Southeast: The crater is about 470 km in diameter and characterized South and East by a series of small gullies and channels (the Brazos Valles). Most of them erode the crater rim and converge toward the basin floor. Other drainage systems located on the south rim are heading away from the crater and join a series of valley networks which supplied a topographic low south of Schiaparelli and North of Evros Vallis. The crater is mentioned in the geologic map of the Sinus Sabeus quadrangle of Mars by Moore (1980), where the it is described as being superimposed on Noachian terrain. Using portions of the MOC image No. 2303, Hartmann et al.,(1999) tried to constrain the age of a unit located north in the crater basin and compared the results to the surrounding 4Gyr-old Arabia Terra. Hartmann et al., (1999) concluded that Schiaparelli is younger than the Arabia Terra formation, and probably 4-3Gyr old. The rim includes rough, hilly, fractured materials that are interpreted as ancient highland rocks and impact breccias (Greeley and Guest, 1987). Moore (1980) and Greeley and Guest (1987) describes the material in the main valley of the Brazos system as being of possible aeolian, fluvial, or volcanic in origin. Rice (1994) proposed that sediments superimposed on the basin floor in the south and southeast parts of the crater are fluvial in origin and possibly dating from Noachian and Hesperian. Barlow (1998) also mentions the plausible role of water in the small gullies that enter Schiaparelli.

- *Science Interests:* Noachian, Hesperian and Amazonian Materials; Evidence for fluvial activity: convergence of fluvial valleys, alluvial and/or deltaic formation in the crater; possible ancient hydrothermal systems; indicators of evaporites as suggested by the presence of high albedo material in the crater. Several potential landing sites with trafficability TBD.

Area 2: Brazos Lakes The new MOC images support the possible role of water for the generation of valleys (Malin and Carr 1999). During Orbit 023, image No. 2306 showed a portion of the Brazos Valles centered at 5.5S/347.7W. The image reveals two important informations: (a) a field of exceptionally bright dunes that covers the bottom of the valley. Bright dunes were first observed in this region by the Viking Orbiter 1 in 1978 with 15m/pxl resolution images. They were located in valleys that debouched northwest in a basin for which Rice (1994) proposed a lacustrine origin. The field of dunes observed by MOC is located in one of the Brazos Valles south of Schiaparelli and might have been active recently (Thomas et al., 1999). These dunes seem to move away from the crater basin into the valley (northwest to southeast), plausibly suggesting that the bright material composing these dunes originates from the crater basin; (b) Similarly bright material is observed on small depressions just south of Schiaparelli. The MGS Imaging team (MOC Release 16-A, B, C, Image No.2036, 1998) proposes that the morphology of the depressions and deposits is similar to dry lake beds with salts or other materials deposited as the lake evaporated. The hypothesis of bright salt deposits could be supported by Viking IRTM measurements (Christensen 1988) showing that a derived albedo of this bright material composing both the dunes and the deposits is ≥ 0.21, when most Martian dunes usually show lower albedo around 0.15 (Edgett and Parker 1998). Thomas et. al., (1999) also propose that the dunes are formed of relatively soft minerals, possibly sulphates which are common components of evaporites. To explain faint dark lines that cross the lighter deposits, an alternate hypothesis involving freezing and thawing of water saturated soil was proposed (MOC Release 16-A, B, C, Image No.2036, 1998, *unpublished*). These observations need to be documented as potential evidence of water ponding on Mars because if verified, this is the type of material that can help achieve some of the most important science objectives of the Surveyor Program (*e.g.* water evolution and favorable environments for life).

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

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

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

Engineering Constraints: The high science interest of the Schiaparelli Crater Region is combined with a favorable configuration for landing that designates this region as a high-priority candidate area for an assessment study and further investigation by MGS. The previous topographic data from the Viking mission placed the 2000 m elevation contour along the rim (USGS I-2125, MC-20 NW, 1991), with a surrounding elevation of the Plateau at an average 3000 m. The central portion of the crater floor corresponding to an approximately 200-km diameter ring was delineated by the 1000-m contour. The recent MOLA altimeter topographic profile No. 23 allows to adjust the crater topography, and shows that the crater and the surrounding region lie significantly lower than previously thought. The floor of Schiaparelli is now located at -500+/-30m (with reference to the Mars datum) and the Plateau West of the crater and immediately South in the region of the Brazos Basin lies between 1000 and 1500 m (Smith et al., 1998).

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

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

The existence of several sites in the same area with similarly high scientific interest provides safety back-ups in case of deviation in ellipse trajectory. In addition, the location of the region is also favorable for solar energy power and potential mission duration as shown by the plots we established for the region of rover solar array energy available (with and without dust cover) and the Lander energy profiles for the Schiaparelli region against the plots proposed by Spencer et al., (1998) for the 01' APEX mission.

Conclusion: The combination of already existing Viking, MOC, and MOLA high quality data and excellent science potential makes the Schiaparelli Crater Region one of the first regions on Mars where an *in-depth* analysis will be possible to reconstruct its hydrogeologic evolution, thus justifies the assessment of its potential as a candidate-landing area for the Surveyor Program and for future human exploration.

THE MARS SURVEYOR PROGRAM, HUMAN EXPLORATION OBJECTIVES AND THE CASE FOR GUSEV CRATER.

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Rationale: It has been demonstrated during the past years that by its configuration, extended history of water ponding and sedimentary deposition, Gusev crater is one of the most favorable sites to consider for the incoming exploration of Mars. It provides exceptional possibilities to document the evolution of water, climate changes, and possibly the evolution of life on Mars through time. Because of all these reasons, it is probably one of the most interesting sites to target for sample return missions and human exploration, but as well, it is by all mean an excellent target for the Surveyor '01, in spite of the current imposed mission constraints, as we propose to demonstrate.

Sciences Objectives: Because they have been developed in many previous publications (see especially Cabrol et al., 1998 *Mars Surveyor 2001* Landing Site Workshop), we will not present all the science arguments again but summarize them in the following tables 1 and 2, and show how Gusev will allow to address the Surveyor Program objectives. We will then develop the rationale to show that there are strong supportive arguments to consider Gusev for '01.

Two candidate-sites in Gusev present comparably high-interest for science return. They are: (a) the Thyra crater (14.5°S/186°W) and the delta of Ma'adim Vallis in Gusev (15°S/184.6°W).

Table 1: Surveyor Program Objectives

Objective	Type of Site
Diverse Geologic Record	Paleolake bed Outflow Runoff outlets
Climate History	Aqueous sediment Lacustrine sediment Deep hydrothermal system
Chemical Evolution	Thermal Springs (possible in Gusev) Lacustrine sediments Aqueous environments
Fossil Life	Thermal Springs Lake beds
Extant Life	Current hydrothermal Sites Frozen in ice Caves Evaporite deposits Endoliths
Resources	Liquid Water/ice

Table 2 Merit and Expected Science Return in Gusev

Science	Merit	Observed Environment
Diversified Geology	high	Crustal mat. Volc/hydroth. mat. Fluvio-lacustrine mat. aeolian mat.
Climate History	high	Fluvio-lacustrine dep. Lacustrine varves
Exobiology	high	2 Gyr of fluvio-lacustrine history Aqueous environment Possible frost mounds (near Thyra only) Possible hydrothermal activity in Thyra
Sampling Diversity	high	Sedimentary rocks Igneous rocks Soil Extinct/extant life (?)
Resources	high	Frost mounds (near Thyra) *need to be documented by MGS*

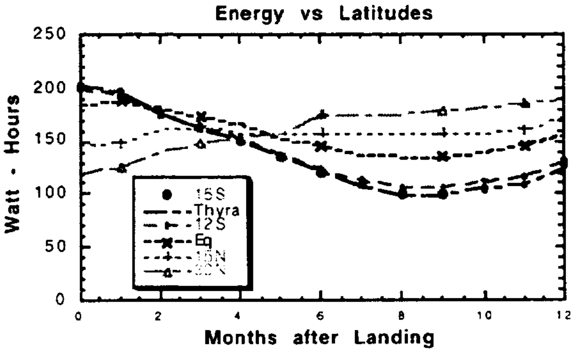
Exobiology and Resources: The existence of possible frost mounds in Gusev has been proposed (Cabrol et al., 1997, 1999). The hypothesis of ice mounds has been tested against volcanism, aeolian and water erosion action on sedimentary deposits. and find support both in the physiography and morphology of the mounds and their lacustrine paleoenvironment (Cabrol et al., 1999). The presence of preserved frost mounds would have critical implications, for it raises the possibility of the existence of current protected subsurface reservoirs of fossil ice, which volume can be significant as shown by the example of Gusev mound No.9 - 420,300 m^3 (Cabrol et al., 1999). The state of preservation of the mounds (shown by only few scar features among the well-preserved structures) indicates that the cores of ice (if ice hypothesis confirmed by new MGS data) are most likely still present under the overburden. We foresee two major implications that are valid not only for Gusev mounds but for Martian pingos and/or masses of segregated ice in general: (1) frost mounds with several meters of overburden that are likely cemented by salts provide an effective protection against the deadly UV bombardment that reaches the surface of Mars, and they provide water; therefore, they could be seen as potential oases for life; (2) large masses of segregated ice are unique potential resources that could be used both by automated robotics and manned missions to generate sources of energy, such as rocket combustible and water. Frost mounds are highly favorable candidates for scout drill missions. According to our current knowledge, the only other (abundant ?) source of liquid water on Mars could be located far from the surface, below one kilometer of frozen breccias and sediment. Although it is absolutely necessary to reach this water in the perspective of human settlement on Mars, such depth will require techniques that might not be ready for the coming robotics (starting 2001) and first manned missions. As a transition, frost mounds could provide sites where lighter equipment could reach the necessary resources and exploit them. The main advantages of frost mounds are that: (a) the ice core can be reached by relatively shallow drilling or excavation of only a few meters of frozen lacustrine sediment, and (b) they consist of an abundant volume of ice. The example of mound No. 9, developed in Cabrol et al., (1999) shows that this mound only could provide about 450 million liters of water. The main inconvenience of frost mounds is the fact that they are a finite resource and that energy will be required to transform ice into water. However, for short term settlement, they represent a more accessible target than deep confined aquifers.

The presence of frost mounds in Gusev crater near Thyra has morphologic, geometric and climatic support. The question of their origin can be resolved by the ongoing Mars Global Surveyor Mission with high resolution imagery and infrared thermal surveys of the clusters. If the hypothesis is confirmed, it is one more critical argument to land a mission in Gusev.

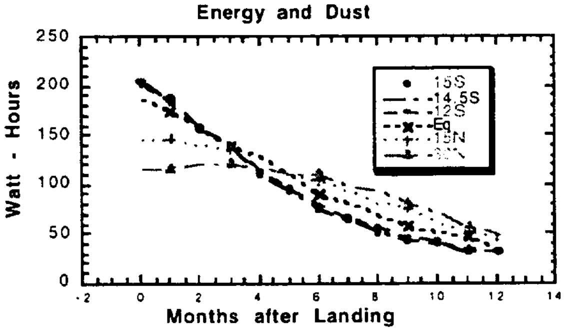
Energy and Engineering Constraints: There is in reality not much difference in energy availability level between the 12S latitudinal limit imposed by the '01 APEX mission and the 14.5S of the Thyra site in Gusev (see graphs 1 to 3). We support the argument that the potential scientific interest and outcome of a mission in Gusev highly exceed the possible (but not even certain) gain in mission survival time between 12 and 15S Lat. We still think that Gusev should be considered as a valuable target for the '01 APEX mission. In the following graphs, we show what difference in energy availability does exist for a mission considered "viable" at 12S and a mission in Gusev (15S or 14.5S) considered out of limits. We plotted our energy estimates against the values proposed by the Mars Surveyor 2001 Project, Mission Design & Navigation Team (1998), see graphs 1, 2, and 3.

Conclusion: (1) The gain in energy for the '01 mission is not dramatic between 12S and 15S and does not justify the rejection of excellent sites located at 15S; (2) The landing ellipse is such as 15S that it may allow oppotunity to traverse rover to any location within the landing ellipse, allowing better pre-mission planning; (3) The energy availability is better at higher latitude during the first 100 sols. There is no certainty that the rover and lander will be still alive after this period (see the Pathfinder mission). There is then a good argument to favor having most of the energy available in the primary phase of the mission. (4) The elevation of Gusev crater (unless contradicted by MOLA) is within the engineering constraints, as are the rock abundance and thermal inertia as known with Viking data; (4) the science objectives that can be met in Gusev-Thyra are highly relevant to the Mars Surveyor Program, including '01 and the human exploration as defined by the HEDS.

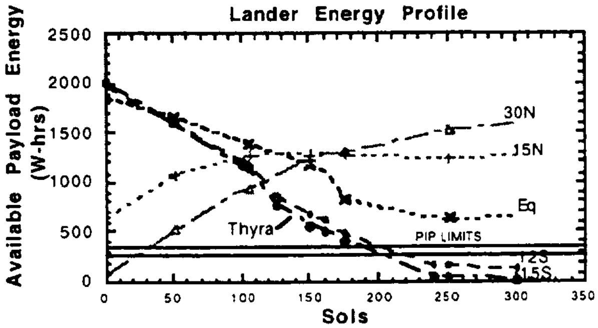
Graph 1: Rover Energy at Various Latitudes and for Gusev Delta and Thyra.



Graph 2: Rover Energy Reduced to Dust Accumulation including Gusev Delta and Thyra.



Graph 3: Lander Energy Profile at Various Latitudes, including Gusev Delta and Thyra.



2001 SITE IN NORTH TERRA MERIDIANI: THE TES CONCENTRATION AREA.

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Introduction: The area detected by TES to have a concentration of hematite, within north Terra Meridiani, is formally proposed as a candidate landing site for the Mars Surveyor 2001 Mission. It is also the only place on Mars where TES has noted a very different surface; therefore, although this area may not contain a diversity of rock types--it is likely to be a unique-appearing site, both visually and chemically dissimilar to Viking and Pathfinder Sites. The candidate site is on the ancient Martian highlands (within required latitude band of 3 N. to 12 S.), shows evidence of nearby ancient channels, and may have experienced some type of hydrothermal alteration during the Hesperian or Amazonian Systems (see below).

The whole of north Terra Meridiani (centered at lat. 0°, long. 0°) contains an unusual and enigmatic terrain unit. On the equatorial geologic maps of Mars, this highland area was mapped as being surfaced by two units of Noachian age: a subdued crater unit and an etched unit [1,2]. The subdued crater unit is a plains unit marked by subdued and buried old crater rims and was interpreted to be thin, interbedded lava flows and eolian deposits that partly bury underlying rocks [1,2]. The etched unit was described as being deeply furrowed by grooves that produce an etched or sculptured surface and was interpreted to be ancient cratered material degraded by wind erosion, decay of ground ice, and minor fluvial erosion [1,2]. However, closer inspection of the 360,000 km^2 area has revealed new details: specifically, the area is surfaced by a younger deposit, which (1) overlies Noachian materials and (2) consists of both intermediate and bright albedo materials, having very different rock attributes [3].

Site Characteristics: The landing ellipse could be safely located at about lat 1.5 S., long 5.5, as high-resolution Viking Orbiter (16 m/p, rev. 746A) and MOC (07704) images show this locale to be very smooth and hazard free (all surface slopes are much less than 10 degs), without any known impediments to mobility. The site also satisfies other engineering requirements of the 2001 Mission, such as rock abundance (between 5-10 %), elevation (approximately 500 m above datum), and thermal inertia (fine component thermal inertia between 6-8 % and bulk thermal inertia between 7-9 %).

Geology: The north Terra Meridiani area is bound by a swath of dark and bright albedo patterns and by impact craters whose floors are filled to variable degrees by dark and bright albedo materials. In the central part of this area (about 90,000 km^2), few impact craters < 5 km in diameter are superposed on what appears to be a relatively smooth, intermediate albedo surface that buries craters of the surrounding Noachian terrains, indicating a much younger age for the overlying material. Observed within the area are at least 18 nearly buried Noachian impact craters ≥30 km in diameter. Using crater rim height/diameter relations [4,5] and an average crater diameter of 35 km, the intermediate albedo material burying the underlying Noachian rocks is about 0.9 km thick. Between lat. 1 to 3° S., and long. 1 to 5°, high-resolution images (25-30 m/p) from Viking Orbiter (VO) revs 746A and 408B show the intermediate albedo material to be very smooth and dotted with small, rimless craters that lack ejecta, are floored by dark material, and trail dark material downwind (SW) of their rims. This physical appearance indicates that the intermediate albedo surface, central to north Terra Meridiani, is likely some type of friable material, eroded by the wind. Portions of this area were measured by TES to have a concentration of hematite, possibly indicating hydrothermal alteration [6]; the measurements also indicate that the deposits in question are still exposed. This intermediate albedo material surfaces the suggested locale for the candidate 2001 landing site. Noachian terrains, to the south, contain ancient channels that terminate at the contact with the intermediate albedo unit; indicating that ancient water may have flowed or pooled beneath the unit.

Northeast of the proposed landing site, stratigraphic relations at about lat 1.5° N., long 359° (observed on VO image 655A64) indicate that this intermediate albedo material overlies somewhat brighter material that crops out in a 100-km-wide band between lat 0 and 5° N. The bright material in turn overlies comparatively dark, heavily cratered highland terrain of Noachian age (VO images 410B04-B07). This bright material covers most of the area previously mapped as the Noachian etched unit. However, the bright material fills older craters as does the intermediate material (but not to the same obscuring degree), indicating that it also is much younger than underlying Noachian materials. High-resolution Viking images (revs 708A and 709A; 25-28 m/p) show that the bright material does indeed appear etched, to the extent that in many places the material erodes into streamlined knobs. These streamlined knobs are likely yardangs. In other areas, the unit has been eroded to expose small scattered mounds or buttes, without streamlining. In several places (for example VO 709A30; 18 m/p) the material forms perfectly circular rimless mesas, indicating that it infilled older craters whose rims appear to have been eroded away leaving the bright material behind. No fluvial features or geomorphic evidence of ground ice is observed. Yardangs and rimless crater fillings indicate that the bright material is lithified and somewhat resistant to erosion. Wind erosion of the bright material may have supplied the material for the windblown bright albedo materials that bound the terrain.

Many impact craters that bound Terra Meridiani appear to be partly filled with the enigmatic deposit. Their floors are filled to variable degrees by younger, similar bright albedo materials. Bounding the west edge of the enigmatic terrain, MOC image 3001 (subframe 3.2 x 3.5 km) shows a bright, wind-eroded deposit on the floor of a 30-km-wide impact crater at 4.2° N., long 5.3°. The MOC image reveals long wind-eroded troughs with scattered mounds or buttes among them. Scatter mounds also can be observed within an inner-crater, bright deposit on the east edge of the terrain at 2.1° N., long 351.5° in high-resolution (16 m/p) Viking images (709A42-43). These scattered mounds and buttes are nearly identical to those produced by wind erosion of the bright material.

To summarize, in contrast to earlier mapped Noachian-age units, north Terra Meridiani is in reality surfaced by a much younger (cratering age undetermined) material. The enigmatic material is now in the process of being heavily eroded by the wind. Local outcrops of older dark Noachian highland material are superposed by an enigmatic deposit: a bright resistant material, overlain by a somewhat friable, intermediate albedo material. These bright and intermediate materials are about 900 m thick. On its bounding edges, the enigmatic deposit appears to have either blown or flowed up impact crater rim slopes to fill topographic lows of the craters. The characteristic ability to flow over topographic highs is common to both eolian and ignimbrite deposits. The enigmatic material could be eroded eolian material, of uncommon and strikingly different albedo and lithification states, or eroded ignimbrite deposits, having exposed unwelded and welded altered zones. In support of an ash flow origin is (1) the compatible concentration of hematite detected by TES within the unit (some terrestrial ignimbrites are known to be enriched in iron (and other elements) due to postmagmatic, cooling alteration [7]) and (2) the scattered mounds and buttes, exposed in bright outcrops, that are similar to fumarolic mounds formed by vapor escape in terrestrial ignimbrites.

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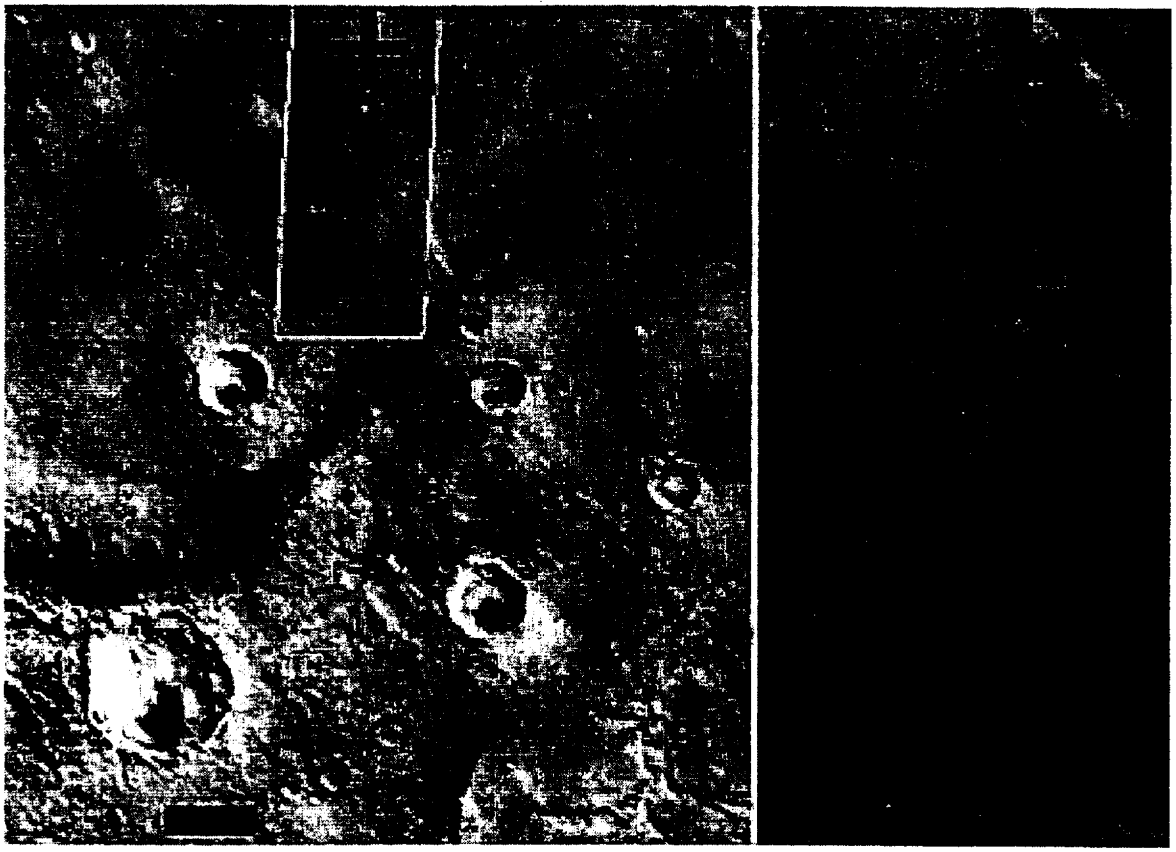

Figure 1. Viking and MOC coverage of landing site region. Viking context image on left shows hematite concentration area (box), 20 km landing site at lat. 1.5 S., long. 5.5 (marked +), location of MOC image 07704 on right (marked 'A'), and ancient highland channels (marked 'B'); scale bar equals 20 km.

A Proposed Landing Site for the 2001 Lander in a Hematite-Rich Region in Sinus Meridiani. Philip R. Christensen, Joshua Bandfield, Victoria Hamilton, and Steven Ruff, Arizona State University, Tempe, AZ 85284, Richard Morris and Melissa Lane, Johnson Space Center, Houston, TX, Michael Malin and Kenneth Edgett, Malin Space Science Systems, San Diego, CA, and the TES Science Team.

The Thermal Emission Spectrometer (TES) instrument on the Mars Global Surveyor (MGS) mission has identified an accumulation of crystalline hematite (α-Fe$_2$O$_3$) that covers an area with very sharp boundaries approximately 350 by 350-750 km in size centered near 2°S latitude between 0 and 5° W longitude (Sinus Meridiani) [*Christensen et al.*, submitted]. The depth and shape of the hematite fundamental bands in the TES spectra show that the hematite is relatively coarse grained (>5-10 μm). The spectrally-derived areal abundance of hematite varies with particle size from ~10% for particles >30 μm in diameter to 40-60% for unpacked 10 μm powders [*Christensen et al.*, submitted]. The hematite in Sinus Meridiani is thus distinct from the fine-grained (diameter <5-10 μm), red, crystalline hematite considered, on the basis of visible and near-IR data, to be a minor spectral component in Martian bright regions.

A map of the hematite index has been constructed using TES data from 11 orbits, including the six in which hematite was detected and five orbits that passed nearby that showed no evidence of hematite. The boundaries of the hematite-rich region are sharp at spatial scales of ~10 km. Within this region there are spatial variations in spectral band depth of a factor of two to three. At the present time the hematite-rich region has not been completely mapped. However, by using the bounding orbits to the east and west in which hematite was not detected, we can establish that this region covers an area that is between 350 and 750 km in length and over ~350 km in width (1.2×10^5 to 2.6×10^5 km^2).

The hematite-rich surface discovered by TES closely corresponds with smooth-surfaced unit ('sm') that appears to be the surface of a layered sequence [*Christensen et al.*, submitted]. The presence of small mesas superposed on 'sm' and the degraded nature of the small impact craters suggests that material has been removed from this unit. These layered materials do not appear to be primary volcanic products (i.e., lava flows) because there are no associated lava flow lobes, fronts or pressure ridges; there are no fissures or calderae, nor any other features that can be interpreted as volcanic within 'sm' [*Christensen et al.*, submitted]. Bowl-shaped depressions in 'sm' and the remnant mesas on top of a portion of this unit suggest that deflation has removed material that was once above the present surface of 'sm'. The most likely cause of the deflation is wind, which suggests that the layered materials are relatively friable. In summary, Sinus Meridiani hematite is closely associated with a smooth, layered, friable surface that is interpreted to be sedimentary in origin [*Christensen et al.*, submitted].

We have considered five possible mechanisms for the formation of an extensive deposit of crystalline grey hematite fall into two classes depending on whether they require a significant amount of near-surface water [*Christensen et al.*, submitted]: (1) chemical precipitation that includes origin by (a) precipitation from oxygenated, Fe-rich water (iron formations), (b) hydrothermal extraction and crystal growth from fluids, (c) low temperature dissolution and precipitation in water; and d) formation of surface coatings, and (2) high-temperature oxidation of magnetite-rich lavas. The formation of red hematite by weathering and alteration is not consistent with the coarse, grey crystalline hematite observed in Sinus Meridiani. None of these models can be eliminated based on currently available data, but precipitation from Fe-rich water may be a slightly more plausible hypothesis based on the association with an apparent sedimentary unit, the extensive size, the distance from a near-surface regional heat source, and the lack of evidence for extensive surface water interactions elsewhere on Mars [*Christensen et al.*, submitted]. The TES results thus provide probable mineralogic evidence for large-scale water interactions. The Sinus Meridiani region therefore may be an ideal candidate for future landed missions searching for biotic and pre-biotic environments.

The thermal inertia in the region of high hematite signature (latitude 3°S to 2°N; longitude 0° to 7°W) measured using high resolution, pre-dawn Viking Infrared Thermal Mapper (IRTM) data [*Christensen and Moore*, 1992] varies from 5.3 to 10.1 (units of 10^{-3} cal cm^{-2} sec$^{-1/2}$ K^{-1}; 221 to 423 in units of J m^{-2} sec$^{-1/2}$ K^{-1}), with an average value of 7.4. These values are only slightly higher than the Martian average value of ~6.5 [*Palluconi and Kieffer*, 1981], and indicate an average particle size of the surface materials of 800-900 μm [*Presley and Christensen*, 1997]. The rock abundance for this area varies from 1 to 13%, with an average value of 7% areal rock cover [*Christensen*, 1986]. These values are typical for much of Mars [*Christensen and Moore*, 1992], but are lower than the values observed at the Viking Lander and Pathfinder sites [*Golombek et al.*, 1999]. Based on these results, the physical characteristics of this site satisfy all of the engineering requirements for the missions currently planned.

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THE CONFLUENCE OF GANGIS AND EOS CHASMAS (5-12°S, 31-41°W): GEOLOGIC, HYDROLOGIC, AND EXOBIOLOGIC CONSIDERATIONS FOR A LANDING SITE AT THE EAST END OF VALLES MARINERIS.

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Over its 3,500 km length, Valles Marineris exhibits an enormous range of geologic and environmental diversity. At its western end, the canyon is dominated by the tectonic complex of Noctis Labyrinthus; while in the east it grades into an extensive region of chaos – where scoured channels and streamlined islands provide evidence of catastrophic floods that spilled into the northern plains [1,2]. In the central portion of the system, debris derived from the massive interior layered deposits of Candor and Ophir Chasmas spills into the central trough. In other areas, 6 km-deep exposures of Hesperian and Noachian-age canyon wall stratigraphy have collapsed in massive landslides that extend many tens of kilometers across the canyon floor. Ejecta from interior craters, aeolian sediments, and possible volcanics emanating from structurally-controlled vents along the base of the scarps, further contribute to the canyon's geologic complexity [1,2].

Following the initial rifting that gave birth to Valles Marineris, water appears to have been a principal agent in the canyon's geomorphic development – an agent whose significance is given added weight by its potential role in both sustaining and preserving evidence of past life. In this regard, the interior layered deposits of Candor, Ophir, and Hebes Chasmas, have been identified as possible lucustrine sediments that may have been laid down in long-standing ice-covered lakes [3,4]. The potential survival and growth of native organisms in such an environment, or in the aquifers whose disruption gave birth to the chaotic terrain and outflow channels to the north and east of the canyon, raises the possibility that fossil indicators of life may be present in the local sediment and rock.

Because of the enormous distances over which these diverse environments occur, identifying a single landing site that maximizes the opportunity for scientific return is not a simple task. However, given the fluvial history and narrow geometry of the canyon, the presence of a single exit at its eastern end provides an opportunity for sampling that appears unequaled elsewhere in the system.

Throughout the western two-thirds of Valles Marineris, the width of the canyon rarely exceeds 100 km. However, as it extends eastward, the canyon broadens significantly to include a region ~10^5 km^2 in size that lies at the confluence of the Aureum Chaos and Gangis and Eos Chasmas (5-12°S, 31-41°W; Figure 1). This area is the largest open expanse that occurs anywhere within the canyon system. At its most northward extent, this region is drained by a 50-75 km-wide channel, which is the sole conduit between the canyon and the northern plains. The region is characterized by large areas of chaos and extensive evidence of fluvial erosion by catastrophic floods (both within the canyon and in the downstream areas adjoining the canyon's principal drainage to the north).

Recently released MOLA topographic data indicate that much of this area lies at an absolute elevation of between -3 and -4 km (Fig 10 in [5]). Although this data indicates that the central portion of the canyon is ~1-2 km lower in elevation, there is considerable geomorphic evidence that enormous fluvial discharges occurred from the eastern end of the canyon and into the northern plains. This flow may have originated from local sources of water in the east end of the canyon, by the flooding and overflow of the central canyon, or by subsequent tectonic uplifting and subsidence that has modified the original topographic relationships within the canyon.

Whatever the cause, the geomorphic evidence for eastward flow, combined with the expanse, depth, and location of the confluence just before the canyon's sole exit to the northern plains, would have made this area an efficient trap for sediment and debris originating from interior sources lying further to the west. It also suggests that this depression may have been one of the most frequently wet regions on the planet, having necessarily been flooded to a minimum depth of several hundreds of meters over an area of as much as ~5×10^4 km^2 before any water discharged from the interior of the canyon could have spilled into the northern plains.

If the aquifers from which this water originated were already sustaining an active subsurface ecosystem, then it is likely that a geologic record of that life is preserved in the sediments and rocks that were deposited on the canyon floor. The repeated occurrence of such discharges, and their inevitable formation of a standing body of water at the terminus of the canyon, may have left a rich stratigraphy of biological and geochemical markers that could provide invaluable insights as to how the subsurface ecosystem evolved with time.

One of the great assets of this location is the opportunity it provides to obtain samples of the planet's oldest rocks. This potential is seen in the presence of valley networks on the plateau to the south, and in the exposure of several kilometers worth of underlying strata in the canyon walls. Samples of this material, originating from all depths within the stratigraphic column, have likely been distributed across the canyon floor by local landslides and extensive flooding, providing a wide variety of potential targets for investigation by the 2001 rover. In both Figure 1 and Table 1 we identify three specific landing sites that maximize the opportunity for: (1) obtaining dramatic descent and surface images of the canyon walls and nearby fluvial landforms; (2) acquiring samples of rocks and sediments of varying age, composition, and origin; and (3) compliance with virtually all of the engineering constraints identified for the 2001 mission.

The elevations of all three proposed sites lie near the -3 km minimum established for the 2001 Lander (although there is some ambiguity based on the spatial density of the early MOLA data and the fidelity of the color reproduction in the recently released high-resolution map of Valles Marineris (Fig. 10 in [5]). The greater air column and surface pressure associated with these low elevations will benefit the Lander mission in several ways. First, by enabling greater landing precision (≤ 20 km landing circle) through the use of aeromaneuvering. Second, by permitting improved discrimination between the surface and orbital radiation environments by MARIE. And, finally, by increasing the efficiency of CO_2 acquisition and O_2 production by MIP.

A common attribute of all three sites is their proximity to the canyon wall – which should provide both dramatic descent images and surface panoramas that are considerably different from those obtained by the Viking Landers and Pathfinder. Depending on which location is chosen, and how closely the landing circle is placed to the canyon wall, the 2-4 km scarps will subtend ~5°-22° on the local horizon. Some additional characteristics of these sites are summarized below and in Table 1:

Site A (-10.5°, 37.1°) The 20-km landing circle seen in Figure 1 lies on smooth canyon floor material that is interpreted to be fluvial deposits derived from Eos Chasma and more westerly sources within the canyon. The center of the landing circle lies approximately midway between a large massif to the north and an ~60-km-diameter cusp in the south canyon wall. The canyon truncates a number of valley networks in the Late Noachian plateau material to the south – a relationship that indicates that the underlying ~3 km stratigraphy, visible in of canyon wall, significantly pre-dates the end of heavy bombardment.

Site B (-6.5°, 37°) Lies on smooth canyon floor material that is interpreted to be a mixture of fluvial deposits originating from Gangis Chasma, local material derived from the collapse and retreat of the north canyon wall, as well as smaller contributions from Eos Chasma and Aureum Chaos. The landing circle is located ~20-km due south of a 60-km crater on the northern plateau whose SE rim has been incised and exposed by the canyon.

Site C (-4.1°, 35.2°) Lies near the point of maximum constriction in the sole channel that drains Valles Marineris to the northern plains. The landing circle again lies on smooth canyon floor material that is likely a mixture of rocks and sediment transported from both local and distant sources. The proposed landing site is located at the eastern edge of the channel. The nearby plateau exhibits considerable evidence of local subsidence and erosion by catastrophic floods, an interpretation that is also supported by the presence of several streamlined islands on the canyon floor ~20 km to the SSW. The plateau material on both sides of the channel appears to be Late Noachian or Early Hesperian in age [2].

Summary. The confluence of Aureum Chaos and Gangis and Eos Chasmas offers a unique potential for conducting geologic, hydrologic, and exobiologic investigations of the planet's past. For this reason, it is logical target, not only for the Mars Surveyor 2001 mission, but also for later, more ambitious robotic and human investigations. Its location within Valles Marineris provides direct access to a stratigraphic record whose exposure and accessibility is unequalled at any other location on the planet. Given the geometry, and hydraulic history of the canyon, eastward flowing floodwaters may have deposited sediments and debris originating from locations up to several thousand kilometers further west. This material is likely to represent a wide range of physical environments, origins, and ages, within the stratigraphic column.

Within the immediate vicinity of the confluence, lie two key relics of the planet's fluvial history -- the valley networks (on the high plateau to the south of Site A), and several vast regions of chaotic terrain that gave birth to the later outflow channels. Investigations of these features will provide important clues to understanding the distribution and cycling of water in the ancient Martian crust.

The presence of a robotic or human outpost on the floor of Valles Marineris would also be invaluable to understanding the state and distribution of subsurface water during the present epoch. Theoretical considerations suggest that the geophysical detection of groundwater, and its eventual accessibility by deep drilling, will be optimized at those sites that combine low latitude (which minimizes the thickness of frozen ground) with low elevation (which minimizes the distance to a water table in hydrostatic equilibrium) [6]. There is no better location on the planet that combines these attributes than Valles Marineris. The identification and sampling of such deep reservoirs of water is a stated goal of the Astrobiology program and a logical step in assessing the availability of *in situ* resources to support future human exploration.

A 2001 Lander mission to Valles Marineris would be an important precursor for these more ambitious future investigations -- providing the initial reconnaissance necessary to plan long distance traverses; geophysical sounding; shallow and deep drilling; and other activities related to the search for water and life, and the eventual establishment of the first human outposts on Mars.

References: [1] Lucchitta et al., Mars, University of Arizona Press, 453-492, 1992; [2] Witbeck et al., Geologic map of Valles Marineris Region, Mars, USGS Map I-2010, 1991; [3] Lucchita, B., NASA TM-85127, 233-234, 1982; [4] Nedell et al., Icarus 70, 409-441, 1987; [5] Smith et al. Science 284, 1495-1503, 1999; [6] Clifford, S.M., Lunar Planet. Sci. Conf. XXVII, 233-234, 1996.

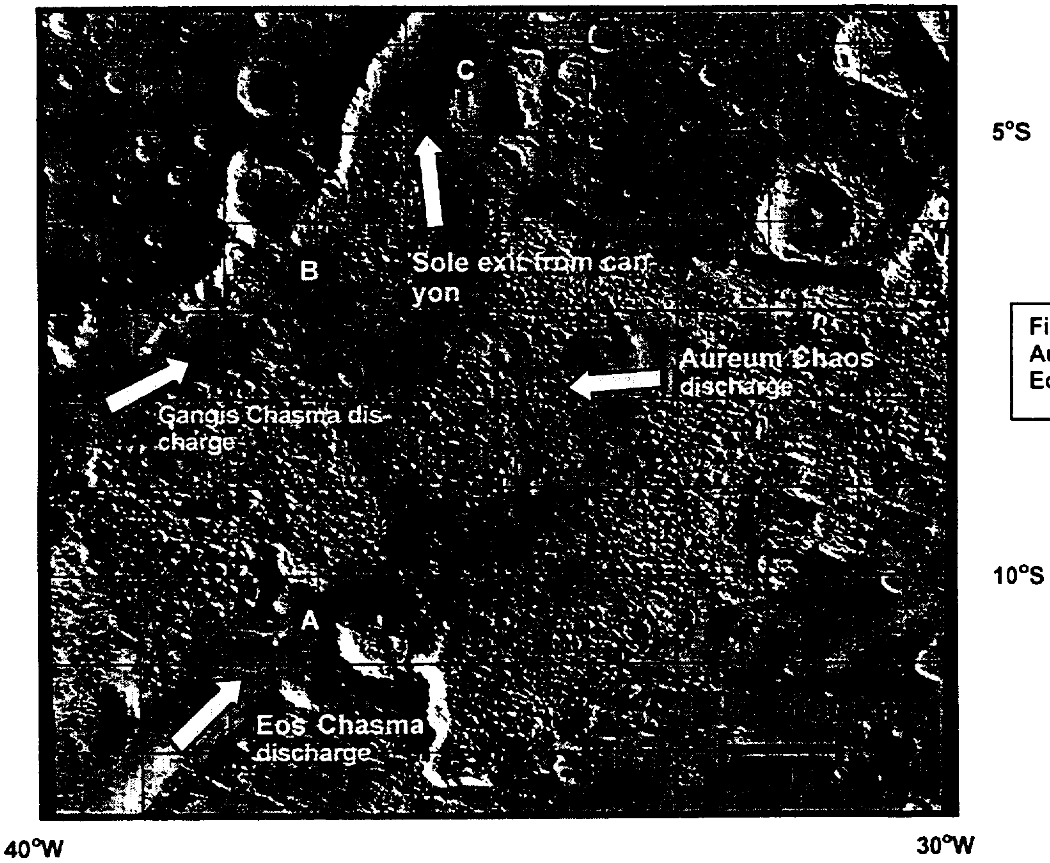

Figure 1. Confluence of Aureum Chaos and Gangis and Eos Chasmas.

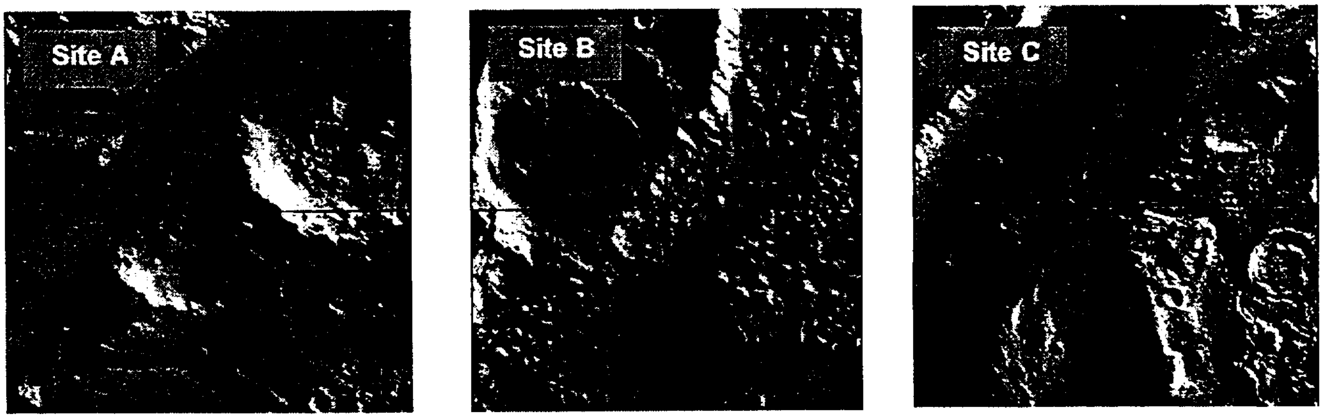

Table 1. Site Location and Compliance with Engineering Constraints.

	Center of 20-km Landing Circle	Elevation (MOLA)	Local Slope (MOLA)	Rock Abundance	Fine Comp. Inertia (cgs)	VO 100-m Coverage	Radar Reflectivity
Site A	(-10.5°, 37.1°)	-3.3 to -3.5 km	≤8°	Appear to be ~5%	≥ 8	~1/2 of landing circle	As yet unverified
Site B	(-6.5°, 37°)	~ -4.3 km	≤8°	~7%	≥ 8	Yes	As yet unverified
Site C	(-4.1°, 35.2°)	~ -3.0 km	≤8°	~12-13%	≥ 8	Yes	As yet unverified

HIGHLAND VALLEY NETWORKS AND EPHEMERAL LAKE BASINS, LIBYA MONTES, SW ISIDIS BASIN MARGIN.

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Introduction. This summarizes the analysis of geology and surface engineering criteria for an area on the southwestern border of Isidis Planitia. In this area basin plains adjoin volcanic plains of Syrtis Major Planum and dissected ancient highlands of Libya Montes. Previously three general categories of landing site [1] have been discussed for this area: scarp-like terrain along the western margin of Isidis Planitia, marginal ridged plains, and terminus of a significant valley network basin draining Libya Montes. On the basis of geologic mapping and reconnaissance around the southwest perimeter, the plains-marginal slopes adjacent to Libya Montes appear to best satisfy the thematic, geologic, and engineering goals and constraints of the Mars Surveyor program.

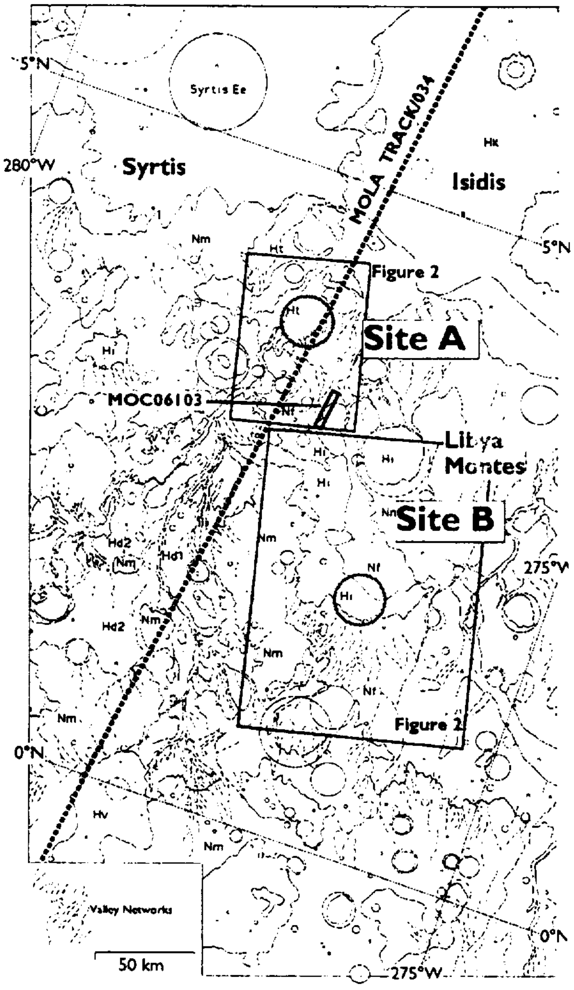

Figure 1. Segment of geologic map prepared for southwestern Isidis Planitia, Syrtis Major Planum, and Libya Montes (1) showing location of MOLA track, MOC image, and sites of A and B. Selected geologic units are noted and discussed in the text. Boxes outline image areas shown in Figure 2.

Science Rationale. Two significant sites are identified in this region within imposed latitudinal constraints. Both sites are areas of recurring valley network formation and/or paleo lake basins as well as significant sedimentation. Both sites offer the opportunity to sample materials associated with ephemeral water bodies of the type thought to have assisted in polymerization of simple organic compounds early in Earth history. Widespread sedimentation in the downstream fans assure that many samples Of early chemistries are buried and well-preserved. "Site A" is notable as it offers the potential for recovering materials, including sediments, deposited during the formation of a long-lived highland valley network basin, as well as diverse materials of other geologic provenance and age. Site B is a significant regional, long-lived, and frequently renewed paleo-lake basin.

Evidence for Persistent Fluvial Activity /Geological History Of Site. Results of geologic mapping have been discussed previously [1]. Sites A and B are within a well-integrated high density valley network system that includes some intermittently closed basins (as adjudged from strand lines). Eight geologic units were mapped, related largely to fluvial deposition and associated incision within valley networks headed within the crater highlands surrounding Isidis Planitia. Identified surface materials span crater ages from middle Noachian to late Hesperian-early Amazonian [segment of map in **Figure 1**]: Nm, ancient highland massifs interpreted to be heavily eroded Isidis basin ejecta; Nf, fluvially dissected foothills and lower slopes of massifs and rolling intermontane plains; Hi, intermontane and crater-interior plains interpreted as sediments; Hd, plains bearing high density valley networks with meandering characteristics; Hv, Syrtis Major lava flows, Hk, knobby, Isidis-marginal plains; and Hr, plains with ridges and aligned-mounds of the Isidis basin interior.

Evidence for Exposed or Accessible Subsurface Material. Site A lies in the terminal fan of a large valley network (**Figure 2**, Site A). As a result of late incision over a broad area of the fan, a thick section of sediments may be examined with a horizontal traverse. Likely aqueously-altered crystalline highland rocks occur in adjacent hills. Samples of intermediate-age Syrtis lava flows are also possible as ejecta from the nearby, young 50-km crater *Syrtis Ee.*

Site B, (**Figure 2**, Site B) lies within the relatively flat floor of a large basin that has been a sink for fluvial sedimentation over much of the history of the regional valley network system. The basin floor is bordered by uniformly sloping surfaces of material shed from surrounding

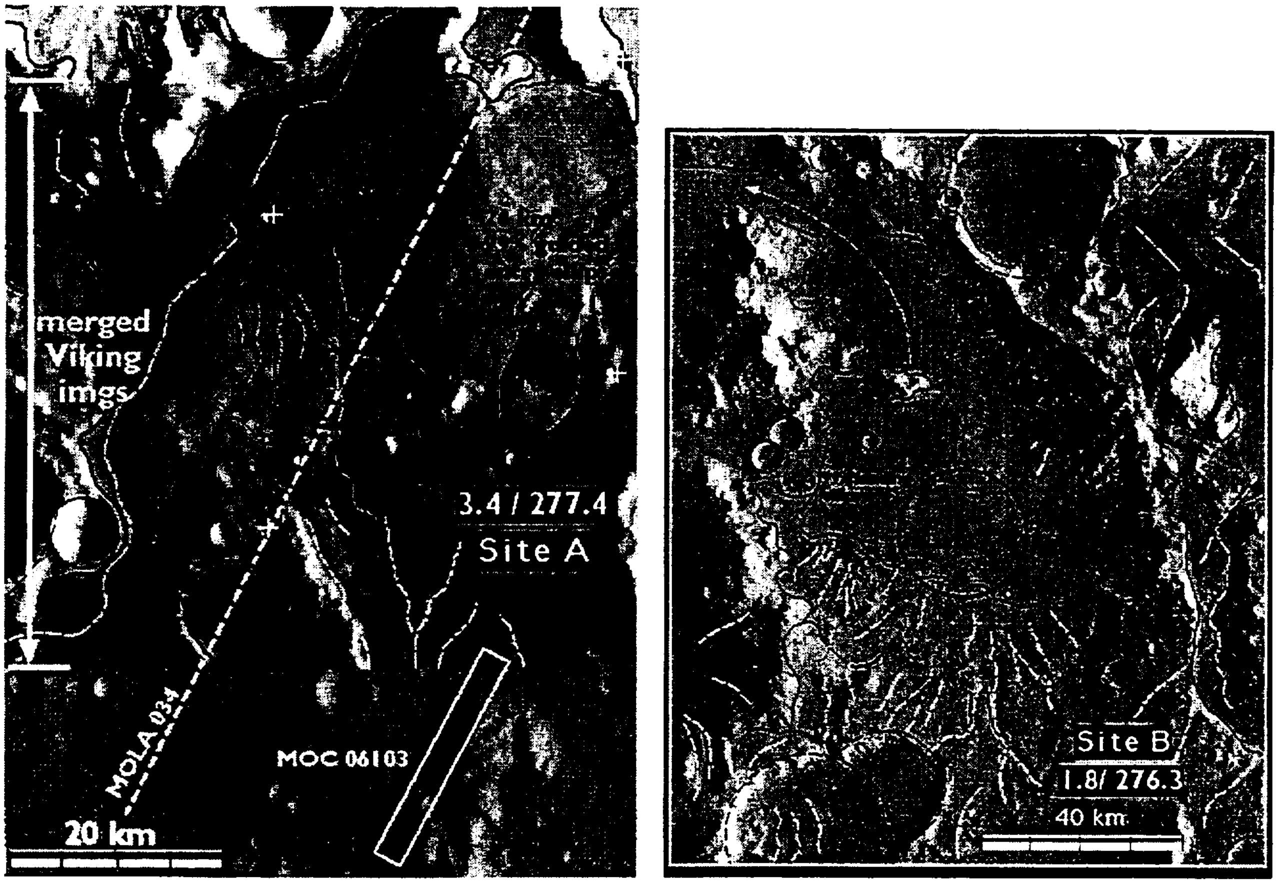

Figure 2. Site A and B with guided 99% landing circle (26 km diameter) indicated. Lines are from geologic mapping and outline differing surface materials. Small dashed lines indicate representative sample of small valley networks.

highlands. These sloping surfaces contain abundant valley networks as well.

Engineering Surface Criteria. Engineering evaluation data were collected (**Table 1**) for this site along the lines established previously in the evaluation of possible Pathfinder sites [2]. As of this writing, the 99% landing error at this latitude is represented by a 26 km diameter circle centered on the target coordinates. When fitted to site A, this encompasses a relatively smooth terminal deposit fed by long-lived outflow of several valley networks draining the interior highlands of Libya Montes. The drainage density within this region is among the highest on Mars and constitutes a prime example of early surface runoff, ephemeral basins, and multiple phases of discharge. Rock abundances, estimated from Viking IRTM [3] imply less than 2 percent of the area is covered by rocks larger than 35 cm. Phobos ISM data [4] suggest ferric iron concentrations typical of highland materials, whereas TES data [5] are indicative of moderate pyroxene abundances. High resolution (16 m) Viking image data are restricted, but include areas to the north and east of Site A in similar borderland terrains potentially suitable for local interpolation.

MOLA Track. The track from Orbit 34 crosses directly over the primary Site A and provides additional high resolution information. Although there is currently a mismatch between inertial coordinates for surface tracks and Viking image mosaic surface coordinates, the location of MOLA profile track for orbit 034 [6] can be precisely located with respect to surface images landforms using several prominent landforms and small impact craters as tie points (**Figure 3**). The results enable a controlled geotraverse down a significant ancient highland valley network. Inflections of 30 to 50 m are detectable where the track crosses significant drainage trunk lines, providing the first estimates of the detailed relief across valley networks and corresponding potential for estimates of probable discharges. As anticipated by the sediment fan environment, the relief across the nominal Site A target is among the most benign (**Figure 3**) along the track and characterized by 20 to 40m swales with several kilometer wavelengths.

MOC Image. A single MOC image has been acquired near Site A. The image includes a geological surface of high valley network density similar to that within and bordering the proposed site. (MOC_06103). The distance between interfluves of valley networks dissecting local fluvial fan sediments is estimated at 80 m. which agrees with observed undulations in regional topography from MOLA results. These valleys are likely to have exposed local sedimentary macrostructures preserving materials deposited late in the drainage basin history. There are likely to be physical and chemical materials deposited, preserved , and exposed within the local sediments representing a wide age range in the history of the drainage system.

Additional details will be provided in a formal summary report in progress. This work was funded by the Mars Surveyor Landing Site Mapping Program, NASA.

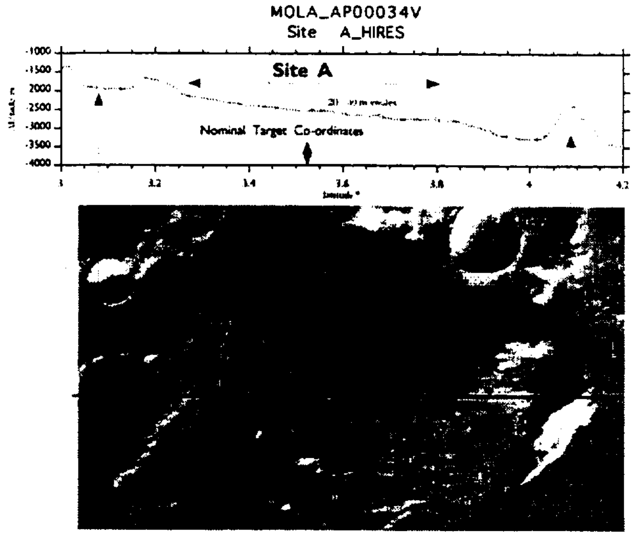

Figure 3. Detail of MOLA altimetry across Site A. Viking image base. 26 km landing circle, here shown slightly SE of its location in Figures 1 and 2.

References. [1] Crumpler, L. S., Lunar Planet. Sci. XXIX, Abstract #1946, Lunar and Planetary Institute, Houston, (CD-ROM), 1998; [2] Golombek, M. and D. Rapp, Jour. Geophys. Res. 102, 4117-4129 1997; [3] based on Christensen, P.R. , Icarus 68, 217-238, 1986; [4] Mustard , J. F.et al., Jour. Geophys. Res., 98, 3387-3400, 1993, calibrated Phobos ISM spectral band minimum, band area, slope avaialble; [5] . Christensen et al., Science; (orbit 034 results), 1998; [6] D. E. Smith et al. , Science,279, 1686 - 1692 ; Fig. 2, orbit 34, 1998; [7] Haldeman, A. et al., Jour. Geophys. Res., 102, 4097-4106., 1997; Goldstone, 1975, G. Downs in Schaber, 1982; [8] Palluconi, F.D. and H.H. Kieffer, Icarus, 45, 415-426, 1981; [9] 16 m resolution data within one degree.

Table 1. Surface engineering evaluation for Sites A, B, and C, Isidis Planitia, Syrtis Major Planum, and Libya Montes.

	measurement	Site A	Site B	Site C	Ares Vallis
Site Environment		highland/ valley networks	highland/ valley networks/ lake bed	lowland/spring?	fluvial ouflow
Location	Center Latitude °N	3.37	1.758	15.3	19.5
	Center Longitude °W	277.539	276.288	281.3	32.8
Region of Interest	NW Corner Lat/Long	4/278	2.5/277		
	NE Corner Lat/Long	04/277	2.5/275.5		
	SW Corner Lat/Long	03/278	1/277		
	SE Corner Lat/Long	03/277	1/275.5		
Elevation	MOLA, km [6]	-2.2 ± 0.04 MOLAAP00034V	nd/similat to A	nd	nd
	Viking DTM, km	0.55±0.5	0.88±0.5	-0.10±0.5	0.8±0.5
	Radar, km	available [7]	available?	~-1.6 [7]	1.3 - 1.7m
Surface Properties	Bulk thermal inertia [9]	8.2	9.6	9.6	10.2
	Fine-component thermal inertia ave ± s.d.	7.2	8.0	9.6	8.2±0.4
	Fine-component thermal inertia range				7.7 - 8.8
	albedo[8]	0.1780	0.1940	0.2020	0.19 - 0.23
	TES Data [5]	Mod to hi px?	nd	nd	nd
	Phobos ISM Data[4]	High Fe^{3+}	High Fe^{3+}	available [4]	nd
Rock Abundance %area	est. from Thermal Inertia [3]	15	15	5	20.4 ± 2.1 [ob.=16]
	est. from [2] %area covered by >35 cm high rocks	1.8	1.8	.02	6.0 [ob.= 2]
MOC Images	SE of proposed ellipse				
Viking image res and coverage (m/px)		227m (100%)[9]	227m (100%)[9]	~27m (?%)	38 - 51 (~80%)

A Highland Strategy for the Mars 2001 Mission: Northwestern Terra Cimmeria.

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Summary: A landing site near 4_N ; 241_W, in northwestern Terra Cimmeria, is proposed as a moderately low elevation site with the potential for sampling and characterizing in situ Noachian material--the most widespread material on the surface of Mars.

Introduction: In earlier considerations of possible martian landing sites, it was argued that any landing site would provide useful science information about the planet [1, 2]. When nothing is known, anything is an advance. We are now beyond that point. Although we are a long way from having comprehensive data base for Mars, we do have some hard knowledge from which to build. What is known is derived from three decades of study, including: imaging from a variety of spacecraft; remote geochemical sensing from orbit; mineralogy and chemistry of Mars meteorites; and rock and soil composition at three landing sites. Future missions must be aimed at specific objectives for maximum value. The 2001 lander has important engineering constraints including restrictions in latitude, elevation, and surface roughness [3]. The 2001 rover will have a limited travel distance from the lander. An acceptable landing site must meet the engineering criteria as well as provide a reasonable science return. The geological questions that can be answered by this mission are primarily those associated with composition and process. Questions concerning absolute age, relative age, and structure are not within the scope of this mission.

Several possible science objectives are acceptable at this stage of exploration, including investigation of highland material, lavas, lake sediments, and crater or basin ejecta. A landing site on volcanic flow material could provide answers to questions concerning martian differentiation. More than one landing on different volcanic terrains would be preferable to a single landing. A landing of lake sediments would be most interesting and significant in investigation of the possibility of a biotic environment. Crater or basin ejecta could be targeted as samples of buried materials.

Scientific goal: This paper presents arguments for a highland material sampling mission. The objective would be to sample ancient crustal material that constitutes some of the oldest and most widespread material on the planet. Chemical and mineralogical analysis could address questions concerning development of the early crust of the planet and whether it is gravitationally segregated as in a magma ocean or by voluminous lava outpouring. A landing site far removed from the Sojourner site could test the diversity of crustal materials.

Ancient crustal material may be sampled in one of three ways: (1) direct landing in the highlands; (2) sampling alluvial materials derived from highland regions; or (3) sampling crater rim materials ejected from a highland site. Of these possibilities, a landing on highland materials at an acceptable low elevation is preferred as the best chance to avoid the ambiguity of distant source areas.

Proposed site: The proposed site is located in the vicinity of 4_ N; 241_ W (Fig. 1). Movement of the landing point by several degrees will not affect the scientific return of the mission. The site is in the highlands of northwestern Terra Cimmeria, between Elysium Planitia and Hesperia Planum.

Northwestern Terra Cimmeria: R.A. De Hon

The materials of the region are cratered plateau materials that are highly dissected by small channels.

Site Characteristics:

Location	4_N; 241_W
DTM elevation	2.0 to 2.5 km
MOLA elevation	1 to 2 km
Geologic unit	Npld
Rock abundance	<10%
Fine thermal inertia (cal cm^{-2} s$^{-0.5}$ K^{-1})	6-8 x 10^{-3}
Bulk thermal inertia (cal cm^{-2} s$^{-0.5}$ K^{-1})	6-8 x 10^{-3}
Delay doppler radar available	None
Viking imaging	<50 m/px
MOC imaging	?

Discussion. This site is on the upper limit of elevation which could affect the safety of the landing maneuver. This site, in a region of Noachian material, need not be tightly targeted. Movement of the aim point by several degrees will not greatly affect the results. Noachian dissected plateau material (Unit Npld) is ancient terrain modified byrunning water [4]. Material may, therefore, be redistributed from its original location and may suffer significant physical and chemical alteration. This unit, at lander scale of observation, can be expected to be quite heterogeneous in composition. Post-Noachian eolian or fluvial materials may be present. However, large rocks can be expected to retain their geochemical and mineralogical character. Comparison of analysis of rock and fine-grained material with those of previous landing sites would provide insight into the homogeneity or diversity of the martian crust and would confirm or reject the presence of a ubiquitous dust component of martian surface materials.

References: [1] De Hon, R.A., 1994, *Mars Pathfinder Landing Site Workshop*, LPI Technical Report No. 94-04, 24-25. [2] De Hon, R.A., 1998, *Mars 2001 Landing Site Workshop*, NASA Ames, Jan. 26-27. [3] Golombek, M. and others, 1999, *LPSC XXX*, Abs. #1383. [4] Greeley, R. and Guest, J.E., 1987, *U.S. Geol. Surv. Misc. Inves. Series* Map I-1802-B.

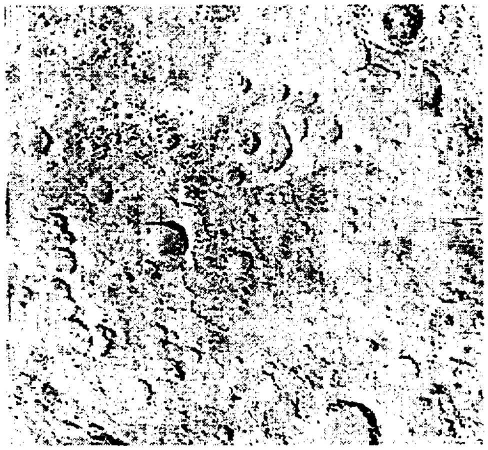

Figure 1. Viking Orbiter mosaic of northwestern Terra Cimmeria. Approximate location of the proposed landing site is marked by an X at 4_N and 241_W . Mosaic is 450 km across.

GANGES CHASMA SAND SHEET: SCIENCE AT A PROPOSED "SAFE" MARS LANDING SITE.

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Introduction: The only place within the elevation and latitude constraints for the Mars Surveyor Project 2001 (MSP01) lander that is almost guaranteed to be safe for landing is the large, smooth, nearly flat sand sheet that covers much of the floor of Ganges Chasma. While at first it might seem that this kind of surface would be boring, an array of topics consistent with Mars Surveyor goals can be addressed at this site.

Rationale: The reason I suggest landing on the smooth sand sheet in Ganges Chasma is very simple. It is safe. When it arrives, the MSP01 lander will have only ~31 cm of clearance with respect to obstacles such as rocks. *Mars Global Surveyor* (MGS) Mars Orbiter Camera (MOC) images obtained within the past several months (March–May 1999) have good focus and clarity qualities, and they have resolutions in the 1.4–12 m/pixel range. These images show that most surfaces within the latitude and elevation constraints of the MSP01 lander exhibit either meter-scale (boulders, yardangs, or grooves) or kilometer-scale (slopes) hazards [1]. The Ganges sand sheet appears to be one of the few exceptions to the "rules" regarding what surfaces appear to be rough *vs.* smooth at the meter scale [1], and it is the only smooth-surfaced exception for which there is an adequate Earth analog. Part of the success of the *Mars Pathfinder* mission was the fact that the Ares Vallis site had a good Earth analog in the Channeled Scabland of Washington.

Proposed Site: A regional view of Ganges Chasma is shown in Figure 1. The proposed landing site is indicated by a circle representing a 20 km-diameter landing zone centered on 8.0°S, 49.3°W. If the size of the ellipse can be shrunk, then the landing site should be moved as close to the layered mesa (to the north) as possible while maintaining the safety of landing on the sand surface. Indeed, nearly any site on the smooth, flat parts of the sand sheet would prove adequate for landing. A representative high resolution image of the surface is shown in Figure 2. A MOC image obtained in May 1999 (610075862.2988.msdp) shows that the site indicated in Figure 1 is safe and that the sand sheet comes close to the interior layered material without losing its smooth, flat characteristics.

Mars Surveyor Program Goals: The choice of a Ganges Chasma landing site is in keeping with the approach of the Mars Surveyor Program for three reasons: (1) the spacecraft will be able to land safely and conduct its experiments, (2) Ganges Chasma is surrounded by evidence of past erosion by liquid water, and (3) the large, layered mesa near the landing site has long been speculated to be of high interest to understanding the nature of early Mars (*e.g.*, aqueous sedimentary origins are among those proposed).

Geologic Setting: Ganges Chasma is one of the troughs of the Valles Marineris system. It is open to the east, and it appears to connect to the Hydraotes/Simud Valles system. There is a notch in the north wall of the chasm that appears to be related to subsurface collapse that connects to Shalbatana Vallis. On the upland west and south of Ganges Chasma, there are relatively small (for Mars) scoured valleys that resemble miniature outflow channels. Both of these appear to have "drained" into Ganges Chasma at some time in the past. In addition to these literal "connections" to valleys that may have been conduits for liquid water, Ganges Chasma has layered rock outcrops in its walls, and a massive unit of nearly horizontal-bedded layers within the north central part of the chasm. Similar layered materials occur within most of the main Valles Marineris troughs, and these have been the center of much speculation (including genesis as aqueous sediment) for nearly three decades. The origin and source of the dark sand that makes up the sand sheet in Ganges Chasma is unknown. The grains could be the product of erosion of the chasm walls and/or the interior layered mesa, or they might have been transported into the trough by wind or water (*i.e.*, via the small "outflow" channels to the west and south).

Weather: The January 2002 landing occurs at L_S 313° (mid-southern summer). In the past few decades, this time of year has been part of the "global dust storm season." During the *Mariner 9* mission, L_S 313° corresponded to the start of atmospheric clearing in mid-December 1971. However, during the MGS mission, L_S 313° occurred in April 1998, and (to my knowledge) no dust storms were observed in the Valles Marineris. Some might conclude that the risk of abrasion by saltating sand during a dust storm would preclude a landing in Ganges; however only a local storm would pose such a threat, and we know very little about the likelihood of there being a storm anywhere in the regions of Mars that are accessible to the MSP01 lander in early 2002.

Science Goals: Science can only be done if the lander arrives safely. There are two main goals that can be addressed in Ganges Chasma. The first is to obtain close-proximity remote sensing observations of the large, layered mesa that occurs to the north of the proposed landing site. The second goal is to provide "ground truth" information about the sand sheet that can be used as a calibration point for orbiter remote sensing—in particular for the GRS and THEMIS on the MSP01 orbiter, as well as previous instruments such as the MGS TES and *Mars Climate Orbiter* MARCI color cameras. "Targets of opportunity" will undoubtedly exist at this site; for example the composition and provenance of the sand sheet sediment is unknown, and might include surprises such as the identification of grains derived from erosion of a preexisting sedimentary rock (*e.g.*, Robot Arm Camera (RAC) images could show spurs of adhering cement or glass on sand grains—these might indicate former occurrence in a sedimentary or welded pyroclastic rock).

Layered Mesa Remote Sensing. During the season in which the Primary Mission occurs, the layered material will be properly illuminated from the south. The composition of the layered material and/or detritus derived from this material can be addressed by the Pancam and Mini-TES instruments. If outcrops of the rock that underlies the sand sheet are accessible to the *Marie Curie* rover (*e.g.*, bright features in Figure 2), then these should also be examined.

Composition "Ground Truth." The mineral composition of the sediment in the sand sheet will provide critical "ground truth" for interpretation of the results obtained by orbiter remote sensing. The sand sheet is nearly large enough to be visible by the Gamma Ray Spectrometer (GRS), and the site is particularly well-suited for study of the thermal and visible/near-infrared observations by instruments such as TES, THEMIS, and MARCI. Of prime interest will be the Mössbauer spectrometer results for the iron mineral content of the sand—*e.g.*, what is the proportion of magnetite, a mineral that cannot be detected in the thermal infrared by looking through the martian atmosphere?

Sand Sheet Physical Properties. Although I interpret the smooth deposit in Ganges as an eolian "sand" sheet, no one has ever conclusively determined that sand-sized (62.5–2000 μm) sediment occurs on Mars. The RAC will allow the opportunity to measure grain sizes and size distribution of sediment on the surface and in the near subsurface. The RAC and engineering data from the robot arm and *Marie Curie* rover will allow examination of bedding, texture, packing, particle shape, sediment maturity, infiltration by dust, cementation, and other properties that indicate the origin, transport history (*i.e.*, only eolian, or was there earlier fluvial transport?) and diagenesis of the material. In addition, the physical properties (*e.g.*, grain size, density) will provide a "ground truth" for thermal inertia observations that have already been made from orbit.

Some Potential "Targets of Opportunity." (1) The presence of sand and/or granule ripples would provide an opportunity to test models for eolian transport physics under martian conditions. (2) Because there will be few rocks in the near field to keep *Marie Curie* busy, the rover can be driven as far from the lander as the UHF antenna will allow, thus offering new vistas and perhaps providing discoveries of unsuspected landforms (*e.g.*, the drifts behind the Rock Garden at the *Mars Pathfinder* site). Finally, (3) the sand might turn out to include exotic or unexpected materials such as grains representing older sedimentary rock.

References: [1] Malin, M. C., K. S. Edgett, and T. J. Parker (1999) Extended abstract, this workshop.

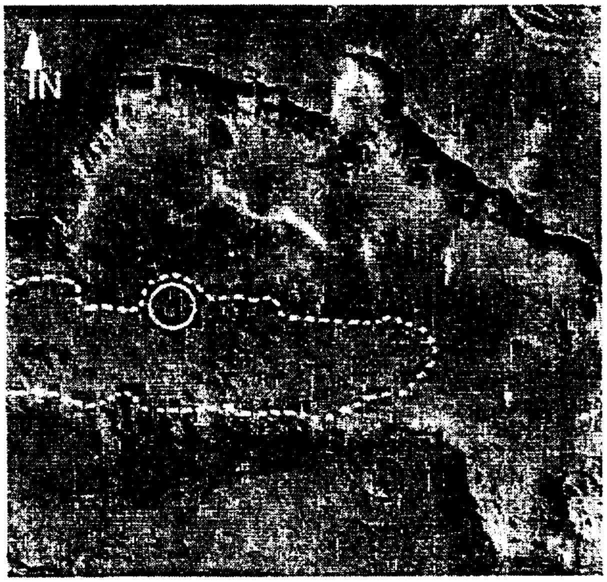

Figure 1. Regional view of Ganges Chasma. Circle represents proposed 20 km-diameter landing zone. Dashed area shows approximate extent of smooth, dark sand sheet, based on MGS MOC image sampling through May 1999.

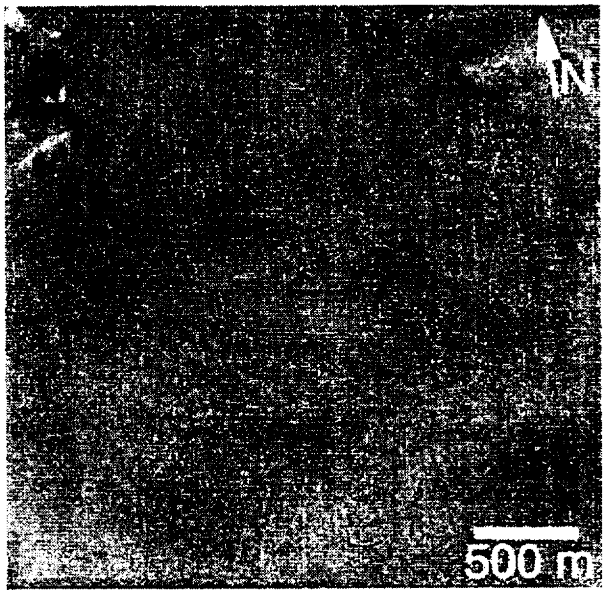

Figure 2. Typical view of the Ganges sand sheet. Subframe of MOC image AB-1-087/07, near 7.6°S, 49.5°W.

Appendix—Requested Details

The following information is submitted in compliance with the "Information to Include in Landing Site Abstract" guidelines for the Second Mars Surveyor Landing Site Workshop. The source for most of the information described here stems from my own analysis of *Viking* and MGS MOC images.

Statement of Scientific Rationale or Science Objectives of Site: See text above for details. The most important objective is to provide a safe landing for a spacecraft with very limited clearance with respect to decimeter-scale hazards. No scientific activity will occur without there being a safe landing. The main research goals of the site include close-proximity remote sensing of the huge layered mesa in the north central part of Ganges Chasma and characterization of the large sand sheet on the floor of the chasm. The sand sheet serves as an excellent point of "ground truth" for orbiter remote sensing, and might just harbor evidence of past fluvial transport, chemical diagenesis of grains, and/or sedimentary rock.

Latitude and Longitude of Site: The proposed site is centered at 8.0°S, 49.3°W. It should be moved northward if the landing ellipse shrinks from the present 20 km diameter—it should move as close as possible to the southern margin of the large layered mesa, while still keeping the landing zone on the safe, smooth sand sheet.

Maximum and Minimum Elevation of Site: The site occurs on or near the 0 km contour in the U.S.G.S. 1991 topographic maps. I do not know what the present MGS MOLA topography says for this site, as this work has only recently begun to be published.

Hazard Analysis: Hazards will be quite minimal. This site was selected to provide nearly 100% confidence that no rocks or other protrusions of ≥ 31 cm will be present.

Slopes: Should be relatively low (<< 2°) over large portions of the sand sheet, as suggested by topographic relationships inferred from MGS MOC images of various parts of the sand sheet.

Rocks: There should be no rocks, but with luck the landing might occur within 500 m of one of the bright rock outcrops that poke through the sand sheet in places. If so, these outcrops could be examined by the *Marie Curie* rover. Otherwise, do not expect any rocks.

Unconsolidated Material: The entire landing site is interpreted to consist of unconsolidated sand and granule-sized material. However, the exact particle size is unknown and is part of the purpose for the lander science investigation.

Characterization of Site Environment: Ganges Chasma is surrounded on all sides by evidence of past liquid water action—small outflow channels "enter" it's west and south sides, and large outflow features "exit" to the east and north. The large layered mesa in the center of the chasm has long been speculated to consist of aqueous sedimentary rock, although many other explanations are possible, including volcanic and eolian deposition. This site is perhaps best described as a "sedimentology site," offering opportunities to test hypotheses about the origin of the interior layered mesa and the nature of surface properties that can be inferred from remote sensing.

Evidence (if any) for persistent fluvial, paleolacustrine, or hydrothermal activity at this site, and evidence that the resulting deposits are still exposed: These topics border on the realm of "fantasy" and cannot be adequately addressed by existing spacecraft observations of Ganges Chasma or any other location on Mars. In light of MGS data obtained 1997-1999, great caution is urged when asking questions such as this.

Geological History of the Site. The history is largely unknown, but relevant aspects are described in the text above. No one knows if the large, layered mesa within Ganges Chasma is (1) a deposit that formed after the chasm was opened, (2) an exhumed deposit that predates the surrounding layered uplands that comprise the walls of the chasm, or (3) simply an outcrop of the same kinds of materials that comprise the layered rock of the chasm walls. No one knows whether the chasm was ever filled with liquid water.

Processes Available to Expose or Excavate Subsurface Materials; Processes to Provide Diversity of Rocks or Outcrops: These things do not apply to this site. The processes which have exposed the layers in the large mesa are largely unknown but likely involved at least mass movement and wind.

Impediments to Mobility at the Site: Mobility for the rover should be no problem. *Marie Curie* has spent many hours in a "sand box:" at the Jet Propulsion Laboratory.

Summary: There is no site on Mars that will provide all of the "answers" that we seek about the nature of the martian past. The Ganges Chasma sand sheet site at least offers the opportunity for a safe landing and provides the opportunity to (1) test hypotheses about the nature of interior layered mesas and buttes that occur in the Valles Marineris, and (2) test our understanding of the utility of remote sensing to interpret the physical and mineral properties of the surface.

SITE SELECTION FOR THE MGS '01 MISSION: AN ASTROBIOLOGICAL PERSPECTIVE.

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Introduction: Major goals of the Mars Global Surveyor Program include: 1) the search for past or present life, and/or evidence of prebiotic chemistry, 2) understanding the volatile and climatic history of Mars, and 3) determining the availability and distribution of mineral resources. The cross-bridging theme for these goals is the history of liquid water. Among the most important objectives of the MGS program is to visit sites that have a high priority for exopaleontology-- that is, to explore sites that have a high potential for harboring a Martian fossil record and/or prebiotic chemistry. Studies of the terrestrial fossil record reveal that microbial fossilization is strongly influenced by the physical, chemical and biological factors of the environment which together, strongly influence the types of information that will be captured and preserved in the rock record. On Earth, the preservation of biogenic signatures in rocks basically occurs in two ways: rapid burial in fine-grained, clay-rich sediments and rapid entombment in fine-grained chemical precipitates. Entombment by aqueous minerals can occur as either primary precipitates (e.g., hydrothermal sinters, or evaporites), or during early diagenetic mineralization (e.g., cementation). The key process is the rapid reduction of permeability following deposition. This creates a closed chemical system that arrests degradation (oxidation). For long-term preservation, organic materials must be sequestered within dense, impermeable host rocks composed of stable minerals that resist chemical weathering, dissolution and extensive reorganization of fabrics during diagenetic recrystallization. Favorable minerals include highly ordered, chemically-stable phases, like silica (forming cherts) or phosphate (forming phosphorites). Such lithologies tend to have very long crustal residence times and (along with carbonates, shales), are the most common host rocks for Precambrian microfossils on Earth. Other potentially important host rocks include evaporites and ice, both of which have comparatively short crustal residence times on Earth. These "taphonomic" constraints provide a fairly narrow set of criteria for site selection. While they are difficult to apply in the absence of mineralogical information, their consideration is nevertheless essential if we are to follow a strategy founded in clear scientific principles.

Scientific Constraints for Site Selection: A key objective of MGS is to identify sites for exopaleontology and then collect samples for return to Earth. Certainly a first step in the process is to target sites where liquid water was present and could have provided a clement environment for life. Next is to identify sites where aqueous sediments were deposited. However, the fact that microbial fossilization only occurs under specific circumstances means the site selection process cannot end with these broad criteria. On Earth, most aqueous sedimentary deposits are actually barren of fossils. Thus, the second step in the process involves identifying those paleoenvironments that were most favorable for the capture and preservation of fossil biosignatures (as noted above). Based on terrestrial analogs, geological environments that are especially favorable for preserving a microbial fossil record include [1,2]: 1) mineralizing hydrological systems (e.g., surface and shallow subsurface hydrothermal, mineralizing cold springs in alkaline lake settings), 2) evaporite basins (e.g., terminal lake basins and arid shorelines), and 3) mineralizing soils (e.g., sub-soil hard pans including silcretes, calcretes and ferracretes).

Engineering Constraints for Site Selection: The 2001 lander will be deployed by parachute and use a retro-rocket landing system similar to Viking. This will constrain landing site elevation to between +2.5 and –3.0 km, and surface rock abundance to between 5-10%. Because the lander will be powered exclusively by solar panels, sites are also limited to equatorial latitudes between 3°N and 12°S. Finally, it has been suggested that, if possible, sites be limited to those that are covered at Viking resolution better than 50 m/pixel. This last constraint places an especially severe limitation on the number of scientifically-interesting sites for Astrobiology. However, this constraint, along with the rock abundances estimated by IRTM, can be relaxed for sites where supplemental high resolution MOC imaging can be obtained (http://mars.jpl.nasa.gov/2001/landingsite/EngConstr.html).

Approach Used: Using composite maps showing the distribution of the above constraints provided by JPL (http://mars.jpl.nasa.gov/2001/landingsite/EngConstr.html) we have reviewed all Viking imaging data for sites that meet the engineering constraints defined above. Each site has been visually examined at the highest Viking resolution available and prioritized according to the following scheme:

Highest priority: Evidence for varied and sustained hydrological activity; sites where water may have ponded (potential terminal lake basins with evaporites or fine-grained detrital sediments, inclusive of impact craters); chaos areas or channels adjacent to volcanic edifices or impact craters (potential hydrothermal mineralization); floors of impact craters with central peaks and associated high albedo features (potential hydrothermal activity and/or evaporites or fine-grained detrital deposits); with pristine features, deflational areas showing little or no evidence for aeolian mantling.

Moderate to high: As for high, but with aeolian mantling evident as isolated dunes.

Moderate priority: Termini or floors of channels (potential grab-bag sites) that originate in highland chaos or adjacent to volcanic edifices (areas of potential hydrothermal mineralization); evidence of general terrain softening due to aeolian mantling or surface weathering, although features still visible.

Low-moderate priority: Evidence of isolated hydrological activity as sparse channels located in intercrater highland areas (potential grab-bag sites?). Heavy to moderate aeolian mantling.

Lowest priority: No evidence of hydrologically-related geomorphic features (e.g., extensive lava flows or pyroclastics), and/or heavily mantled (or otherwise featureless) terranes.

Results: Within the engineering constraints outlined above, Table 1 presents the results of our preliminary global reconnaissance of potential landing sites for exopaleontology. The overall impact of the Viking resolution requirement (50 m/pixel) and strict adherence to rock abundance data eliminated all but one of the highest priority sites we had identified previously, based only on elevation and latitude constraints (Table 2). While a number of moderately-high priority sites remain (Table 1), clearly the highest priority (most scientifically compelling) sites for Astrobiology lie outside of the Viking resolution requirements or are marginal in terms of rock abundance.

TABLE 1. High to moderately-high priority sites for Astrobiology. Sites identified meet all engineering constraints (within 3°N-12°S; rock abundance 5-10%) and Viking Orbiter Imagery at <50 m/pixel.

Site Name	Latitude/Longitude	Site Type	VO Image Coverage
HIGHEST PRIORITY			
Terra Cimmeria	8-11°S 216-220°W	1, 2	760A01-12
Mangala Valles	3-12°S 150-155°W	1, 2	442S-460S image series
MODERATE TO HIGH PRIORITY			
MC-11			
Xanthe/Da Vinci crater	0-3°N 40-44°W	2	742A01-66
S. Ares Vallis	0-3°N 17-19°W	2	405B19-40
MC-13			
Libya Montes	1-3°N 272-274°W	1, 2	137S02-24
MC-19			
SE Xanthe/Iani Chaos	9-12°S 27-29°W	3	962A21-29
SE Xanthe/Iani Chaos	9-12°S 29-30°W	3	963A21-30
SE Xanthe/Iani Chaos	8-12°S 30-31°W	3	964A21-30
Iani Chaos	0-3°N 13-15°W	3	406B01-18
MC-23			
Apollinaris Chaos	12-4°S 188-190°W	3	372B01-26
NE of Gusev crater	14-9°S 180-181°W	1, 2	386B01-26
Al-Qahira Vallis	15-14°S 194-196°W	1, 2	452A01-08

TABLE 2. High to Moderately-High priority sites nearly meeting present engineering constraints (within 3°N - 12°S), marginal rock abundance, and Viking Orbiter Imagery ~50 to 100 m/pixel.

Site Name	Latitude/Longitude	Site Type	VO Image
HIGHEST PRIORITY SITES			
Amenthes Rupes	2.9°S 249.5°W	1, 2	379S45, 47
Apollinaris "chaos"	11.1°S 188.5°W	2, 3	596A35-36; 635A57
Da Vinci crater	1.2°N 39.1°W	2, 3	014A72-80
Ganges Chasma (1)	8.5°S 43.9°W	1, 2	014A29-41
Ganges Chasma (2)	8.8°S 42.5°W	1, 2	014A29-41
Libya Montes (region)	1-3°N 270-280°W	1, 2	377S75-80; 876A02-05
N Memnonia Terra (1)	11.3°S 174.2°W	1, 2	38S10-14; 439S03-09; 440S02-08
N Memnonia Terra (2)	11.2°S 178.2°W	1, 2	437S07-09; 438S02-05
Nicholson crater	0° 164°W	2, 3	387S31-34; 637A47-50
Reuyl crater	9.9°S 192.8°W	2, 3	596A31-34
Shalbatana source (1)	0.2°N 46.3°W	1, 2, 3	897A33-36, 66, 68
Shalbatana source (2)	0.7°N 44.5°W	1, 2, 3	897A33-36, 66, 68

Key for Site Types

1 = grab bag site
2 = fluvial-lacustrine
3 = potential hydrothermal

ASTROBIOLOGY PERSPECTIVE FOR MGS '01 SITE SELECTION: J.D. Farmer et al.

Conclusions and Recommendations: The Mars Observer Camera (MOC), presently in orbit at Mars, has been providing very high resolution images (as good as 1.5 m/pixel) for selected sites on Mars. While these images are rapidly changing our view of the Martian surface, the present distribution is nevertheless quite limited. Thus, our present recommendations are of necessity based on photogeologic evidence obtained by Viking. To address the site selection concerns of Astrobiology, we recommend that there be a focus on the highest priority sites given in Tables 1 and 2. Furthermore, we recommend that these sites be specifically targeted for high resolution imaging by MOC as soon as possible, to assist in the process of site prioritization.

The most important powerful information for reconstructing paleoenvironments (and therefore the most useful information for refining site selection for Astrobiology) is mineralogy. However, because most of the orbital data obtained by the '96 mission will not be available until after landing site selection '01, it is important that there be an ongoing effort to update site priorities for sample return missions in '03 and '05. It is also important that mapping studies be carried out now at the highest priority sites using available data and that these mapping efforts be updated as new data becomes available.

The inability to identify many smaller geological features presently impedes geological interpretations and therefore the site selection process. Targeted high resolution observations by MOC are likely to significantly advance our knowledge of finer-scale geologic features, and alter our prioritization sites for 2003 and '05. The Thermal Emission Spectrometer (TES) is presently mapping the Martian surface in the mid-IR and is expected to provide important new information about global mineralogy over the course of next year. For example, during the pre-mapping phase, TES identified a large deposit of coarse-grained hematite that is suggestive of aqueous activity. Unfortunately, this type of mineralogical data is presently too limited in distribution to provide a framework for site selection. While TES will provide globally-distributed data at 3 km/pixel, there will still be a need for follow-on mapping of key sites at higher spatial resolution. This requirement will hopefully be met by the THEMIS instrument, which is to be launched in 2001.

References: [1] Farmer, J.D., D.J. Des Marais, *Lun. Planet. Sci. XXV*, 367-368, 1994. [2] Farmer, J.D. and D.J. Des Merais, *Exopaleontology and the search for a fossil record on Mars*, (in press).

TWO CRATER PALEOLAKE SITES THAT MEET PRELIMINARY ENGINEERING CONSTRAINTS FOR THE 2001 ATHENA LANDER MISSION.

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We have identified two potential paleolake/closed drainage basins that should meet engineering criteria for the Athena lander. These are unnamed, but for the purposes of discussion, will here be referred to as the White Rock basin site (334.75°W, 07.8°S), and the Evros paleolake site (348.5°W,10°S). The science rational for the two sites are similar, but the two vary somewhat in the science opportunities that are present due to site specific characteristics within each of the prospective landing zones.

Rationale for a Paleolake Site

Any site chosen for the Athena Lander should minimally address the following three areas of inquiry: 1) validation and advancement of the general lithostratigraphic framework for Mars, 2) advancing our knowledge of the ancient Martian hydrosphere, and 3) the search for possible life, or past life, on Mars.

Lander investigations (with the potential for sample return) of the two proposed early Martian lake sites provide a reasonable probability for the discovery of chemical and biological sediments that may have a revolutionary impact. Lake, playa, salina, and sabkha depositional environments are all possible to have existed in the early history of Mars; a period for which evidence leads many to believe that water flowed and ponded on the Martian surface under a warmer and wetter climatic regime. Given the prospects for these environments to have been analogous to the Earth's arid and hyperarid regions, low lying basins would have been relatively poor in clastic inputs, and have had a dominance of chemical (and/or biological) deposits. On earth these basins have carbonate, silicate, or iron mineral accumulations in dilute lakes, and carbonate, sulfate, clorite, and silicate (e.g. zeolites where volcanic glass falls into alkaline lakes) minerals in more saline environments. Each of the two proposed sites has attributes which are consistent with the evaporite basin model, and have prospects for accessible exposures of chemical deposits for sample return. Due to thermodynamic and hydraulic constraints that control precipitation of chemical sediment, studies on these environments provide the greatest potential for objective and quantitative advances in our paleoclimate models for Mars. Return samples of salts would also potentially carry abundant encapsulated gas and fluid inclusions of the ancient Martian hydrosphere and atmosphere.

In many terrestrial evaporite sequences one can also find abundant microfossils (e.g. diatoms). Due to low clastic inputs, biotic remains are often easier to find here than in lucustrine environs dominated by clastic deposition. Water rich environs may have been, in analogy to life on earth, oases that persisted within an otherwise expanding and freezing desert on Mars during the late Noachian to early Hesperian, thus a paleolake site is a logical choice for exobiologic research.

Lastly, each of the two sites are located in regions of the Highlands near the dichotomy boundary and provide sampling opportunities for Noachian to early Hesperian layered regolith. The steep, angle of repose, crater margins have provided, largely by mass wasting processes, a source of clastic input to the basins. The floors are thus a collector of debris representing over 1 kilometer of Highlands' stratigraphy. High resolution images for the White Rock basin show a strataform character to the crater margin regolith.

Possible Hazards

The landing area within the White Rock basin is essentially flat, and most likely underlain by strata laid down down in a liquid state. High resolution images of the marginal areas of the basin indicate the presence of debris flows. Small diameter craters are also found on the floor of the basin. The presence of small craters and debris flows suggest that much of the surface area in the potential landing site is represented by a deflation surface and may therefore be relatively free of appreciable sand and loess deposits. One would thus expect a hypsometry controlled by small impact structures, and clasts of chemically resistent debris and ejecta materials.

An inspection of the high resolution imagery has not yet been performed for the Evros paleolake site to determine the surface characteristics of the landing area. However, like the White Rock basin, the basin floor is largely represented by a flat lying surface underlain presumably by strata laid down in a liquid state. The north and northeast margins of the basin have some uneven ground where, by analogy to the White Rock basin, are likely underlain by colluvium shed from the adjacent basin margins. A potential former ground water sapping front may be present along the east side of the basin. If so it suggests that the adjacent floor of the basin may be a salt-facilitated erosional suface, akin to that seen along some of the African Sabka margins.

Science Opportunities

1) Both sites have basin floors which have undergone some excavation due to later cratering. Thus strata laid down presumably in the presence of water should be available for sampling within each of the landing zones. In White Rock basin there is the additional opportunity to sample White Rock, a hypothetical erosional evaporite remanent within the basin. This inselberg also adds further evidence for deflation within the basin. We can expect lag deposits throughout the area which will be a grab bag of resistent materials younger than the current erosional level in the basin.

2) Both basins will have colluvial fans extending into the landing area, thus providing opportunity to sample surrounding Highlands regolith. In the case of White Rock the surrounding regolith is clearly stratified, and debris fans would contain approximately 1 to 1.5 km of highland stratigraphy.

3) The potential chemical deposits to be found here are: carbonates, sulfates, clorites, and silicates (if volcanic ash fell into the salt lake). The chemical deposits provide thermodynamic constraints on the ancient climate and hydrosphere on Mars; and if returned, would have abundant gas

and fluid inclusions that represent the ancient hydrosphere and atmosphere of Mars.

4) While a long shot, past life could be preserved in these areas in forms analogous to terrestrial lakes/seas with low clastic inputs such as happens with diatomaceous layers or stromatolites. If one wishes to identify past life by fossil evidence, low clastic inputs within the depositional environment are essential to improving the odds. Without the garantee of sample return, improving the odds for locating fossil evidence in the Athena mission becomes a higher priority.

Landing Data for the Two Paleolake Sites

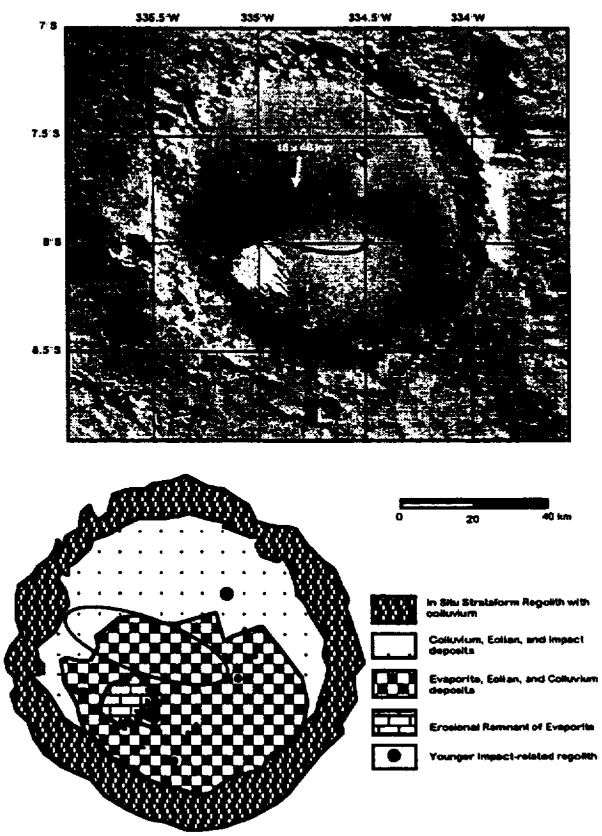
Parameter	White Rock #	Evros Paleolake^*
Elevation	~1 - 1.5 km	~1 - 1.5 km
Center Latitude	07.8° S	-10 ° S
Center Longitude	334.75° W	348.5 °W
Upper Left Latitude of AOI	7° S	9 °S
Upper Left Longitude of AOI	336°W	349.5 °W
Lower Right Latitude of AOI	9° S	11 °S
Lower Right Longitude of AOI	333.5° W	347.5 °W
Radar Reflectivity		
Delay Doppler	.03	in progress
Continuous Wave	.06 +/- .03	“
12.6 cm	.066 +/- .027	“
RMS Slopes		
3.5 cm DD	2° - 10°	“
3.5 cm CW	5° - 10°	“
12.6 cm	~6°	“
Surface Properties		
Bulk Thermal Inertia	5 - 7	5 - 7
Fine Component T.I.	6 - 8	6 - 8
Albedo	.18 - .23	in progress
Red Reflectivity	.09 - .11	“
Violet Reflectivity	.05	“
Red:Violet		
Average and S.D.	10.3 +/- 5.2	“
Range	1 - 20	“
Rock Abundances	2 - 8%	3 - 8 %
Viking Image Resolution		
<50m/pixel		
<50m/pixel		-

#Data sources: Pleskot, L.K. and E. D. Miner (1981) Time variability of Martian bolometric albedo, ICARUS, 45, 19-201, Christensen, P. R., (1981) Global albedo variations on Mars: Implications for active aeolian transport, deposition, and erosion. J. Geophys. Res., 93, 7611-7624., Palluconi, F. D. and J.H. Kiefer (1981) Thermal inertia mapping of Mars from 60°N to 60°S, Icarus, 455, 415-426, Christensen, P. R., (1986) The spatial distribution of rocks on Mars, Icarus, 68, 217-238.

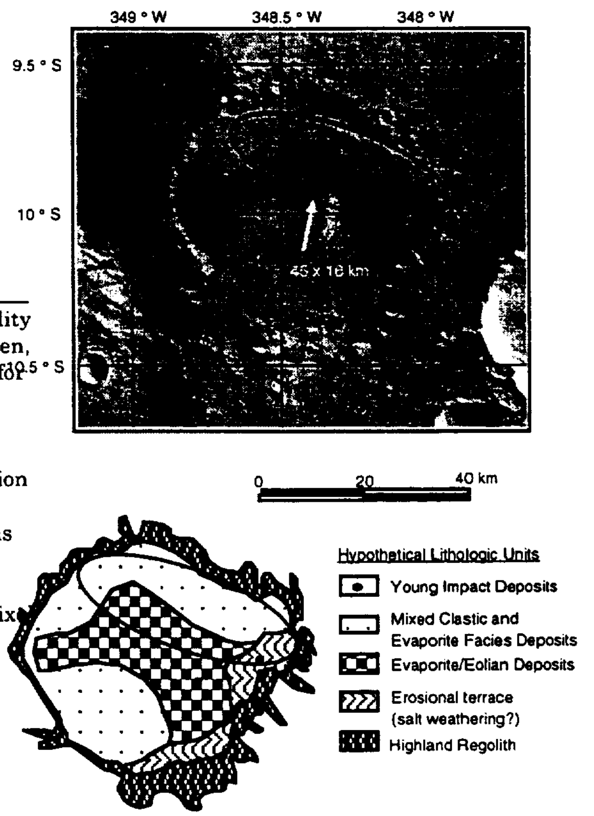
^Data sources: Secondary source of the presumed above sources as displayed within: HTTP://mars.jpl.nasa.gov/2001/landingsite.

*the area of this site appears on the JPL webpage of "Regions on Mars that satisfy the Engineering Criteria and have 100 m/pix or better Viking coverage" (http://mars.jpl.nasa.gov/2001/landingsite/Regions.html)

White Rock Basin Site



EVROS Paleolake Site



POTENTIAL MARS 2001 SITES COINCIDENT WITH MAGNETIC ANOMALIES.

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Introduction. Of the areas that meet the engineering criteria for MSP 01, only two are coincident with magnetic anomalies measured by the MAG/ER instrument on MGS [1,2]. Area A is centered on ~10°S, 202°W and extends from ~7.5°S to 15°S. This area is associated with three bands of magnetic anomalies, two with positive values surrounding an area with negative values. Area B corresponds with a circular high positive magnetic anomaly and is centered at 13.5°S, 166°W. In addition to magnetic anomalies, the proposed sites have other attributes that make then attractive from of standpoint of meeting the objectives of the Mars Program.

The landing site candidates meet the engineering requirements outlined on the Mars '01 landing site page http://mars.jpl.nasa.gov/2001/landingsite. These are (source of data in parentheses): latitude between 3N and 12S, rock abundance between 5-10% (IRTM), fine-component thermal inertia > 4 cgs units (IRTM), topography <2.5 km (MOLA). There are three exceptions: 1) Area B contains sites that lie up to ~15°S, 2) some sites are considered that have rock abundance values of 3-13%. 3) High resolution Viking coverage may not be available. These exceptions will be noted below.

Area A. This area (Fig. 1) offers the opportunity to land at the highland/lowland boundary. From south to north, a positive magnetic anomaly correlates with the extensive Noachian cratered unit (Npl1, 3) and dissected unit (Npld). The anomaly becomes negative northward, where the highest negative values roughly correspond to the knobby plains material (Apk) at the HH/LL boundary. The proposed landing site is within the knobby plains material, in the center of what can be seen as an older crater remnant, likely part of Npl1. Inferring from the color scale bar provided by the MOLA team [4], the site lies ~1 km below the highlands to the south and may offer views of the boundary if the spacecraft lands close to the boundary. Local knobs and mesas may offer views of the stratigraphy of the area and examples of Noachian materials. Two channels can be seen in the Viking EDR (596A26; 8.29°S, 202.1°, 225m/px) to flow northward from the highlands into the landing site area; one channel continues through the area. The site is smooth and crater-free on this scale. Channels, knobs and some polygonal terrain in the smoother areas are visible and are present within a 20 km landing ellipse.

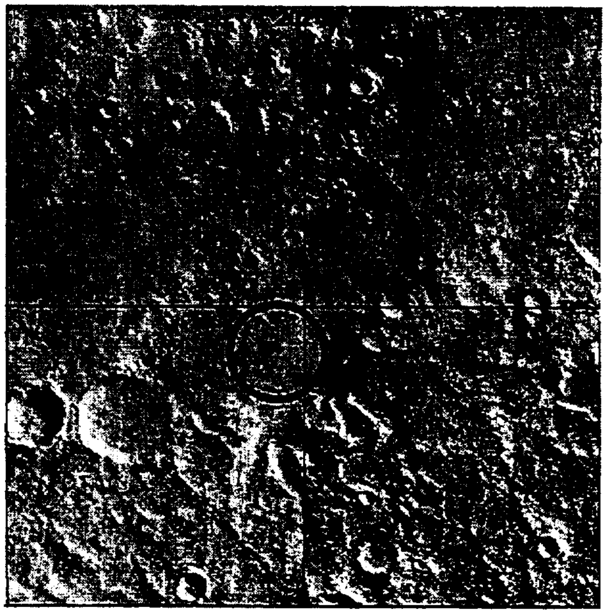

Figure 1. MDIM of Area A, with overlay of magnetometer data. Colors are from [2], where blues indicate negative values of the radial component of the magnetic field. A 20 km landing ellipse is indicated.

Area B. (Only qualifies in the 3-13% rock abundance range). A semicircular positive anomaly is present in this area centered on ~13.2°S, 165.2°W. The values are within the darkest red of the colorbar provided in [2], and thus may include values as high as 1500nT. These high values are present within an area that satisfies the 01 constraints (3-13%) at ~13°-15°S, 165°-165.8°W (Fig. 2). This range encompasses two Noachian units, the cratered unit, Npl1, and the ridged unit, Nplr. The maximum values for the magnetic anomaly roughly correspond with the limits of the cratered unit. MDIM resolution (231m/px) images show the site to be smooth, with the largest crater ~3km diameter. Broad ridges trend N, NNE and are ~5km across. Numerous channels are visible and flow into several local craters. A high-resolution Viking EDR (441S13; 13.47°S, 165.4°, 56m/px), within the MDIM shows numerous ridges, channels, and etched terrain An area smooth at the 56 km scale is entirely within a 20 km landing ellipse and contains ridges and at least one buried crater. In sum, this site offers a high probability of sampling and characterizing Noachian aged rocks including channel deposits and excavated materials.

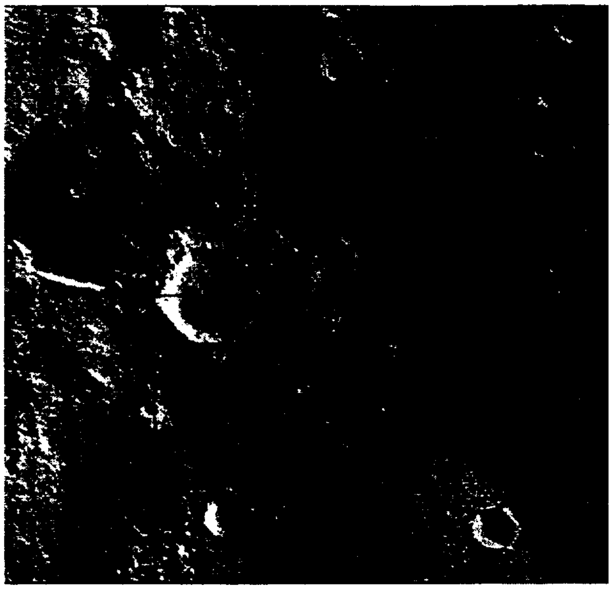

Figure 2. MDIM of Area B with overlay of magnetometer data. Colors are from [2], where the red hues may include values as high as 1500nT. A 20 km landing ellipse is indicated.

Landed science investigations. While '01 does not have a magnetometer, it may be possible to test some of the ideas emerging from the magnetometer data using the instruments on '01. One hypothesis suggests the magnetic anomalies are coincident with ancient seafloor spreading of some kind; this can be investigated at site A, contained within one full magnetic reversal. Several types of morphologies and rock chemistry are typical of spreading centers on the Earth. Morphologies such as sheeted dikes, gabbro dikes within harzburgite or dunite, and gabbros that display magmatic foliation are typical of terrestrial ophiolites [5]. Realizing the extreme difficulty in landing on Mars and observing bedrock exposures, we may have to rely on impact cratering in Noachian terranes to expose layers and distribute a representative sample of the crust within observation of the lander and rover. The observation of a boulder containing cumulate layered gabbro sequences is strong indicator of a large magma chamber predicted to be associated with both seafloor spreading and with large volcanoes.

Confirmation of the presence of martian spreading center rocks will be difficult, if not impossible to derive from APXS measurements. Basalts, dunite, harzburgite and pyroxenites, all typical of mid-ocean ridge assemblages, are represented in the SNC meteorites, but we have no way, to my current knowledge, of classifying these rocks as a martian MORB vs. a flood basalt or some other local magmatic phenomenon. If we landed at Mars and identified an orthopyroxenite like ALH84001, the only Noachian aged SNC, we could only confirm a plutonic origin.

Both Sites A & B offer the opportunity to search for anomalous compositions that could produce the very high magnetic values; site B contains values that may be as high as the 1500 nT range.

The discovery of magnetic anomalies at Mars argues for the placement of a magnetometer on the '03 and '05 rovers. Such a rover-deployed magnetometer could be placed against rocks and orientation and magnitude of magnetism could be measured. Such measurements of rocks from which samples are cached and returned will provide invaluable information about the timing of the magnetic field at Mars. I further suggest that if the '01 engineering requirements also constrain '03 and '05, these two areas should be targeted by MOC for more detailed investigation.

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CONSTRAINTS AND APPROACH FOR SELECTING THE MARS SURVEYOR '01 LANDING SITE.

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

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

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

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

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

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

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

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

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

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

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

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

Data sets, announcements and a schedule for the selection of the MS '01 landing site is being maintained on our web site (URL above). After the June 1999 landing site workshop, the number of sites being studied in detail will be limited to order 10. Further downselection to a handful of sites is expected following a MS '01 workshop in October 1999. Targeted MGS data will be evaluated throughout the process and site selection will take place by 1/00, with some flexibility for changes until launch in 4/01.

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Potential Landing Sites in Margaritifer Basin, Margaritifer Sinus, Mars;

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Overview of Proposed Landing Sites: Two landing sites (10.00°S, 21.79°W and 10.85°S, 21.62°W) within the confluence plain of Samara, Parana/Loire, and Margaritifer Valles are proposed for either the 2001, 2003, or 2005 Mars Surveyor Lander. Both of the proposed landing sites are approximately 1 km above the planetary datum (1). Observation and sampling of a portion of this depositional plain, hereafter referred to as Margaritifer Basin, should help constrain the origin of the enigmatic valley systems and help define the water and climate cycle during the early history of the planet (see below). Moreover, the high probability of directly sampling water-lain deposits derived from a broad area of the Martian highlands maximizes the likelihood of identifying possible evidence of biotic or pre-biotic processes. The opportunity to sample material ejected during formation of nearby craters or exposed in erosional remnants adjacent to the sites enhances the possibility of achieving these objectives.

The long axis of the expected landing ellipse will be 10-15 km (2) and fits well within relatively low relief (at coarse topographic scales) sections of the areally extensive basin surface characterizing both sites. Viking images, IRTM, and albedo data for the sites (3-6) suggest the surface is characterized by minimal eolian cover and a rock abundance that fits in a range of possible values. Estimated surface rock abundance is between 2-20%, but actual values on the lower relief landing site surfaces may lie towards the lower end of this range. While the "best" estimate of rock abundance is ~8-20%, this value may reflect the coarse scale of the data that incorporates relief punctuating portions of the confluence plain (mainly erosional remnants and outliers of collapse associated with nearby Margaritifer Chaos). Unfortunately, the best Viking Orbiter images of the landing sites possess resolutions <100 m/pixel and are not sufficient to evaluate the detailed morphology, thereby helping to better refine estimates of block abundance. Collection of MGS MOC and TES data of the sites is therefore considered a high priority.

Estimated thermal inertia, rock abundance, and other parameters that help to characterize the proposed sites are listed below. Predicted radar reflectivity and RMS slope are poorly constrained, but could be improved using recent radar data for the region (7).

- **Latitude:** 10.00°S, 21.79°W (northern) and 10.85°S, 21.62°W (southern)
- **Elevation:** Approximately 1 km above planetary datum (both sites)
- **Thermal Inertia:** ~8-10 (10^{-3}cal cm^{-2}s$^{-1/2}$K^{-1})
- **Albedo:** ~0.15 (approximate)
- **Rock Abundance:** 2%-20% (best estimate 8-20%?)
- **Radar Reflectivity:** ~3%-9% (estimated from data in 4)
- **RMS Slope:** ~1.5-3 (estimated from data in 4)

Regional Drainage Networks: The basins of the northwest draining Samara and Parana/Loire valley systems cover a combined area of 535,550 km^2 and incorporate some of the best integrated valleys on Mars (8-15). By contrast, Margaritifer Valles is the terminal segment of an integrated meso-scale outflow system heading south of Uzboi Valles and draining northeast through Holden Crater, Ladon Valles, and Ladon Basin. The confluence plain at the terminus of these systems straddles the axis of the Chryse Trough and both landing sites together with nearby Margaritifer Chaos may comprise the source region for some of the fine sediment transported along Ares Vallis to the vicinity of the Sagan Memorial Station (16). As a depositional plain formed at the confluence of valley networks and a meso-scale outflow channel, Margaritifer Basin likely contains a diverse assemblage of sediments recording the geologic and climatic evolution of the Martian highlands.

Sequence of Geologic Events: Geologic mapping of Margaritifer Basin at 1:500,000 (MTM quadrangles -10012 and -15022) is underway as part of a NASA funded effort. Assessment of morphologic and stratigraphic relationships in the region is assisted by interpretation of crater statistics (compiled using methods described in 13, 17) and results of other studies (*e.g.*, 18-23). The oldest recognizable features are the degraded Holden, Ladon, and Noachis multi-ringed impact basins (21, 22) whose structural elements influenced the location of the later forming valleys and channels. Three events resurfaced portions of the region after formation of these basins: the first two were during the early-Noachian period of heavy bombardment (21) with the second drawing to a close at an N5 age of 1400 (number of craters larger than or equal to 5 km in diameter per 1,000,000 km^2). The third resurfacing event began during the mid-Noachian (N5 of 500) and drew to a close in the late-Noachian (N5 of 300) coincident with waning highland volcanism (21).

Formation of all valley networks, the nearby Uzboi/Holdon/Ladon/Margaritifer meso-scale outflow system, and their associated depositional sinks (including Margaritifer Basin) followed the third resurfacing event and occurred between the late-Noachian and early-Hesperian (N5 of 300 to 150). The low albedo markings on the floor of Margaritifer Valles extend across a portion of the basin and suggest flow from the outflow system dominated the last stages of basin infilling. Margaritifer Chaos lies at the northern end of the basin and began to form near the end of the third resurfacing event with collapse likely continuing into the latest-Hesperian/earliest-Amazonian (21). A final, more localized resurfacing event emplaced materials that always embay valleys and continued through much of the early and mid-Hesperian (N5 ages 200 to 70). More recent events include localized eolian and mass wasting modification.

Summary: The proposed landing sites occur within a portion of the Martian highlands preserving a long and complex history of geologic activity. Observation and sampling of materials emplaced within Margaritifer Basin during the late-Noachian and early-Hesperian should lead to a refined understanding of early Mars climate during formation of valley networks and would help calibrate crater production models (*e.g.*, 24-26). Collectively, this information would help constrain the global water cycle.

Finally, landing on the materials forming the confluence plain suggests a diverse assemblage of water-lain materials may be directly sampled and could help evaluate the possibility of past biotic activity on Mars. Distinction between the better of the two sites awaits further definition of the allowable latitude band for landing and analysis of radar and higher resolution MGS TES and MOC data. Research supported by NASA grant NAG5-4157.

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NORTHERN MEMNONIA AREA: A POTENTIAL SITE FOR "MODERN" GROUND WATER.

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Introduction: Locating "modern" (i.e., geologically young) sites of ground water activity is difficult because processes associated with water on the surface occurred primarily in the Noachian-Hesperian Periods [4]. Nevertheless, some regions display morphological signatures of more recent water-related processes [5-8]. The problem is to locate such sites that also meet the engineering constrains of landed missions. A potential area lies in Northern Memnonia.

The region selected for detailed study is at the northern edge of Memnonia in the transition zone between the ancient highland plateau and young lowland plains. The plateau includes ancient cratered materials (unit Npl_1) and hilly materials (unit Nplh) [9, 5].

General Geology: Hesperian ridged plains comprise the floors of some craters, along with mantles of younger fluvial and aeolian deposits. Rimless craters and networks of small valleys are common in the area. The valleys incised the highland surface, as well as the Medusae Fossae deposits [5]. Because some channels cut parts of the Lower and Middle Medusae Fossae deposits, Scott and Chapman [10, 5] suggested that water was available in Lower and Middle Amazonian epochs, younger than the youngest fluvial activity in the Gusev crater area. They also suggested that the fluvial activity may have been hydrothermally-driven by the ascent of magma leading to the eruption of Medusae Fossae materials. Consequently the area proposed for study could contain materials altered by ground water that was released to the surface by hydrothermal activity.

Potential landing site: The proposed landing site is in the lower, delta-like part of the channel system on alluvial deposits associated with more recent fluvial processes. Ejecta from two fresh craters are within the site and could provide samples of ancient highland materials and younger material of the Medusae Fossae Formation.

Scientific rationale: The landing site is in a geologically complex region. It includes evidence of late-stage fluvial activity (possibly triggered by regional magmatic activity), making the site important for sample return missions. The potential diversity of the rocks and sediments could enable understanding of the more recent climatic environments on Mars involving ground water, fluvial activity, and lacustrine sedimentation.

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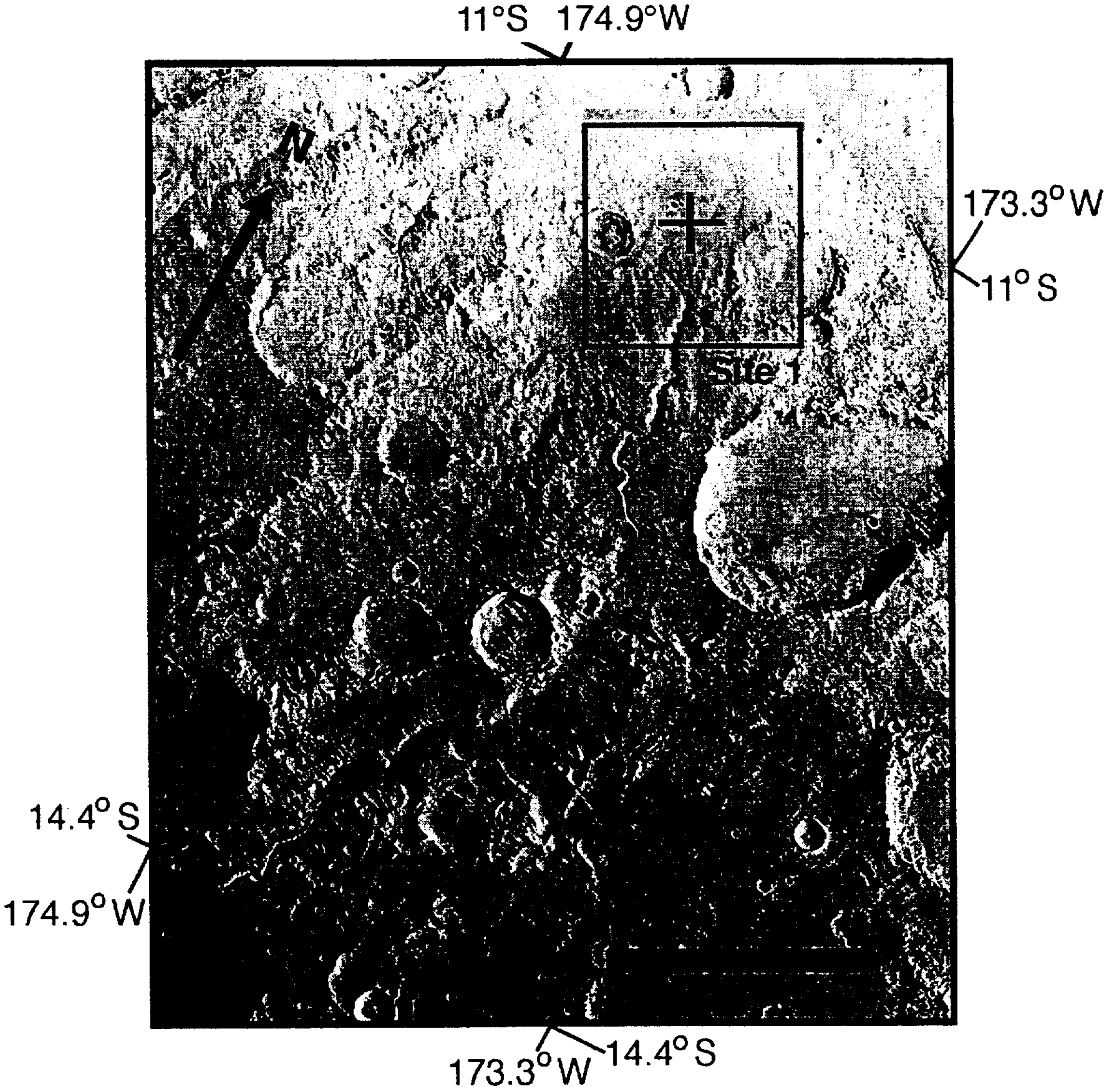

Viking Orbiter mosaic of the northern Memnonia area. The landing site is located at 11.3°S, 174.2°W, +1 to +2 km.

SHALBATANA VALLIS: A POTENTIAL SITE FOR ANCIENT GROUND WATER.

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Introduction: Within current mission constraints, most potential ancient ground water settings are found in the area between western Lunae Planum and western Arabia Terra. The geologic history of this area has significant implications for understanding Mars' hydrologic and climate history. Large collapse depression (chasmas), chaotic terrain, and multiple outflow channels are concentrated in the area. The formation of these features involves the influence of tectono-magmatic activity which are thought to have occurred during and immediately following the uplift of the Tharsis area early in Mars' geologic history [1-4]. The hydrological regime in the area is interpreted to include charging the ground water system by juvenile water and the release of water by melting of ice in the megaregolith [5]. Shalbatana Vallis is selected for detail study to assess their potential as landing sites for the exploration of ancient underground water systems.

General geology: Shalbatana Vallis is one of the narrowest (10-50 km cross) and deepest (as much as 3 km deep) channels in the Lunae Planum-Xanthe Terra area. Similar to other outflow channels, it originates in chaotic terrain within a circular depression 120 km in diameter. The channel trends NE down the general slope of Xanthe Terra and cuts through one of the oldest units of the highland terrain (unit Npl_2).

The channel is unusual because it appears to represent a single outflow initiated by a large impact. This impact could have excavated materials from the Martian crust from depths of several kilometers, apparently "tapping" the aquifer system leading to catastrophic flooding to form the channel. Ejecta from the Noachian impact crater [6, 7] is preserved NW-W and SE from the source area. The width of Shalbatana Vallis near its source is about 50 km and then it continues 500 km NE as a sinuous, narrow channel of nearly constant width (10 -20 km cross) and depth (~2 km). The channel then becomes wider (40-50 km), bifurcates, and enters Simud Vallis [7].

Mapping by Scott and Tanaka [6] and Rotto and Tanaka [7] suggests that Shalbatana Vallis drained a ground water system primarily during Hesperian times and could have continued activity into the Early Amazonian Epoch. The walls of the channel are cut into materials of Hesperian age and Noachian rocks of the plateau sequence, possibly including megaregolith [6].

Shalbatana Site 1: This site is in the NE part of the Shalbatana Vallis source depression on smooth plains between the inner cliff of the depression and the chaotic terrain. Sample targets include materials which were in contact with the inferred ancient ground water system: 1) ancient highland crust, 2) ancient impact breccias (megaregolith), 3) products from potential hydrothermal activity resulting from the interaction of ground water with impact melt, and 4) sediments associated with the outflow and seepage of ground water from the depression walls. In addition, samples of windblown deposits would provide information on modern aeolian and weathering processes.

Shalbatana Site 2: This site is near the SE base of the Shalbatana wall near the outlet from the source depression. It is on channel floor deposits and could afford sampling the same rock as from Site 1, but which was transported downstream by channel flow. Also included are materials from Shalbatana Vallis (unit AHchl), suggested to be young outflow channel sediments [7]. East of the site are deposits derived from mass wasting and slope failure of the channel walls derived from ancient plateau materials (unit Npl2), which could represent some of the earliest resurfacing processes in the highlands. Sampling Noachian rocks and younger channel materials (unit AHchl of Hesperian-Amazonian age) is important for addressing the early climate history and the hydrological regime.

Scientific rationale: The potential landing sites associated with Shalbatana Vallis include a suite of rocks and sediments that are accessible to sampling by a rover. Materials include: 1) the oldest stratigraphic sequence of Noachian highland plateau materials, including ancient impact breccias, and 2) Hesperian-age materials derived from outflow of ground water from the source depression. These rocks and sediments may contain geochemical signatures of the early Mars ground water ecosystem and climatic conditions. In addition, samples of modern aeolian sediments could provide information on more recent surface processes.

The location of the channel source within the large impact crater affords the potential to sample hydrothermally-altered materials resulting from the interaction of impact melt with ground water. This material could provide geochemical information on hydrothermal systems that have been modified by impact processes, which might have been widespread in early Mars history.

Carr [8] suggested that the evolution of Shalbatana Vallis is closely connected with the hydrological regime of Ganges Chasma. For example, shallow depressions with channel-like and collapsed features are found between the Shalbatana Vallis source area and the northern edge of Ganges Chasma. This relationship might reflect ground water drainage from a paleolake in Ganges Chasma into the source area of Shalbatana Vallis.

A key issue in the evolution of Shalbatana Vallis is to determine when water was released to form the channel. Although the impact inferred to have initiated the process is mapped as Noachian [6, 7], superposition of its ejecta on younger channel deposits (unit Hchh) and the smooth unit of the plateau sequence (unit Hpl_3) suggests that the crater formed during the Hesperian. Mapping these and other relationships may constrain models of when ground water discharge occurred.

The different ages for the channel-branches of Shalbatana Vallis and their relations with units of the plateau sequence suggest a complex hydrological regime in Xanthe Terra. Detailed investigations of this area as part of landing site studies will lead to a better understanding of the sequence and potential magnitude of the ground water system.

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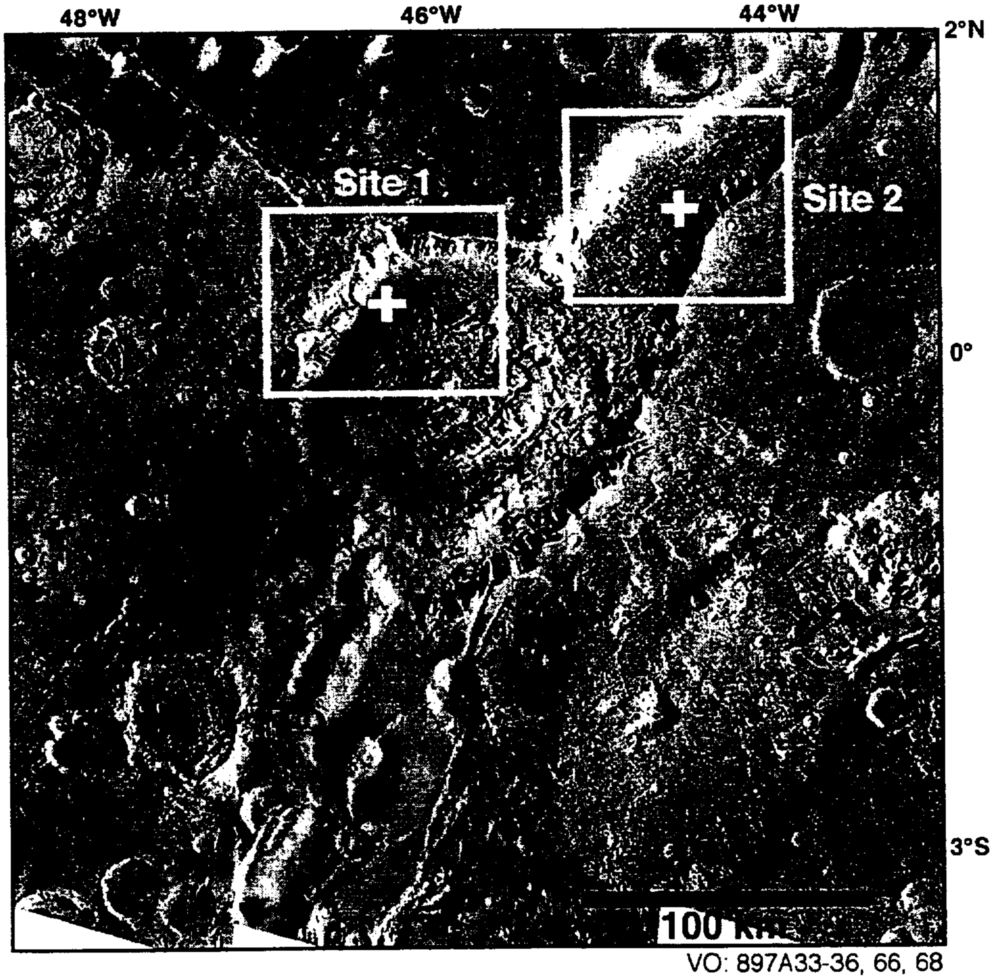

Viking Orbiter mosaic of Shalbatana Vallis. The landing sites are located at 0.2°N, 46.3°W, 0 to +1 km, and 0.7°N, 44.5°W, 0 to –1 km.

CANDIDATE MARS SURVEYOR LANDING SITES NEAR APOLLINARIS PATERA.

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Introduction: Regions near Apollinaris Patera are proposed for consideration as Mars Surveyor landing sites. Gulick (1998) proposed this region at the First Mars Surveyor Landing Site workshop; Bulmer and Gregg (1998) provided additional support.

Review of Science Rationale:

Apollinaris Patera (Fig. 1) is situated on the highlands/lowlands boundary at 8.5°S, 186°W. The volcano itself has been mapped as Hesperian in age. The regions surrounding Apollinaris show evidence for volcanism, volcano-ice interactions, and erosion by water. Numerous valleys modified by fluvial processes dissect a large fan structure emanating from the southern flank of the volcano. Sapping valleys have formed along the southern terminus of the fan structure.

Regions near Apollinaris Patera provide a unique opportunity to sample outcrop lithologies ranging from highland Noachian basement rocks, to Hesperian aged lava flows, channel and flood plain materials, to Amazonian volcanic, ash and channel deposits. The close proximity of volcanic and fluvial features strongly suggests that volcanic hydrothermal processes have had a pervasive influence in the region.

There is extensive evidence of ground water in the region. A 23-km diameter impact crater lies on the northwest flank of the volcano and exhibits a fresh lobate ejecta blanket. Gulick (1998) argues that hydrothermal systems associated with the volcano could have mobilized this ground water, discharging it along the volcano's flanks. She concludes that hydrothermal systems associated with the growth of the volcano could have lasted 10^8 years.

Numerous isolated mesas are located to the southwest and west of Apollinaris. These mesas likely formed in one of two ways. The mesas may have formed by the melting of large volumes of ground ice as a result of volcanic activity of Apollinaris (Sharp, 1973, Carr and Schaber, 1977, Robinson et al. 1993, Scott et al. 1993). Alternatively they may be dissected fluvial deposits perhaps resulting from flooding from Ma'adim vallis (Scott and Chapman, 1995, Cabrol et al. 1996). Regardless of which origin mechanism is correct, the proximity of a persistent subsurface heat source to abundant ground water or ice could have provided a favorable environment for life. Hence the mesas and surrounding deposits would be excellent locales to search for signs of past biological activity. Here I continue to support two possible landing sites in this region.

Two sites near the flanks of the volcano may provide the opportunity to sample material altered by the possible discharge of hydrothermal fluids along the volcano's basal scarp. Site 1 (8.6°S, 187.5°W) offers the opportunity to sample the ejecta of a nearby impact crater and mesa material from the nearby chaotic terrain. The mesa material would be in place while the crater material would be exhumed from depth. Because of the lack of high resolution Viking images available for this area, further high-resolution MOC images are required to fully evaluate this site.

Site 2 (12°S, 185.5°W) lies in a valley (Figure 2) near the southern edge of the fan feature where sapping processes have eroded back into the fan along fault scarps. This area was likely a locale for thermal springs as it lies at the base of the fan that is both cut by scarps and incipient valleys. The floor material of the channel is darker than the surrounding volcanic terrain and appears smooth in available 70 m/pixel Viking images.

Engineering Constraints: Based on the maps posted on the JPL Mars Surveyor '01 Landing Site web page, this region appears not to meet the engineering constraints for the '01 mission. However, values obtained from the USGS PIGWAD web site for Landing Site Selection demonstrates that this region indeed satisfies all engineering requirements for the 2001 mission. Below is a list of the values for each of the required engineering parameters.

Table 1.

Engineering parameter	Constraints for MS '01	Apollinaris Patera region
Thermal Inertia (cgs)	5-10 cgs	5.9 cgs
Rock Abundance	5-10%	5-9%
Fine Comp. TI	>4 cgs	4.5-4.8 cgs
Slopes	<10deg.	No info. Avail.
Albedo	low	0.25-0.26
Elevation	<2.5 km	0-1km

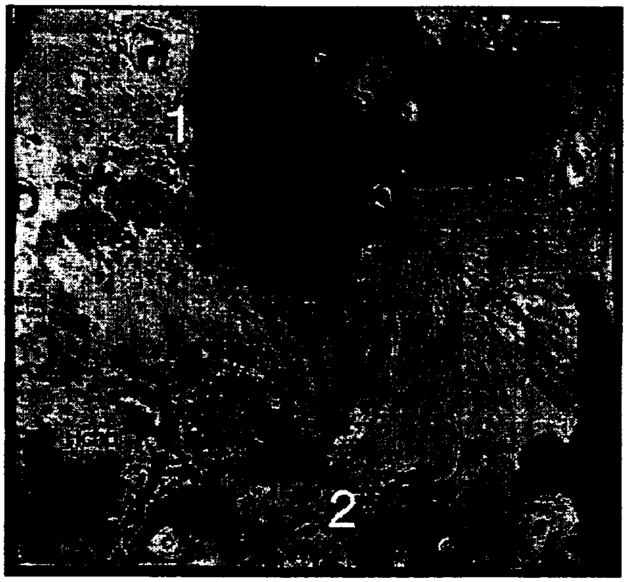

Figure 1: Regional geologic map of Apollinaris Patera region based on geologic map by Scott et al.

(1993). Ha is a smooth fan shaped flow possibly composed of lava. Hcht is chaotic material interpreted as a melange of ancient highland rocks and Apollinaris lava flows. Landing sites both sit on Hchp material interpreted as channel and floodplain deposits.

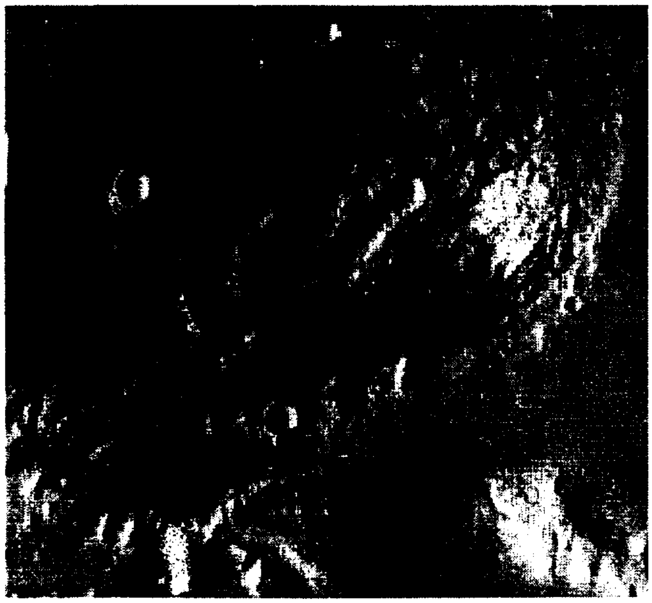

Figure 2: High-resolution (70 m/pixel) view of landing site 2 (channel floor SW of prominent crater in south-central part of image). Channel floor in this region is 15 km across.

Table 2: Other data for Site 2.

Latitude	12°S
Longitude	185.75°W
Max. elevation	1km
Min. Elevation	0 km
Hazard analysis	Channel deposits appear smooth in Viking images at 70m/px Some isolated mesas along perimeter
Slopes	No info. avail. Appears fairly flat
Unconsolidated material	Unknown; Channel material may be unconsolidated.
Site Environment	hydrothermal, fluvial, volcanic, and possible paleolacustrine or marine environments
Processes to expose or excavate subsuface materials	Isolated mesas and valley walls provide stratigraphic cross-sections; fluvial processes
Impediments to mobility	Based on Viking resolution 70m/px- the landing site appears smooth
Image #s and resolution	433S01-72m/px 434S01-73m/px

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A VIRTUAL COLLABORATIVE ENVIRONMENT FOR MARS SURVEYOR LANDING SITE STUDIES.

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INTRODUCTION: Over the past year and a half, the Center for Mars Exploration (CMEX) at NASA Ames Research Center (ARC) has been working with the Mars Surveyor Project Office at JPL to promote interactions among the planetary community and to coordinate landing site activities for the Mars Surveyor Project Office. To date, CMEX has been responsible for organizing the first two Mars Surveyor Landing Site workshops, web-archiving resulting information from these workshops, aiding in science evaluations of candidate landing sites, and serving as a liaison between the community and the Project.

Most recently, CMEX has also been working with information technologists at Ames to develop a state-of-the-art collaborative web site environment to foster interaction of interested members of the planetary community with the Mars Surveyor Program and the Project Office. The web site will continue to evolve over the next several years as new tools and features are added to support the ongoing Mars Surveyor missions.

WEB SITE FEATURES: A variety of tools have been developed and are accessible at the Ames Mars Surveyor Landing Site Studies web page. These tools include:

A Clickable, Zoomable Map Interface. We have implemented a clickable, zoomable map interface from which web pages for all candidate Mars Surveyor 2001 landing sites can be accessed. Individual landing site web pages include links to workshop abstracts, the PDS image atlas for Viking images, VRML virtual reality environments (see below), and landing site evaluations.

MOC images with annotated Viking context images. We have collected all aerobraking, SPO 1 and SPO 2 phase high-resolution MOC images that lie within the latitude belt being considered for the '01 mission. Each MOC image is associated with an annotated Viking context image that contains the footprint location of each MOC image. Annotated Viking context images are provided by Alfred McEwen (University of Arizona), courtesy of the Mars Surveyor '01 Project. We plan to make subsequent MOC data available at this site in a similar format for regions located within the acceptable latitude band for Mars Surveyor landing sites.

A Postdoc Mars Surveyor Landing Site Studies group. Postdoc (for Post document) is a collaborative, web-based environment that allows individuals to post and retrieve documents in virtually any format, including image, text, slide, spreadsheet, audio and video files. Users can employ Postdoc to propose a landing site, submit both science and engineering evaluations, post supporting image, graphics or word documents of their proposed landing site(s), or create their own email subgroup list for their respective landing sites. Others in the landing site community may request membership to those subgroups from the "owner" of that subgroup. Postdoc creates a common meeting place where the landing site community can post their work on candidate landing sites both to inform and to facilitate collaborations within the community and with the Project.

Low and high-resolution, zoomable, rotatable (VRML) models of landing sites proposed for this 1999 landing site workshop. We have constructed three-dimensional perspective VRML *(Virtual Reality Markup Language)* models for all proposed landing sites. MOLA PEDR (Precision Experiment Data Records) profiles have been incorporated when available and we plan to add MOC data as well. Some sites have the option to view geologic map overlays in this 3D format. Viewing the images with a web browser requires a VRML CosmoPlayer plug-in that is available free (www.cosmosoftware.com). Plug-ins are available for UNIX, Windows and MAC platforms. Information for obtaining and using VRML plug-ins is posted on our web site. Because VRML technology is new, your viewing experience may be "less than satisfying" in some cases. For example, loading two or more consecutive VRML files may cause some browsers to crash. The VRML plug-in is most stable on UNIX machines and least stable on Macintosh platforms. Therefore, we recommend that only the newest versions of the VRML plug-in be used.

A web-based GIS interface for obtaining engineering data of proposed sites. This features is provided by the U.S Geological Survey, courtesy of the Mars Surveyor Project. The interface allows one to easily locate the landing site of interest and to obtain rock abundance, albedo, slope, topography, thermal inertia, and fine component thermal inertia data for any spot on the planet.

PLANNED ENHANCEMENTS: Near-future enhancements to the web site include integration of geology and mineralogy (from TES released data) maps composited with surface images and as overlays on 3D VRML terrains. We also plan to integrate rock abundance, thermal inertia data and landing ellipses. Other future enhancements include the use of Concept Maps as a user interface for links to relevant site data (e.g. abstracts, science evaluations, images, maps, and online reference materials). The goal is to have the Concept Maps createable and editable by peer reviewers in a collaborative fashion.

Collaborative tools will be enhanced to include collaborative whiteboards, collaborative image viewing and annotation, and support for possible Usenet news groups, chat rooms, and/or list-serve mailing lists. Some of these capabilities are already provided on Postdoc, which allows user-uploadable and retrievable materials and threaded mail archives.

The website is intended to be a general repository for the latest Mars mission images, data, and data products that pertain to landing site selection, with on-the-fly image retrieval and auto-mosaicking and VRML creation, with options to include surface images, geological maps, maps of surface composition, and other relevant data.

Lybia Montes: A Safe, Ancient Cratered Terrain, Mars Surveyor Landing Site at the Isidis Basin Rim.

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Introduction: The Isidis basin rim may be key to under-standing Mars' past with future lander missions: this area enables the mission objective to explore Mars' climatic and geologic history, including the search for liquid water and evidence of prior or extant life in ancient terrains. While two safe candidate landing sites for Mars Pathfinder were identified in Isidis Planitia [1], and one is being pursued for the Mars Surveyor 2001 Lander [Crumpler: 3.4°N, 277.8°W], the region around Isidis Planitia, in contrast to Tharsis for example, has only been lightly studied [2,3,4,5,6]. The advent of new high resolution data sets provides an opportunity to re-assess the geologic context of this impact basin and its rim within the Martian geologic sequence as a candidate site for studying Mars' ancient cratered terrain and ancient hydrosphere. This reexamination is warranted by the various hypotheses that Isidis was once filled with ice or water [5,7,8,9,10].

Lybia Montes: Based on the stated landing site selection criterion of 50 m/pixel or better Viking imagery, we restrict ourselves to looking for safe landing sites within the Lybia Montes region of the Isidis Basin rim massif. In particular, we only consider the areas where Viking 20 m/pixel coverage exists from VL1 orbits 1137 and 1138 (locations shown in Figure 1). The area lies at the northern edge of the Mars Surveyor 2001 latitude range, around 272.5°W, 2.5°N. The elevations here are within the current engineering constraints. Future detailed MOLA data should be used to confirm this, as the elevations are near the upper limit, at around +2 km.

Greeley and Guest [4] map this region as unit Nplh, a Noachian hilly unit, interpreted as ancient highland rocks and impact breccia generated during heavy bombardment. Situated as it is on the Isidis Basin rim massif, this unit may offer an opportunity to sample Martian deep crustal rocks. Examination of the high resolution Viking images (Figure 2) shows that while the terrain is indeed rough and hilly, other processes have acted on the surface since heavy bombardment. The ancient cratered terrain is cut in many places by channels and gullies (see lower left portion of Figure 2), which have been previously analyzed [3]. These channels in the Viking images are of order 100 m across, and might pose a slope hazard for landing.

There are also areas of more homogeneous appearance, and topographically flatter, that lie between the rough hills and heavily cratered areas in our Lybia Montes scene. It is these locations that we believe offer interesting target landing sites. These surfaces may contain a sampling of the ancient cratered terrain rocks brought down the nearby channels, aeolian, fluvial, hydrothermal, and/or ejecta materials from more recent craters reworking the ancient brecciated surface. As it is unavoidable that any exposed rocks will have experienced weathering since their emplacement, these locations suggest that the Lybia Montes offers a safe way to reach samples of ancient cratered terrain rocks.

IRTM thermal inertias are low in our target area ($\sim 3\times10^{-3}$ cal cm^{-2} s$^{-0.5}$ K^{-1}), suggesting that it is dusty. At the same time, rock abundance maps suggest that the area has ~12% rock coverage. These contradictory observations, which on first look would exclude these sites, bear further study. We suggest that the spatial resolution of these properties is responsible. The intermassif channel plains unit, in which we propose our target sites, are sampled by the more southerly nearby MOC image (Figure 1). The MOC image is apparently devoid of aeolian dune deposits, suggesting that this unit is stable, and thereby less dusty than previously identified. Additionally, Phobos ISM data [12] suggest that the southern Isidis Basin rim shows less hydrated minerals than the Isidis Basin itself. This may indicate that our candidate landing sites on the basin rim massif are significantly less dusty than the adjacent impact basin.

Figure 1. Viking regional context for this landing site study. Image extends from about 276°W to 268°W and from about 0°N to 6°N. The area with 20 m/pixel Viking image coverage is outlined. The white stripes indicate pre-mapping phase MGS MOC images.

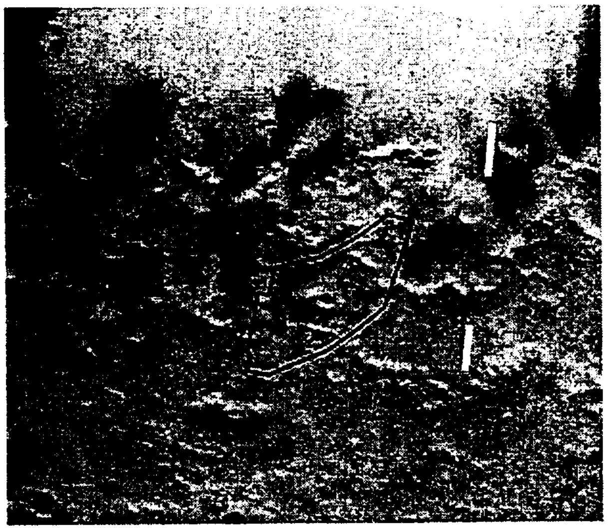
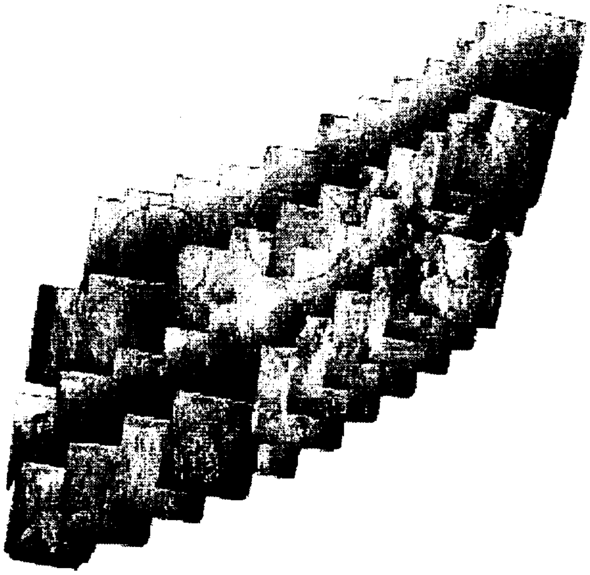


Figure 2. Mosaic of 20 m/pixel Viking image coverage in Lybia Montes (Isidis Basin Rim Massif) centered at 272.5°W and 2.5°N. Four (approx. 25 km diameter circles: Southwest, Northwest, Middle, and

East) are placed in regions that appear safe for landing and roving.



Summary: Four target landing sites are proposed in the inter-massif channeled plains in the Lybia Montes (LM) of the southern Isidis Basin rim massif: Southwest (LMSW 273.0°W, 2.8°N), Northwest (LMNW 272.9°W, 3.0°N), Middle (LMM 272.5°W, 3.0°N), East (LME 272.0°W, 3.1°N). These sites all lie in reworked and/or altered ancient cratered highlands materials. The geographic locations, in the Viking cartographic frame, are at the northern latitude range limit. These sites are at acceptable elevations near +2 km. These sites all have 20 m/pixel Viking image coverage. It is somewhat contradictory that these sites are both somewhat too rocky (<13%), as well as somewhat too dusty (both fine component and bulk thermal inertias ~3×10^{-3} cal cm^{-2} $s^{-0.5}$ K^{-1}), and we suggest that, based on nearby MOC images in similar terrain, the sites are in fact acceptable in both regards. Surface slopes are not yet known; radar tracks do not cross this location. From visual inspection of the 20 m/pixel Viking images and of MOC images, they appear in acceptable range.

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GLOBAL DATABASE OF GSSR MARS DELAY-DOPPLER RADAR OBSERVATIONS: ANALYSIS FOR LANDING SITE CHARACTERIZATION AND ROVER TRAFFICABILITY.

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Introduction: Earth-based radar data remain an important part of the information set used to select and certify spacecraft landing sites on Mars. Constraints on robotic landings on Mars include: terrain elevation, radar reflectivity, regional and local slopes, rock distribution and coverage, and surface roughness, all of which are addressed by radar data [1]. Indeed, the usefulness of radar data for Mars exploration has been demonstrated in the past. Radar data were critical in assessing the Viking Lander 1 site [2, 3], and more recently, the Mars Pathfinder landing site [4].

Radar Data: The Goldstone Solar System Radar (GSSR) facility has successfully collected radar echo data from Mars over the past 30 years. The older data provided local elevation information for Mars (ranging-only data), along with radar scattering information with global resolution (Doppler-only or continuous-wave data), and some small amount of higher spatial resolution range and scattering data (delay-Doppler data) [5, 6]. Since the upgrade to the 70-m DSN antenna at Goldstone completed in 1986, delay-Doppler data were collected during the 1988, 1990, 1992-93, and 1994-95 Mars oppositions. Much of this Mars data since 1990 has not been analyzed beyond a cursory examination of data quality. The ranging information provided by these data [7] is in fact similar to that offered by earlier delay-Doppler experiments from the 1970's.

Delay-Doppler radar data, after significant data processing, yields the elevation, reflectivity and roughness of the reflecting surface. The further interpretation of these parameters, while limited by the complexities of electromagnetic scattering, does provide information directly relevant to geophysical and geomorphic analyses of Mars. The improved quality of the more recent GSSR data allows for more consistent analysis of the scattering behavior which can be related to surface roughness and rock coverage than was possible in the 1970's. In general, scattering parameters are sampled every 0.09° of longitude along a radar track. The size of the resolution cell this information relates to is about 0.17° of longitude by 2.6° of latitude (approximately 10 km by 160 km). That portion of recent GSSR delay-Doppler data that has been fully examined, is the half of the 1994-1994 Mars opposition data analyzed expressly for the Mars Pathfinder Project [4].

In general, processed radar data have not commonly been available to the Mars exploration community at large. (The pre-1986 data are publicly available via anonymous ftp at ftp://asylum.jpl.nasa.gov/marty/, filenames mars6mb.lbl and mars6mb.tab.Z). In aid of the landing site selection process for future missions in the Mars Surveyor program, a comprehensive effort has been undertaken to present all the data since 1988 in a coherent form, accessible to the Mars research community. The data are viewable via the World Wide Web at http://wireless.jpl.nasa.gov/RADAR/Mars/.

Landing Site Selection: New datasets other than radar offer some of the site selection information provided by radar in the past. However, radar data still retain certain strengths. A critical element of NASA's future robotic Mars exploration is roving, and **rover trafficability** on the surface becomes a key landing site selection criterion. Two parameters for rover trafficability, **rock coverage**, and in particular, **surface roughness**, are ascertained from radar echo modelling.

With the advent of the Mars Orbiter Laser Altimeter (MOLA) instrument on Mars Global Surveyor (MGS), the importance of Earth-based radar to provide Mars elevation and regional slope information with ranging is diminished. However, the roughness parameters extracted from the scattering modeling of delay-Doppler echoes at 3.5 cm wavelength directly probe the scales of roughness that meter-sized rovers will encounter. MOLA data may provide some surface roughness information, and would certainly profit from a careful and direct comparison with the better-understood radar results in different regions. More generally, the correlation of radar roughness with Martian geomorphic units is worthy of further study.

The **radar reflectivity** of the surface of Mars as a whole is known well enough now [8] for the purposes of lander radar altimeters. However, radar reflectivity also provides a measure of rock abundance versus dustiness on and near the surface. Certainly this is also probed by thermal measurements with the Thermal Emission Spectrometer (TES) on MGS and existing Viking Infrared Thermal Mapper (IRTM) datasets, but corroborating data are most useful when "policy" decisions such as landing site selection are required.

Mars Surveyor 2001: One constraint on the Mars Surveyor 2001 landing site is a latitude range from 12°S to 3°N. The relevant radar data coverage is from the 1990 oppositios, and is shown graphically in Figure 1 and tabulated in Table 1. The data have been used for initial landing site assessment: regions and locations with appropriate elevations within the radar data set have been identified, and their radar scattering properties documented. Any interested party may now examine radar data pertinent to a candidate landing site.

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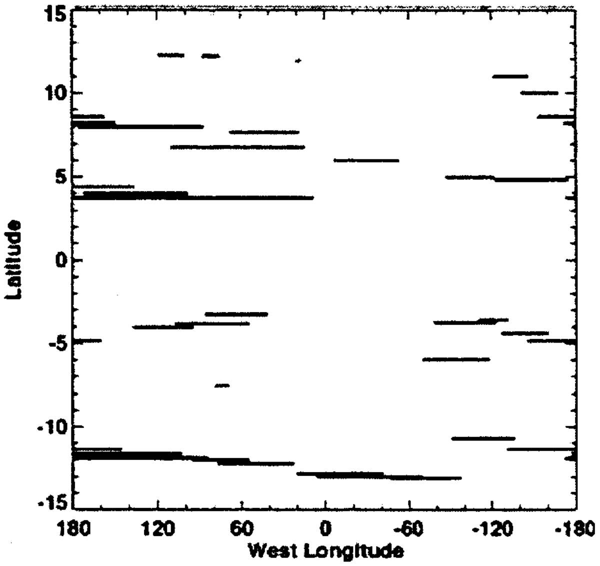
Table 1. 1990 Mars Opposition GSSR Data

Track Date	Latitude (°)	Longitude (°) Begin	Longitude (°) End
1990-12-30	-13.1	262.7	313.9
1990-12-28	-13.0	-70.6	6.0
1990-12-24	-12.8	-41.5	20.7
1990-12-17	-12.2	22.4	77.8
1990-12-15	-12.0	54.9	95.3
1990-12-14	-11.9	84.2	187.9
1990-12-12	-11.6	102.7	183.1
1990-12-10	-11.3	145.0	228.8
1990-12-06	-10.7	223.6	269.2
1990-11-20	-7.6	68.7	79.3
1990-11-02	-4.4	199.2	233.3
1990-10-27	-3.7	-122.8	-77.7
1990-10-25	-3.6	-131.7	-110.0
1990-10-12	-3.3	41.5	86.3
1990-10-02	-3.8	53.9	107.2
1990-09-29	-4.0	94.1	136.9
1990-09-22	-4.8	160.0	214.1
1990-09-14	-6.0	-118.5	-70.6

Figure 1. Delay-Doppler Radar Track coverage in the Mars Surveyor 2001 Lander Latitude Band.



WEB-BASED GIS SUPPORT FOR SELECTION OF THE MARS '01 LANDER SITE.

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Introduction. We have been producing a web-based, user-friendly interface built on a powerful Geographic Information System (GIS) that integrates statistical and spatial relational tools for analyses of planetary datasets. The interface, known as "Planetary Interactive GIS-on-the-Web Analyzable Database" (PIGWAD), provides database support for the research and academic planetary science communities, particularly for geologic mapping and other surface-related investigations. The PIGWAD address is http://webgis.wr.usgs.gov. We are now implementing a Mars '01 Lander page to support that mission's landing-site selection activity.

GIS is an organized collection of computer hardware, software, and geographic data whose operations can be tailored to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information [1]. Application of GIS in the planetary sciences has grown dramatically over the past few years, as scientists have been able to prepare thematic maps and determine spatial relations among multiple datasets [2-10].

GIS interface. Datasets relevant to the Mars '01 landing-site selection have been incorporated into PIGWAD, including the Viking-based rock abundance map, fine-component thermal inertia, albedo, and USGS topography. The USGS Mars Digital Image Mosaic is used as an image base, and a 5° latitude and longitude grid is included. A key element to the utility of the database is the spatial coregistration of the datasets. This requirement necessitates the adjustment of datasets into a common geodetic framework. In addition, as geodesy is updated based on Mars Orbital Laser Altimeter (MOLA) data, the GIS datasets also will require modification. The Mars map displays a scale bar and measurement of map locations in meters or degrees, depending on projection used.

The first time a user connects to the web-site interface via Netscape or Internet Explorer, a small JAVA applet will be loaded into their machine. Each time the user submits a request with the JAVA applet, the web server will process the request and return either a compressed image or tabular information. This approach allows the user to browse the data as if it were on the user's computer. Subsequent requests will result in a refresh of the map, guaranteeing the most up-to-date version of the database. The user also has the option of downloading the data to use on their own machine. When possible, we will use ESRI's Shape file format, which nearly all GIS packages can recognize.

The Mars '01 interface allows one to view a base image and any number of GIS layers in a common projection (similar to the Mars '98 interface shown in Fig. 1). From this interface, one can navigate, zoom, measure distances, query the datasets, and print maps (e.g., Fig. 2).

Future work. The Mars'01 Lander GIS web site is currently on line. We will be adding the 1:15M-scale geology, a Viking image resolution map, a Viking stereo coverage map, searchable Mars Orbiter Camera (MOC) footprints, MOC imagery, MOLA topographic data, and any other layers that may help with the landing site selection.

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Try it out. The PIGWAD web site can be found at the following address: http://webgis.wr.usgs.gov

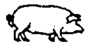

Figure 1. The beginner PIGWAD interface showing the South Polar region of Mars, which is being designed to help with the 1998 Mars Lander site selection.

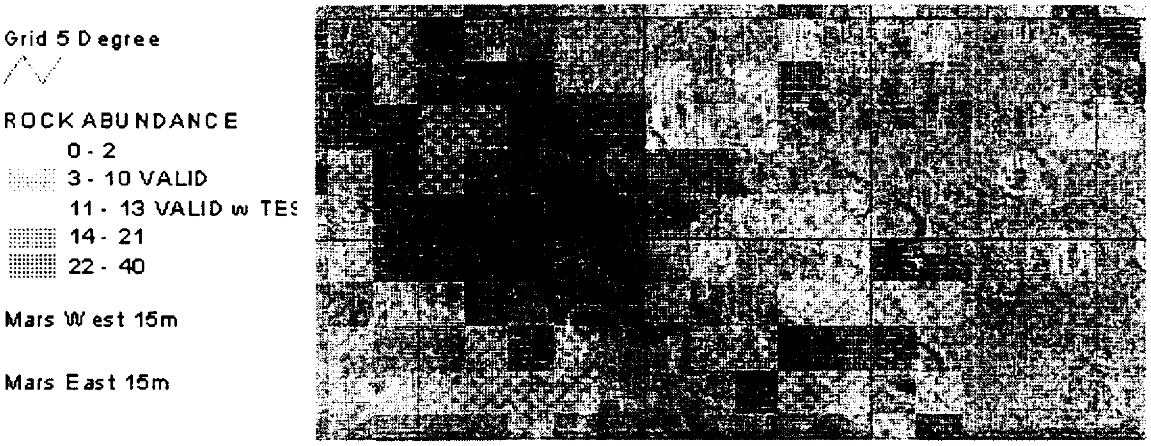

Figure 2. Amenthes region of Mars showing Mars Digital Image Mosaic (black-and-white background), rock abundance, in percent (1° X 1° colored pixels), and 5° X 5° coordinate grid.

LANDING SITE STUDIES USING HIGH RESOLUTION MGS CRATER COUNTS AND PHOBOS-2 TERMOSKAN DATA.

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Introduction We have examined a number of potential landing sites to study effects associated with impact crater populations. We used Mars Global Surveyor high resolution MOC images, and emphasized "ground truth" by calibrating with the MOC images of Viking 1 and Pathfinder sites. An interesting result is that most of Mars (all surfaces with model ages older than 100 My) have small crater populations in saturation equilibrium below diameters D ~ 60 meters (and down to the smallest resolvable, countable sizes, ~ 15 m).

This may have consequences for preservation of surface bedrock exposures accessible to rovers. In the lunar maria, a similar saturation equilibrium is reached for crater diameters below about 300 meters, and this has produced a regolith depth of about 10-20 meters in those areas. Assuming linear scaling, we infer that saturation at D ~ 60 m would produce gardening and Martian regolith, or fragmental layers, about 2 to 4 meters deep over all but extremely young surfaces (such as the very fresh thin surface flows in southern Elysium Planitia, which have model ages around 10 My or less).

This result may explain the global production of ubiquitous dust and fragmental material on Mars. Removal of fines may leave the boulders that have been seen at all three of the first landing sites. Accumulation of the fines elsewhere produces dunes. Due to these effects, it may be difficult to set down rovers in areas where bedrock is well preserved at depths of centimeters, unless we find cliff sides or areas of deflation where wind has exposed clean surfaces (among residual boulders?)

We have also surveyed the PHOBOS 2 Termoskan data to look for regions of thermal anomalies that might produce interesting landing sites. For landing site selection, two of the more interesting types of features are thermally distinct ejecta blankets (Betts and Murray, 1993) and thermally distinct channels and valleys (Betts and Murray, 1994). Martian "thermal features" such as these that correlate closely with non-aeolian geologic features are extremely rare, presumably due to reworking of the surface as discussed above, and due to aeolian processes. Thermally distinct ejecta blankets are excellent potential future locations for landers, as well as remote sensing, because they represent relatively dust free exposures of material excavated from depth. However, few, if any meet the current constraints on elevation for Mars '01.

Thermally distinct channels, which tend to have fretted morphologies, and are higher in inertia than their surroundings, offer a unique history and probable surface presence of material from various stratigraphic layers and locations, views of the surrounding walls, and possible areas of past standing water, flowing water, or increased amounts of diffusing water. Any presence of water (e.g., diffusing) may have enhanced duricrust formation in the channels, thus increasing the thermal inertias (flowing water may alternatively have enhanced rock deposition, which also could explain the inertia enhancements instead of crust formation). Some of the thermally distinct channels do meet the elevation criteria for '01. We are looking particularly at the relatively flat areas at the northern end of Hydraotes Chaos (eastern end of Valles Marineris), near the beginnings of Tiu and Simud Valles, which appear to meet most all of the current '01 landing criteria. For thermally distinct channels, valleys, and ejecta blankets, we have searched and continue to search for MOC images that may help clarify their characteristics and assist with potential landing site characterization.

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Recent Mars Orbiter Laser Altimeter (MOLA) Results and Implications for Site Selection.

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Analysis of data from the Mars Orbiter Laser Altimeter (MOLA) has revealed important information about geological and geophysical processes on Mars that have a bearing on the scientific goals and objectives of future Mars orbiter and lander missions. Here we 1) summarize some preliminary scientific findings relevant to the goals and objectives of future Mars exploration that are also important for landing site selection and surface operations, and 2) show how MOLA data can be used in landing site analyses and engineering studies.

In 1997-1998 the MGS Mars Observer Laser Altimeter (MOLA) [1,2] produced over 2.6 million measurements of surface elevation [3]. This initial survey covered the northern hemisphere of Mars, with a high concentration of measurements at high latitudes. Following orbit circularization, a global topographic map was produced [4]. Individual topographic profiles contain significantly more information than a generalized topographic map and analysis of individual profiles, together with images of the surface, can provide important information about geological processes and history. For example, MOLA data have been used to assess impact crater characteristics [*5*], characterize the dichotomy boundary [*6*], analyze volcano morphometry [*7*], test the hypothesis of former oceans and lakes in the northern lowlands [*8*], assess the opacity of the martian atmosphere [9], and study polar topography and processes [3]. All of these analyses have a bearing on the major goals and objectives of the Mars exploration program. In addition, MOLA data provide important information on the shape of the northern hemisphere [10] and the relationship between MOLA topography and the 6.1-Mbar atmospheric pressure surface [11]. Data on surface roughness and slopes at various scales were also obtained [12-14].

The large volume of individual data points cannot all be analyzed individually and statistical characterization of surface topography, such as kilometer-scale surface roughness, can also provide important information complimentary to general topography. Typically, slope distributions are described in terms of RMS slopes, but this approach may not be optimal for the description of slopes using laser altimeter data. Inter-quartile scale of topography has been proposed as a general characteristic of 100-km-scale surface roughness [13]. Median slope has been shown to be a robust statistical characteristic of surface roughness [14]. Median slope and its scale dependence can be used to assess the surface characteristics of different terrain types and geological units on Mars [14]. Here we outline the the surface roughness of a variety of units in the northern hemisphere of Mars and provide an overview of the steepest slopes yet observed there.

For each MOLA surface data point we calculated the point-to-point surface slope. We also calculated a set of slope values for a set of longer baseline lengths (0.8, 1.6, 3.2, 6.4, 12.8 and 25.6 km). For each point for each baseline, points about one-half-baseline ahead and about one-half-baseline behind were found. The slope between these points was considered as the slope at the given baseline.

Roughness of geological units. We digitized the geological maps of Mars [*15-17*] in order to select MOLA data points corresponding to specific geological units. The purpose of this exercise was to determine if individual units or groups of units were characterized by distinctive surface slopes, and whether such characteristics were sufficiently different that they could be used in the definition and characterization of units, and as an aid in the interpretation of their origin and evolution. We limited our study to geological units that have sufficient area in the northern hemisphere of Mars to contain more than 10,000 MOLA data points. We excluded segments of MOLA passes located 25 km on both sides of unit boundaries in order to ensure that the whole baselines were located within a specific unit. Thus, our statistics reflect the nature of inner or typical roughness of units, rather than topography associated with their boundaries.

The units studied are the following [15-17]. (1) *Old heavily cratered highland plateau units*: Npl_1, cratered unit; Npl_2, subdued cratered unit; Npld, dissected unit; Nple, etched unit. (2) *Relatively old tectonized volcanic plains*: Hr, ridged plains. (3) *Relatively old Vastitas Borealis Formation members, plain units that occupy the vast majority of the northern lowlands on Mars*: Hvk, knobby member; Hvm, mottled member; Hvg, grooved member; Hvr, ridged member. (4) *Different relatively young volcanic plains*: Ael_1 and Ael_3, two members of Elysium Formation; Aa_1, Aa_3, and Aa_4, Arcadia Formation members; Aam, a member of Alba Patera Formation. (5) *Relatively young plains of uncertain or diverse origin*: Apk, knobby plains; Aps, smooth plains. (6) *The polar cap material*: Api, ice deposits; Apl, layered deposits. (7) *Circumpolar plains material*: Am, mantling deposits; Adl, linear dune fields.

For each of these units we calculated the median slope for our set of seven baselines. This allowed us to study how typical surface roughness varies with scale. Fig. 1 shows the relationship of median slope as a function of baseline length for various geologic units, and this provides information on the distinctiveness of units as a whole. Three fundamental observations can be made: (1) Most units have distinctive characteristics of median slope at these scales and are commonly separable from one another (e.g., the lines do not cross). For example, old heavily cratered highland plateau units are significantly different at all scales from the Vastitas Borealis Formation (compare Fig. 1a,b). (2) Several units show very tight clustering, suggesting that they share similar slope characteristics. For example, the subunits of the Vastitas Borealis Formation are very similar, despite distinctive morphologic/topographic differences in their definition (grooves, craters, knobs and ridges). (3) A few units show major variations as a function of baseline length (for example, linear dunes, Fig. 1d).

The members of the Hesperian-aged Vastitas Borealis Formation, plains units that occupy the vast majority of the northern lowlands on Mars, are smoother than the global average at all wavelengths. Hvg, the grooved member, is the roughest of the subunits, and is rougher at shorter wavelengths, consistent with the presence of pervasive troughs and polygons of a few kilometers across. The old Nectarian-aged heavily cratered highland plateau units (Fig. 1b) are tightly clustered and all rougher than the global average at all scales. Among these units, Npl_2, the subdued cratered unit, tends to be smoother than the others, consistent with its interpretation as a cratered unit subdued by eolian processes and deposits. The relatively old Hesperian-aged tectonized volcanic plains, Hr (ridged plains; Fig. 1b), are much smoother at all scales than the heavily cratered highlands but still uniformly rougher than the global average and all members of the Vastitas Borealis Formation (compare Fig. 1a and b).

A large number of young (Amazonian-aged) plains units interpreted to be of volcanic origin are seen in this region in Tharsis, Elysium, and portions of the northern lowlands, particularly Arcadia. These units are predominantly smoother than the global average (compare Fig. 1c and 5a). Two of these units (Arcadia Formation member Aa_1; Elysium Formation member Ael_3) fall in the range of the subunits of the Vastitas Borealis Formation. Unit Aa_1 is slightly rougher at longer baselines and this may be due to the fact that it is somewhat older and characterized by the presence of mare-type wrinkle ridges. One member of the Elysium Formation, Ael_1, falls in this same group at short baselines, but is distinctly rougher at longer baselines, exceeding the global average at baselines in excess of 3 km. The reason for this is related to the fact that this unit appears to be of volcanic origin and derived from the main shields and related vents of the Elysium rise; thus the regional slopes of the rise are observed at longer baselines.

A remarkably smooth unit is observed among this group. The Amazonian-aged member Aa_3 of the Arcadia Formation is the smoothest unit observed in the northern hemisphere at all baselines (Fig. 1). Aa_3 consists of smooth plains that occur west of the Olympus Mons aureoles; these plains embay the aureoles and the nearby fractured terra of Acheron Fossae [15], and are the middle member of the Arcadia Formation. This unit shows flow fronts in places, and together with other members of the Arcadia is interpreted to be of volcanic origin. This unit is younger in age than the Hesperian Vastitas Borealis Formation, which probably underlies it. If so, than the emplacement of these lava flows has smoothed the surface topography of the Vastitas Borealis Formation at all baselines, particularly at the 1-3 km scale so typical of the Vastitas Borealis Formation. These lavas must have an unusual character compared to other volcanic units (Fig. 1c), one which is related to smoothness at all scales. In part this may be due to their emplacement on the already-smooth Vastitas Borealis Formation (particularly at longer baselines), but their surfaces must also be very smooth at shorter baselines (hundreds of meters) more indicative of flow surface morphology. Analysis of high-resolution images of nearby Elysium Planitia shows evidence for resurfacing by a very young, thin, apparently very fluid flow unit that appears regionally very smooth, although rough at the few meter scale length [18]. Similar surface characteristics may occur in member Aa_3 of the Arcadia Formation.

Amazonian-aged polar units also show distinctive characteristics (Fig. 1d). The polar cap material, Api, interpreted as ice deposits, is smoother than the global average except at the longest baseline. In addition, the median slope does not vary significantly as a function of baseline, in contrast to almost all other units. This is almost certainly related to the properties of the ice substrate. Among the circumpolar plains materials occur a variety of mantling deposits, including dune fields [17, 19]. The linear dune field unit, Adl, is plotted in Fig. 1d and is characterized by a very high median slope at short baselines (comparable to the heavily cratered terrain) due to the presence of dunes whose wavelength is in this baseline range, and much smoother surfaces at longer baselines, smoother than the global average but generally rougher than the slopes of the Vastitas Borealis Formation and most volcanic plains.

In summary, this analysis demonstrates that many individual units and groups of units are characterized by distinctive surface slopes (Fig. 1), and these characteristics are sufficiently different that they hold promise in the definition and characterization of units. This analysis also shows that further characterization of the slope properties of these and other global units will provide information useful in the interpretation of their origin and evolution. In the future, data will be obtained for a wider range of units in the southern hemisphere, including the south polar cap and circumpolar deposits, units within the large impact basins Hellas and Argyre, a range of upland plains of possible volcanic origin, and crater fill units of possible fluvial origin [e.g., 15-17].

The steepest slopes. For kilometer-scale baselines, slopes steeper than the angle of repose are scarce. Such slopes indicate either relative youth or an unusual mechanical strength of the material. We searched the complete pre-circularization MOLA data set for the steepest point-to-point slopes and found a total of 105 point-to-point segments with slopes steeper than 35°. Nine of these are probably data errors associated with some processing problems or caused by near-surface haze or clouds. The rest are associated with apparently steep features on the surface(Fig. 2). *Impact craters.* Only 6 steep measured segments of impact crater walls have slopes steeper than 35°, and none of them are steeper than 38°. Crater walls are formed during the modification stage of crater formation, when surface material is collapses inward after the shock wave has passed. In this situation walls with slopes steeper than the angle of repose are not easily formed except at the scarp at the inner crater lip. *Tectonic and erosion features.* The steepest segments in tectonic and erosion features are usually parts of very high scarps (more than 1 km high). For these scarps, as well as for the crater walls, the steepest segments of slopes tend to be in the upper part of the scarp (Fig. 2a,b). This can be relatively easily understood in terms of slope processes: mass-wasted material forms relatively gentler slope near the scarp base, while active downward sliding of material favors steeper intermediate to upper parts of the scarps, and bedrock cliffs, from which debris is being weathered and shed, have the highest slopes. Although the orbits cross virtually all graben systems in the northern hemisphere, only a few graben systems display very steep slopes in MOLA profiles. The orbits cross several outflow channels in the northern hemisphere, but only Kasei Valles has very steep slopes. *Olympus Mons aureole.* Here the steepest slopes are observed predominantly in the youngest subdivision [15] of unit Aoa_4, although orbits also cross other subdivisions. This difference seems most plausibly attributed to slope degradation with time. *The polar cap.* The polar cap scarp has some very steep slopes (Fig. 2c) [3]. The upper part of Chasma Boreale is characterized by the steepest site in the polar cap and in the entire surveyed part of the surface. The presence of the extremely steep slopes in this material is evidence for young and/or dynamically formed steep topography.

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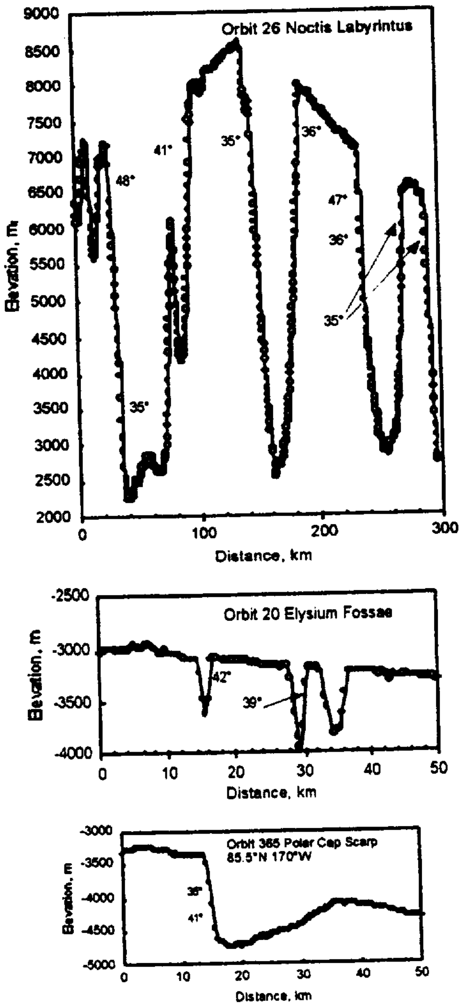

Fig. 1. Dependence of the median slope on the baseline length for selected geological units. Logarithmic scale on both axes. The dependence for units Npl_1 (typical highland plateau unit), Hvk (typical Vastitas Borealis Formation unit), and Aa_3 (extremely flat plains) are shown on all plots *a–d* as a reference.

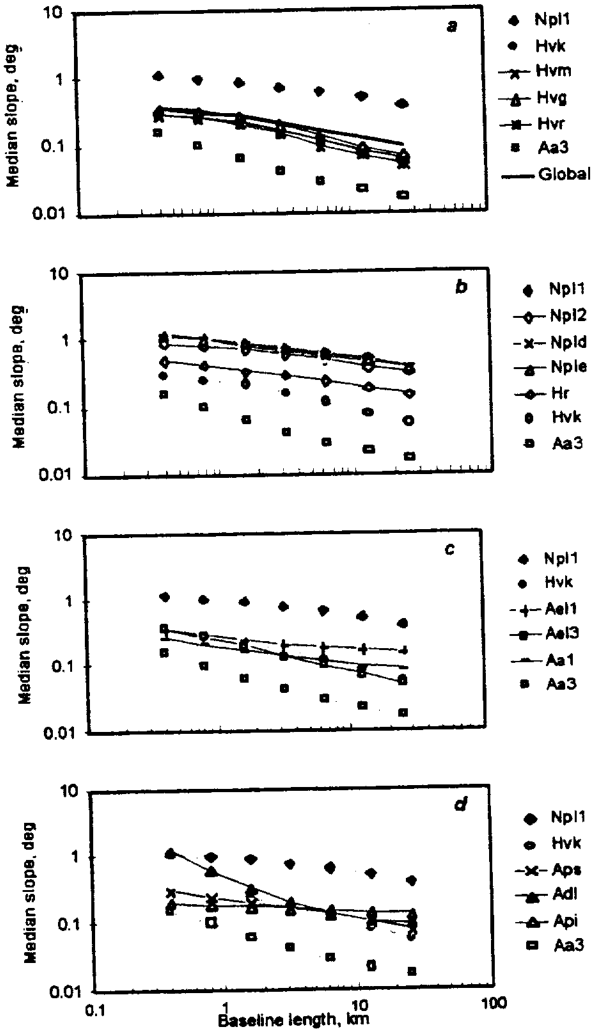

Fig. 2. Sample profiles illustrating the location of some of the steepest slopes on Mars detected by MOLA. a. Section of Orbit 20 in Elysium Fossae. b. Section of Orbit 26 in Noctis Labyrithus. c. Section of Orbit 365 in the north polar cap region.

AMENTHES RUPES AREA: A POTENTIAL SITE FOR ANCIENT FLUVIAL DEPOSITS.

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Introduction: The channel system south of Amenthes Rupes is proposed to sample ancient fluvial environments on Mars. This area shows evidence for ponding in a 52-km diameter crater, similar to the Gusev Crater-Ma'adim Vallis system. The proposed study region suggests fluvial activity during Noachian-Hesperian times.

General geology. Amenthes Rupes includes a fluvial system in the Martian highlands. Much of the terrain in this area was modified by extensive resurfacing [1-3], and is mapped as a Noachian unit (unit Npld) dissected by multiple small channels, channels networks and troughs.

The area also contains a large population of flat-floored, rimless craters. Lower Hesperian age ridged plains (unit Hr) floor the large craters and form smooth surfaces on some of the surrounding highlands [2]. In places, units Npld and Hr are mantled by Amazonian smooth plains (unit Aps), which apparently consist of aeolian deposits. The proposed landing site is in a degraded impact crater (52-km in diameter) which received flow from a channel from the SW. The sinuous channel is 2-3 km wide and is similar to Nirgal, Nanedy, and Bahram Valles [2], whose origin is interpreted to involve sapping processes [5]. The NW part of the crater rim is breached by a gap 3-km wide, which could have formed by the release of water from a former lake within the crater.

Potential site. A proposed landing site is located in the southern part of the crater floor on smooth plains at 4°S; 249.5°W, near the mouth of the channel. The geologic setting is similar to Ma'adim Vallis and Gusev Crater, but on a smaller scale. The upstream 100 km part of the channel is narrow and shallow then widens and deepens downstream. Deep layers of rock were eroded during the latest stages of channel activity and the products of erosion could be deposited in the crater as lacustrine sediments. The transition between the upper and lower parts of the channel is complicated by a chain of collapsed pits 2-4 km across that could represent karstic processes.

A short (40 km) wide (3-4 km), branch channel intersects the mouth of the main channel. The upper part of the branch is partly blocked by mass-wasted material. Small amphitheater-headed tributaries along the branch channel walls might be evidence for ground water seepage, or sapping processes. Crater floor deposits merge with the highland plains through the gap in the N-NW crater rim. Apparently the crater lake served as a reservoir for the channel system and "fed" sediments to the surrounding plains. Faint erosional features on the crater floor might represent the last stage of fluvial activity.

Scientific rationale. The landing site is characterized by sedimentary facies formed in ancient fluvial and lacustrine environments and may enable sampling of rocks and sediments of Early Noachian to Late Hesperian ages. Such samples could provide information on the: 1) early climatic environments, 2) ground water regime and associated mineralization and, 3) fluvial-lacustrine processes.

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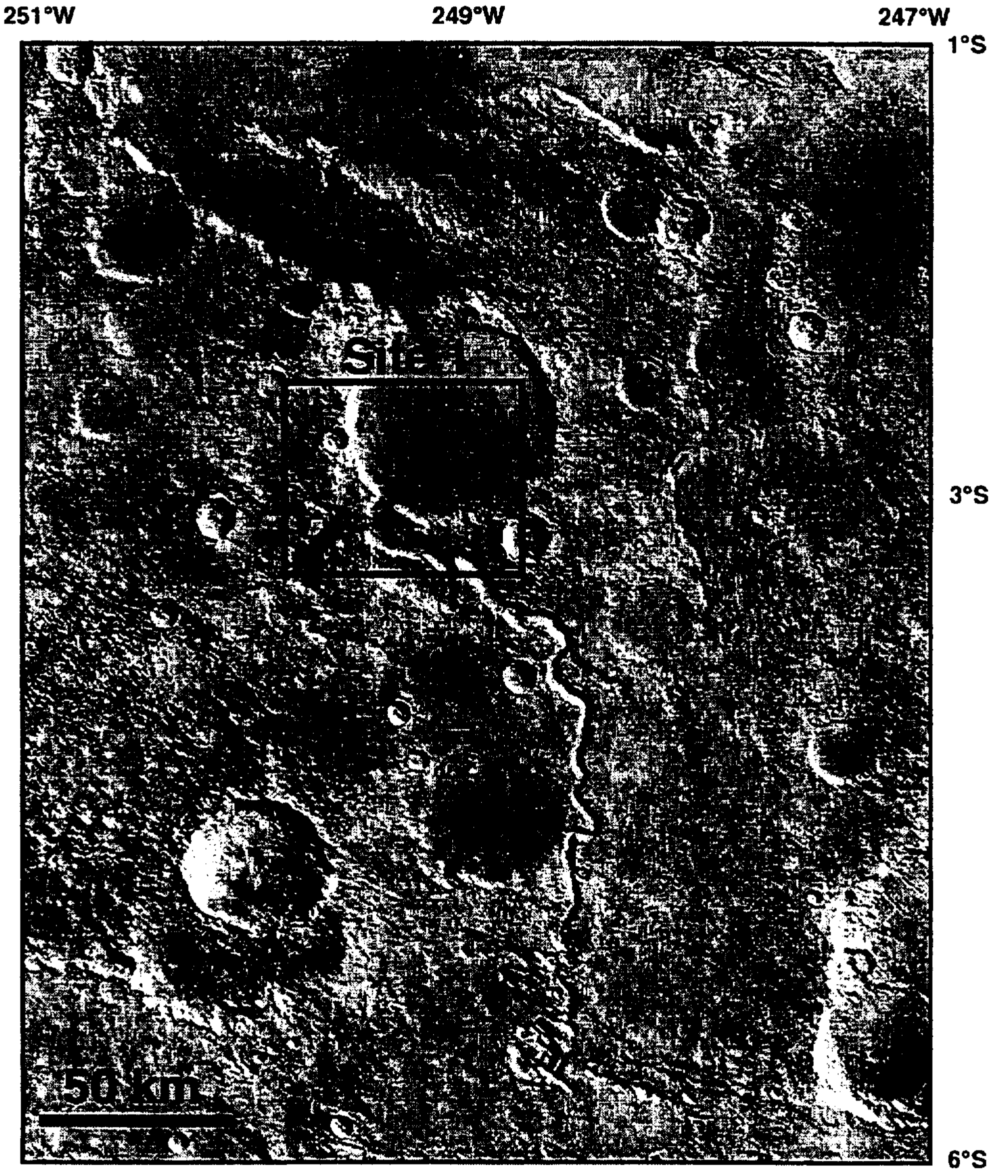

Viking Orbiter mosaic of the Amenthes Rupes region of Mars. The landing site is located at 2.9°S, 249.5°W, and lies between +1 and +2 km.

GANGES CHASMA: A POTENTIAL LANDING SITE.

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General geology. Ganges Chasma is in the NE part of the Valles Marineris system. Together with Capri Chasma, it is the source area for Simud and Tiu Valles. The formation of Ganges Chasma and similar features in Xanthe Terra is attributed to withdrawal of ground water and collapse of plateau rocks along fault systems [1-3]. The main part of Ganges Chasma cuts through younger Hesperian plains (unit Hpl_3) [4], interpreted to represent resurfacing of older units by low viscous lavas [5].

Some of the features attributed to catastrophic flooding in Hesperian times [4] modified the surface of the Hpl_3 unit (as well as units Npl_1 and Npl_2). These features could indicate fluvial erosion from the release of ground water. Carr [6] suggested that when the chasmata formed, the permafrost layer was thinner than today and that ground water flowed or seeped from the chasmata walls to form lakes. The lakes were subsequently drained by catastrophic outflow, forming channels in the Xanthe Terra region.

Remnants of the layered deposits visible in western Ganges Chasma could be paleolake sediments [7]. McKay and Nedell [8] suggested that the putative lakes could have been environments for the precipitation of carbonates. McEwen and Soderblom [9] suggested that some of the bright layers could be carbonates. Most of the layered deposits are superposed on chaotic terrain, suggesting a younger age than the outflow channels. Sediments associated with ground water could be also deposited on the floor of Ganges Chasma, along with mass-wasted and debris flow materials [6].

Potential landing sites. Two potential landing sites are selected for study in the eastern part of Ganges Chasma where there is a transition from the chasma depression to the channel. This part of Ganges Chasma may have served as the source area for the outflow channel, similar to that in the west where chaotic terrain is preserved. The map of Rotto and Tanaka [4] shows that the youngest floor deposits are mostly alluvium and mass-wasted material. These materials represent a wide range of rock ages, including the ancient megaregolith and highland plateau materials. Modern low albedo aeolian materials are found on the chasma floor [10].

Ganges Chasma Site 1. This site is located on smooth Hesperian outflow sediments [5], which are partly mantled by Amazonian-age mass-wasted and aeolian deposits [4]. Ganges Chasma cuts rocks of the plateau sequence (potentially including the underlying impact breccias from the period of early bombardment) to a depth > 2 km, and mass-wasted rocks from this sequence might be accessible for sampling at the base of the wall. The area is characterized by evidence of fluvial erosion, sapping, and outflow processes, making the site attractive for the exploration of ground water systems. Multiple landslides occur south of the site and could be accessed by a rover. The proposed site is between the landslides and the deposits from ground water outflow at the base of the chasma wall. West of the site are young aeolian deposits, some of which are dunes.

Ganges Chasma Site 2. This site is located a few hundred kilometers east of site 1. Multiple episodes of fluvial erosion and deposition are indicated by multiple incised channels and terraces. The rocks and soils available for sampling are similar to those at site 1, with the addition of terrace deposits and other sediments from the channels.

Scientific rationale. The potential landing sites in Ganges Chasma provide an excellent opportunity to maximize the scientific return of a mission because they might afford a wide range of rocks ages and possible compositions, and are accessible. Some of the materials have been modified by ancient ground water processes. Samples might also help establish the Martian time scale for the Noachian and Hesperian plateau sequence and enable calibration of impact crater statistics.

The discontinuity observed at the base of the 1 km-thick section exposed in the chasma could represent the base of the former cryosphere [11], marking differences in mechanical or chemical processes. The origin of the interchasma layered deposits is not well understood and at last 5 hypotheses have been proposed for them. Sampling these materials may constrain these ideas and shed light on the history of the chasma.

Samples from the chasma also could provide clues to ground water mineralization on Mars. For example Fanale, [11], Clifford [12], and Kuzmin and Zabalueva [13] suggested that zones of salt solutions could be present in the Martian cryosphere, which would have significant effects on the hydrological system. Finally, samples of the landslide material might address the style(s) of emplacement (dry avalanche or the wet debris flows), which would lead to better understandings of the hydrological characteristics of the Martian megaregolith.

Study of the regional geology and the potential landing sites would address: 1) the nature of wide spread resurfacing of the Noachian plateau, 2) relative ages for the initiation of outflow activity forming Shalbatana Vallis, 3) the possible relationship between water released from the Shalbatana Vallis source area and the Ganges Chasma paleolake, and 4) clues to the origin of the Ganges Chasma paleolake and the layered deposits.

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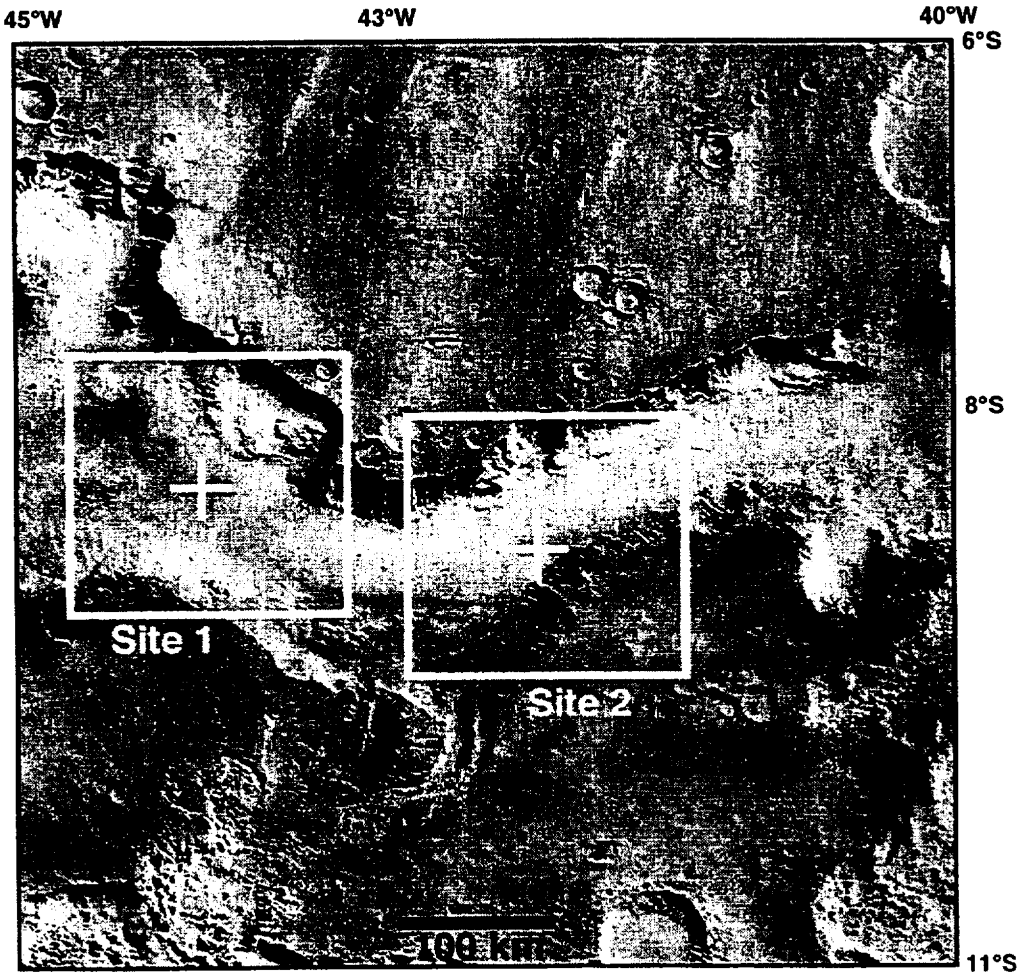

Viking Orbiter mosaic of Ganges Chasma. The landing sites are located at 8.5°S, 43.9°W, < -2 km, and 8.8°S, 42.5°, -2 km.

CHARACTERIZATION OF TERRAIN IN THE MARS SURVEYOR 2001 LANDING SITE LATITUDE AND ELEVATION REGION USING MAPPING PHASE MARS GLOBAL SURVEYOR MOC IMAGES.

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Introduction

One of the original objectives of the Mars Orbiter Camera (MOC), as proposed in 1985, was to acquire observations to be used in assessing future spacecraft landing sites. Images obtained by the Mars Global Surveyor MOC since March 1999 provide the highest resolution views (1.5–4.5 m/pixel) of the planet ever seen. We have been examining these new data to develop a general view of what Mars is like at meter-scale within the latitudes and elevations that are accessible to the Mars Surveyor 2001 lander. Our goal is to provide guidance to the 2001 landing site selection process, rather than to use MOC images to recommend a specific landing site.

Data

The data used in this study were acquired March–May 1999. We examined ~130 MOC images that occur between 5°N and 15°S and at elevations lower than the 2.5 km contour in the pre-MGS USGS topographic maps. Only images that showed obvious kilometer-scale hazards, such as the steep slopes in chaotic terrain and the walls of Valles Marineris were excluded from the study.

Background

Over the entire course of the MOC mission thus far, we have learned four important lessons about Mars at the meter-scale:

(1) Most of the martian surface is unlike what might be expected on the basis of photos from Viking and other previous orbiting spacecraft. Many meter-scale surface features defy explanation on the basis of terrestrial analogs and field experience.

(2) Most surfaces on Mars, including many that occur within the elevation and latitude constraints of the 2001 lander, do not resemble the Viking and Mars Pathfinder landing sites.

(3) Surface properties interpreted from remote sensing (*e.g.*, albedo, thermal inertia, rock abundance, radar reflectance) do not necessarily match what is seen in MOC images. For example, a portion of Daedalia Planum appears to consist of patchy, windblown sand and bare exposures of rock (lava flows), despite having an extremely low Viking IRTM-derived rock abundance and thermal inertia (which previously implied the presence of a thick mantle of dust). Another important observation is that some of the large, low albedo regions of Mars (*e.g.*, Sinus Sabaeus) are covered by indurated, dark mantles, not sand. Large (*i.e.*, > 1 km^2) outcrops of bare rock are also seen on the planet.

(4) Interpretation of meter-scale features visible in MOC images can typically be extended to textures and patterns on the surrounding terrain, even when the surroundings are only seen in lower resolution images. For example, a surface covered by small, meter-scale yardangs in a MOC image might appear as a dark patch in a Viking image (owing to shadows cast between yardang ridges). The meter-scale aspect of nearby dark patches in the Viking image can be inferred to be similar. This predictive capability has served well as a model for selecting targets for new MOC images and it is the key to using earlier mission data (*e.g.*, Viking, Mariner 9) to assess proposed sites for the 2001 lander.

Results

We have identified three general "rules" that can be used to provide a ~70% predictive capability with respect to interpreting the nature of potential landing sites. This percentage improves if one considers exceptions that group geographically. These "rules" can be applied to any Viking orbiter image up to about 300 m/pixel that occurs within the latitude and elevation range accessible to the 2001 lander.

General Rules

(1) Surfaces that are topographically rugged ("hummocky") in Viking orbiter images (over 10s–1000s of meter scale) are smooth at meter-scale. Some of the best examples of surfaces of this type (within the latitudes 5°N–15°S) occur in the cratered terrains of the Amenthes/Nepenthes regions. The meter-scale character is dictated typically by the upper surfaces of mantle deposits that appear to drape all but the steepest topography. The mantles often appear to be indurated, as indicated by the crisp nature of features associated with superposed impact craters and/or occasional narrow cracks in the surface. However, we do not know if the induration is merely a thin crust, or if the entire deposit is solid (*i.e.*, we cannot estimate the weight-bearing strength of this material). Based on the absence of meter-scale boulders, we suspect that few rocks are present on these surfaces, but patches of what appears to be bedrock can commonly be found on non-mantled surfaces.

(2) Surfaces that are smooth in Viking orbiter images (10s–1000s of meter scales) are extremely rough at meter scales. This roughness is commonly expressed in the form of ridges and grooves spaced a few meters

(or less) apart. Some of the ridged surfaces are clearly the result of eolian erosion (*i.e.*, they are yardangs). However, many other surfaces are grooved, ridged, or pitted, but show no obvious features that would indicate their origin. Such surfaces are new to us and have only been clearly observed in the latest (1999) MOC images. The best examples of ridged and grooved terrain occur on the mare-like surfaces in the Amenthes Rupes region, the surface in Terra Meridiani identified by the MGS TES team to have a hematite signature, and the floor of Melas Chasma.

(3) It is rare to find a surface that is texturally homogeneous at the kilometer scale. Most MOC images taken in recent months cover areas that are 1.5 to 3 km wide by 3 to 12 km long. Within any one of these images (in the latitude and elevation range accessible to the 2001 lander), we find that most of the surfaces show a range of meter-scale morphologies.

Exceptions

Some geographical locations have specific landform relationships that, while exceptions to "rules" 1 and 2, are equally predictable. In particular, these regions are:

(1) The Medusae Fossae Formation (MFF) and immediately adjacent highland surfaces. These surfaces generally exhibit yardangs all the way down to the meter scale, although there are a few smooth surfaces at the very top of major MFF units in south Amazonis Planitia. The highlands adjacent to the MFF in the Memnonia region exhibit so many small yardangs that older landforms (*e.g.*, Mangala Valles fluvial features) can be completely obscured.

(2) The lowland known as the Elysium Basin (north of Apollinaris Patera, south of the Elysium volcanic rise) exhibits several exceptions to the "rules". Surfaces that appear to be dark and smooth in the ~230 m/pixel Viking images that cover most of this region appear to be quite rough at the meter scale. These rough surfaces include "platey" and flow-like textures. However, nearby bright surfaces that also appear to be smooth in Viking images are found to usually be smooth at the meter scale in MOC images.

Most exceptions involve surfaces that are smooth at both Viking and MOC image scales. However, we have seen very few exceptions. These, too, occur in specific geographic locations (and include the bright, smooth surfaces in Elysium Basin noted above):

(1) The bright feature located west of Schiaparelli Basin (generally centered at 6°S, 349°W). This surface appears to be relatively smooth and flat in Viking images. In MOC images, the surface appears to be somewhat etched, with about 15–20% pits and craters of 100s of meters diameter. However, the surface is otherwise smooth and boulder-free, and has the appearance of being hard (like rock). Other bright, smooth (and not pitted) surfaces occur in rather limited patches to the north of this area and in south Schiaparelli Basin.

(2) Relatively smooth, flat, dark surfaces occur in some parts of the Sinus Meridiani low albedo region. These surfaces do not correlate with the crystalline hematite observed by the MGS TES, but often occur along the margins of the hematite-bearing surface. Terrains further south of these are rough at Viking scales (*i.e.*, typical martian cratered highlands) and follow "Rule #1" by being relatively smooth at the meter scale. Similar smooth, dark surfaces occur in Sinus Sabaeus and on the southern floor of the Schiaparelli Basin (although most of these areas probably lie outside the elevation range of the 2001 lander).

(3) A smooth dark surface also occurs on the floor of Ganges Chasma. This surface is a thick, eolian sand sheet. A similar deposit might occur on the floor of Juventae Chasma.

Discussion

In the context of landing site selection, it is comforting to know that there are surfaces that do not appear to pose many meter-scale hazards. However, these types of surfaces tend to be the exceptions—the surfaces that appear to be smooth and flat at both Viking and MOC image scales. With the exception of the Ganges site, these smooth, flat surfaces would not likely present interesting vistas (*e.g.*, horizon features such as hills or cliffs) for the lander to "see". In addition, and again except for the Ganges sand sheet, the processes that formed the smooth bright and dark surfaces are not known. Likewise, the processes that made most surfaces that appear smooth at Viking scales to appear rough at MOC scales are not known.

Additional Work

During June 1999, we will refine our observations and test the proposed predictive capability (by targeting new images). The ideas presented in this abstract should be viewed as a "work-in-progress." By early July we plan to submit a report to the Mars Surveyor 2001 Project that details and illustrates our findings.

Conclusions

MOC images provide new and often unexpected information about the surface of Mars at the meter scale. What is seen in a MOC image can be easily extrapolated to the terrain seen in Viking images. In fact, "rules" presented here can be used to predict the nature of the meter-scale surface in places (within the 2001 lander elevation/latitude constraints) where MOC images are unavailable.

POTENTIAL LANDING SITES FOR THE 2001 LANDER IN THE NOACHIAN HIGHLANDS AND IN VALLES MARINERIS.

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Introduction:

The French community will be involved with the Mars Sample Return missions and begins to study potential landing sites. Our team proposes several sites for the 2001 Surveyor mission. Studies of these regions are still in progress. The scientific goal of the two first landing sites is the understanding of the early Mars climate. These two sites are focused on processes related to water like run-off or hydrothermal areas. Such processes include possible biochemical investigations for the potential of primitive life on Mars. The third site is devoted to the complex and diversified geology of Valles Marineris. This selection of landing sites takes into account all the technical parameters described on the Surveyor 2001 web page [1]. We also took into account the availability of Viking High Resolution images and of MOC images when possible.

1st site: Terra Meridiani, SW Schiaparelli.

- *Lat/Long*: 7°S-346°.
- *Elevation*:1/2.5 km.
- *Viking Orbiter Image coverage*:

HR	747a35-60	17 m/pix
LR	618a04	220 m/pix
	655a46	248 m/pix
	369s65	233 m/pix

- *MOC Images*:

4405	4.7 m/pix

- *Thermal Inertia (IRTM)*: >4 cgs units.
- *Rock abundance*: 5-10%
- *Stratigraphy [2]*:

NPld	Cratered units with fluvial processes.
HPl3	Interbedded sedimentary-volcanic deposits.

- *Geological setting*:

The studied area consists of run-off valleys inside Noachian terrain at the boundary of an Hesperian plain (Fig. 1). The Noachian terrain could have experienced primitive volcanism because the morphology of some valleys is similar to that of Appollinaris or Hadriarca Patera. In this case fluvial processes may be associated to hydrothermalism.

A first landing site can be proposed at the outlet of valleys where High Resolution Viking Images show fine morphologic details. Such area may have a fluvio-deltaic origin. It is furthermore flat and hazard-free providing good safety for landing. The problem is that sedimentary material may have been buried by volcanic lavas. Indeed younger volcanic deposits are possible because the nearby flat plain may have a volcanic origin. Eolian materials can also blanket some areas like the valleys observed on the MOC image.

A second landing site can be proposed in the upstream part of the valleys. If this region did correspond to an old degraded volcanic shield, hydrothermalism would have been possible at the valleys springs. The plateau is relatively flat but hazard-free areas are more difficult to identify for a precise landing site.

2nd site: Lybia Montes

- *Lat/long*: 2°N, 273°.
- *Elevation*: 1/2 km.
- *Viking Orbiter Images coverage*:

HR	137s01-09	15m/pix
LR	876a01	176 m/pix

No MOC images available at the present time.
- *Thermal Inertia (IRTM)*: >4 cgs units.
- *Rock abundance*: 5-10%.
- *Stratigraphy [2]*:

NPld	Cratered units with fluvial processes.
HPl3	Interbedded sedimentary and volcanic deposits.
Nm	Very primitive crust.

- *Geological setting*:

The proposed area consists of a very ancient crust affected by many small valley networks (Fig. 2). Flat plains at the valleys outlet could include sedimentary materials that would be interesting for exobiological investigations. Outcrops of very old crust could be useful for geochemical purposes. The HR Viking images are focused on the valley network corresponding to the left arrow of figure 2. These valleys seem to have their origin on the crater rim located southward. An hydrothermal activity due to the impact heating is possible to explain their formation. The network is highly degraded and consequenting valleys may have very gentle slopes. Landing would then be safe even if it would occur inside the valleys. However the occurrence of eolian material that is not visible on Viking HR Images could be problematic in case of landing on the valley floors.

3rd site: Melas Chasma, Valles Marineris

- *Lat/Long*: 10°S- 73°
- *Elevation*: -1/0 km
- *Viking Orbiter Image coverage*:

HR	915a13-25	60 m/pix
	914a13-25	60 m/pix
	915a53-64	42 m/pix
	914a51-62	44 m/pix
MR	058a81-92	125 m/pix
LR	608a73	232 m/pix

No MOC images available at the present time.

- *Thermal Inertia (IRTM)*: >4 cgs units.
- *Rock abundance*: 5-15%
- *Stratigraphy [3]*:

Avf	Valles Marineris Interior deposits.
Hvl	Layered outcrops of Valles Marineris.

- *Geological setting*:

This site takes place on the flat floor of Melas Chasma. The nature of the deposits is uncertain. Several hypotheses were proposed including eolian, landslide debris, alluvial, lacustrine or volcanic origins [4,5,6]. Lacustrine deposits would improved our knowledge on climate evolution and exobiology. Debris coming from landslides may present a large variety of materials with different age that would be useful for geochemical purposes. Such landing site would help to the understanding of Valles Marineris formation and evolution, and therefore the evolution of the whole Tharsis region.

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Fig. 1: Terra Meridiani, SW Schiaparelli Basin (7°S, 347).

Fig.2: Lybia Montes (2°N, 273).

TOPOGRAPHIC EVALUATION OF MARS 2001 CANDIDATE LANDING SITES: A MGS–VIKING SYNERGISTIC STUDY.

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Introduction: One of the greatest unresolved issues concerns the evolution of Mars early in its history; during the time period that accretion was winding down but the frequency of impacting debris was still heavy. Ancient cratered terrain that has only been moderately modified since the period of heavy bombardment covers about a quarter of the planet's surface but the environment during its formation is still uncertain. This terrain was dominantly formed by cratering. But unlike on the airless Moon, the impacting craters were strongly modified by other contemporary surface processes that have produced distinctive features such as 1) dendritic channel networks, 2) rimless, flat-floored craters, 3) obliteration of most craters smaller than a few kilometers in diameter (except for post heavy-bombardment impacts), and 4) smooth inter-crater plains. The involvement of water in these modification processes seems unavoidable, but interpretations of the surface conditions on early Mars range from the extremes of 1) the *"cold"* model which envisions a thin atmosphere and surface temperatures below freezing except for local hydrothermal springs; and 2) the *"warm"* model, which invokes a thick atmosphere, seasonal temperatures above freezing in temperate and equatorial regions, and at least occasional precipitation as part of an active hydrological cycle. The nature of hydrologic cycles, if they occurred on Mars, would have been critically dependent on the environment. The resolution of where along this spectrum the actual environment of early Mars occurred is clearly a major issue, particularly because the alternate scenarios have much different implications about the possibility that life might have evolved on Mars.

Objectives and Technique: The objectives of our investigation are two-fold: (1) We are producing high resolution Digital Terrain Models (DTM) of a number of regions within the equatorial martian highlands which are registered to accurate global control using Viking Orbiter camera stereo coverage combined with Mars Orbiter Laser Altimeter (MOLA) ground tracks. Either data set separately suffers from serious shortcomings that are overcome by the synergistic combination of the two. A DTM-producing auto-correlation process developed by one of us (Schenk) has been successfully applied to several test areas using Viking stereo data (Fig 1). We have successfully used this technique in an analysis of the South Polar region of Mars in support of the MVACS lander site selection activity[1]. Several of the near-equatorial localities for which Viking stereo data are available have been identified as high priority Mars Surveyor Program landing sites for 2001 and later.

(2) We are using our DTMs to evaluate the sequence and extent of various landform-modifying processes that have shaped the martian equatorial highlands using models that simulates these processes on a three-dimensional synthetic landscape. This modeling has been developed by one of us (Howard) and emulates the following processes: 1) cratering; 2) fluvial erosion and sedimentation; 3) weathering and mass wasting; 4) aeolian erosion and deposition; and 5) groundwater flow and groundwater sapping. The models have been successfully used to predict the evolution of terrestrial landscapes. The models provide explicit simulations of landform development and thusly predict the topographic evolution of the surface and final landscape form. Prior to the generation of our Viking-MOLA DTMs, the models are severely hampered by the lack of absolute regional *and* high resolution topographic information. This is a consequence of the complex interplay between high and low frequency topography on landform modification. With our DTMs we will be able to much more realistically evaluate the evolution of the cratered uplands of Mars. Results of this analysis have direct import to Mars Surveyor Program landing site selection and science.

Demonstration of Model: Fig. 2 is a typical saturation crater simulation starting from an initially flat landscape. Fig. 3 is a simulated cratered landscape superimposed upon an initial fractal topography that has a relief of the same order of magnitude as the depth of the largest craters. This simulates the effects of large-scale topographic features that might have formed, such as tectonic ridges or basin rings. Fig. 4 shows erosional modification of the cratered landscape of Fig. 2 by a combination of mass wasting, fluvial erosion, and sediment deposition. All surface materials are assumed to be equally erodible, that is, they are either loose or are weatherable at a rate that keeps pace with erosion. Inner crater rims suffer the greatest amount of erosion, and locally become gullied. Relatively few large channels develop because of the restrictive assumption that no depression is drained. The overall drainage density thus appears to be very low. Crater floors fill in with low-gradient alluvial fans, obscuring small craters on the floors of larger ones. All these characteristics are common on the Martian cratered terrain. Figure 5 shows erosional modification of the hilly cratered terrain in Fig. 3. In contrast to Fig. 4, strong dissection occurs on regional slopes, producing well-developed divides and valleys.

Initial Study Areas: We have selected two areas for our initial studies: 1) the south edge of the "hematite" deposit detected by TES[2] and observed to be bordered by scarps and knobs exhibiting layers in Viking[3] and MOC SPO images located at ~2°S, 4°W; and 2) an enclosed basin into which several channels terminate at ~2°N, 240.5°W just west of the crater Escalante. Both regions were optimally imaged by Viking for the generation of DTMs, lie within the Mars 2001 landing constraints, and are potential locations for fluvial or lacustrine deposits. At the workshop, we will present our analysis of these two localities.

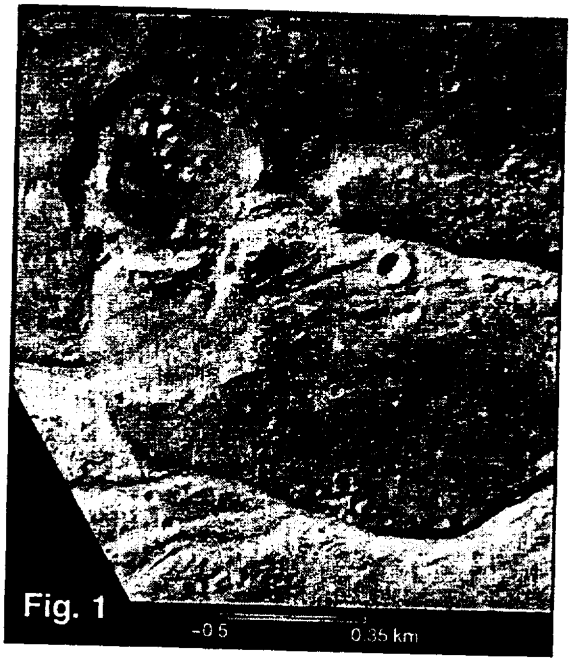

Fig. 1

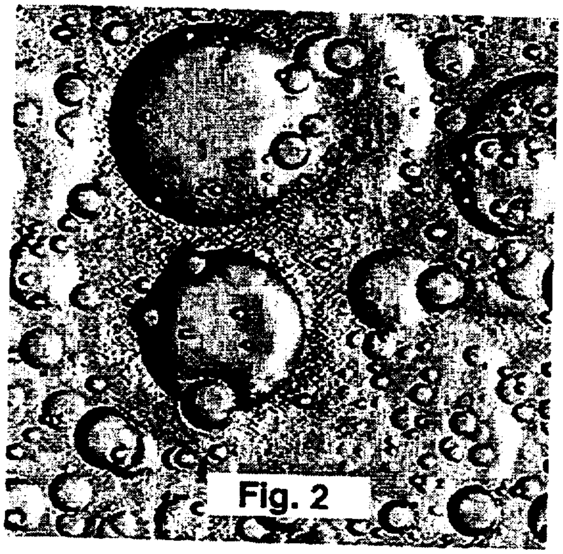

Fig. 2

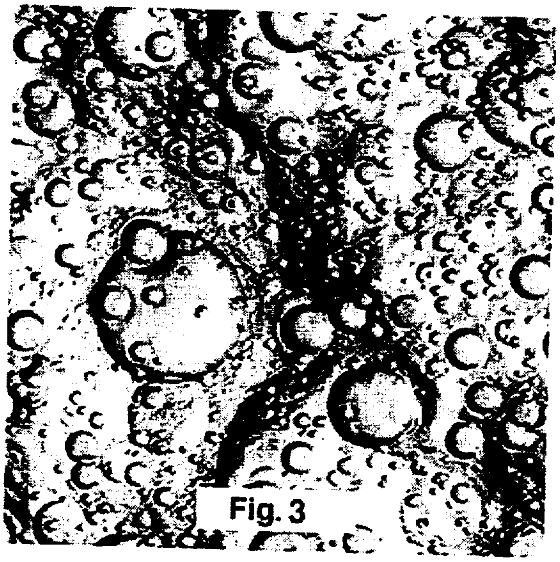

Fig. 3

Fig. 1. Viking stereo-based DTM of the Vedra Valles region. Data were generated by an automated stereogrammetric package (see text) and have a contour interval of ~10 m and a horizontal resolution of 40 m. Topographic data have been used to color-code a Viking image mosaic of this region.

Figs. 2 through 5. Synthetic Martian surfaces showing the modeled effects of several geologic process. The geologic process show here are a subset of the range of processes that can be evaluated by the model used in this work. See text for details.

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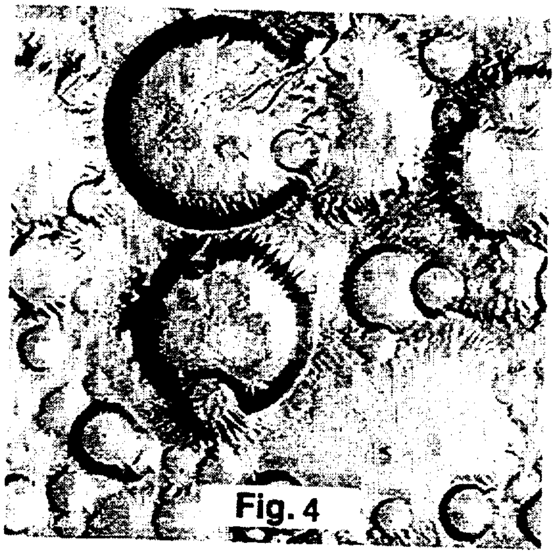

Fig. 4

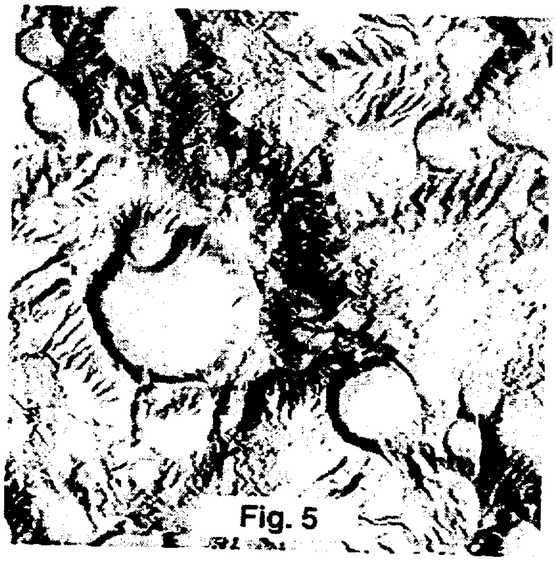

Fig. 5

PALEOLAKE DEPOSITS IN CENTRAL VALLES MARINERIS: A UNIQUE OPPORTUNITY FOR 2001.

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Introduction

Paleolake deposits have been mapped in Central Valles Marineris since Mariner 9 and Viking (McCauley, 1978; Nedell et al., 1988;Witbeck et al., 1991). Accordingly, the region has been proposed as a priority target for landed payloads intended to detect diagnostic mineral evidence of a permanent lake environment, and, especially, biogenic signatures that could have survived from such promising candidate Martian habitats. (eg, Murray, et al, 1996; Yen, et al, 1999, Murray, et al, 1999). Just-released MOLA data strongly buttress the hydrological case for long-duration ice-covered lakes there during Hesperian times at least. And terrestrial discoveries within the last decade have extended the known subsurface distribution and seemingly ancient character of terrestrial chemotrophic microbes. These results, combined with the ground-water biogenic signature inferred by some from the Allen Hills meteorite, have strengthened significantly the scientific case for Central Valles Marineris.

Until now, the difficulty has been the absence of a technical means within the Surveyor or New Milenium DS-2 capabilities for landing upon outcrops of interior layered deposits. Now the improved 2001 lander design brings exposures of interior paleolake deposits within the Surveyor program targeting capability for the first time. It is my purpose to argue here that several candidate paleolake deposits within the Central Vallis Marineris should be included as candidate landing sites pending definitive high-resolution MGS and Surveyor '98 observations.

Geological Setting and Biological Potential.

Carr (1996) suggested that ground water flowed from the Tharsis uplands into the deep canyons of Valles Marineris before debouching onto Chryse Planitia in the northern plains. Such a flow may have persisted for billions of years, and is generally inferred to have maintained deep lakes beneath which lacustrine sediments accumulated. Remnants of these Hesperian Age lake deposits survive today as conspicuous layered strata in Central Valles Marineris. Just published MOLA data (Smith, et al, 1999) confirm in detail this topographic trend and, most importantly, prove that deep, permanent lakes did indeed exist, especially in Central and Western Valles Marineris. Because the canyons in the Valles Marineris are deeper than the probable ground water table at that period, large portions of the canyons would have filled with water and formed ice-covered lakes.

Research in the dry valleys of Antarctica suggests the possibility that even though the surface of Mars was too cold to be habitable, early life might have survived in highly specialized environments under relatively thin layers of ice in perennially ice-covered lakes (McKay 1985, McKay and Davis 1991). The Valles Marineris ice-covered lakes not only might have contained martian chemotrophs from the incoming ground water, but also offered habitat for any martian phototrophs under the relatively thin ice, as is the case in now in Antarctica. It is even possible that traces of biogenic organic material might still be preserved below the surface oxidant layer in the cold, stable lacustrine strata within Valles Marineris.

Where in Central Valles Marineris?

Witbeck et al., 1991, mapped at 1:2M scale the geology of part of central Valles Marineris based on Viking data. They show large patches (10's of km) of layered deposits (unit Hvl, bluish green unit color on their map) within the deep, broad Hebes, Ophir, Candor, and Melas Chasmata. (More detailed studies have been compiled recently by Tanaka, and by Lucchitta.) These layered deposits form the oldest interior materials; in turn, they are embayed or partly buried by several varieties of unlayered floor deposits and landslide materials.

Candor Mensa (6.5 S, 73.5 W) for example, forms a 50-70 km elongate mesa about 4 to 5 km above the floor (but still apparently below the ancient lake level). The surface is a flat plateau which might facilitate access to surface exposures of the youngest lake strata. The highest resolution of Viking images of this feature ranges from about 60 to 90 meters per pixel, permitting only very thick layers to be measured; Even so, Nedell et al. (1987) found layers varying in albedo and competence that were 100-200 m thick. Extensive MOC and MARCI imagery of this feature could indicate whether indeed ancient layering can be sampled there, as well as the presence of any small-scale roughness of significance to the 2001 lander safety.

Smaller and lower mounds of this same unit (but still relatively flat-topped over an area seemingly within the targeting capability of the 2001 lander) occur at 9.7 S, 75.3 W, and at 11 S, 73.5 W. As with Candor Mensa, MOC and MARCI imagery should clarify their landing safety and the likelihood of bedrock exposures. These might provide access to somewhat older portions of the same Hesperian lake deposits, and also may exhibit an erosional surface at the landing site. Unlike the younger units that comprise the lowest elevations of Valles Marineris, none of the three Hesperian exposures proposed here appears to be mantled with eolian deposits.

Another benefit of all three sites is that distant cliff exposures of older crustal material (mapped as HNu by Witbeck, et al) may be visible in the distance. MOC discovered that this older crustal unit, which comprises the main walls of Valles Marineris, is comprised of thick and horizontally very extensive layers, not the megabreccia many had inferred by analogy with the Moon. Thus the 2001 multi-spectral imaging and miniTES instruments may be able to determine if these older deposits are of likely igneous (pyroxene, feldspar) or sedimentary (carbonate, sulfate, phosphate or hydrated minerals) origin.

The same two instruments would be able to study the surface exposures adjacent to the lander itself, looking for paleolake mineral signatures and diagnostic morphology. The rover camera and traction observations could add close-up imaging and textural and induration information as well. Anomalously high abundances of Na, S, P, Ca, or Cl detected by the APXS would be suggestive of lake-deposited origins.

The robotic arm would be able to image within a trench, possibly acquiring diagnostic sedimentary information in-situ. Samples collected by the arm for analysis by the Mossbauer Spectrometer and by MECA could further aid the interpretation of origin.

Altogether, it is reasonable to suppose that the 2001 lander located at sites such are proposed here could:

1. Determine if bedrock, or debris derived from bedrock, can be sampled at that site.
2. Determine whether or not that bedrock carries a mineralogical and/or textural signature consistent with deposition from a permanent lake.
3. Determine the requirements for the design of a follow-up Surveyor mission capable of searching effectively for a biogenic signature in those ancient strata (eg, a drill). (If relatively unaltered lacustrine samples are indeed accessible). That follow-up conceivably could be a sample return mission; Alternatively, in-situ collection and analysis might be deemed more cost-effective.
4. Provide excellent panoramic and spectral coverage of surrounding elevated areas, including diagnostic spectral information regarding the igneous vs. sedimentary origin of the older (HNu) crustal unit.
5. Provide a most compelling site for public education and interest because of the biogenic implications of the site as well as its dramatic location.

Why 2001?

Each new Mars lander faces a tough challenge. It must attempt to do something of critical scientific importance and of compelling public interest, and yet at modest cost! Pathfinder took the risk of landing on a rough, bouldery terrain to discover and describe a remarkably well-preserved surface evidently dating from the last catastrophic flood there. The '98 MVACS is pushing the engineering latitude limits to about 75 S in order to collect critical information about the polar layered terrains and the underlying processes of Martian climatic fluctuations. DS-2 hopes to demonstrate an inexpensive way to probe the soil or emplace network instruments over much of Mars.

What is the fundamental aspect of Mars that the 2001 lander will attack? How will it justify its existence in the increasingly cost-constrained Mars program environment? What will attract broad and sustained public interest?

2001 must aim for major accomplishment on its own, as well as to provide an essential legacy for later Mars missions. That will likely require require accepting some landing risk. I believe the Hesperian lake strata offer a unique and especially promising objective for 2001.

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GEOLOGY AND LANDING SITES OF THE ELYSIUM BASIN-TERRA CIMMERIA REGION, MARS.

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Introduction: Of key importance to future Mars missions is the search for evidence of past or present life. Potential sites for the 2001 lander are limited to low latitudes and elevations <2.5 km because of engineering constraints. We have identified landing sites that hold high priority for astrobiology that fall within these constraints. Three of the potential sites are in the Elysium Basin-Terra Cimmeria region, an area that has experienced a prolonged and complex hydrologic history. We recommend these sites be targeted early for high resolution orbital imaging and spectral mapping.

Astrobiology in Mars Missions: The search for life on Mars, whether it be extant or extinct, began systematically with the Viking missions of the 1970s [1]. While results of the biology experiments from the two Viking Landers have been widely interpreted as being due to inorganic processes [1], the Orbiters revealed that early Mars was more Earth-like and that liquid water played an important role in shaping the early Martian surface [2] making conditions favorable for exopaleontology [3-7].

The Mars 2001 Lander does not as yet have a landing site identified. However, in keeping with the objectives of the NASA's Astrobiology Institute (NAI), a site with a clear potential for astrobiology must be a top priority. Such a site should include a region with a definite hydrological history. This includes locales with valley networks, outflow channels, lacustrine basins, or outflow plains. Hydrothermal deposits are also important targets and may be associated with identifiable features such as volcanic constructs, pyroclastic flows, chaotic terrains formed by magma-ground ice interaction, and impact sites. Although hydrothermal deposits have not yet been discovered, it is hoped that new high resolution imaging from the Mars Observer Camera (MOC) and compositional information from the Thermal Emission Spectrometer (TES) might help locate such features.

Mars 2001 Site Selection Constraints: Several important engineering constraints have been imposed on possible landing sites for the 2001 mission. Latitudes are presently restricted to 3°N to 12°S, to ensure maximum solar power for the longest time. The elevation must be below +2.5 km but above -3 km. In addition, surfaces must have rock abundances (estimated from IRTM data [8, 9]) of 5-10% coverage to provide high probability for a safe landing. In addition, dust coverage at the site needs to be at a minimum so that the lander is not in danger of sinking into the regolith and that local rocks are not buried. Finally, it is preferable that sites under consideration have been (or will be) imaged at high resolution (<50 m/pixel) either by Viking or by MOC to improve our assessment of potential engineering safety hazards (e.g., boulders, steep slopes, etc.).

Geology and Potential Sites of the Elysium basin / Terra Cimmeria region: As part of an extended reconnaissance of the equatorial region of Mars to find sites that have the highest priority for exopaleontology [10], the geology of the southern Elysium basin and north Terra Cimmeria has been mapped at 1:2M scale [11]. The area covered ranges from 5°S to 23°S and 170°W to 200°W, and includes Gusev crater, north Ma'adim Vallis, and Apollinaris Patera. This area is scientifically interesting and astrobiologically significant as it has been shown to have had a varied and prolonged hydrologic history with its valley networks, multiple outflow channels, and evidence of cryospheric melting near Apollinaris Patera.

In developing a detailed geologic framework for potential landing sites within Elysium Basin/Terra Cimmeria, we utilized the highest resolution data available, including both Viking Orbiter and MOC images. Our visible range mapping will be combined with spectral (and eventually mineralogical) data obtained from the Thermal Emission Spectrometer as they become available from the MGS '96 mission. Data from the Thermal Emission Imaging System (THEMIS) instrument, to be obtained during the 2001 orbital opportunity, may also provide important mineralogical data needed to refine site priorities.

In our investigation, we targeted specific sites that meet criteria relevant for exopaleontology. The types of sites are (in order of priority): hydrothermal, lacustrine, and grab-bag. The chaotic terrain west of Apollinaris Patera and Reuyl crater are potential hydrothermal regions, Reuyl is also a likely lacustrine environment, and the mouth of a valley network in north Memnonia Terra is a grab-bag site. Characteristics of these sites are listed in Table 1.

The disrupted, blocky regions west of Apollinaris Patera appear to have formed where ground water erupted from a subsurface aquifer adjacent to the volcano [12]. Such outflows could have resulted from pressure increases that occurred during periodic subsurface geothermal heating. Because Apollinaris was active throughout most of the Hesperian period [13], it is possible that magma-ground ice interaction formed the chaos and may have sustained hydrothermal activity in the area. On Earth, hydrothermal deposits have been shown to be excellent repositories for a microbial fossil record [4, 14]. For example, fossil biosignatures can often be captured and preserved in silica, carbonate and Fe-oxide sinters [15-18]. We have identified a smooth depression within the chaos as a potential landing site (11.1°S, 188.5°W). VO image coverage includes the series (596A35-36; 635A57) at ~225 m/pixel resolution, and (372B01-26) at ~35 m/pixel resolution, although rock abundance models suggest that surface dust might be too deep.

In addition to a hydrothermal site, ponding of water in the Reuyl crater basin (9.9°S, 192.8°W) may have deposited lacustrine shales. Drying up of such a lake could have left behind evaporites (e.g., halite, gypsum, and carbonate), which are also important targets for a potential Martian fossil record. Reuyl crater is a large (~100 km diameter) relatively young impact crater which possesses an anomalously large central peak and floor deposits of high albedo. Impact into an ice-rich lithosphere could have produced hydrothermal systems within the crater adjacent to the central peak with outflows ponding to form a lake (possibly ice-covered). Evaporation of an ice-covered lake would have left aqueous minerals (hydrothermal deposits, evaporites, etc.) on the crater floor, perhaps accounting for the high albedo observed near the central peak. If biota were present, they could have been preserved within these deposits. Although we consider this an interesting and important target, there is presently a lack of high resolution orbital coverage (see VO 596A31-34), making it an ideal candidate for high resolution MOC imaging.

A small valley network system in northern Memnonia (11.2°S, 178.2°W) is the site of a possible lacustrine environment where ancient materials were transported from the highlands and deposited in a shallow basin in the lowland transition zone (see 437S07-09; 438S02-25; ~70 m/pixel). Because the valley cuts into ancient surfaces and materials were fluvially deposited on Hesperian plains, the period of activity is suggested to be Late Hesperian, when most other hydrologic activity was occurring in the area. A landing site near the mouth of the valley network could provide access to a variety of different rock types derived from the adjacent highlands making this a "grab bag" site. In addition, more basinal sediments could provide access to fine-grained detridal material (shale) which are good targets for preserved organic matter.

Unfortunately, with the further constriction of the latitudinal constraints, several other high-priority sites have been discarded. One such site is at the mouth of Ma'adim Vallis where it debauches into Gusev crater (16.2°S, 184.0°W), a possible former lacustrine environment. This channel had been active throughout the Hesperian period and into the Amazonian [19]. Sediments from the oldest highland units were incised and the material was transported down the channel in a series of events and emplaced in overlapping deposits on the crater floor. These materials should have a wide range of ages, be fairly well sorted in the delta, and might have preserved fossils in possible shales. Similar sites are at the mouths of Al-Qahira Vallis (15.5°S, 195.2°W) and Durius Vallis (15.7°S, 188.2°W).

Conclusions: The discovery of evidence for past life is a main driving forced behind the current Mars missions. Because the Mars 2001 Lander is limited with respect to its possible landing sites by a very restrictive set of engineering constraints, only a few high priority targets have been identified to date. A geologic map of the Elysium Basin-Terra Cimmeria region was produced to better understand the nature of potential landing sites in a terrain of prolonged and varied hydrothermal activity. The chaos and channels adjacent to Apollinaris Patera provide access to a potential hydrothermal area, where groundwater-magma interaction might have provided an environment suitable for sustaining and preserving life. Reuyl crater is a potential lacustrine environment where evaporite deposits might have accumulated. Hydrothermal activity may have occurred near the central peak. Sediments at the mouth of a valley network system in north Memnonia could provide a grab-bag of rock materials transported from the southern highlands. However, images of these sites are either not available at preferred resolution or are of marginal image quality. Because of this, we recommend that a high priority be assigned to targeting the chaos west of Apollinaris Patera, Reuyl crater, and the valley network in north Memnonia for high resolution MOC imaging and for mineralogical mapping by TES.

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TABLE 1. Landing site characteristics.

	APOLLINARIS CHAOS	REUYL CRATER	MEMNONIA VALLEY
Center Lat. Center Long.	11.1°S 188.5°W	9.9°S 192.8°W	11.2°S 178.2°W
Lat. Range Long. Range	10°-12°S 187.5-189.5°W	9°-11°S 192°-194°W	10°-12°S 177°-179°W
Elevation*	+1 to +2 km	-1 to 0 km	+1 to +2 km
Landing Ellipse	10 x 20 km	10 x 20 km	10 x 20 km
Slope	low	low	low
Rock Abundance	0-5%	0-5%	0-5%
Unconsolidated** Material [+]	dusty some mantling	moderate dust low mantling	dusty low mantling
Site Type	hydrothermal lacustrine outflow lowlands	hydrothermal lacustrine	valley network grab-bag lacustrine
Image coverage (m/pixel)	596A35-36; 635A57; 372B01-26 ~225; 255; 35	596A31-34 ~225	437S07-09; 438S02-05 ~62-66

* USGS 1:15M Topographic Map, I-2160, 1991

** Based on composite maps from http://mars.jpl.nasa.gov/2001/landingsite/EngConstr.html

[+] Based on VO image observation

PROPOSED MARS SURVEYOR 2001 LANDING SITE AT "IBISHEAD PENINSULA", SOUTHERN ELYSIUM PLANITIA.

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Introduction

Our objective is to propose a landing site that the Mars Surveyor 2001 Lander and Curie Rover could go to on Mars that should meet the safety requirements of the spacecraft landing system and optimize surface operations (chiefly driven by power and communications requirements). This site lies between 1.5-3.5°S latitude, 195-198°W longitude, along a sharp albedo contact between the low-viscosity flow units of southern Elysium Planitia and the eroded highlands margin east of Aeolis Mensae. A relatively-bright "peninsula-like" protrusion of the eroded highlands into the south Elysium plains in this area reminds us of the head of an Ibis, and so we nickname this site "Ibishead Peninsula" (Figure 1).

This site is designed to be situated as close to a diversity of geologic units within view of the lander instruments. Based on our experience with the visibility of horizon details from the Mars Pathfinder and Viking landing sites, we stipulate that for horizon features to be resolved suitably for detailed study from the lander, they must be no more than several kilometers distant. This is so that diversity can be placed in a geologic context, in a region that we feel has some exciting science potential. This objective is different from the Mars Pathfinder requirement to land at a site with a maximum chance for containing a diversity of rocks within a few tens of meters of the lander, which resulted in the selection of a "grab bag" site. That requirement was driven, in large part, by the Sojourner mobility limit of a few tens of meters, but also by the poor image coverage available for site selection at the time (~40m pixel).

It can be argued that the 2001 mission, which will benefit from MOC images of up to 1.5m/pixel, might actually want to avoid such a site, because placing observations of rocks that are not in situ in even a local geologic context would be difficult, if not impossible. For example, while it has been argued, both before and after the Mars Pathfinder landing, that the provenance for local blocks may be determined by orbiter spectra, primarily from the MGS TES instrument, our ability to do so has yet to be demonstrated. Indeed, nearly two years after the conclusion of the Pathfinder mission, we have yet to reach a consensus on the composition of local materials, or even whether we truly had a "grab bag" of rock materials at all.

Our preliminary data set for selecting a landing site within the latitude and elevation constraints of the 2001 mission is the Viking Orbiter image archive. The site must be selected to place the landing ellipse so as to avoid obvious hazards, such as steep slopes, large or numerous craters, or abundant large knobs over an area at least as large as the landing ellipse, currently a circle 20 km in diameter. For this purpose, we chose a site covered by Viking Orbiter images with a resolution of about 15-20m/pixel. MOC has imaged surfaces in the vicinity that we are using to help us assess the safety of the surfaces in the region at the several meter-scale, and additional images may be acquired if this site "survives" the initial screening after this meeting.

A second requirement, as stated by the project [e.g., Golombek et al., this volume], is that the fine-component thermal inertia data, [1] compiled by P. Christensen and made available to the Mars Pathfinder project, should be greater than about 4 cgs units ($\cdot 10^{-3}\, cal \cdot cm^{-2} \cdot s^{-0.5} \cdot K^{-1}$). Low thermal inertias seem to imply dusty environments, which could pose a mobility hazard. However, based on our assessment of the crispness of details visible in the MOC images acquired in this area and of surrounding surfaces (Figure 2), we feel that it is unlikely that the Ibishead area is very dusty. We feel that the thermal inertia models should not be used to exclude ANY proposed site unless the MOC images verify that high dust is likely.

Similarly, the albedo ([2] digital file made available to the project by P. Christensen) of the site should not be particularly high, which would also seem to suggest dusty surfaces. Low albedos are preferred, as they often coincide with low Viking red:violet ratios and suggest less dusty surfaces. Again, however, relying on albedo to determine the presence or lack of dust or rock would likely preclude materials such as aqueous sediments that are high-priority science targets for this mission.

Next, the Modeled Block Abundance [1] should also not be too high or too low. Based on the Viking Lander and Mars Pathfinder experiences, a block percentage range on the order of 3-13% was selected. Too many blocks could pose a hazard to the landing and mobility. Too few blocks could also indicate a dusty surface. But the MOC is capable of imaging blocks down to meter-scales, so dangerously blocky surfaces should be identifiable as such based on MOC images. And again, crisp details visible in MOC images would contradict the suggestion of a low modeled rock abundance that the surface is dusty.

In summary, we have the means to determine directly, through very high-resolution MOC images, the dust, rock, and slope hazards at a given site. We should place the results from the MOC at the top of our list of requirements for assessing the safety, as well as the scientific interest, of any proposed landing site. Models based on the remote-sensing data should also be considered, but only to the extent that they provide an additional explanation of the surfaces and features visible in the images.

"Ibishead Peninsula" Site.

Vital Statistics:

**Latitude, Longitude:* 1.5-3.5°S, 195-198°W.

**Elevation (Viking):* -1.0 km.

**Viking Orbiter Image coverage:* Excellent coverage by 15-25 m/pixel images (orbit 725A). Possible stereo coverage between images from beginning and end of orbit that overlap (probably small parallax angle, as these orbits are not listed in [3])*

**Albedo:* ~.27-.28

**Block Abundance:* 4-7%

**Fine-Component TI:* 3.2 to 3.8 cgs units

**Thermal Inertia:* 3.6 cgs units

**Slope:* 0°

Science Objectives:

Primary science objectives for this site will be to determine the nature and composition of the geologic materials emplaced in this sector of the Elysium basin (lacustrine, volcanic, mudflows, other). Investigations into the morphology of the site may also confirm/refute the presence of shorelines in this region of Elysium Planitia. Various investigators have attributed the morphology of the plains material located on the floor of the Elysium basin to a wide range of geologic processes/landforms. [4] states that the plains are composed of low-viscosity flood lavas, while [5,6,7] argue for lacustrine / marine processes. If the lacustrine / marine theory is verified it would have major implications for the geologic, hydrologic and possibly even biologic evolution of the planet. This important question could be answered by landing at this site.

Geologic Setting:

This region consists of eroded knobby material, with bedrock probably of Noachian and Hesperian age, though much of the crater population has been destroyed (so the surface is as young as Amazonian), that is onlapped at a sharp contact by an extensive plains flow unit in southern Elysium Planitia that may be as young as late Amazonian in age. The plains materials have been attributed to unusually low-viscosity flood lavas [4] from fissures south of the Elysium volcanic rise, or to lacustrine materials associated with a large, Amazonian lake at the source of Marte Vallis [5, 6]. [7] presented evidence in support of the latter interpretation, though they attributed the putative shore morphology to an embayment of a northern plains ocean into the southern Elysium region. Detailed examination of the margin of the deposit, showing erosion, not simply burial, of small crater rims and fluidized ejecta blankets, also points to lacustrine or marine sedimentation rather than volcanic plains burial.

The plains surface exhibits a "crusty" appearance that many researchers have attributed to pressure ridges in lava flows. We are examining MOC images of this flow material, in the Ibishead area and in the greater southern Elysium and southern Amazonis Planitiae. We find that the flows are often directly associated with fluvial scour features, such that water appears to have emanated from the flows themselves. This is in contradiction to the interpretation by Plescia [4] that the flows are low-viscosity lavas that fill the pre-existing Marte Vallis channel. Instead, the flows must be the frozen or dried remnants of hyperconcentrated floods or mudflows (Figure 2).

The eroded highland margin surface adjacent to these plains appears to be fairly smooth, even at 15 m/pixel. Isolated knob inliers are scattered from a few kilometers to several tens of kilometers apart. Heights of the knobs have not been measured yet but, based on experience with similar features in the Pathfinder landing ellipse, are probably typically on the order of several tens of meters high and smaller, though some of the largest knobs in the region are probably up to a few hundred meters high. Two craters larger than a kilometer in diameter, with fluidized ejecta deposits, lie nearby the proposed landing site, forming the "eyes" of Ibishead Peninsula.

Additional MOC images should help to determine whether a landing site, safe for the lander and navigable by the Curie rover could be placed in this region. The space between knobs and craters is large enough to enable placement of a target landing ellipse between them but still provide horizon views of one or more of them and the margin of the Elysium plains material. Alternatively, it may be possible to identify a safe site on the south Elysium flows themselves. MOC images of this material elsewhere suggest that some areas of the flow surfaces are smooth at the several-meter scale.

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Figure 1. Ibishead Region in Elysium Planitia.

Figure 2. Marte Vallis Mudflows.

Ganges Chasma Landing Site: Access to Sand Sheets, Wall Rock and Layered Mesa Material. James W. Rice, Jr., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, jrice@lpl.arizona.edu

The floor of Ganges Chasma offers an ideal landing site for the MSP 2001 lander (Fig. 1). This site is exquisite both in terms of engineering constraints and science objectives. The floor of Ganges Chasma is mantled with an extensive sand sheet (Fig. 2). Sand sheets develop in conditions which are unfavorable for dune formation. These may include a high water table, periodic flooding, surface cementation, and coarse grained sands [1]. The most extensive sand sheets on Earth are located in the eastern Sahara. These sheets have a relief of less than 1m over wide areas and total thickness ranges from a few cm to 10 m. The surfaces of sand sheets are composed of granule to pebbly lag deposits.

Sand sheets provide an extremely safe landing site and have very low relief. The safety concerns regarding slopes, rocks, and dust would be alleviated by the sand sheet. Furthermore, this vast sand sheet would allow the Marie Curie Rover to cover great distances. Rover navigability would be very easy compared to the tedious rock avoidance maneuvers that Sojourner had to accomplish. This exercise would be an important precursor test for the more capable Athena Rover which will execute longer traverses. Moreover, the Rover has already been "field tested" on sand at the JPL Mars sandbox. Dust should not be a problem: Thermal inertia is 7.7 to 8.9 cgs units. This site satisfies all engineering constraints.

Science Objectives:

*What is the nature and source of the sand?

*What is the composition, grain size, shape, sorting, and stratigraphy of the sand?

*Is the sand monomineralic, lithic fragments, ice or salt cemented dust?

*What is the nature and composition of the Layered Mesa Material (lacustrine, aeolian, volcanic, other)?

*What is the nature and composition of the canyon wall material?

The philosophy for selecting this site is that it would allow analysis of Chasma floor material which should be composed of wall material and the layered mesa material, there is also abundant evidence of channels emptying into the canyon thereby providing a source for aqueous sediments. The morphology of the layered mesa material suggest that it is different from the surrounding canyon wall rock because no landslides are observed around the mesa walls, fine parallel fluting is observed on the mesa instead of the spur and gully morphology of canyon walls. The layered mesa material also unconformably overlies the conical hills located on the canyon floor. The Robotic Arm (RA) will dig trenches into the substrate and be able to perform grain size analysis studies with the Robotic Arm Camera (RAC). The RAC is a lightweight monoscopic camera attached to the RA. RAC has a maximum resolution of 25 µm/pixel at close focus and 1.7 mrad/pixel at far focus (with a 50° X 25° field of view)[2]. A sample RAC high resolution scoop image from Baker, CA field test is shown in Fig. 3.

Geologic Setting:

Ganges Chasma is located south of Shalbatana Vallis and north of Capri Chasma. Ganges Chasma is the type area for the Layered Material (interior layered deposits) located on the floors of the Valles Marineris. The wall are mapped as Noachian/Hesperian material with Hesperian layered material 100's m thick located on the floor of Ganges: this enigmatic material has been interpreted to be lacustrine, volcanic, aeolian deposits or remnant wall material. Amazonian alluvial deposits, landslides, sand sheets and dune fields are also found on the floor.

Numerous channels also empty into Ganges Chasma, the largest is Elaver Vallis, 160 km long. Elaver Vallis flows across 160 km of the upper surface of Aurorae Planum before emptying onto the floor of Ganges Chasma, 4 - 5 km below, forming the largest waterfall in the Solar System. The source of Elaver Vallis is a 77 km diameter crater. The source crater has a outlet channel 5 km wide, located on its southeastern flank. The crater rim height is calculated (shadow measurement) to be 450m above the crater floor. Using this as the upper limit for the water level in the crater yields a volume of water nearing 2,100 km^3 that would have drained into Ganges Chasma. This crater also has what appears to be a sinkhole (40 km diam) located on its southern floor. The source regions of Shalbatana Vallis also appear to display a karst topography. This "karst topography" begs the question: what is the composition of the underlying layered plateau rock ?

Ganges Chasma Landing Site Characteristics:

Landing Site Options:
Sand Sheet A: 7.9°S, 49.3°W
Sand Sheet B: 8.1°S, 48°W
Layered Mesa: 7.4°S, 49.5°W
Elevation: -1 to +1 km
Rock Abundance: 8 to 10 % (Floor and Mesa)
Thermal Inertia: Floor: 7.7 to 8.8
Mesa: 8.8 to 8.9
Fine Component: Floor: 7.0 to 8.3
Mesa: 7.2 to 7.8
Albedo: Floor: 0.1530 to 0.1740
Mesa: 0.1650 to 0.1700
Slopes: Floor: 0° to 3°
Layered Mesa Material: 0° to 5°
Layered Mesa Material: 100 X 45 km

Wall Imaging: Landing at the various Sand Sheet locations would place the lander 30 km from the south wall (4 km high) of Ganges Chasma and only 5 to 10 km from the Layered Mesa (1-2 km high). If lander touchdown is 50 km from the wall, then RAC can image the wall. The wall would rise 4.2° above the horizon (43 RAC pixels; 150 Pancam pixels). From this distance only the shape of the wall would be observable. However, at a distance of 15 km from the wall of the Layered Mesa, which is 2 km high, the Mesa would rise 5.6 ° above the horizon (57 RAC pixels). Layers, >30m thick, would be visible. For comparison Twin Peaks is about 1° above the horizon (20-30 pixels).

Specific site characteristics such as rock abundance, thermal inertia, and albedo data were provided by [3,4,5].

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STRATEGIES AND RECOMMENDED TARGETS FOR MARS SURVEYOR PROGRAM LANDING SITES.

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Introduction

Engineering criteria (latitude, elevation, surface slopes, rock and dust coverage) constrain and dictate to a certain extent where a lander/rover spacecraft can safely land. Scientist must "live" within these guidelines and work to find a geologically interesting landing site. Models of thermal inertia and rock abundance [1,2] are often used to limit regions for candidate landing sites. However, one must remember that the thermal inertia and rock abundance models are averages and bins are 2 by 2 degree lat, lon and 1 by 1 degree lat, lon, respectively. It is this investigators view that hi-res imagery, of an area in question, should take precedence over models in determining the fitness of landing sites. For instance, numerous hi-res MOC images in the Elysium region exhibit a dust free surface yet the models predict low thermal inertias (fine grained materials/dust). Additionally, there is no evidence for drifts or dunes of fine grained materials in this region of Elysium. The surface in this region has been interpreted to be the result of fluid volcanism [3], however [4] interpret this as being the deposit of ice charged mudflows.

Uniform Geology vs. Compact Geology:

The two major competing scientific strategies for selecting a landing site are: geologically uniform simple sites and geologically diverse complex sites. Simple sites contain regions with extensive, uniform surface materials that are a typical representation of a widely occurring type of terrain of clear global importance (Hr: Hesperian ridged plains material).

Complex sites contain regions with compact geology, which is defined as regions with a wide variety of surface materials in terms of age and origins (Avf: Amazonian Ganges Chasma floor material). The obvious advantage of a site with compact geology is the availability of a maximum variety of materials and ages. However, the geologic history of a complex site might prove to be very difficult to decipher.

One caveat regarding the sampling of Martian crater ejecta deposits for stratigraphy should be noted: namely ejecta mixing and destruction of the systematic pattern seen on the Moon due to the Martian atmosphere. The present day Martian atmosphere can cause this affect to occur [5] and a thicker earlier atmosphere would only accentuate this process.

Most of these candidate landing sites have been proposed by the author before this meeting and are referenced.

Mars Surveyor Program Candidate Landing Sites

Site: ***Terra Sirenum*** [6]

Science Objectives: Highland-lowland dichotomy site with valley networks, fan-deltas, lava flows, fresh crater ejecta, fluvial deposits (fan-deltas) may be good locales for preservation of biogenic materials.

Location: 4.9° to 5.2° S; 147.0° to 147.5° W

Elevation: 1 km

Geologic Setting: Noachian ridged plateau (early crust), Hesperian intercrater plains: lava flows, Amazonian/Hesperian Tharsis Montes Fm: lava flows, Amazonian lava flows, Amazonian/Hesperian valley network fluvial deposits (fan-deltas at Abus and Isara Vallis), ejecta blanket of 10 km diam. Amazonian crater.

Landing Site: Smooth, flat Outwash Plains of Valley Networks, Abus and Sensus Valles. This site is located along the hemispheric dichotomy and would provide an ideal compact geology site. Hazards would be minimal on these small outwash plains.

Rock Abundance: 7%

Thermal Inertia (10-3 cgs units): 0

Fine Component (10-3 cgs units): 2.4

Albedo: 0.2970

Slope: 0°

Site: ***Aeolis Mensa***
Science Objectives: Investigate the nature of this layered terrain in the ancient highlands. Layered Material may be good locale for burial and preservation of any biogenic material.
Location: 6° to 9° S; 214° to 216° W
Elevation: -1 to 1 km
Geologic Setting: Ancient highlands: Noachian plateau sequence material.
Landing Site: Ancient Highlands with smooth, flat layered plains of Aeolis Mensa. This site is located south of the hemispheric dichotomy.
Rock Abundance: 7 to 9%
Thermal Inertia (10-3 cgs units): 5.1
Fine Component (10-3 cgs units): 5.2 to 6.0
Albedo: 0.2630
Slope: 0° to 1°

Site: ***SE Terra Meridiani*** [7]
Science Objectives: Investigate the nature of these Noachian and Hesperian layered ancient highlands and valley network /lacustrine deposits.
Location: 0° to 12° S; 340° to 356° W;
Landing site: 7°S, 347°W
Elevation: 1 to 2 km
Geologic Setting: Ancient highlands 130 km southwest of Schiaparelli crater. Noachian plateau material dissected by numerous valley networks. Valley networks flow down the southern and eastern rims of this region into the smooth plain (lacustrine). Smooth featureless plains embay isolated hills and massifs.
Landing Site: Smooth plains, this site may be a paleolake basin.
Rock Abundance: 4 to 8%
Thermal Inertia (10-3 cgs units): 5.2 to 6.2
Fine Component (10-3 cgs units): 4.8 to 5.4
Albedo: 0.1620 to 0.2090
Slope: 0° to 2°

Site: ***Schiaparelli Crater Floor*** [8]
Science Objectives: Investigate the nature of the deposits on the floor of Schiaparelli. Brazos Valles empties into this crater basin, lobes of material (fan-deltas) are observed along the southern half of the crater floor/rim interface.
Location: 0° to 6° S; 339° to 347° W;
Landing site: 5°S, 342°W
Elevation: 1 to 2 km
Geologic Setting: Floor of Schiaparelli crater.
Landing Site: fan-delta deposits from Brazos Valles.
Rock Abundance: 3 to 5%
Thermal Inertia (10-3 cgs units): 2.0 to 4.9
Fine Component (10-3 cgs units): 3.3 to 4.9
Albedo: 0.2270 to 0.2580
Slope: 0° to 5°

Site: **Elysium Basin** [9]
Science Objectives: Investigate the nature of the floor of Elysium Planitia
(volcanic, lacustrine, fluvial, mudflows) and possible shorelines.
Location: 0° to 3°S; 195° to 200°W;
Landing site: 2°S, 196°W
Elevation: -2 to 0 km
Geologic Setting: Extremely young (40my) Elysium basin floor nestled against ancient highlands.
Landing Site: Near margin of Elysium basin floor and cratered highlands.
Rock Abundance: 4 to 7%
Thermal Inertia (10-3 cgs units): 3.6
Fine Component (10-3 cgs units): 3.2 to 3.8
Albedo: 0.2740 to 0.2800
Slope: 0°

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ESTIMATING SURFACE ROUGHNESS AT SCALES BELOW SENSOR RESOLUTION.

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Descriptive Abstract. We present a simple but physically-based method by which surface roughness (RMS slopes or heights) can be estimated from larger or smaller scales of known topography. The method is based upon the assumption that the surface topography can be reasonably characterized by self-affine or fractal statistics. We present an illustration of the method which estimates the hazards associated with placing a soft lander on Mars.

Introduction. There are many instances in which one may know quantitative roughness characteristics of topography, and from this knowledge, wish to extrapolate the behavior of the topography to greater or lesser scales. One example of this includes determining the relative safety of potential landing sites for planetary missions. Often, one only has topographic information at relatively large scales – tens to hundreds of meters and up. However, landers are most sensitive to topography at scales of a few meters or less. In this brief, we will illustrate a method by which topography at these scales may be reasonably estimated.

Methodology. We assume that topographic parameters are known for a limited range of scales. We also assume that the surface topography is reasonably well characterized by self-affine "fractal" statistics. Over a limited range of scales, it has been well documented that the following properties are observed to apply to most terrestrial and extraterrestrial surfaces (*cf.* [1,2,3,4] for illustrations and a thorough review of the literature):

$$s(x) = s_0 x^{H-1} \quad (1)$$

$$\xi(L) = \xi_0 L^H \quad (2)$$

where $s(x) = \tan(\theta)$ is the RMS slope of a surface measured between points spaced a distance, x, apart; s_0 is the RMS slope of that surface at a unit distance spacing; ξ is the RMS height of the surface measured from a profile of length, L; ξ_0 is the RMS height of a profile of unit length, and H is a scaling parameter referred to in this work as the Hurst exponent. For topography, it has been observed that $0 < H < 1$, with H tending to a central value of 0.5. Topography falling into this central category is termed *Brownian.*

If one knows the topography at any scale, x_2 or L_2, and the scaling behavior of that surface, H, one can reasonably estimate the topography at any other scale from Eqs. (1) and (2) [1]:

$$s(x_1) = s(x_2)\left(\frac{x_1}{x_2}\right)^{H-1} \quad (3)$$

$$\xi(L_1) = \xi(L_2)\left(\frac{L_1}{L_2}\right)^{H} \quad (4).$$

Below, we give an example and actual application of this result.

Example. Suppose that one wishes to place a lander on Mars. We will assume that the lander has a lateral or base dimension of 3 meters, and an engineering tolerance for landing in terrains with slopes no greater than 10° from the horizontal. Additionally, we assume that the lander has an engineering height clearance of 0.5 meters. Now assume that we are examining two areas as potential landing sites, sites A and B. Site A has good imaging coverage, and a topographic map of the area in interest has been generated with a resolution of 20 m/pixel. Upon analysis, we find that it can be well characterized by a Hurst exponent of 0.5 from scales of several hundred meters down to 20m, and has an RMS slope at 20 m of 2.0°. We apply Eq. (3) and find that the estimated slope of the surface at the 3 m scale is 5.1 °. If we make the assumption that the surface is described by Gaussian slope statistics, then we will encounter slopes greater than our engineering tolerance approximately 5% of the time. If we make no assumptions about the distribution of surface slopes, then we must adopt a very conservative estimate (from Chebychev's Inequality [5]) that we will encounter slopes greater 10° no more than 25% of the time.

Site B is also well covered by images from previous missions but the derived topographic products have a resolution of 30m/pixel. However, at this scale the site is found to have an RMS slope of 1.5° and a Hurst exponent of 0.4. Applying Eq. (3), we find that the estimated RMS slope at 3 m scale is 6.0°, somewhat rougher than Site A. Although Site B initially appeared smoother than Site A, this was misleading because of the scale at which it occurred. Additionally, the roughness of Site B increases more rapidly than Site A because of the lower Hurst exponent. Finally, we must always keep in mind that these are extrapolations based upon the observed scaling behavior at larger scales. Our estimate for Site A will be more reliable than for Site B because it is closer to our desired scale (20 m/pixel vice 30 m/pixel).

Caveats. Our experience with topographic data shows that the use of a single Hurst exponent is rarely sufficient to characterize topography over more than two orders of magnitude in scale. More often, there are observed "breaks" in the scaling behavior whereby one value of H is valid for some range of scales, but different values of H are valid at higher and lower scales. As an example, pahoehoe lava flows in Hawaii were observed to have a Hurst exponent of 0.7 for scales from 1m to 10m, but a value of 0.5 for scales less than 1m (site 1 of reference [2]). This break in scaling behavior is attributed to the role of different processes operating on the topography. At the 1-10m scale, topography is controlled by flow rheologic properties – billows and ropy textures are abundant. However, at scales less than 1m, weathering has caused the glassy surface to spall and fragment, littering the surface with innumerable glassy shards. It is therefore of critical importance that the data used for extrapolation be as close as possible to the desired scale. In general, extrapolations from scales more than 1–1.5 orders in magnitude away will be unreliable.

It will also be noted that the engineering height clearances in the above example were ignored. In fact, the RMS height and slope behavior of a fractal surface are functions of one another, and the engineering height and slope constraints are therefore not independent of one another. In general, the RMS slope at some scale, x, and the RMS height from a profile of length, x, are related by [3]

$$\xi(x) = \frac{x\,s(x)}{\sqrt{2}} \qquad (5).$$

In the example above, the lander had a slope tolerance of 10° and a height tolerance of 0.5m. Using Eq. (5), we find that a surface with RMS slope of 10° at a scale of 3m will have an RMS height of 0.37m at the same scale. In other words, the slope tolerance is the more restrictive parameter for site selection in this example.

Application to Mars 2001 Lander. The engineering constraints on the surface roughness for the Mars 2001 lander are: (1) surface tilts of <10° (presumably at the lander scale of ~3 meters) and (2) less than 1% chance of landing on a rock higher than 0.31m (again, presumably for a horizontal scale of ~3 meters). We will assume the surface roughness to be characterized by self-affine fractal behavior and Gaussian height statistics. In this case, the height clearance is the most restrictive engineering constraint. A 1% chance of landing on a 3 meter spot with height of <0.31m is equivalent to requiring an RMS height (1 sigma) of <0.12m for the landing area (0.31÷ 2.58 sigma). Using Eq. (5), we find this corresponds to RMS slopes (1 sigma) of <3.2° at the lander scale, which gives us less than 0.2% probability of landing on a slope >10°. None of this is dependent upon the Hurst exponent.

If we wish to extrapolate this limiting roughness to larger known topographic scales, we must assume some Hurst exponent. Experience has shown most topography to fall between the values of H = 0.3 – 0.7 and so we will adopt these extremes and present a high, low, and intermediate (H = 0.5) scenario. We can use Eq. (3) to estimate the RMS slopes for any horizontal scale and Hurst exponent. Assuming that topographic data is available at the 30m horizontal scale, the maximum tolerable RMS slopes at this scale are 0.64° (H = 0.3), 1.0° (H = 0.5), and 1.6° (H = 0.7). These values would decrease with increasing known horizontal scales (*i.e.,* slopes must be even less at 50m horizontal scales). Additionally, these estimates become less reliable at larger horizontal scales (greater distance to extrapolate).

Conclusions. Natural surfaces have been observed to obey fractal statistics over a wide range of scales. This property provides a way to extrapolate surface properties at scales above and below those which are known and may prove to be of value in estimating lander scale hazards.

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LANDING SITE ENGINEERING CONSTRAINTS. D. Spencer, MSP'01 Mission Manager, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099 (david.a.spencer@jpl.nasa.gov).

Based upon the lander design, constraints are placed upon the landing site selection process in order to mitigate landing risk and optimize mission performance. Constraints are placed on the landing site latitude, elevation, measured rock abundance and terrain slopes within the landing footprint. Estimated mission lifetime and power availability as a function of landing site latitude will be presented. The dimensions of the landing footprint will be given. Plans for obtaining high resolution MOC images of candidate landing sites will be discussed.

THE AMENTHES TROUGH, MARS: NOACHIAN FLUVIAL/MASS-WASTING SEDIMENTS FOR INVESTIGATION BY THE MARS '01 LANDER.

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Introduction: The Amenthes trough forms a northwest-trending depression within the heavily cratered highlands of Mars. A landing site proposed here affords a well-defined geologic setting that will allow scrutiny of ancient Noachian sedimentary materials and processes. The proposed landing site, in the vicinity of 1.7°S, 246.4°W (Fig. 1), generally satisfies mission engineering requirements for the Mars Surveyor '01 lander (Table 1).

Herein I describe the rich geology of the landing site from an examination of the regional context as well as local features. I also describe some of the kinds of science that might be performed by the lander/rover instrument package in this area.

Table 1. Data for the proposed Mars '01 landing site in the Amenthes trough (1.7°S, 246.4°W).

Data type	*Values*
Viking image coverage	14-16 m/pixel (124S)
MOC images (3 nearby)	6, 8, 9 m/pixel
Topography, MOLA	~-2.0 km
Rock abundance	12%
Fine component TI	7 cgs units

Regional setting: The Amenthes trough extends southeastward from Isidis Planitia, forming a ~100-km-wide breach in the Isidis basin rim. The trough is ~1,100 km long, and the proposed landing side is near the southeast end of the trough. The northwest half of the trough is flanked by Early to Middle Noachian massifs and rugged cratered terrain of the ancient Isidis basin rim [1]. This part of the rim is cut by several linear, wide, NNE-trending fractures of Amenthes Fossae [2]. The southeast half of the trough is flanked by Middle Noachian dissected cratered material [1]; prominent scarps of Amenthes Rupes form parts of the trough walls [1]. These scarps are thought to be contractional thrust and fold features [3]. Most of the floor of Amenthes trough is covered by smooth plains material [1] that is locally deformed by wrinkle ridges.

The new MOLA global topographic mapping [4] indicates that the floor of Amenthes trough rises slightly from ~-2.5 km elevation where it connects with Isidis Planitia to about -2 km elevation near the landing site. In the vicinity of the proposed landing site, the trough floor is ~-2 km and the crest of Amenthes Rupes reaches ~2 km.

Landing site geology: The 124S orbit of Viking images (Fig. 1) provides a high-resolution swath across Amenthes Rupes and trough. These images elucidate well the erosional history of the trough wall and the depositional history on the trough floor. Cited stratigraphic ages (Noachian and Hesperian) are estimates based on morphological state.

The oldest rocks in the image swath (unit Nar) make up the rugged crest and southwest flank of Amenthes Rupes. These appear to be rugged Noachian highland materials whose morphology is dominated by (1) southwest-trending, moderately sinuous valleys 1-2 km wide and up to ~10 km long, (2) generally southwest-facing alcoves up to a few km wide, and (3) impact craters up to 2 km in diameter. This terrain is relatively steep. The general lack of connection and organization of the alcove and valley features indicates that most of these features were formed by localized, discrete erosional events, presumably driven by ground-water sapping and mass wasting. The valley walls appear to be steepest on top, and valley floors appear to have narrow channels a few hundred meters wide. Subtle northwest-trending scarps and ridges in this terrain indicate that the material was only moderately deformed (except for possible broad-scale deformation) after valley and alcove development.

Below the rugged highland material, a series of planar deposits form sloping steps in the lower part of the Amenthes trough. These deposits are progressively younger in age toward the bottom of the trough. They appear to correspond with successive levels of downcutting and deposition.

The first of these trough units (unit Nat_1) embays one of the more prominent valleys in the wall material. It appears that significant erosion has removed the upper part of the older unit in places, and elsewhere the older unit is exposed and apparently embayed by the upper trough unit. Contacts between these units are mostly indistinct. Small wrinkle ridges aligned with the trough deform the unit's surface.

The upper trough unit is dissected by deep, broad (>5 km wide), long (~20 km), round-headed, flat-floored troughs filled by the next younger trough unit (unit Nat_2). Some of the valleys that dissect the rupes unit (unit Nar) also dissect the upper trough unit and connect with the troughs of the second trough unit.

The next lower trough unit (unit Nat_3) covers much of the broad floor of Amenthes trough across the 124S image swath, as well as the floors of connected troughs that cut the floor material (unit Nat_2) of higher-level troughs. The troughs are generally 2-6 km wide. This broad unit, while planar, shows considerable fine-scale texture and morphologies. A broad, sinuous channel-like feature courses along the trend of the image swath, whereas local narrow channels trend across the swath. Small, short ridges appear to be aligned in the along-swath direction and may be dunes. The surface is densely pocked by impact craters; the larger craters display layering in their upper, interior rims and are filled by smooth floor deposits. The crater rims and ejecta ramparts appear etched. Shallow, broad circular depressions in the unit appear to be areas where the unit has compacted above underlying crater forms.

At the southwest end of the swath, the next lower unit (unit HNat$_4$) infills a 23-km-diameter crater and embays unit Nat$_3$. The eastern part of the degraded crater rim is partly exposed, whereas the southwestern part is buried but marked by a prominent northwest-trending wrinkle-ridge system. Within the crater, the unit is superposed by scattered remnant mesas up to a few kilometers across made up of a younger deposit (unit HNat$_5$).

The lower trough units (units Nat$_3$ and HNat$_4$) also embay a rugged trough floor unit (Natr) east of the large crater. In lower resolution images, the unit appears dissected and may have contributed to the sedimentation of the lower trough unit. A narrow, sinuous channel that dissects unit HNat$_4$ in the eastern part of the large crater may emanate from the rugged floor unit.

Lander and rover science: The high-resolution Viking 124S image swath provides excellent visualization of part of the Amenthes trough. The proposed landing site generally fits within engineering constraints, with the possible exceptions that the topography may be rather rough in places and the ellipse must include some large impact craters and trough walls, unless the ellipse size is reduced to about 15 km.

Perhaps the greatest strength of this landing site proposal is the degree to which the geologic context can be mapped and interpreted. Obviously, without strong geomorphic evidence, the origin of many Noachian rocks cannot be deciphered; various sedimentary, volcanic, and impact origins may be plausible. The proposed Amenthes trough site is covered by a deposit (unit Nat$_3$) that clearly originates from ancient, uplifted crustal material (unit Nar). In addition, the alcoves and valleys above the site indicate that the deposit was emplaced by a series of sapping and mass-wasting events. The proposed landing-site materials would be ideal for site analysis of paleoclimatic and paleobiologic indicators, because they formed from ancient crustal material that had contained ground water during the Noachian.

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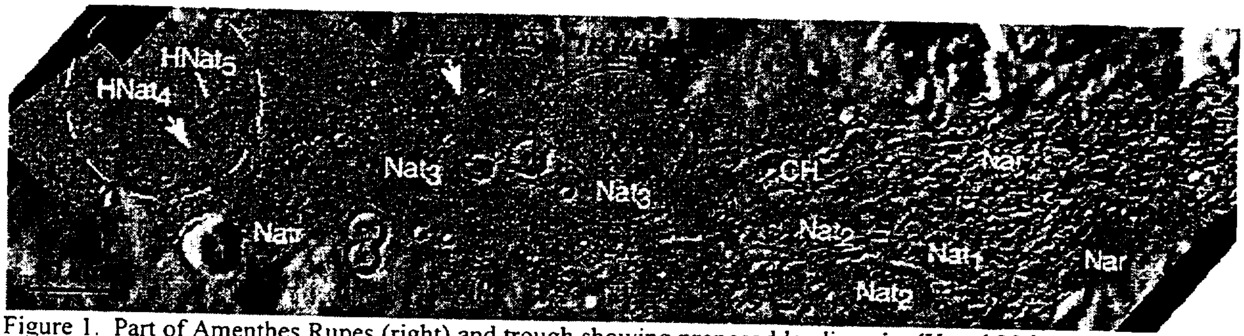

Figure 1. Part of Amenthes Rupes (right) and trough showing proposed landing site (X and 20-km-diameter circle). Geologic units described in text. Note valleys (V), alcoves (black arrows), channels (CH), partly buried crater rim (dashed line), and narrow sinuous channels (white arrows). [north at upper left; Viking images 124S1-24, 16-18 m/pixel superposed on image 381S41, 250 m/pixel]

MANGALA VALLES PALEOLAKE LANDING SITE.

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Introduction: Mangala Valles (see Fig. 1) is an outflow channel system about 850 km long and as much as 300 km wide that cuts the equatorial martian highlands. The channel system originates at one of the northeast-trending Memnonia Fossae graben and ends at the highland-lowland boundary scarp. The debouchment area on Amazonis Planitia extends from lat 4° S. to at least lat 2.5° N. Mangala Valles channel-floor deposits offer grab-bag collection areas as do most of the outflow channels. The channel has ponded areas where floods have accumulated over long periods, similar to Ma'adim Vallis and Gusev crater. The unique and compelling characteristics of Mangala Valles for lander investigations are that it (1) heads at a likely source of thermal water; (2) includes both lava flows and flood deposits; (3) contains areas where water ponded; (4) is mostly covered by high-resolution Viking imagery (<50 m/pixel); and (5) has had detailed 1:500,000-scale geologic maps produced for nearly the entire channel system.

Numerous sites of high scientific interest occur along the length of the Mangala Valles channel system. We propose the floor of a 45-km-diameter impact crater breached by a branch of Mangala Valles for the Mars '01 Lander site (centered at lat 6.3° S., long 153.2°). The crater floor possibly includes material deposited within paleolakes.

Site Characteristics: The landing ellipse could be safely located within the 45-km-diameter smooth floor of the impact crater (Fig. 1). In this region, MOLA data indicate that the elevation ranges from about –2 to 0 km [1]. The crater floor is marked by a few broad, low ridges (all surface slopes are likely to be much less than 10°). The site has a moderate rock abundance (between 5-7%) and an elevation of about 2 km above datum, but fine-component thermal inertia values are a bit low (2.7 cgs units). However, observation of MOC images in other areas of low thermal inertia do not necessarily support the interpretation of abundant dust; therefore, low thermal inertia values should not necessarily preclude the Mangala site as a candidate 2001 landing area.

Site Geology: Detailed geologic mapping at 1:500,000 scale (Fig. 1) [2] indicates only one type of material crops out within the proposed landing ellipse—lacustrine material. This material likely includes rocks of many different origins and ages, because the crater floor was periodically covered by debris derived from various highland and lava-flow deposits during catastrophic-flood episodes. In addition, impact gardening would bring older material, possibly buried by later eolian deposition, to the surface. The lacustrine material was mapped as Amazonian-Hesperian smooth material (unit AHms) of the Mangala Valles assemblage emplaced within a Noachian impact crater. Water from each stage of two postulated catastrophic flood stages of Mangala Valles breached the impact crater lying in the path of the floods and flowed into the low-lying crater floor [2-3]. The decrease in stream energy of the floods as they entered the craters, as well as the possible development of temporary lakes [4] and eolian infilling, may explain the unit's smooth surface in Viking images. Outcrops near the landing site contain nested, semicircular ridges that decrease in circumference toward a breach of the crater's north rim. These ridges appear similar to paleoshoreline gravel ridges (not the well-known lake terraces) formed by wind and wave interaction during recession of ancient Lake Bonneville at Spring Valley, Utah [2].

Science Justification: A number of factors make the Mangala Valles site scientifically desirable, including:

(1) The search for life. Mangala Valles is a highly relevant area for exobiologic studies. Our site offers access to recent and ancient rocks that can be sectioned and examined for evidence of fossils. Hydrothermal systems are thought to have formed early habitats on Earth; sites that include materials resulting from hydrothermal activity are thus important targets in searching for martian fossils [5]. The Mangala channels may provide such a setting, because it emanates from a tectonic graben of Memnonia Fossae that is thought to have released thermal waters associated with Tharsis volcanism [3, 6]. Moreover, young channel deposits and lake beds are particularly important exobiologic targets, because recent water outflows may have exposed and deposited molecular evidence of extant life; also, ice-covered lakes might have been sites for life's "last stand" on the martian surface [7]. Some postulated channel and lacustrine deposits of Mangala Valles are as young as Amazonian [2, 3, 6, 8-10]. The proposed candidate 2001 site is within a crater thought to contain lacustrine deposits (Fig. 1) [2].

(2) Resource assessment. A lander investigation at our proposed site would sample martian crustal materials of various ages and origins. The catastrophic outflow channels of Mangala Valles cut across a complex region composed of rocks of Noachian highlands and of Hesperian to Amazonian volcanic and sedimentary terrains (Fig. 1).

(3) Geologic history. Understanding of crustal hydrothermal activity, volcanism, and sedimentary

MANGALA VALLES PALEOLAKE LANDING SITE. K. .L. Tanaka and M. G. Chapman

processes are primary geologic science goals for Mars missions [11]. Rocks at the proposed landing site record the flooding of both thermal waters and lava flows that emanated from a Memnonia Fossae graben [2, 6, 12].

(4) Volatile and climatic history. Formation of martian outflow channels has been attributed to catastrophic flooding [13], glacial erosion [14], and debris flows [15]. Investigation of the geomorphology, lithology, and rock distributions at the proposed site may elucidate the channeling and sedimentary processes and climate conditions when the deposits formed at the proposed lander site.

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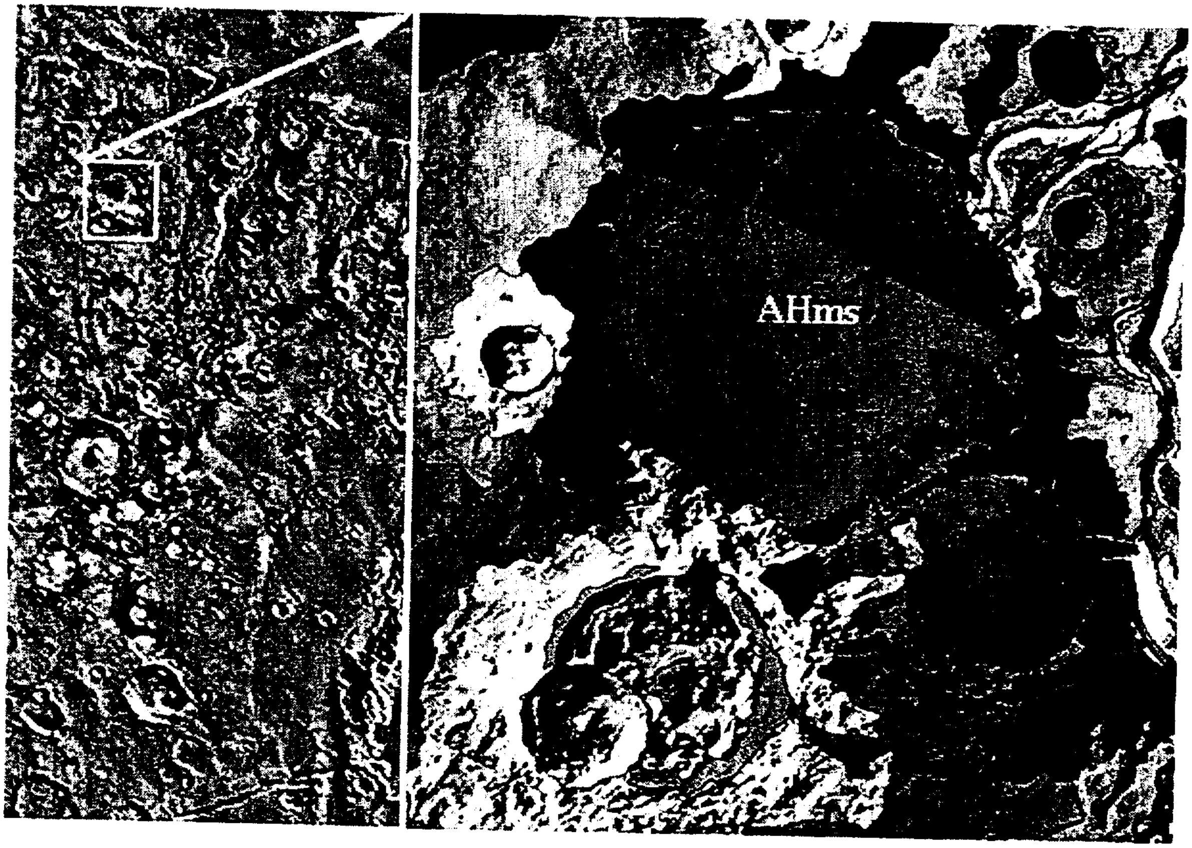

Figure 1. Mangala Valles region (left), showing full extent of the channel system from a linear graben system (bottom of image) to where it debouches into southern Amazonis Planitia (top). (Part of Mars Digital Image Mosaic; lat 18.5° S. to 2.5° N. and long 149° to 157°; north at top). White box shows location of area of geologic map on right (from [7]), which includes the 45-km-diameter floor of a Noachian crater, containing smooth material (unit AHms). Note that branches of Mangala Valles breach the right side of the adjacent, smaller (~20 km) crater to the lower right and the upper right side of the larger crater. Our proposed Mangala Valles site for the Mars '01 lander is within the northern part of the larger crater where ridges are absent.

VIKING HIGH-RESOLUTION TOPOGRAPHY AND MARS '01 SITE SELECTION: APPLICATION TO THE WHITE ROCK AREA.

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Introduction: Definition of the local topography of the Mars '01 Lander site is crucial for assessment of lander safety and rover trafficability. According to Golombek et al. [1], steep surface slopes may (1) cause retro-rockets to be fired too early or late for a safe landing, (2) the landing site slope needs to be <10° to ensure lander stability, and (3) a nearly level site is better for power generation of both the lander and the rover and for rover trafficability.

Presently available datasets are largely inadequate to determine surface slope at scales pertinent to landing-site issues. Ideally, a topographic model of the entire landing site at meter-scale resolution would permit the best assessment of the pertinent topographic issues. MOLA data, while providing highly accurate vertical measurements, are inadequate to address slopes along paths of less than several hundred meters, because of along-track data spacings of hundreds of meters and horizontal errors in positioning of 500 to 2000 m [2]. The capability to produce stereotopography from MOC image pairs is not yet in hand, nor can we necessarily expect a suitable number of stereo image pairs to be acquired. However, for a limited number of sites, high-resolution Viking stereo imaging is available at tens of meters horizontal resolution, capable of covering landing-ellipse sized areas [3]. Although we would not necessarily suggest that the chosen Mars '01 Lander site should be located where good Viking stereotopography is available, an assessment of typical surface slopes at these scales for a range of surface types may be quite valuable in landing-site selection. Thus this study has a two-fold application: (1) to support the proposal of White Rock as a candidate Mars '01 Lander site, and (2) to evaluate how Viking high-resolution stereotopography may be of value in the overall Mars '01 Lander site selection process.

Example site: White Rock. We are examining high-resolution stereo pairs (Viking rev 826A, ~24-29 m/pixel) covering part of the deep, 93-km-diameter impact crater centered near 8°S., 335.5°W that contains the well-known, bright feature known as "White Rock" (Fig. 1). This feature has been interpreted as a fine-grained paleolake, perhaps salt-pan, deposit eroded into yardangs by the wind [4-6]

The surface morphologies of White Rock and the surrounding crater floor are complex. White Rock itself appears to have been sculptured by irregular grooves up to several hundred meters wide and several kilometers long. The grooves form two sets oriented perpendicular to one another. One set is pervasive through the deposit, whereas the other mainly forms troughs along the eastern margin of White Rock, giving the outcrops a streamlined, flame-like appearance. The troughs are filled by relatively low-albedo plains material, which may be an eolian mantle. Farther west, the crater floor becomes somewhat lighter in color (see image 826A66). The crater floor is marked by impact craters, wrinkle ridges, and other irregular landforms.

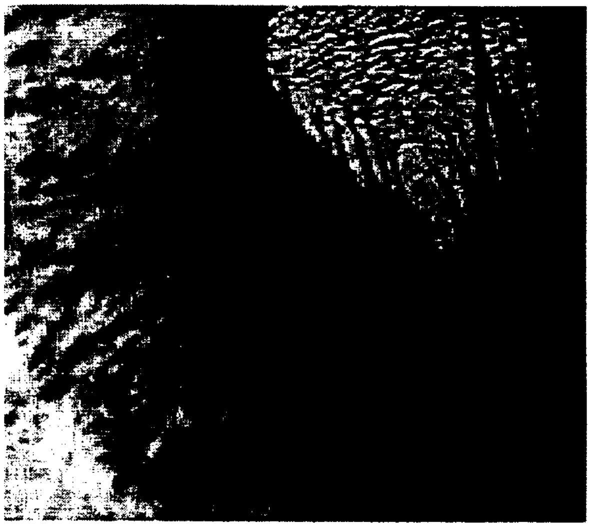
Figure 1. White Rock, Mars (Viking image 826A36; image width, 34 km; north at upper right).

The crater floor is broad enough (~60 km across) to be considered for a Mars '01 Lander site. The site also satisfies current nominal engineering constraints, as follows: (1) rock abundance, 4-5%; (2) fine-component thermal inertia, 4.6 to 5.1 cgs units; (3) elevation, ~0 to 1 km [7].

Approximate stereo topographic measurements of the height of White Rock using the same images that we are working with were performed by Williams and Zimbelman [5]. They estimated a parallax-height ratio based on a *model* depth estimate for a bowl-shaped crater within the scene, rather than on the actual viewing geometry of the images.

Expected results: The Viking 826A images include two sequences taken of the crater floor. One set is with the blue filter, and the other is with the red filter. The parallax-height ratio is ~0.55, which indicates an expected vertical precision of ~10 m. Stereoscopic viewing resolves impact crater rims and ridge and trough features of White Rock and the surrounding plains.

We plan to produce uncontrolled topographic models for one or more of the stereo pairs covering the White Rock area. The models should resolve vertical differences of a few tens of meters across several pixels (~100 m).

This resolution will enable topographic measurements of a variety of landforms at the site, including crater rims, wrinkle ridges, and various eolian features. Many of these features are likely to be common to other proposed Mars '01 Lander sites, and so our analysis should have broad applicability to judging the suitability of proposed sites based on their landforms.

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POTENTIAL 2001 LANDING SITES IN MELAS CHASMA, MARS.

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Introduction: We have selected four areas in Valles Marineris as potential landing sites for the 2001 mission. After 20 years of analyses, the formation of the Valles Marineris system of troughs and its associated deposits still has not been sufficiently explained. They could have formed by collapse [1], as tectonic grabens [2], or in two stages involving ancestral collapse basins later cut by grabens [3,4]. Understanding all aspects of the Valles Marineris, in particular the interior layered deposits, would significantly contribute to deciphering the internal and external history of Mars. The deposits have been postulated to be remnants of wall rock [5], lacustrine deposits [6,7,8], mass wasting deposits [8,3], eolian deposits [9,7], carbonate deposits [10,11], or volcanic deposits [9, 12,13,14]. Because an understanding of the formation of Valles Marineris and its interior deposits is so important to deciphering the history of Mars, we have proposed landing sites for the 2001 mission on flat shelves of interior deposits in Melas Chasma (Figure 1).

Site Characteristics: The four sites we identified in Valles Marineris meet the current engineering criteria defined by the 2001 Project. All of these sites lie below 2.5 km in elevation and are at a pressure lower than 10.66 mbar. They are centered in southern Melas Chasma at approximately 11° S lat; the guided entry ellipse size is about 20 km in diameter at this latitude. An Earth-based delay-doppler-radar strip is located in Melas Chasma nearby. Surface slopes in each ellipse are less than 10°. There is less than 1% chance of landing on a rock greater than 31 cm high based upon the IRTM rock abundances, which show that all three sites are below 10% rock abundance. Viking images appear hazard free over the entire ellipse areas. In essence, the sites fit all of the engineering constraints and have the required 100 m/pixel or better resolution. However, the Viking images are poor in quality and therefore MOC coverage of the areas would be required to verify the sites are hazard-free.

Geology of the Sites: All four sites lie on a bench above the floor of Melas Chasma, which is a potential down-dropped fault block, surfaced with young (Amazonian) smooth floor deposits (likely eolian material) and rough landslide deposits [3,4,15]. The bench consists of eroded interior layered deposits (Late Hesperian to Early Amazonian in age) locally surfaced by a thin veneer of floor deposits (thin relative to that of the floor of Melas Chasma) [16]. Any encountered rocks would therefore likely be those of the interior layered deposits.

The interior deposits are the oldest unit of the Valles Marineris assemblage [15]. In Melas Chasma, they have a stratigraphic succession almost identical to that found in Candor and Ophir Chasma, which indicates that depositional processes forming individual interior units in the troughs were widespread and not local events [16]. Interior layered material is composed of layers of varying thickness and albedo. Where it is capped by resistant material it crops out as cliffs, but without this cap and within the ellipses the material weathers to smooth, flat lying surfaces. On the basis of horizontality, continuity, and layered aspect, the favored hypothesis has been that the deposits are of lacustrine origin [6,7,8,10,11], perhaps interbedded with air fall tuffs [12,15].

Ellipse A (Figure 1) is centered at lat 11.5° S, long 71.0°. The central part of the ellipse is mapped as smooth floor deposits on layered material, with remnant wall rock just to the northeast of the ellipse. Ellipse B is centered at lat 11.5° S, long 71.4° and has a similar geologic setting as ellipse A. An outcrop of wallrock material is located to the northwest, just outside of the ellipse. Ellipse C is centered at lat 11.6° S, long 72.1°. The central part of the ellipse is on smooth floor material with outcrops of light colored layers in scarps to the southwest and an exposure of remnant wallrock to the east. Finally, ellipse D is centered at 10.4°S, long 73.2° on smooth floor deposits. Outcrops of dark and light layers occur in scarps to the southwest.

Expected Results: The four sites we have selected in Melas Chasma would provide much needed insight into the interior layered deposits. Because of the likely possibility that water once existed in Valles Marineris and because the interior deposits may be of lacustrine or carbonate origin [6,7,8,10,11], analyses at one of the landing sites would have profound implications toward the climatic evolution of Mars. Exploration of Valles Marineris to search for fossil life forms would also be feasible given the likelihood for water and heat sources in the canyons [1,9,17]. If the deposits are determined to have a volcanic, perhaps silicic, origin, then analyses of the compositions would shed light on the volcanic history of Mars and have implications toward its tectonic and outgassing history.

The four sites will permit both the lander and rover to study rocks in-situ or derived from nearby scarps to determine the composition and origin of the interior layered deposits. One problem with the Pathfinder and Viking analyses of rock compositions was that the rocks' provenance was unknown. Hence, they could have been volcanic, impact, or sedimentary rocks from any number of sources. In contrast, at the four proposed sites rocks may be identified in outcrops. The rover may be able to use the APXS to analyze rocks from different layers in exposures, thereby determining the causes of light and dark banding in many of the interior deposits. From this information, it should also be possible to determine the origin of the deposits and obtain important insights into the history of the Valles Marineris system. Color and spectral data from the lander PanCam and Mini-TES can also be used to analyze individual layers in exposures and rocks from nearby scarps. Atmospheric exploration could focus on hazes and clouds, which are occasionally observed in the troughs. In addition, landing in the Valles Marineris would not only yield valuable scientific returns, but would also provide spectacular scenery for the Earth-bound observer.

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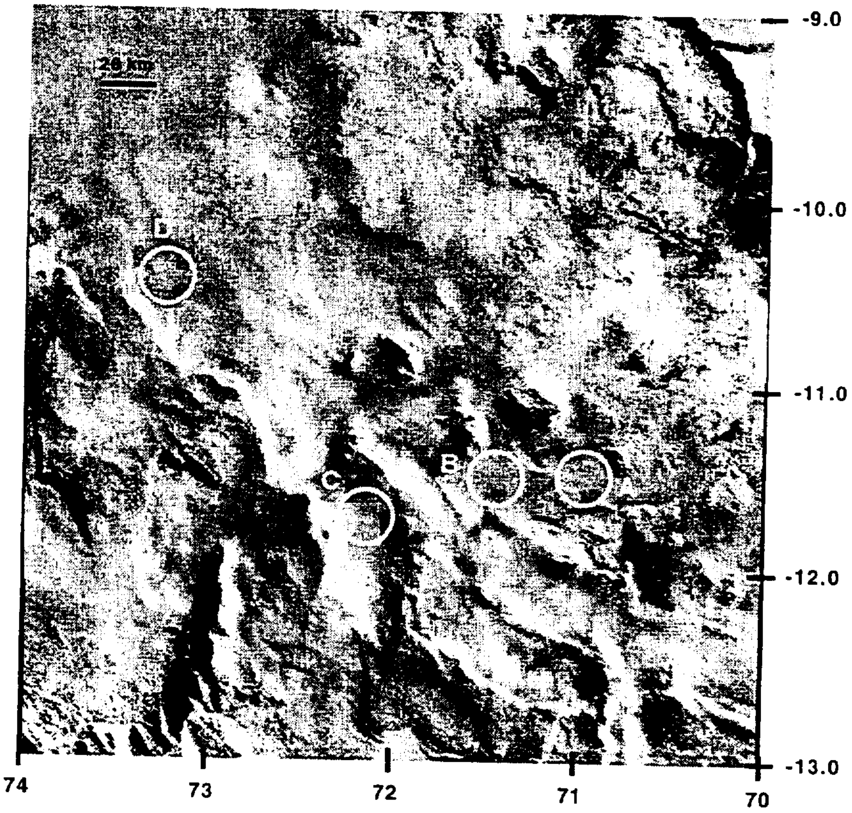

PROPOSED 2001 MARS LANDING SITE IN CENTRAL CANDOR CHASMA.

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Summary

A potential landing site for the Mars 2001 mission is proposed in central Candor Chasma, in Valles Marineris. This site will be able to address key questions regarding the formation of the Valles Marineris system, composition of the interior materials, local wall rock structure, and implications for the fluvial and climatic history of Mars.

Geologic Context

The proposed site is located in Valles Marineris, within the central part of Candor Chasma, centered at 7.7° S latitude, 72.5° W longitude (Figures 1 & 2). Valles Marineris is a region of massive extension and erosion which created a large (4000 km) equatorial canyon system. Numerous individual troughs run parallel to each other and join together near the center forming a depression as wide as 600 km and as deep as 8 km below the regional topography [1]. The proposed site is in this widest, central section of Valles Marineris (Figures 1 & 2).

Figure 1. From top to bottom, Ophir Chasma, central Candor Chasma and the northern portion of Melas Chasma. ~230 meter/pixel resolution. North is to top of image.

Valles Marineris is thought to have formed mostly through tectonics which occurred as a result or in tandem with the formation of the Tharsis rise [2]. Fluvial process have most likely further eroded the region, either by direct fluvial erosion, large standing bodies of water or aiding in the mass-wasting of the trough walls [1,3]. The proposed landing site has been mapped by Tanaka & Scott [4] as Valles Marineris floor material of Amazonian age (Avf). Avf is described as a mixture of landslide and debris flow deposits, originating from the trough walls. Since the exact composition of the trough walls is uncertain, these floor deposits may include eolian material, volcanic deposits, channel deposits and possibly lacustrine deposits [4].

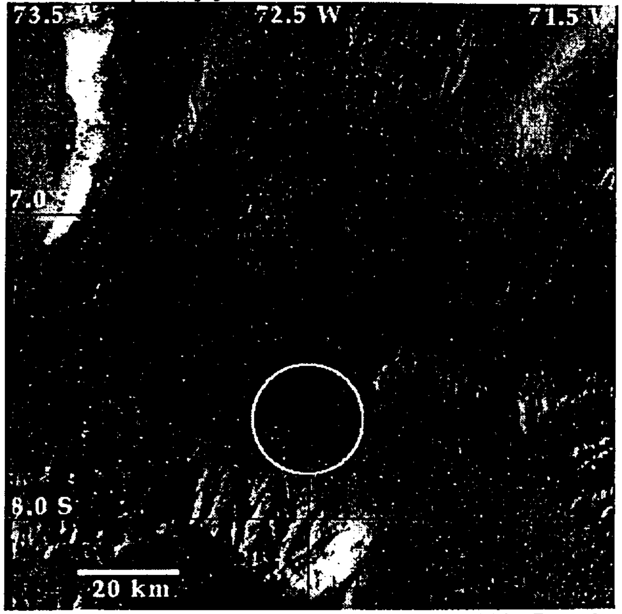

Figure 2. Proposed site location (white circle) within Central Candor Chasma. ~230 meter/pixel resolution. North is to top.

Site Location and Description

This site meets all the engineering constraints for safety and optimum science return of the mission as outlined in [5,6]. Both the fine thermal inertia and the bulk thermal inertia are above 4×10^{-3} cal/cm^{2}s$^{1/2}$K at 8×10^{-3} cal/cm^{2}s$^{1/2}$K and 10×10^{-3} cal/cm^{2}s$^{1/2}$K respectively [5]. The rock abundance is estimated to be ~9% [5]. The elevation is below that needed to deploy the parachutes and land safely, at about 0 km elevation. At a latitude of 7.7° south, the 99% confidence landing ellipse required is ~22 km in diameter, fitting nicely between two wall rock outcrops in the region. The average slope in the region is less than 10°. The proposed site is smooth at 61 meter/pixel Viking resolution (Figure 3).

Although 61 meter/pixel resolution Viking imaging is available, the specific engineering constraint requires at least 50 meter/pixel resolution images. Therefore, it will be necessary to image this proposed site using MOC before this particular engineering constraint can be met completely.

Scientific Framework

A recent review [7] of the present state of understanding of the Valles Marineris system indicated many open questions, including: composition of the interior deposits, method of formation of Valles Marineris, wall rock structure, morphology and composition, implications for the climate history of Mars and evidence for water within Valles Marineris. This proposed site addresses many of these subjects using the instruments available on the lander and rover [8].

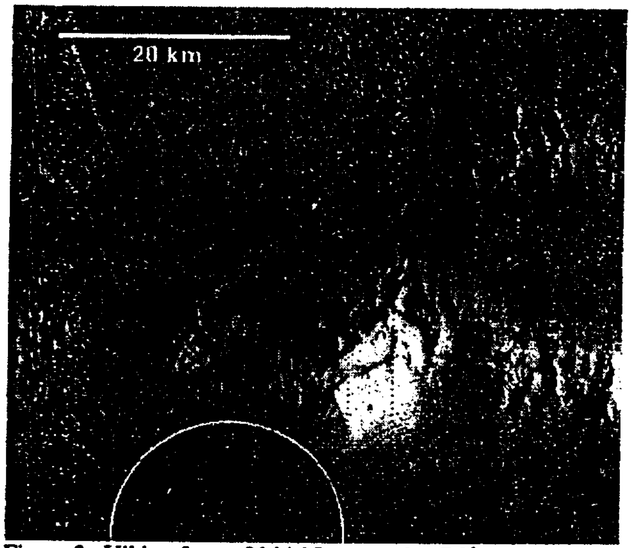

Figure 3. Viking frame 914A15 centered at 7.7° south latitude, 72.$^{5\circ}$ west longitude, 61 meter/pixel resolution image of the northern half of the proposed landing site. North is to top.

The composition of the ***interior deposits*** remain the most enigmatic problem regarding Valles Marineris. The method of formation would directly influence the type of rock found in the interior deposits (i.e. volcanics, eolian, carbonates, mass-wasting of wall rock and/or lacustrine deposits) [7]. Pancam, Mini-TES and the Mossbauer spectrometer would be well suited to address this issue and determine the composition of the interior deposits which comprise the landing site and other rover-accessible areas.

The proposed site is within 15 km of two outcrops of ***wall rock*** and could image these outcrops using Pancam to give further information about their interior structure and morphology. It may be possible to see layers in these outcrops which have previously been below our resolution. Also, this cross-sectional view would yield information about regolith development on Mars. Stereo images of the wall rock taken with Pancam may show evidence for local faulting or other indications of tectonics processes.

By imaging local ***landslide deposits*** using Pancam and Mini-TES, it may be possible to determine whether or not these landslides occurred in the presence of water or ice. This would generate evidence for a ground ice layer present within a few 100s of meters depth of the Martian equatorial surface and could be used to further models for the present and past climatic evolution of the Martian hydrosphere [9,10]. If Mini-TES or the Mossbauer spectrometer found the interior deposits to be lacustrine or contain carbonates, this would imply that a standing body of water existed within Valles Marineris for a period in Mars's past, also having implications for the past water cycle and possible large standing bodies of water on Mars [10,11,12].

Atmospheric studies of the ***Martian atmosphere*** at higher pressures and at lower elevations will have implications for the history of the atmosphere as well as the past Martian climate. Wind patterns within Valles Marineris could be substantially different, in both direction and magnitude than at the regional elevation. It will be possible to study the clouds which form within Valles Marineris as well as other atmospheric disturbances such as possible dust devils and dust storms using Pancam to image the local Martian sky.

The Mars Descent Imager will be able to image many of the ***surrounding rock units*** in the proposed site, including (1) outcrops of Valles Marineris wall rock (HNu of [4]) to the south and north-east, (2) Hesperian age layered material and channel deposits (Hvl and Hch, respectively, of [4]) to the north-west and west and (3) Amazonian age slide material (As of [4]) to the south-east. The descent imager will also provide needed geologic context for the samples and immediate landing site.

As other proposals for lander sites within Valles Marineris have mentioned [13,14], an extremely important reason to land in Valles Marineris concerns the ***provenance*** of the observed rocks at the landing sites. Viking 1 and 2 as well as the Pathfinder lander all landed within or nearby outflow channel deposits, where rocks from many different regions of Mars are concentrated, allowing for the most information of varying rock types in the smallest region. However, the compositions of these rocks cannot easily be tied to their place of origin, since it could be anywhere upstream of the landing site. Thus, while the composition of general rock types on Mars is known, their exact provenance is not. Landing in Valles Marineris among wall rock outcrops would offer information regarding the provenance of examined rocks. This site benefits in two ways: (1) rocks are deposited here from mass-wasting of nearby outcrops and thus the lander and rover do not have to enter hazardous territory in order to retrieve a variety of samples, yet (2) the provenance of these samples is well constrained by investigating the landslide deposits and determining from which topographic high they originated. Landing in Valles Marineris will allow determination of sample provenance, which can then be extended throughout the Valles Marineris system.

Finally, perhaps the best return of this proposed mission would be ***fantastic panoramic images*** and spectacular views from a region of Mars that easily captures the public's interest and enthusiasm -- the largest "Grand Canyon" in the solar system. Instead of landing within a smooth ancient river plain, the lander will touch down in a setting that will be easily interpreted by the general public; a setting which will feel familiar to the people of earth and make Mars a closer planet than ever before.

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SINUS MERIDIANI HEMATITE DEPOSITS: PROPOSED MARS 2001 LANDING SITES.

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Overview: A strong spectral signature of coarse-grained hematite detected by the Thermal Emission Spectrometer (TES) in Sinus Meridiani led Christensen and the TES team [1,2] to propose that this region may be a large hydrothermal deposit from a past era of Mars' history. Coarse-grained hematite typically forms by alteration due to hot fluids or precipitation from large volumes of water, as opposed to fine-grained hematite, which is usually a low-temperature alteration product [1]. While most of the bright dust on Mars contains fine-grained or nanophase hematite, the localized coarse-grained deposit in this region is unique.

With the TES discovery, this portion of Sinus Meridiani represents the most likely location for deposits from past hydrothermal activity on Mars and should therefore be targeted by the Mars Surveyor 2001 lander. The focus of the mission would be on finding and analyzing rocks containing coarse-grained hematite to determine the origin of this deposit. As a potential hot-spring deposit, this is a good site to investigate for exobiology. The complement of instruments on the lander and rover are especially well-suited to studying the mineralogy of the types of minerals expected for a hydrothermal deposit.

A variety of other sites in Sinus Meridiani have been proposed previously for this and earlier missions [3,4,5,6,7]. These sites focussed on investigating the compositions of major albedo units [3,4], gathering Noachian materials [4,6,7], and investigating potential lacustrine and exobiology sites [3,4,5,6]. However, these proposals were not designed with the current engineering constraints, and some required Athena traverses to accomplish their goals.

Site Location and Description: Two sites in the hematite area are proposed as candidate landing sites (Fig. 1). Both lie in unit Npl$_2$, cratered Noachian plains and are at -1.5 km elevation. The first (5.5°W, 1.2°S) is located in images 746A02 and 746A04 (20 m/pixel) of the Viking mission. This is near the edge of one of the regions of hematite. Sufficient overlap exists between this pair of images to provide stereo coverage over approximately one-half of the target ellipse (26 km diameter). The surface is smooth and gently rolling with a few knobs. Rock abundances are ~5-7%, with both bulk and fine component thermal inertias ~7-9 cgs units.

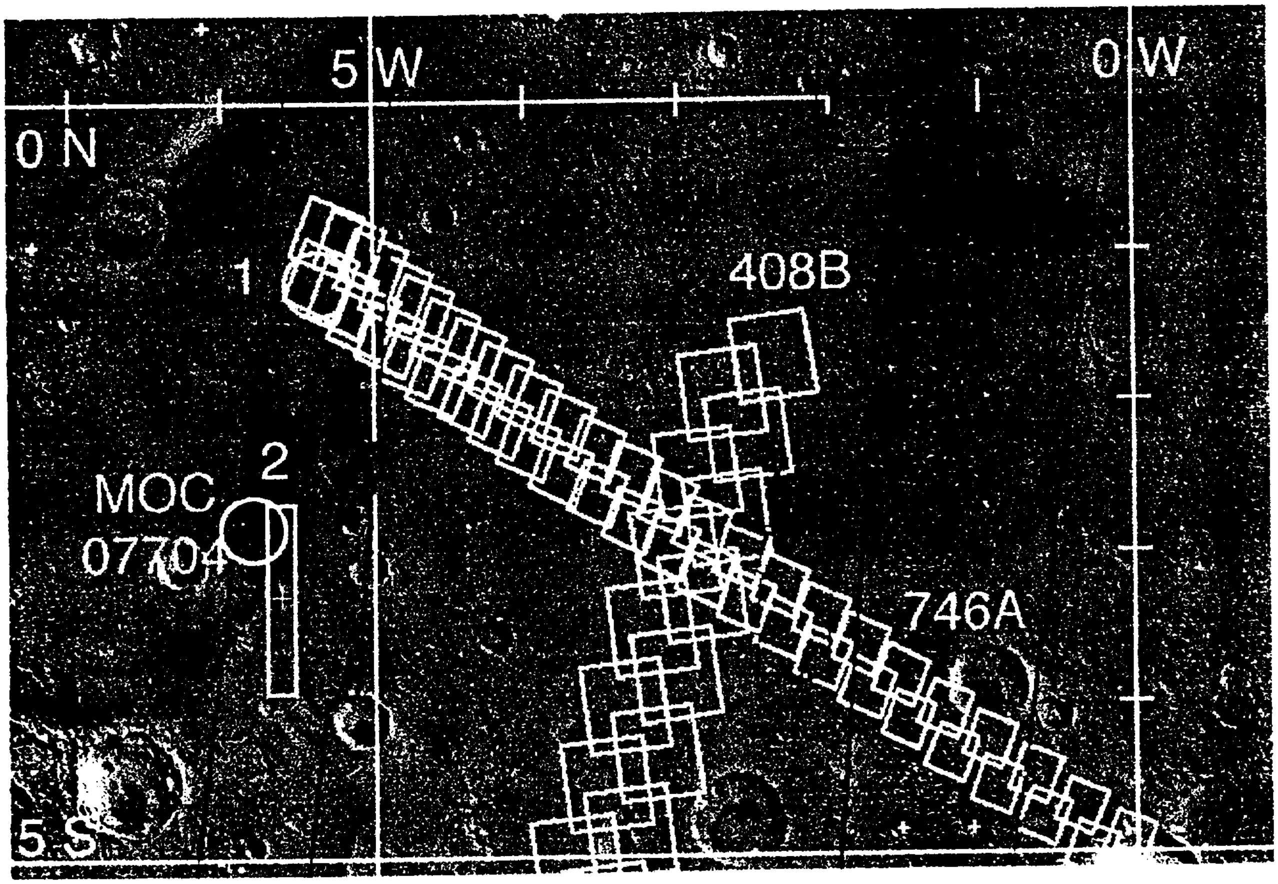

Figure 1. Detailed image showing location of TES observation boundaries (green), TES hematite abundances (red), Viking and MOC image locations (yellow), and proposed landing sites (white).

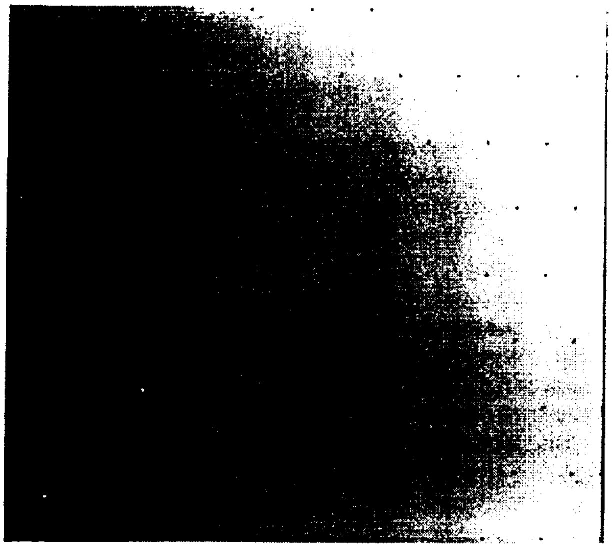

Figure 2. Viking Orbiter image 746A02 showing the location of the first proposed landing site. The image is 24 km wide (20 m/pixel resolution).

The second site (5.8°W, 2.8°S) does not have <50 m/pixel Viking imagery but is partially covered by a 14 m/pixel MOC image (07704). Rock abundances are modeled to be somewhat less (~4-6%), with both fine component and bulk thermal inertias of ~7-9 cgs units. However, inspection of the MOC image shows a less mantled appearance than the Viking images of the first proposed site. Hematite abundance is spectrally greater at this second site, which would make for better geological studies.

Scientific Objectives: The scientific goals for a mission to these landing sites include characterization of the hematite deposits detected by TES, analysis of Noachian aged materials, investigation of a potential hot spring site, and characterization of low albedo materials. Characterization includes determining chemistry, mineralogy, and oxidation state of rocks in the area and geomorphology of the landing site.

Mini-TES and the Mössbauer spectrometer on the lander will be utilized to determine silicate and iron oxide mineralogies. The Mössbauer will be particularly useful in analyzing potential hematite deposits to determine exact mineralogy hence oxidation state. The calibrated APXS on the rover will give chemical compositions of rocks. This will be the first synchronous measurements of chemistry and mineralogy (through spectroscopy) *in situ* on Mars. These measurements will provide information on composition and will help elucidate the mode of formation of these deposits.

Characterization of the dark gray albedo unit [8] from the ground will also be important in trying to understand global differences. These materials are probably more mafic and different in nature than those found at the Viking Lander or Pathfinder sites. Finally, this would be the first landing site on a Noachian aged surface.

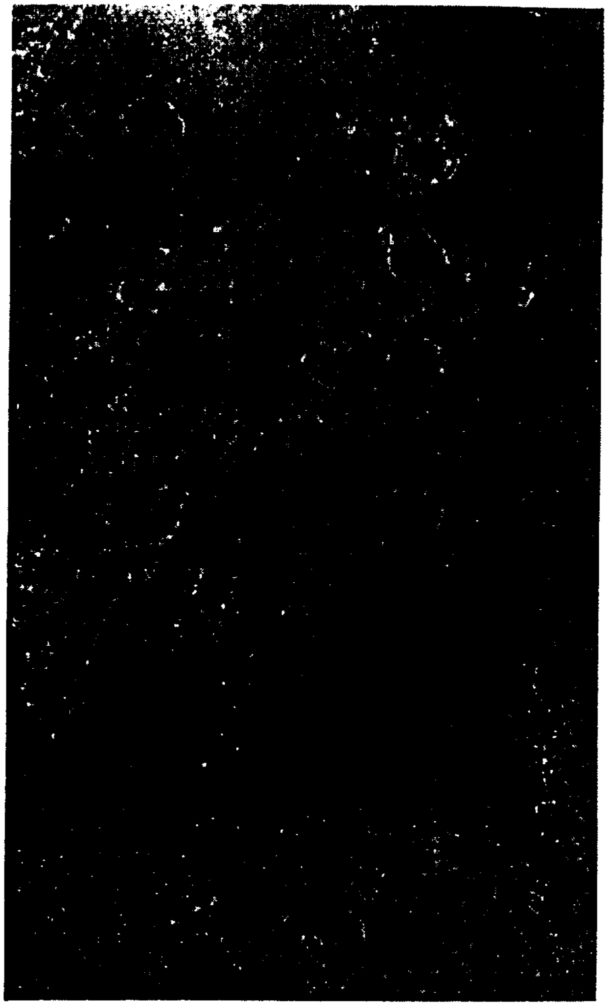

Figure 3. Northern quarter of MOC frame 07704 showing general region of second proposed landing site. Image is 10.8 km wide (14 m/pixel). Note the existence of layered materials and the dust-free general appearance of the scene.

Conclusions: A landing site in Sinus Meridiani will provide important ground truth for the recent TES observations of coarse-grained hematite. These deposits, which are not observed on a widespread basis, may represent Noachian hot springs and thus may harbor potential clues to the past climate, water budget, and potential for life on Mars.

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A SUITE OF PROPOSED LANDING SITES FOR THE MARS SURVEYOR '01 MISSION: NORTHERN TERRA TYRRHENA.

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Introduction: With the Mars Surveyor Program 2001 mission, the global characterization phase of Mars exploration nears completion and the combined exploration of Mars by the NASA's Human Exploration and Development of Space (HEDS) and Space Science Enterprises begins [1]. The Mars '01 Orbiter carries instruments that will perform global mapping of elemental abundance (Gamma Ray Spectrometer), hydrogen abundance, and CO^2 abundance (Neutron Spectrometer and High Energy Neutron Detector) for the purpose of defining surface compositions and locating *in situ* propellant resources at about 300 km spatial resolution. Also on the orbiter are instruments specifically designed to determine surface mineralogy and morphology (Thermal Emission Imaging System), as well as characterize the near-space radiation environment in order to assess radiation hazards for future human exploration (Mars Radiation Environment Experiment).

In addition to the Orbiter, a Lander and Rover will be deployed to a site on the Martian surface. These modules will be used to obtain high resolution images of surface features in the vicinity of the landing site (Mars Descent Imager and Robotic Arm Camera), determine the nature of local surface geologic processes and materials (Athena Precursor Experiment, including Pancam/Mini-TES, the Mossbauer Spectrometer, and the Alpha/Proton/X-ray Spectrometer), characterize the surface environment (Mars Radiation Environment Experiment and Mars Environmental Compatibility Assessment), and demonstrate *in situ* propellant production for future missions (Mars In-situ Propellant Production Precursor).

The Lander and Rover are critical to overall mission success. They will perform detailed analyses on surface materials and provide detailed views of surface morphology. Lander and Rover instruments will thus provide ground truth, not only for Mars '01 orbiter instruments, but for previous remote sensing, as well. Furthermore, a careful choice of landing sites can provide valuable information about Martian interior characteristics and processes that occurred early in Martian history.

Site Selection Rationale: To date, three landers have been sent to the surface of Mars: Viking 1 (22.48° N, 49.97° W), Viking 2 (47.97° N, 225.74° W), and Mars Pathfinder (19.33° N, 3.55° W) [2,3]. All three are located at sites within the Martian northern lowlands. Viking 1 landed on the knobby member of the Hesperian-aged Vastitas Borealis formation [4], on or near the northeastern rim of the Utopia impact basin [5]. Viking 2 landed in Hesperian-aged terrain, near the boundary between ridged plains material and floodplain material at the mouth of Maja Vallis in the Chryse Planitia region. Mars Pathfinder also landed near Chryse Planitia, on Hesperian-aged floodplain materials at the mouth of Ares Vallis [6]. All are located on materials transported over possibly long distances by fluvial processes and possibly deposited into large bodies of standing water [7,8,9,10]. While fascinating, these landing sites represent a somewhat restricted set of geologic settings, both temporally and depositionally. If indeed this mission is intended to bring the global characterization phase of Mars characterization near to completion, it will be important to choose a landing site that samples highland material rather than lowland sediment, while addressing some of the fundamental questions about the planet's interior composition, surface evolution, and hydrogeological history.

Landing Site Characteristics: In order to meet the aforementioned criteria, I propose a suite of possible Mars '01 landing sites in the northern Terra Tyrrhena region (Figure 1). The sites lie in a region of cratered uplands between 2° and 3° N latitude and between 267° and 269° W longitude. These sites match all mission landing site criteria, including targeting within a 20-km diameter circle (aeromanuevering option) and adherence to current latitude restrictions. Topography, rock abundance, thermal inertia, and hi-res Viking image coverage requirements are satisfied

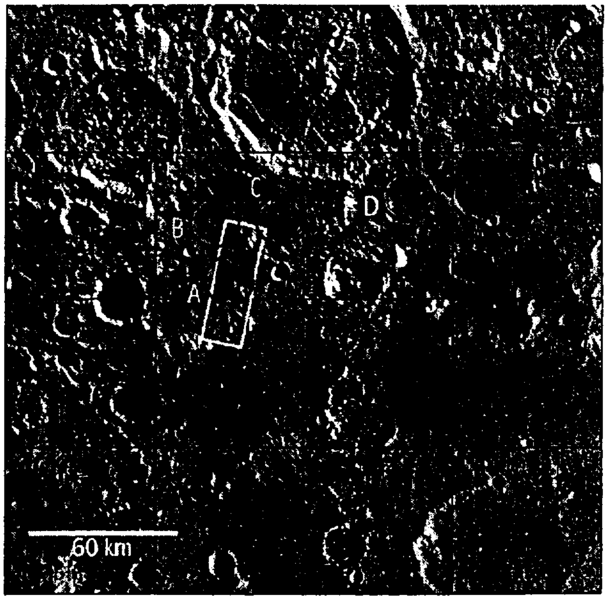

Figure 1: Proposed landing sites. Suite of proposed Mars '01 landing sites in northern Terra Tyrrhena. Image center located at 2.0° N, 268.0° W. Grid lines are 1° apart. Black circles delimit landing sites A through D. Mars Orbiter Camera coverage is outlined in white.

as well [11,12]. Additionally, a Doppler-delay radar strip crosses approximately 2° north of the site.

This suite of landing sites lies in an area of Noachian hilly plains interpreted as ancient highland rocks and impact breccia generated during the period of heavy bombardment [4]. The geologic unit exposed at the site occupies the bottom of the global stratigraphic column and may represent some of the oldest exposed rock on the planet. Along with its age, its position adjacent to the Isidis basin indicates that the unit in this area may contain a large component of ejecta excavated from Isidis during its formation. Hence, detailed spectrometry using mini-TES, the Mossbauer spectrometer, and APXS could yield important insight regarding the composition of the Martian lower crust and upper mantle.

In addition to compositional studies, the region may reveal new information on the early hydrologic history of Mars and changes in Martian global climate. At Viking Orbiter image resolutions, the area shows evidence for fluvial erosion and/or groundwater sapping and collapse. A Mars Orbiter Camera image of Landing Site A (Figure 2) shows small incised channels just south of the landing area, as well as a basin-like confluence of channels that may have drained to the northeast. Determining the age of these channels may be crucial, as they may provide evidence for Noachian fluvial activity which significantly predates the Hesperian outflow channels which empty into the northern lowlands [13].

Several craters in the region show subdued topography and partial burial, and two large craters just north of the landing sites have chaotic and highly dissected floors. These disturbances may be linked to a crater obliteration event in the region caused by melting or deformation of ice or permafrost in the subsurface [14].

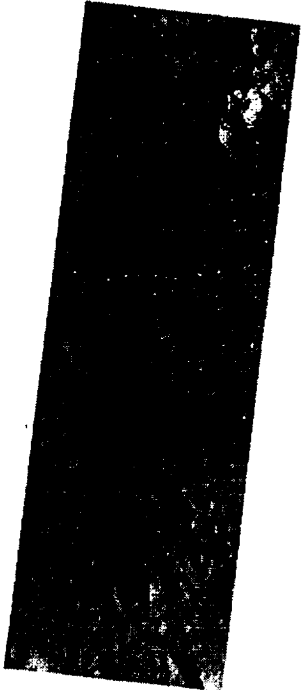

Figure 2: MOC Coverage. Mars Orbiter Camera image of proposed landing site A. Image location is 2.08° N, 268.74° W. Note small incised channels near the south of the image and basin-like feature just north of center.

Finally, as previously stated, the lander and rover will provide ground truth for remote sensing for both this mission and previous missions. For example, the Imaging Spectrometer for Mars (ISM) on the Russian Phobos 2 mission made spectroscopic observations of the area (Figure 3). Detailed surface spectrometry in this region can provide calibration for spectrometry of highland units globally.

Figure 3: ISM Coverage. Overlapping white boxes indicate locations of individual ISM pixels.

Acknowledgements: I wish to thank Chris Cooper for providing ISM coverage data, Kate Fishbaugh for advice on image processing, and Brad Thomson for editorial comments. This material is based on work partially supported by a National Science Foundation Graduate Fellowship

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A PROPOSED MARS 2001 LANDING SITE IN THE SOUTHERN TERRA MERIDIANI REGION

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Summary

This proposed landing site for the Mars 2001 lander is in southern Terra Meridiani. This site lies in the Noachian highlands near the contact of the dissected unit (Npld) and the cratered unit (Npl$_1$) [1] and near the convergence of three small, narrow, sinuous channels [1]. This site can be classified as a grab bag site in that it will provide an opportunity for the study of diverse rock types, including: ancient highland rocks, impact breccias, and fluvially modified rocks.

Geologic Context

The Terra Meridiani region, previously described by Edgett and Parker [2], has a low albedo. Thermal inertia measurements lead to the interpretation that Meridiani has a variable spatial distribution of sand and rocks with few dunes. Ancient cratered terrain underlies the southern half of Meridiani in which there are many valley networks which appear to drain towards the smoother northern half of the region. Many crater rims near the border of the smooth and cratered units have been highly eroded (see Fig. 2).

The cratered unit (Npl$_1$) in the Noachian highlands [1] is the most areally extensive unit in the southern highlands, is highly cratered and has numerous faults, fractures, valley networks and small channels. This unit has been interpreted [1] to have been formed during the period of heavy bombardment and consists of impact breccias, lava flows, and pyroclastics. The dissected unit (Npld) has more valley networks and troughs than the cratered unit and has thus been modified by fluvial processes [1].

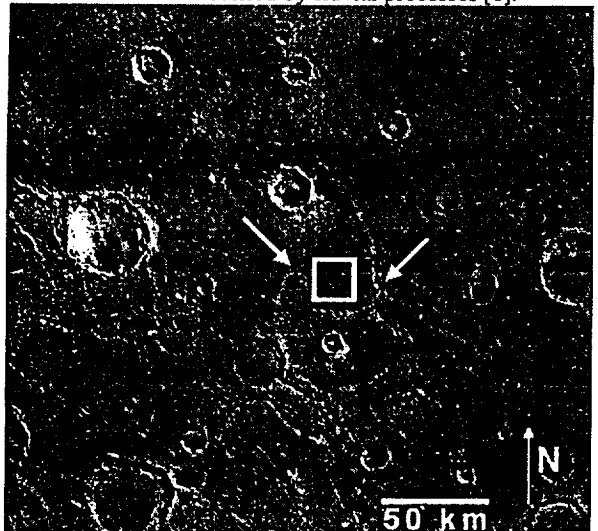

Figure 1: Context of the landing site: Viking image mosaic at ~230 m resolution of the region between 2.5°S-7.5°S and 2.5°W-7.5°W. The landing site lies within the white square which is ~24 km per side and centered at 4.75°S, 4.75°W. The arrows point to the degraded crater rim and the convergent valley networks.

Site Description

The proposed site (Figs. 1, 2) lies within Southern Terra Meridiani near the contact of the cratered unit (Npl$_1$) and the dissected unit (Npld) and is centered at 4.75°W, 4.75°S. Three small valley network channels converge near this site [1]. The site also lies within a degraded crater, evidenced by a highly eroded rim remnant, into which at least one of the small channels may have emptied.

This site meets engineering constraints for safety except for the availability of <50 m resolution Viking images. However, ~230 m resolution images show a smooth surface. A nearby Mars Orbiter Camera (MOC) image with a resolution of 14.05 m, centered at 3.26°S, 5.26°W, also reveals a smooth surface (Fig. 3). A high resolution MOC image centered on the site would be beneficial for further safety analysis. The fine component thermal inertia of the site is $\sim 7\times10^{-3}$ cal cm^{-2} s$^{-0.5}$ K^{-1}, and the bulk thermal inertia is $\sim 8.5\times10^{-3}$ cal cm^{-2} s$^{-0.5}$ K^{-1} [3]. The elevation is below the critical 2.5 km contour, and the rock abundance is ~9% [3]. The rms slope is ~2.25°, and the radar reflectivity is between ~0.04-0.08 [4].

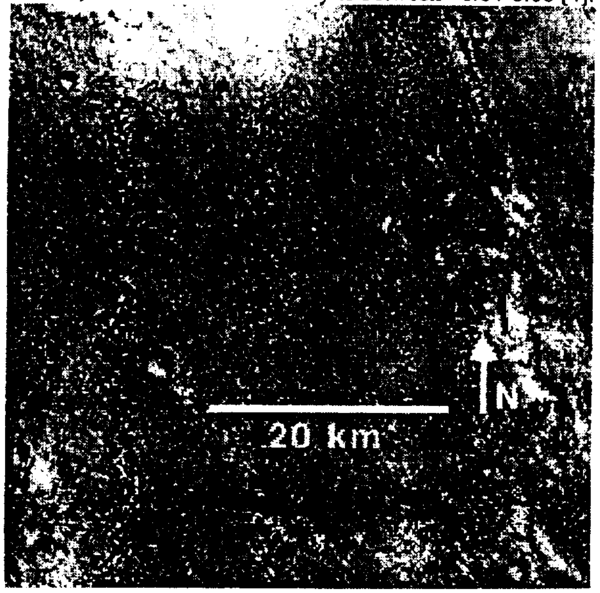

Figure 2: Viking image mosaic of the landing site at ~230 m resolution, centered within the square in Fig. 1. The region appears generally smooth at this resolution. Note the degraded crater rim and convergent valley networks.

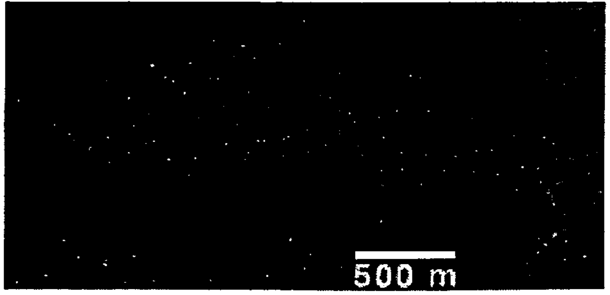

Figure 3: Nearby MOC image at 14.05 m resolution, centered at (3.26°S, 5.26°W), reveals a generally smooth surface.

Scientific Framework

This location of this site provides the opportunity to address several geological points of study, including: evidence of polar wander, characteristics of ancient highland terrain, possible layering in the degraded crater rim walls and in channel walls, the origin of valley networks, possible lacustrine sediments, an environment possibly conducive to the existence of Martian life, and possible shoreline sediments of a Noachian ocean.

The proposed site lies within the path of polar wander hypothesized by Schultz and Lutz [5] and near what the authors mapped as stripped terrain. The stripped terrain is part of the equatorial layered deposits and consists of layers which have undergone differential erosion, with the cratered plains exhibiting the least erosion. The authors compare these layers to those of the polar layered deposits. Evidence of layering has also been found in MOC images throughout the cratered highlands and on crater floors [6]. One possible place to search for evidence of these layers (on a scale of 100s of meters) at this site would be within the degraded crater rim (if the lander is sufficiently close to it) and the crater floor and, if observational constraints permit, within the walls of the nearby valley networks, using the APEX Pancam.

Because the proposed site lies within Noachian-aged cratered terrain, rocks formed early in Mars' history can be analyzed. These will include ancient highland rocks, impact breccias from the period of heavy bombardment, and ancient lava flow and pyroclastic deposits. Analyses of these rocks will complement analyses of Amazonian and Hesperian aged rocks analyzed by previous landers and will provide valuable insight into the geologic and climatic evolution of Mars. No other lander thus far has imaged highland rocks within the ancient highlands. For example, chemical analyses of ancient rocks using mini-TES and the Mossbauer spectrometer could provide clues to a changing atmospheric content and weathering processes, the opportunity for comparison with the composition of SNC meteorites, investigation into the inferred felsic components of highland rocks as seen in Pathfinder results [7], and a further understanding of the differentiation of the early Martian crust. Analyses of ancient volcanic deposits could also provide insight into differentiation and changing mantle composition.

The origin of the valley networks remains an intense subject of study, particularly in its relation to climatic evolution. Hypotheses of origin have included surface runoff [8], which would imply an early warmer, wetter climate, with possible greenhouse periods resulting from injections of CO_2 due to an ancient ocean [9]. Sapping by groundwater flow [10] has also been proposed, which would not require and early, warmer climate, especially if the model of [11] is correct, and the valleys could be carved under present day atmospheric conditions. This site lies at the convergence of three valley networks which makes this location ideal for investigation into the origin of these valley using in situ imaging by the APEX Pancam, thus providing insight into "warmer, wetter" hypotheses.

The nearby valley networks also present the opportunity of studying a possible lacustrine environment formed within the degraded crater by the emptying valley (Fig. 2). Layers due to lake sedimentation could possibly be observed in the crater rim by the Pancam. Rock and soil analyses could provide insight into the composition of Martian flood and lake water and the character of aqueous alteration products. Evidence of a former lake within this crater would imply that at some time in the past, a climate existed which was conducive to the stability of liquid water on the surface. Dating these rocks would provide valuable insight into Martian climatic evolution. This crater could have served as a playa lake which would provide an environment for the production of carbonates which are now buried and are observed in meteorites, such as ALH84001, but have not been identified by remote sensing or by previous landers [11, 12]. These carbonates could possibly be observed in crater floor layers or in lake sediments in the crater by mini-TES. The former existence of a playa would also be evidenced by evaporites at the site by mini-TES. Flood highstands in the form of terraces could also be searched for on the crater rim. A relatively stable lake environment could provide an ideal location for the development of life which could then be fossilized within the lake sediments. Evidence of organic material within the crater and in layers could also be investigated.

Edgett and Parker [2] have postulated the existence of a former ocean in the Arabia and Sinus Meridiani regions between 10°S-30°N and 40°W-40°E. This landing site lies within about 60 km of the shoreline of the proposed ocean. Thus, landing in this location provides the opportunity to investigate evidence of possible shoreline features able to be examined by a lander using the entire suite of instruments (e.g. the presence of sand, evaporites, carbonates, sedimentary layers, and aqueously altered rocks). The authors postulated that this ocean existed sometime early in Mars' history. It is possible that this ocean may correspond to the Noachian ocean proposed by Clifford [13] to have existed as a result of the hydraulic and thermal conditions present during that time.

Conclusions

Landing in this location provides the opportunity to investigate one or more of several long - standing issues concerning the geologic evolution of Mars by providing ground truth for remote sensing observations and by testing the consistency of observations made at the site with any of these hypotheses. This location also affords the opportunity of possibly observing lacustrine or even oceanic sediments. These sediments in the ancient highlands could have provided an ideal location for the development of Martian life, the type that may exist as nanofossils in the ALH84001 Martian meteorite that has so captured the public imagination. It is this possibility that makes this site ideal for fostering public interest in this Mars mission and those of the future.

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POTENTIAL 2001 LANDING SITE IN VALLES MARINERIS.

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Summary: I propose a landing site for the 2001 Mars mission in Valles Marineris, near Melas Chasma, centered at 73°W and -10°S. This landing site would provide information pertaining to Mars' volcanic and climatic history. It could potentially help solve some of the mysteries of how Valles Marineris was formed and the origin of its interior deposits.

Introduction: Despite being one of the most obvious and easily recognizable landmarks on Mars, Valles Marineris still has uncertain origins. The three leading hypotheses are formation through tectonism, erosion, or collapse (or a combination of these); however, none of these methods of formation sufficiently explains all of the observations [1]. Understanding how Valles Marineris came to be is important to learning about the history of Mars.

The floor deposits on which the lander would land are also of an unknown origin. They are interpreted to be mixtures of landslides and debris flows from canyon walls, eolian material, volcanic deposits, and channel and possibly lacustrine deposits [2]. Some of these explanations, especially the lacustrine deposits, cause important implications for the history of Mars.

Candidate Site: The primary concern in the selection of the site is that the spacecraft will land safely, since scientific data can only be collected after a safe landing. The site which I have proposed meets all of the engineering constraints for the lander [3]. It is located within the latitude range of 3°N to 12°S. The elevation is below the required 2.5 km (to allow the parachute sufficient time to slow down the spacecraft) and above –3 km (to ensure the proper opening of the solar panels). The thermal inertia for the proposed site is 7-8 x 10^{-3}cal $cm^{-2}s^{-0.5}K^{-1}$. The rock abundance is between 7 and 8% which means that there is <1% chance of landing on a rock greater than 31 cm high; yet there is not too much dust as to cause problems for the instruments. Unfortunately, there are no <50 m/pixel Viking images of the area, although there are some <100 m/pixel images. MOC images will be required to examine the area with a higher resolution.

The landing site that I have chosen is shown in a general sense in Figure 1, but more specifically in Figure 2. The cross represents the 21 km uncertainty landing ellipse. The lander could actually land in most of the central smooth area shown in Figure 2 as it is mapped as one unit; I therefore recommend using MOC images to better locate the exact landing site ellipse.

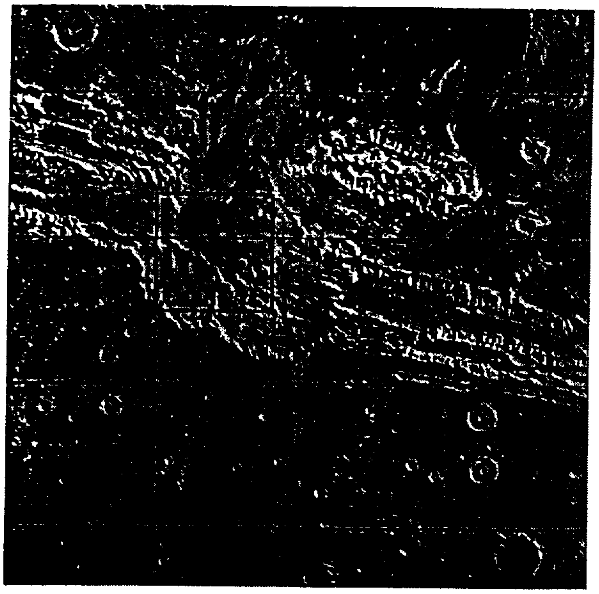

Figure 1. A Viking image with latitude 0 to 22°S and longitude 80 to 60°W. The box is the area shown in Figure 2.

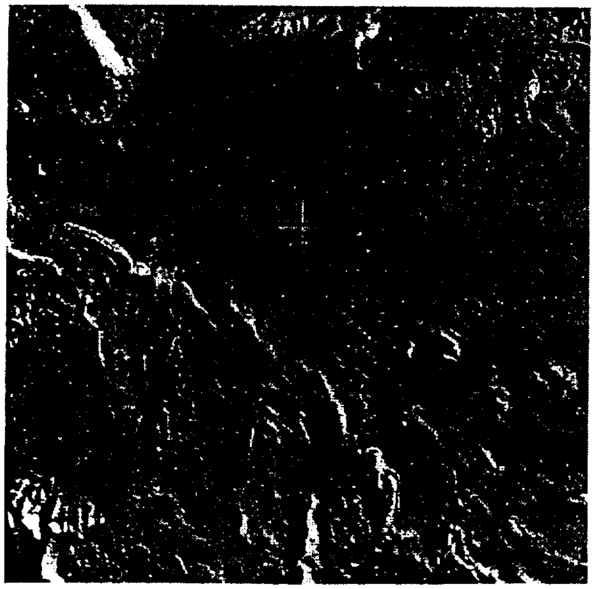

Figure 2. The location of the candidate landing site. The cross is 21 km on a side (the diameter of the landing ellipse) and is centered at (10°S, 73°W).

This landing site is located on Amazonian floor deposits near Melas Chasma within Valles Marineris. Landing on the deposits has several advantages. These deposits, as I have mentioned before, have an unknown origin. It should be possible to identify the origin of the rocks using all the instruments aboard the lander and rover. The mineralogy and physical characteristics of the area, as determined by the Pancam/Mini-TES, Alpha-Proton-X-Ray Spectrometer (APXS), Mössbauer Spectrometer, and Magnet Array, should provide enough information to determine this [4].

If these deposits are formed by mass wasting from the walls of the canyon, then we will be able to examine in close detail the materials of which the walls are composed. As opposed to examining rocks in outflow channels, we will know fairly precisely where these rock came from. The wall rocks are thought to be basaltic flows [5]. These rocks will be from as many as 3 or 4 km beneath the surface of Mars, and the debris will probably represent the range of ages of the vertical column of wall rocks of Valles Marineris [6]. Also, by examining the nature of the mass wasting, it may be possible to determine whether the deposits and their matrix were wet debris flows or dry rock avalanches. Either of these methods of formation have implications for the theories of the presence of water on Mars.

If the deposits are lacustrine deposits, then this obviously also has very important inferences for the presence, duration, amount, and geologic timing of surface water on Mars. Water on Mars also leads to questions of the possible presence of Martian life or fossilized lifeforms. Lacustrine deposits would be a key area to examine for the pursuit of this issue.

If the deposits on which the spacecraft lands are volcanic, we can determine if they're lava flows or pyroclastic flows. We could determine the composition and infer the rheology of lava flows. These may be interesting and unusual because Valles Marineris may be an extremely large rift zone from which the lavas erupted. If the landing site is composed of pyroclastics, this would verify that there are definite pyroclastics on Mars. It would be possible to measure their composition in order to determine if the composition is unusual, because if it is not, then we would expect pyroclastics to be more widespread, and reinterpretation of some geologic units may be in order.

Valles Marineris is also interesting meteorology. Clouds and haze are often observed within it [7] which the Pancam can observe and measure [4]. Also, there are probably separate wind patterns in Valles Marineris that may prove to be interesting.

Conclusion: This proposed landing site would provide much useful information about Mars. It will also be a good landing site because the general public has heard of Valles Marineris, and, in addition to the scientific objectives, public support of the mission is also important. The panoramic view will also be spectacular. Valles Marineris has always been a puzzle as to the nature of its formation. Its interior deposits have also not been unambiguously characterized. Whatever the origin of the unit of the proposed landing site, the scientific results will be important and useful.

References: [1] B.K. Lucchitta et al. (1992) in *Mars*, Univ. of Arizona Press, 453-492. [2] D.H. Scott and K.L. Tanaka (1986) USGS Map I-1802-A. [3] Mars 01 Landing Site Website; available at http://marsweb1.jpl.nasa.gov/site01/ [4] S.W. Squyres et al. (1999) *LPS XXX*, #1672. [5] A. McEwen et al. (1999) *Nature*, 397, 584-586. [6] R.A. Schultz (1999) *LPS XXX*, #1057. [7] B.K. Lucchitta et al. (1999) *LPS XXX*, #1736.

POSSIBLE LANDING SITE IN MERIDANI SINUS.

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Summary: A candidate landing site for the Mars '01 mission has been chosen at 5°S, 358°W in central Meridiani Sinus.

Introduction: All three Martian landers (Viking 1 and 2 and Pathfinder) have landed in Mars' northern lowlands. Mars '01 is finally an opportunity to explore the ancient highlands. Additionally, one of the major considerations of this mission is to search for evidence of possible prebiotic or biotic processes and the emergence of life. Ideally then, a landing site should be located in a region where there is evidence of aqueous sediments that were deposited early in Mars' history. Such a region undergoing deflation would be desirable so that these ancient sediments are accessible to the lander and/or rover.

Proposed Site: Safety must, of course, be our first concern; if we don't land safely, we don't get any data. The landing site I propose appears to meet all the safety criterion established [1]. It is located in an impact crater centered at 5°S, 358°W. This crater is located in central Meridiani Sinus near a landing site region proposed by Edgett and Parker [2]. The crater is about 50km in diameter. Thermal inertia for the area is about 7-8 x 10^{-3}cal cm^{-2} $s^{-0.5}$ K^{-1}; and rock abundances are around 8%. The elevation is near 0.5km. There are some moderate quality high resolution images (>50 m/pixel) of portions of the area from Viking orbit 435A, though it will be very important to get MOC images of the region. There is a sharp albedo contrast between the southern and northern halves of the crater. Ideally, a landing near this boundary would allow us to investigate both the bright and dark materials.

Viking images of nearby regions suggest that eolian deflation has occurred [2,3,4]. The crater is located at the southern edge of the unit Npl_2 (subdued crater unit), where it meets Npld (dissected plains unit). This is a flat floored crater similar to many craters in the area that have been interpreted as lucustrine basins and possibly evaporite deposits [5,6]. There is no visible channel leading into or out of the crater, though there is a very large valley system located just to the south (figure 2). Such lacustrine plains are by nature smooth, flat, and level, making them an ideal place to land a spacecraft.

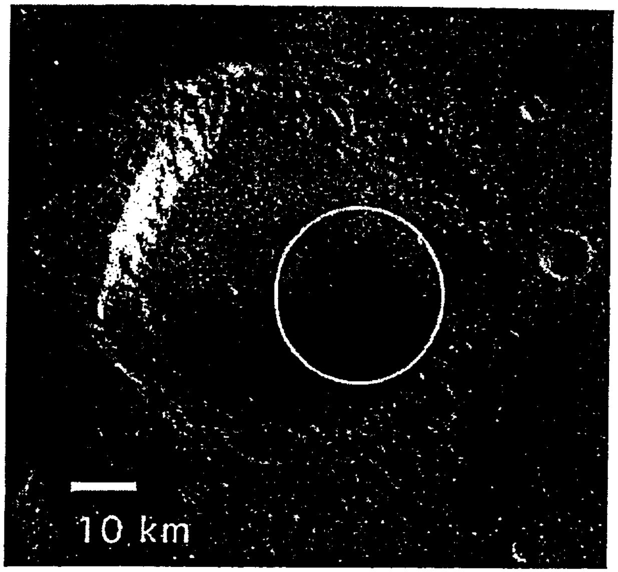

Figure 1. Crater centered at 5°S, 358°W. Crater is apprximately 50 km in diameter.

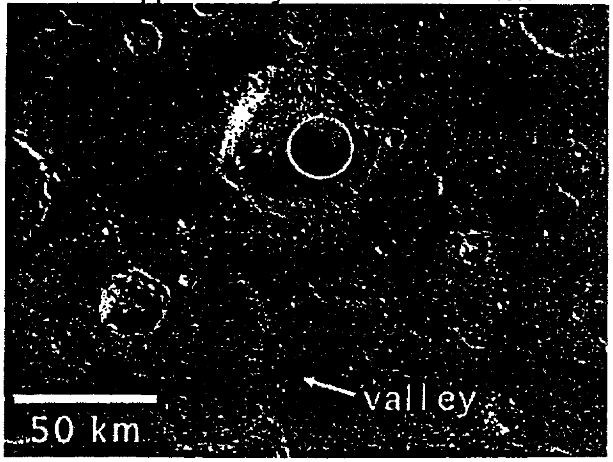

Figure 2. Note large valley system just south of crater.

We have never landed inside a crater before. This would be a wonderful opportunity to improve our knowledge of the cratering process. Particularly benificial will be photos of the crater walls, which in a sense, should act like nature's own roadcut, allowing us to image what is effectively a cross section of the terrain.

The crater is at the southern edge of a region proposed to be a Noachian ocean by Edgett and Parker [4]. If this is the case, one would again expect carbonates and evaporates to be present. Chapman [3] believes that the terrain of Terra Meridiani is a much younger material deposited on top of older Noachian highland units. He argues that the morphology of the region would be consistent with either eolian deposits or ignimbrite sheets.

The TES instrument on Mars Observer has recently recognized a substantial deposit of crystalline hematite near this region. This deposit could indicate true intermediate-to-felsic magmatism, not just fractionation of a basaltic magma [7]. Terrestrial hematite is largely formed in two ways, from submarine volcanism, which produces banded iron formation, and from direct marine precipitation. Both of these mechanisms would be very consistent with the ocean of Edgett and Parker [4]. The proposed site will provide an opportunity to test these theories and to look for smaller amounts of hematite that may be below the resolution of TES.

The crater is also within a region defined by Schultz and Lutz [8] to be an ancient polar deposit. Comparison of sediment in this area to that in the region of the polar lander may provide evidence for this hypothesis.

Conclusion: This site provides the opportunity to investigate some very interesting geology. It is on ancient Noachian terrain which has been modified by certainly eolian, and possibly either volcanic and/or fluvial processes. The valley system to the south shows that there was water in the region, and layers seen in Viking images nearby would seem to indicate fluvial depositional processes. If that is the case, this would be an excellent place to look for evidence of life. The area appears to be undergoing deflation, which will bring older underlying rocks within reach. The location provides an opportunity to test several hypotheses. Is this an ancient polar deposit? Is it the southern extent of a great Noachian ocean? Did craters such as this one pond with water from nearby drainage valleys, and did that water remain long enough to create evaporite deposits? Carbonates? Life? Is there hematite here, or are the boundries of the nearby deposit so sharp that no evidence of crystalline hematite can be found? Why is there such a sharp albedo contrast across the crater and what are those materials? In addition, this would be the first time we have landed within a crater, and thus, the first opportunity to explore such a place on Mars. Compositional data from mini TES and the APXS may answer many of these questions and gives us an important opportunity for ground truthing of our remote sensing data. Also, pancam photos will give us a much better idea of the local morphology and thus insight in the processes active in these region now and throughout Martian history.

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THE BIG DIG ON MARS: VALLES MARINERIS PROPOSED AS A LANDING SITE FOR THE MARS SURVEYOR 2001 MISSION.

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Introduction: The goal of the Mars Surveyor 2001 mission is to study the ancient terrain and determine the role of water, climate, and possibly life on Mars. It is tempting to send a mission such as this to areas that may determine the origin of the highland lowland dichotomy, or answer the question concerning polar wandering on Mars. However it seems that the prime landing sites to resolve such issues are outside of the current engineering constraints of the mission. Another boon would be to land upon the ancient highlands, which makes up the majority of the Martian surface. Again, the engineering constraints make such a choice impossible. Therefore, if we can not up to the highlands, I propose that we should go down into an area where highlands material is ample to sample. A feature such as Valles Marineris provides such an opportunity where highlands material may be found at lower elevations, both in the stratigraphy of deposits and as mass-wasted materials. Ophir Chasma can provide an abundant science return and meets the engineering constraints listed as of 4/15/99.

Rationale: There are many questions to be answered about the origin and history of Valles Marineris: did water or ice play a role in its formation? How is it tectonically related to the Tharsis rise? What is the composition and origin of the interior layered deposits? Did lakes exist within the valley and were these responsible for neighboring outflow channels? If this area was a lake, did life exist within it? How much of a role did volcanism play in the formation and modification of Valles Marineris? These questions can be answered and/or constrained by a sample return mission to this area of Ophir Chasma, near Central Candor Chasma.

Landing site: Figure 1 illustrates the landing ellipse for the selected landing site. We have medium quality Viking 30 m/pxl images of both areas, as well as many beautifully detailed 5 m/pxl MOC images from these sites which show it to be safe from hazard. The elevation of the site is between 0 and 1 km in elevation. Figure 2 is an excerpt of a geologic map from [1] and indicates the type of units that would be available to sample.

The site is located at (4.2°S, 70.8°W). A 20 meter landing ellipse would yield the best location to sample a diversity of rocks with a minimum of travel distance for the rover; this maximizes the scientific instrument opportunities at the site. The undivided floor deposits could be easily obtained from the initial landing location. Along the way to outcrops, the rover could sample various materials along the floor of the canyon which vary in albedo. Some of these darker materials have been suggested to be mafic [2] and may be volcanic in origin. If local volcanism occurred concurrently with the suggested existence of a lake at Valles Marineris [3], life could have flourished in such an environment. Understanding the origin of these dark soils is therefore critical to eventually resolving the question concerning the history of Valles Marineris. There are also darker knobs which are found near the landing site. These may actually be volcanic vents (which could have provided hydrothermal energy were there a lake at Valles Marineris at the time) or more erosion resistant material; a sample should be obtained if possible within the 10 km traverse guidelines. Also, studying the eolian deposits along the canyon floor would be important to understanding the global dust distribution: does trapping within Valles Marineris occur or is this dust similar to that found elsewhere on Mars?

Traverses: A short trek to the north would yield samples from both the Noachian basement and diverse wall-rocks and also sample the landslide deposits present. Here we would be able to sample the ancient terrain that has cascaded down the slopes. It would be a great imaging opportunity to study the spur-and-gully morphology of the canyon wall, as well as to study in situ stratigraphy. The origin of this type of feature is still uncertain and samples from this area may provide information about the past climate on Mars and the local environment which created these features: was it a submarine canyon within a lake? Or was ground-ice or water involved? The age of such features is also in question and thus detailed imaging of the stratigraphy may resolve the question: are spur-and-gully features currently forming? Absolute dating of any dislodged caprocks from the above terrain may provide an anchor to the chronology of Mars. To be able to image the local faulting and structures would also work to resolve the issues concerning the formation of Valles Marineris: did it open as grabens due to the Tharsis bulge?

Next the rover could make a long traverse (approximately 10 km) south to the next outcrop. There the rover could sample rocks from the landslides and the interior layered deposits. The nature of the landslides (wet or dry) and the composition and origin of the interior layered deposits are also under debate. The interior layered deposits may be volcanic [1] which would support the structural origin of the troughs as related to the Tharsis rise. These layered deposits may also be the result of the presence of a lake filling the canyon [4]. If a lake existed within the canyon and life existed on the ancient highlands, surely fossils should be found here on the remnant lakebed. Therefore the determination of the emplacement and modification processes of these stratigraphic sequences is crucial to understanding the evolution of Valles Marineris.

Conclusion: The selection of this landing site would guarantee a strong science return and provide much information concerning the history of Mars. With what promises to be stunning images and diverse samples, this mission to Ophir Chasma could answer key questions about volcanism, water, climate, and possibly even life on Mars.

References: [1] Lucchitta, B. K., et al., The Canyon Systems on Mars, in Mars, University of Arizona Press, Tucson, 453 - 491, 1992. [2] Geissler, P. E., et al., Dark Materials in Valles Marineris: Indications of the Style of Volcanism and Magmatism on Mars, JGR, 95, 14399 - 14413, 1990. [3] Shaller, P. J., et al., Subaqueous Landslides on Mars?, LPSC XX, 990 - 991, 1989. [4] Nedell, S., et al., Origin and Evolution of the Layered Deposits in the Valles Marineris, Mars, Icarus, 70, 409 - 441, 1987.

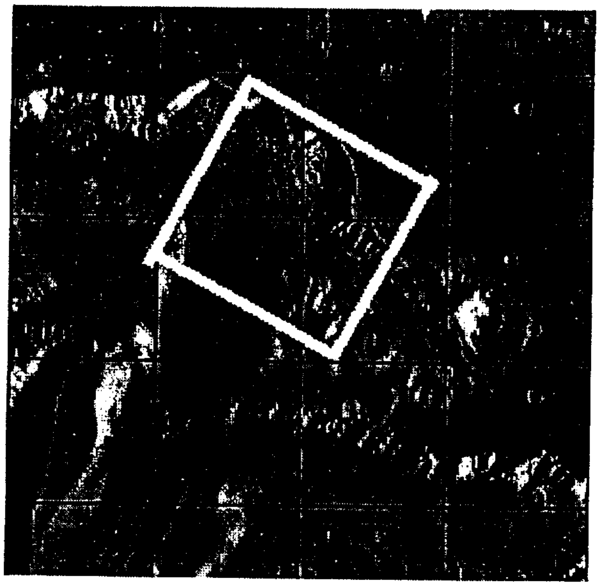

Figure 1a: Viking image map of proposed landing site in Ophir Chasma. Grid is in 1° intervals. White box indicates coverage of Figure 1b. Landing site is located at (4.2°S, 70.8°).

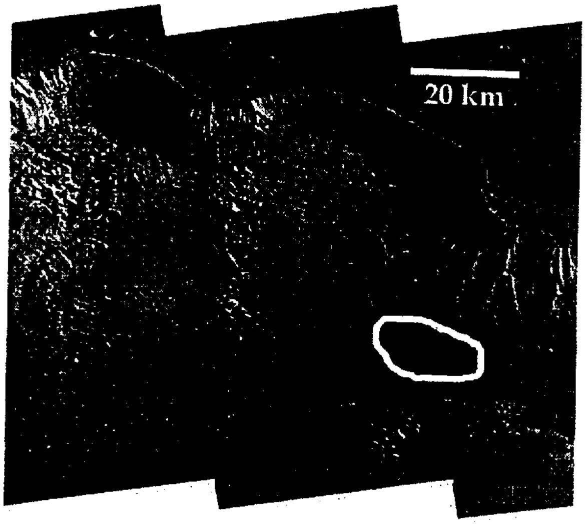

Figure 1b: Vertically exaggerated oblique Viking image mosaic of Ophir Chasma from [1]. The proposed landing ellipse is shown in white.

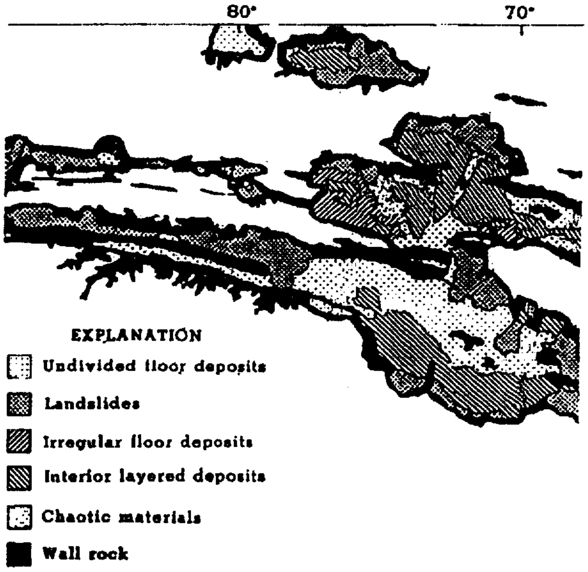

Figure 2: Geologic map of Valles Marineris from [1]. The site allows access to wallrock, caprock, landslide material, interior layered deposits, and dark albedo material, as outlined in Figure 2.

MARS 2001 LANDING SITE: USING CRATERS TO EXPLORE THE MARTIAN SUBSURFACE

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Introduction: Landing within an impact crater on Mars would support both stated science objectives of the Mars Surveyor 2001 landing mission [1]. Craters on Mars may have acted as natural traps for postulated surface water flow [2]. If so, they are a natural location to explore for evidence of the biological and climatological history of the planet. Impact craters also act as a mechanism for excavating material from depth and for cutting cross sections through planetary crusts. Study of crater ejecta and wall structure can therefore lend important insight into planetary history. A landing site is here proposed on the ejecta of a fresh crater within the crater Madler, a candidate ancient crater lake.

Site Geology: Madler is a smooth-floored, ancient crater approximately 100 km in diameter, centered at 11°S, 357°W (See Figure 1). It is located on the fluvially dissected highlands of Sinus Meridiani, an area that has been extensively studied by several researchers (see [3] for summary). One large valley network empties into it from the west. This, combined with the smooth, flat floor and abrupt change in slope between wall and floor, indicates that liquid water was likely present as a lake within the crater in the past [2]. The southern two thirds of the floor of Madler shows an albedo darkening that is also visible in the other flat floored craters in the vicinity, possibly indicating the presence of duricrust [3].

A small crater about 18 km in diameter is located in the northwestern quadrant of Madler. Its central peak and visible ejecta blanket indicate that it is relatively fresh, and large enough to have excavated material as much as 3 km beneath Madler's floor. This crater provides a unique window into the material underlying the floor of Madler's postulated lake bed.

Three possible landing sites within Madler are proposed; the eventual choice of landing site will depend upon investigation of the site with MOC images and upon the final decision about site ellipse dimensions made by the Mars Surveyor '01 Project Team. All three sites are located on the floor of Madler crater, on the ejecta of the small, fresh crater. Sites were chosen to minimize the distance between the landing site and both the small crater and the wall of Madler while ensuring a safe landing on smooth material.

The optimum site (see Figure 1a), 20 km in diameter around 10.8°S, 356.5°, is located on the possible duricrust between the fresh crater and the nearest crater wall to the east, a wall which is steep and shows evidence of possibly water-carved canyons. The crater wall would easily be within visual range of the lander's APEX Pancam at this site. The other two sites (see Figure 1b and c), 40 and 50 km in diameter, and at 10.3°S, 357.4° and 10.9°S, 357.6°, respectively, are located farther from the crater wall, and so would have a poorer view of structure within the crater wall.

Mission Constraints: Compliance with the engineering criteria is summarized in the table below. The site meets all engineering criteria defined by the Mars Surveyor '01 Project Team [4] except for the requirement of < 50 m/pixel Viking image coverage. Many high-resolution images exist of the region around the periphery of the crater, but there are none within the crater itself. Thus MOC coverage of the site will be necessary.

Table 1. Compliance with Mission Constraints

Characteristic	Mission requirements	Madler crater
Location	between 3°N and 15° S	11°S, 357°
Elevation	between -2 and +1.5 km	-.25 km [5]
Surface Slope	< 10°	<1° [5]
Rock abundance	5-10%	6% [3]
Dust abundance	Fine Component Thermal Inertia > 4 cgs units	6.4 [3]
Viking image resolution	< 50 m/pixel	238 m/pixel

Expected Results: Investigation of the nature and composition of the materials forming the floor of Madler crater would provide opportunities to test many hypotheses about hydrogeological processes on Mars. The presence or absence of sediments has implications could validate or invalidate the hypothesis of a lacustrine origin for smooth-floored martian craters [2]. If the crater is found to be an ancient lake bed, the presence or absence of evaporites has implications for the estimation of the longevity of liquid water in martian crater lakes [2, 6]. Sediment composition is important for understanding ground and surface water chemistry and may possibly indicate the presence of martian life. The lander's position on the ejecta blanket of a small crater within Madler could allow the rover to visit rocks from many different depths beneath the crater, giving clues to climatological and geological history of the lake [7]. Alternatively, the crater floor deposits may be found to be volcanic in nature; while disappointing, this would be a significant result.

If the lander lands close enough to the wall of Madler, it could also image the wall, resulting in the first visible cross section through martian crust. Such images would allow the testing of hypotheses about the nature of layering in Noachian materials [8] and the relative importance of fluvial, periglacial, and aeolian processes in degrading martian topography [9].

References: [1] V. Gulick et al., *LPSC 30* #2039, 1999. [2] N. Cabrol and E. Grin, *LPSC 30* #1023, 1999. [3] M. Presley and R. Arvidson, *Icarus* **75**: 499-517, 1988. [4] C. Weitz, Mars 01 Landing Site Website, 15 Apr. 1999. [5] S. Pratt, personal communication. [6] M. Carr, *Icarus* **56**: 476-495, 1983. [7] N. Cabrol, *LPSC 30* #1024, 1999. [8] M. Malin and K. Edgett, *LPSC 30* #1028, 1999. [9] K. Tanaka, *Proc. 18th. LPSC*, 665-678, 1988.

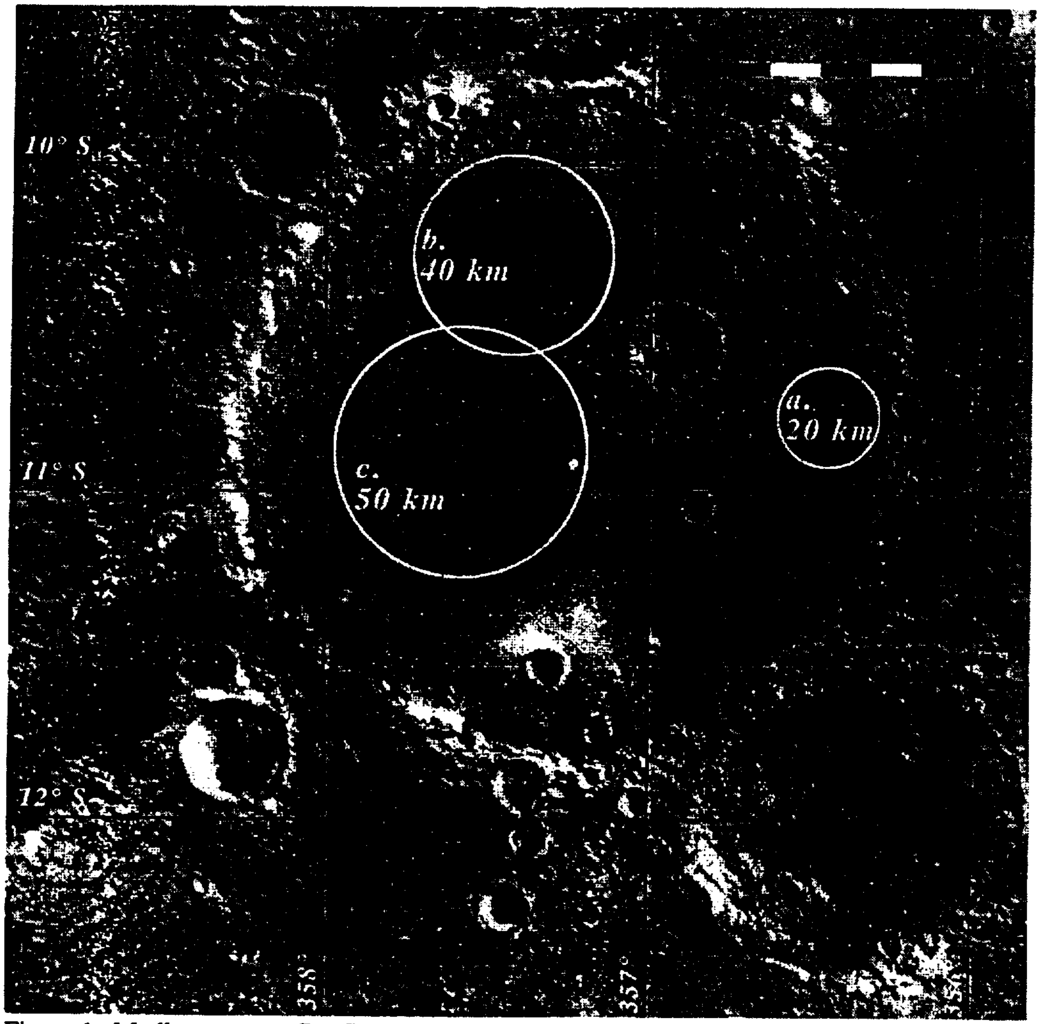

Figure 1. Madler crater, a flat-floored crater postulated to be an ancient crater lake, in Sinus Meridiani, Mars [2]. Length of the bar scale is 50 km. White circles show possible Mars Surveyor 2001 landing sites. Note the valley network emptying into the crater from the west and the fresh crater in the northwest quadrant of the large crater.