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.

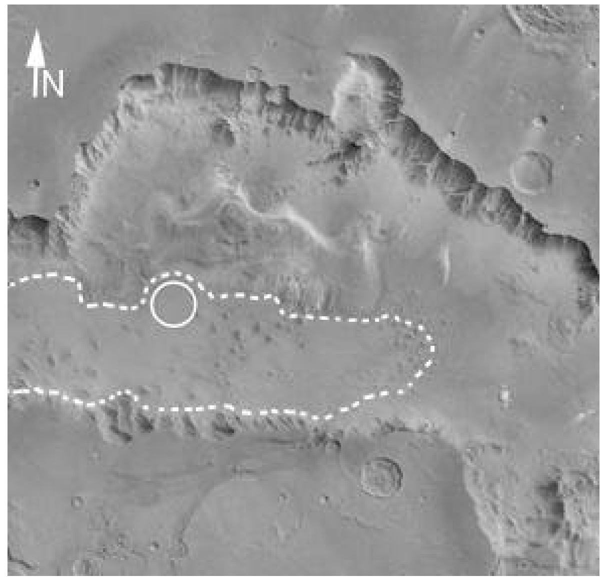

Figure 1. Regional view of Ganges Chasma. Circle represents proposed 20 km-diameter landing zone. Dashed area shows approximate extent of smooth, dark sand sheet, based on MGS MOC image sampling through May 1999.

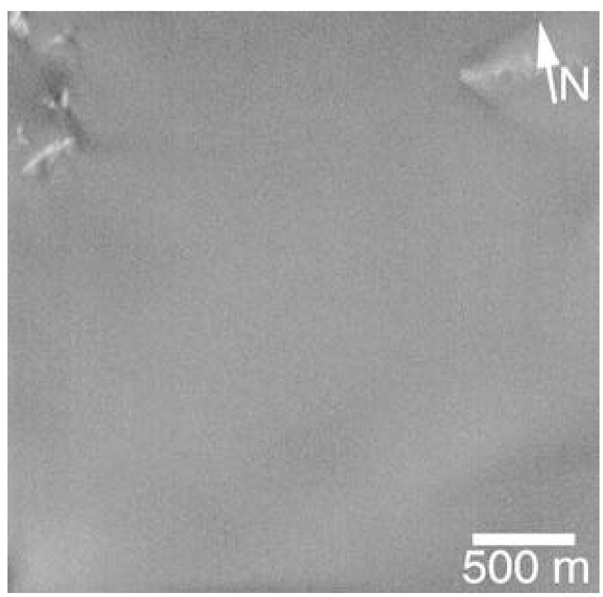

Figure 2. Typical view of the Ganges sand sheet. Subframe of MOC image AB-1-087/07, near 7.6°S, 49.5°W.

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 $\geq$ 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.