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The Northwestern Slope Valleys as a Possible Landing Site for MSL

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Abstract. The Northwestern Slope Valleys (NSVs) lie on the western edge of the Tharsis bulge on Mars, and are hypothesized to be structurally controlled cataclysmic outflow channels through which much of the water which had been trapped in Tharsis as it evolved was released during times of volcanic activity. As such, they would be privy to at least three distinct hypothesized hydrologic regimes, as well as recent sapping valley formation. Because of these, significant paleosol formation may have taken place, which would provide valuable records of climate. The heat from Tharsis may have kept liquid water near the surface for extended periods of time, thus providing a possible locale for life to flourish. The site is 148 km from Abus Vallis, a suspected sapping valley, indicating a possible regional water supply. In spite of the low thermal inertia of the region (which is probably due to fine grained volcanic ash), a potential landing site for the Mars Science Laboratory (MSL) rover was located. This site would provide access to a fresh-looking crater and its debris apron, channeled lava flows, sheet lava flows, and steep overhangs which would potentially afford access to old sedimentary strata and possible paleosols. A primary mission track of 35 km is proposed, along with an extended mission track of approximately 30 km. The extended track would take the rover past additional overhangs, past slopes upon which there are found dark slope streaks which change in time, and finally to a spot downhill from an erosional notch from which rocks exposing deeper strata may have fallen. The potential threats to this mission are the fact that the landing site is just outside of the "Stealth Terrain" as defined as Edgett et al. (1997), and that the extended mission would take the rover into terrain which has a thermal inertia of 80 – 120 J $m^{-2}s^{-0.5}k^{-1}$.

1. Introduction

In their 2004 report, the Mars Exploration Program Analysis Group, which was assembled by the NASA Jet Propulsion Laboratory, set out four primary goals for future science driven missions to Mars (MEPAG, 2004). These were:

1) Determine if life ever arose on Mars
2) Understanding the processes and history of climate on Mars
3) Determine the evolution of the surface and interior of Mars
4) Prepare for human exploration

It was with these goals in mind that the instrumentation of the Mars Science Laboratory rover was designed (JPL MSL Website, 2005). It has ten highly advanced scientific instruments which, when combined, will provide a powerful lens into Martian geologic and climatic history. In order to best utilize the unprecedented abilities of this rover, a landing site must be chosen which will expose as much Martian history as possible. For the first objective, to determine if life ever evolved, it is imperative to choose a landing site which has had a long hydrologic history, as well as possible signs of present liquid water, since life as we know it requires water in order to exist. For the second and third objectives, to characterize climatic and geologic history respectively, it should be in a region which will have exposed sedimentary sequences. The longer these are, the better. Additionally, rocks which have been eroded out of the subsurface and craters both can provide valuable data. The last goal, preparing for human exploration, would also be served by finding present day water and/or ice. The optimal site for the rover would have all of these.

Until recently, it was thought that ground ice and/or liquid water lied between 2.27 and 11.0 kilometers in depth at the equator (Carr, 1996; Clifford, 1993), which would have made this difficult. Recent data, however, from the 2001 Mars Odyssey's neutron spectrometer indicate that there are substantial amounts of water within the first few meters of the surface, even in equatorial regions (Feldman et al., 2004; Jakosky et al., 2005). This makes the NASA mantra 'Follow the water' much easier to do.

There are even regions of Mars that may have had very recent hydrological activity, which would make prime targets for a rover. Valleys and gullies which have been recently formed by groundwater springs on their slopes, called sapping valleys, have been found in modest numbers (Goldspiel and Squyres, 2000; Gulick, 2001). Additionally, while many believe that the dark slope streaks that have been observed in MOC images are the results of dust avalanches (Sullivan et al., 2001), other researchers believe that, in a subset of them, water may have been involved (Ferris et al., 2002; Miyamoto et al., 2004; Schorghofer et al., 2002). Perhaps the best evidence to be presented for this interpretation is in the Schorghofer, et al. study. It notes that in their dataset, which consisted of 761 sites, these streaks would only occur where peak temperatures exceed 275 k. This suggests that water is involved in many of them. If there are indeed small amounts of water present, direct analyses by a rover could prove to be very interesting.

In the present treatment, the northwestern slope valleys (NSVs) region, on the western flank of the Tharsis bulge will be examined as a possible landing site for the MSL Rover. The geology and hypothesized hydrology of the NSVs will be covered, followed by the selection of a specific landing site. Its qualification for the engineering requirements, and then its specific scientific value will be examined. The NSV region is shown in Figure (1).

II. Geology and Hydrology of the NSVs

The NSVs are hypothesized to have a very rich hydrological history, with at least three distinct hydrological regimes in play.

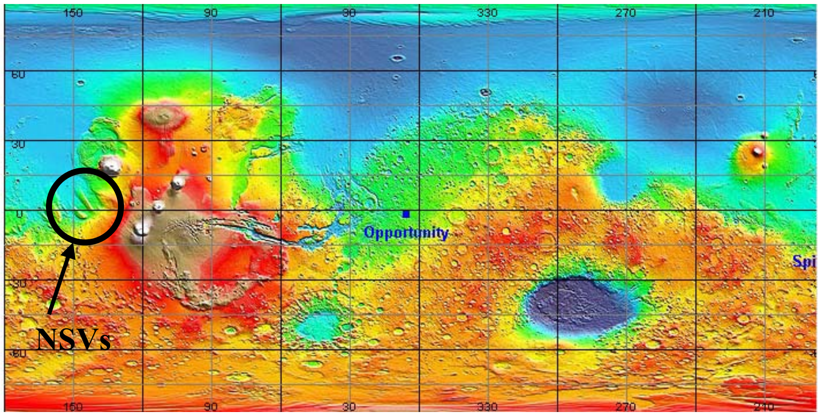

Figure 1 – MOLA Topography of Mars, with location of the NSVs indicated
Source: JPL Marsoweb

These span Martian history, and are shown in Figure (2). It is thought to have been the scene of extensive water/magma interactions, and even cataclysmic floods with discharges up to 10^8 m/s, as shown in Figure (3). The pacemaker for all of this is, of course, the heat flux associated with the Tharsis superplume. This heat likely kept liquid water present for long periods of time, making it a very good area to look for paleo evidence of life. It even has sapping valleys which may still be active. (Dohm et al., 2004). Water maps from the Mars Odyssey approximate the mass percentage of water in this region as 8% in the first couple of meters (Feldman et al., 2004).

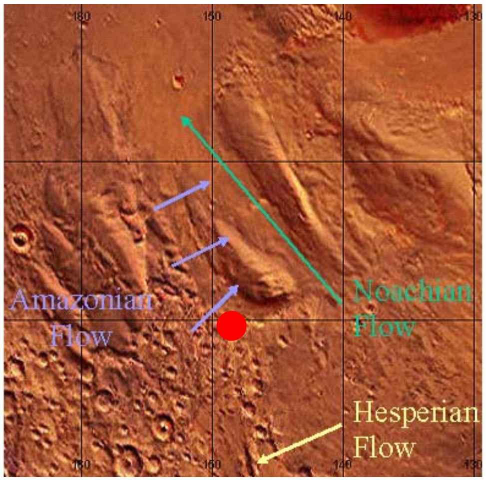

Figure 2 – Major hydrologic regimes in the NSVs. The proposed landing site is shown in red.

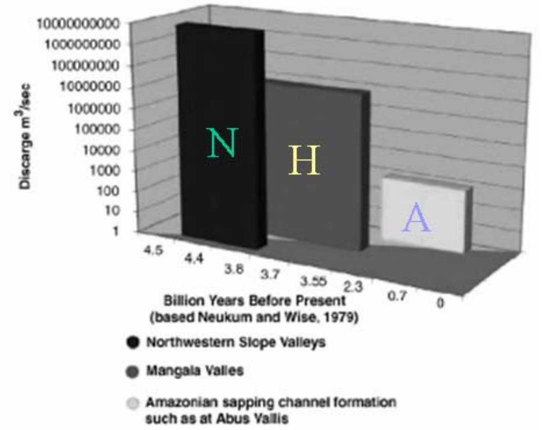

Figure 3 – With time on the x-axis, hypothesized discharge for each of these regimes is shown. Source: Dohm, Ferris et al. (2004)

According to one hypothesis, which is based on detailed mapping of the area, an aquifer roughly the size of Europe is beneath the Tharsis bulge. The theory predicts that as Tharsis was slowly built over its 3.5 Ga history, there were likely sediments emplaced along with all of these basaltic shield lavas. Both of these can serve as excellent aquifer materials. If Mars did indeed have a warm, wet climate for part of its history (Baker, 2001; Paige, 2005), one could expect more coarse grained sediment, which makes a better aquifer, and significant storage of water. Thus, when magma would approach the surface, massive amounts of water were released from this area. The eastern drainage for this would be the circum-Chryse outflow channels, which have been studied extensively (Ivanov and Head, 2001; Rice and Edgett, 1997), and the western would be the NSVs. (Dohm et al., 2001; Dohm et al., 2004). One of the primary justifications for a landing in the NSVs would be as a test for these theories.

One result of the amount of water and heat which were both a part of this area's geologic history is that there could have been significant paleosol development. Weathering rates would have been the highest during the Noachian, slowing significantly with time. There is a slight chance that these ancient soils might still be found since Mars is a mono-plate planet (Dohm et al., 2004). Since the Martian climate has varied significantly over its history, these paleosols are likely to be fairly complex, with soil peds having deep and non-uniform weathering mantles. Antarctic 'polar desert' soils on Earth have been shown to support bacteria in thin brines. Such conditions could conceivably exist on Mars (Mahaney et al., 2001). In Antarctica, these soils form very slowly, 1 cm in 500,000 – 800,000 years. Mars has had at least 1 Gy of cold climate, but weathering would proceed at a much slower pace because of the temperature. (Dohm et al., 2004) One of the most effective ways to accomplish MEPAG goal #2, to characterize Mars' past climate, would be to examine such paleosols.

The NSVs are structurally controlled and lie in an existing topographic low which is hypothesized to exist because of the weight of the Tharsis bulge on the mono-plate. They have a negative gravity anomaly, indicating that they are likely infilled by volcanic and sedimentary materials (Dohm et al., 2001). The highest strata is the Medusae Fossae Formation, a 2.3 million square kilometer area west of Tharsis, which has surfacial ages estimated all the way from early Hesperian to late Amazonian. It is thought to be predominately fine grain ash deposits. Beneath this area lies the buried crustal dichotomy (Hynek et al., 2003).

III. The Landing Site

The preliminary engineering constraints for this mission are given in Table (1), along with the values at the proposed landing site.

	Requirement	**Value**
Elevation (m)	<0	-2400
Latitude	+60° <x > -60°	~ -4°
Surface Slope	< 15°	< 5°
Radar Reflectivity	> 0.05	OK
Surface Roughness	Not Rough	Smooth - Moderate
Thermal Inertia (J $m^{-2}s^{-0.5}k^{-1}$)	125 - 165	OK
Landing Ellipse (km)	10 x 30	16 x 33

Table 1 – A comparison of the engineering requirements for a landing site with the values of the site presented herein. Note that numeric values are from JPL Marsoweb, and that the landing ellipse size is what the GIS determined the hand drawn ellipse to be. Engineering constraints provided by A. McEwen.

The most significant problem for landing in the NSV region is the thermal inertia requirement. Much of the area has thermal inertias which are less than the lower bound of 125 J $m^{-2}s^{-0.5}k^{-1}$. This is shown in Figure (5), which is TES data from Marsoweb. The second, and likely associated problem was that much of the area was in the so called "stealth terrain", in which there is poor radar return, probably because of fine grained ash (Edgett et al., 1997). This is shown in Figure (6). The landing site is marked in both figures. The low thermal inertia over the region is likely due to fine grain volcanic ash, as that is the primary constituent of the Medusae Fossae Formation (Hynek et al., 2003). Thermal inertia depends on several different variables, of which particle size is just one. Others include: rock abundance, amount of bedrock exposure, and degree of induration (Putzig et al., 2005). A ~8112 km^2 area of acceptable thermal inertia, labeled "dust free area" in Figure (6) was found for the landing site. It is hoped that the thermal inertia is higher here both because of decreased dust cover and an increase in exposed rocks. In Figure (6), the landing ellipse is shown, along with proposed rover paths. The primary rover mission is about 35 km. Visiting a very fresh looking crater next to the landing site to examine the deeper strata and ejection blanket would add an estimated 2 – 4 km to the mission.

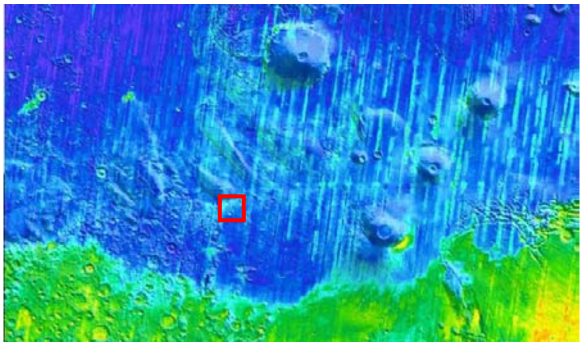

Figure 4 – TES thermal inertial map. Green indicates a value of 180, and dark blue is about 50 J $m^{-2}s^{-0.5}k^{-1}$. Lght blue is the target color.
Source: JPL Marsoweb.

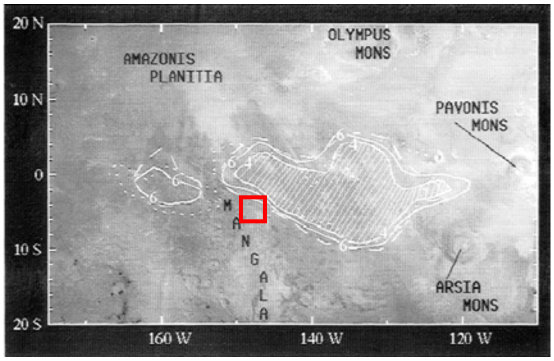

Figure 5 – Hatched internal contour indicates a signal to noise ratio of 4, while the outer is a ratio of 6. 4 is considered the new definition of Stealth Terrain. The landing site is *very* close to it. Source: Edgett et al., 1997.

The first destination on the primary mission track are some young volcanic lava channels that overlie an older volcanic flow. Both of them are almost totally uncratered, indicating a young age. One can tell that they are volcanic and not fluvial because the parallel ridges next to the channel are consistent with lava flows, as are the lobate deposits at the upper left (Baker, 2005). Using its instruments, the rover would be able to sample these channel lavas, as well as the ash cover to glean information on Tharsis and Mars mantle composition. Then, making its way over the older to the outcrop area shown in Figure (6), it would have the opportunity to sample a lower viscosity lava, along with any other rocks that lie in its path. A close up of these areas is given as Figure (8). The primary rover track would take the rover to the "outcrop area", shown in blue cross-hatching in Figure (6). From Figure (7), one can see that the steepest part of the area is the beginning, which actually appears to have an overhang. This would very likely have exposed sedimentary strata and rocks to examine. Significant data acquisition could likely be done in this location, and the primary mission ends in this spot. Thus if the rover does not last longer, it will have had the best possible chance at finding older strata. The extended mission, with the rover track going another 30 km, continues along the face and stops at a point where there is a significant chunk eroded from the top of the hill face. It is hoped that this incision would have resulted in older rocks being at its base. On its way to that notch, it will pass by the base of slopes which have the dark slope streaks mentioned earlier.

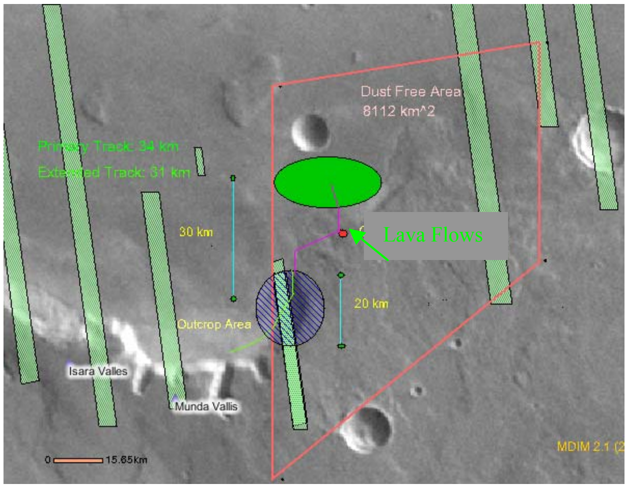

Figure 6 – The proposed landing ellipse with primary (pink) and extended (green) rover mission tracks are shown. The "dust free area" is outlined in salmon. The first stop, volcanic channel flows is shown. The blue hashed area are the outcrops, which can be seen better in Figure (7) to the right. The MOC images which intersect the outcrop area are shown in Figures (8) and (9). Source: USGS Pigwash GIS

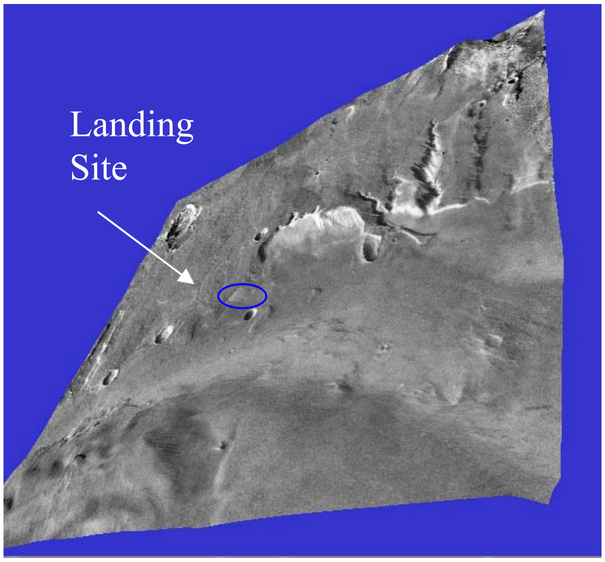

Figure 7 – MOLA based 3-D image of the landing area. Notice that the rover will encounter the steepest overhang first. Thus if it does not last for an extended mission, it will have the best chances of valuable results. Source: JPL Marsoweb.

In Figures (9) and (10) are shown MOC images in the same spot, approximately 30 months apart. The dark slope streaks in them have changed between the two pictures. According to the argument in Schorghofer et al. (2002), this would indicate that some amount of water was involved in their formation. Since some of the streaks are long lived and don't change locations (at least since the Viking days) (Aharonson et al., 2003), this could be a line of evidence that the area is water enriched, and thus a good place for exploration. Since scientists haven't come to a consensus on the genesis of these streaks this also may not be the case. Further study should clarify the issue. Between the two pictures, the lines have changed somewhat, and have faded, indicating that dust has been in the process of being redeposited (Aharonson et al., 2003).

A MSL landing in the NSVs could also examine evidence for recent flow of water on the Martian surface. While not a suitable landing site itself, eastward from the landing site is Abus Vallis, thought to be a sapping channel (Dohm et al., 2004). Its mouth lies approximately 148 km from the center of the landing ellipse.

Figure 8 – Themis visible photo of the landing site. Note the fresh looking crater and the uncratered lobate lava flow, along with later lava channels. Themis image #V06572001

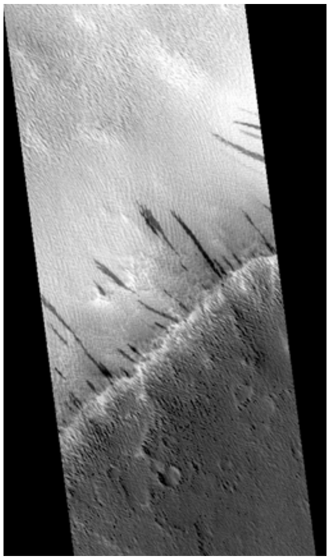

Figure 9 – Note the dark slope streaks in this photo. They change significantly in Figure (10). For context, see Figure (6). MOC narrow field photo, taken November 27, 1999 at 02:14:27 SCET. MOC image #M0806563

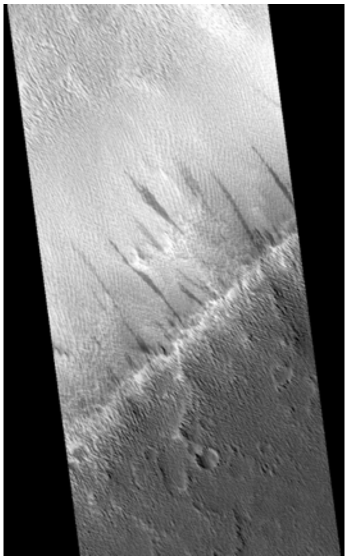

Figure 10 – Note that the steaks have changed. They also have gotten dimmer which is thought to vary with dust deposition rates (Aharonson et al., 2003). MOC narrow field photo, taken July 14, 2003 at 9:20:27 SCET. MOC image #R0701015

If it really is a sapping channel, this means that there is/was in the recent past near surface water in this area. While volcanic ash would make a poor aquifer, basalt, particularly fractured basalt, can in many cases have a high effective porosity.

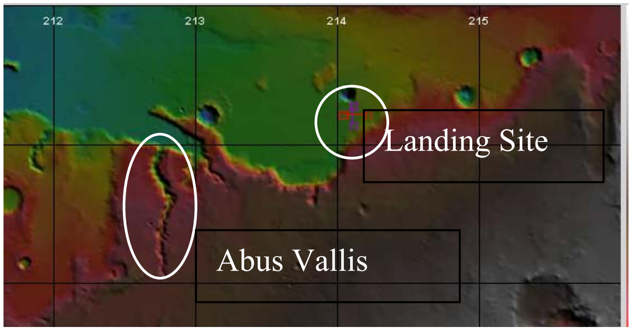

Figure 11 – Proposed Landing site's proximity to Abus Vallis, which evidence suggests is a sapping channel (Dohm et al., 2004). Its mouth is approximately 148 km from the center of the landing ellipse. High Resolution MOLA topography. Source: JPL Marsoweb

Furthermore, if paleosols do exist, examining them could reveal details of Martian climate. It has been suggested that there is a cyclical nature to the warming and cooling governed by Tharsis volcanism, catastrophic flooding and the formation of a northern planes ocean (Baker et al., 2004; Baker et al., 2000; Baker et al., 1991). Baker et al. (1991) called this the MEGAOUTFLO (A **M**ars **E**pisodic **G**lacial **A**tmospheric **O**ceanic **U**pwelling by **T**hermotectonic **FL**ood **O**utbursts) hypothesis. It, and all competing ideas (Carr, 1996), are highly theoretical. Data from paleosols would be essential to prove or disprove such theories. And on a more basic climatic level, it may shine light on whether Mars did have a warm and wet climate in the early Noachian (Baker, 2001; Paige, 2005).

V. Strengths, Weaknesses and Threats (SWAT)

- Strengths:
  - Hydrologically and geologically interesting and varied site.
  - Good extended mission track available for rover
  - Rover internal power source lessens the negative impact of dust.
  - One of very few 'dust free' areas in NSV region.
- Weaknesses:
  - Region likely has a lot of fine grained volcanic ash
  - Extended mission would take rover into an area with lower thermal inertia
- Threats:
  - Close to the "stealth zone"
  - Large rocks on ejecta blanket and/or sheet lava flow
  - High winds are possible and unconstrained

VI. Conclusions

The NSVs potentially catalog at least three major hydrological regimes, from Noachian catastrophic outflow channels to Amazonian flow, and even very recent sapping channels. Through potential pedological records, a significant amount of Martian paleoclimatic data may be available. The primary mission from the proposed landing site would allow direct analysis of very recent lava flows of at least two different viscosities, analysis of a fresh-looking crater and its debris apron, rocks which may have been eroded from higher in the Tharsis bulge, and lastly the base of a very steep overhang that may afford access to significant sedimentary strata. The extended mission track would have it continue along the same overhang, past the base of a slope on which there are dark slope streaks, and finally to a spot where there is a large notch in the cliff, from which rocks from deeper strata were likely eroded. The potential threats to such a mission are proximity to the "stealth terrain" (Edgett et al., 1997), and an extended mission track which takes it into areas of low thermal inertia.

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