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May 27th, 2011

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Dear Michael and John:

This letter summarizes the outcomes and findings of the fifth and final Mars Science Laboratory (MSL) Landing Site Workshop held May 16-18, 201, in Monrovia, CA, on. The meeting was well attended on all three days, with well over 150 participants from the science community and the MSL science teams. The workshop objective was focused on discussion of unresolved scientific uncertainties for the four remaining candidate landing sites, including those identified at the last (4th) MSL Landing Site Workshop. The product of the workshop was a series of summary statements or "quad charts" that highlight their science merits, deficiencies, and uncertainties as measured against major science objectives of the MSL mission.

Workshop presentations were grouped into an introductory session followed by individual sessions for each of the four remaining sites. There was also discussion of possible planetary protection issues related to the candidate sites, and a closing session related to ongoing characterization of the candidate sites with respect to landing hazard safety and rover terrain traversability. Time was provided for discussion at the end of each session and on the final day of the workshop which focused on completion of the quad charts. All discussion sessions were lively, and we thank all of the participants for their effort in preparing for the workshop. Supporting materials and all presentations were posted in real time at http://marsoweb.nas.nasa.gov/landingsites/. These workshop presentations provided an additional means for participants to review each site and prepare for discussion sessions.

The four remaining candidate landing sites include in order of presentation: Mawrth Vallis (24°N, 341°E), Gale Crater (4.5S, 137.4E), Eberswalde crater (23.9°S, 327°E), and Holden crater (26°S, 325°E). All four sites possess high scientific merit and were deemed to be safe for landing and trafficable for the rover by the MSL project. The extremely high science merit of each of the sites was best expressed by the unanimous agreement from workshop

participants that all four sites still represent acceptable science targets for exploration by MSL.

A lunch meeting of the Landing Site Steering Committee was held on the final day of the workshop and yielded broad support for the ongoing process for selecting the MSL landing site. In addition, the luncheon was used to kick off the process of developing summary statements for the sites, in the form of quad charts, as a means of focusing the afternoon's workshop discussions.

The quad charts that emerged from the workshop follow (below) in alphabetical order and represent the consensus of workshop participants on the scientific merits, shortcomings, and uncertainties of the four sites. It is important to note that while the statements in the charts represent consensus, they do not represent a unanimous opinion of the community (or the Steering Committee) in a few instances. The quad charts comprise input to the MSL Project as they formulate a recommendation on which landing site might be selected by the NASA Associate Administrator for the Science Mission Directorate. It is worth stating again that there is very strong advocacy for each site.

The quad charts will be posted at the MSL landing site websites and the science community is encouraged to review and comment, thereby allowing for additions and revisions over the coming weeks. Any substantive suggestions from the community will be passed along to the MSL Project for consideration.

We appreciate the opportunity for the science community to provide input to the MSL landing site selection process. We hope that NASA will continue to solicit this input for potential future landing sites in order to achieve the most comprehensive evaluation of their relative merits.

Sincerely,

John Grant

Matt Golombek
Co-Chairs, MSL Landing Site Steering Committee
On behalf of the MSL Landing Site Steering Committee

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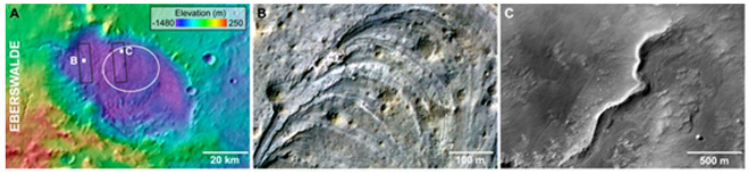
Eberswalde Crater Site



23.9S, 327E

Overarching Hypothesis:

- Eberswalde crater stratigraphy, geomorphology, and mineralogy record the evolution of a crater lake, the history of hydrologic and climatic changes resulting in the formation of fluvial-deltaic systems, and a sedimentary depositional environment that might have been favorable to the preservation of organic materials and/or other kinds of biosignatures.

Possible Cons of Site:

•Relatively limited variety and modeled abundance of phyllosilicate minerals known to preserve organics detected from orbit.

•Science in landing ellipse is secondary to that outside of the ellipse.

Specific Pros of Site:

Setting -

•Eberswalde shows excellent preservation of a fluvial-deltaic system emplaced into a standing body of water that integrates sedimentary material from a broad source region. Additional, smaller fluvial-deltaic systems and possible lacustrine deposits are also present.

•The landing site provides the opportunity to reconstruct quantitatively the sedimentary, hydrologic, and climate conditions during deposition. Specific formation models allow prediction of locations to target for exploration with MSL. Bottom set beds from each lobe of the delta can be defined and provide targets in which to seek organics.

•Evidence for episodic channel-meandering migration is recorded in the delta and associated estimates of discharge suggest its deposition extended for several hundred thousand years or more based on terrestrial analogs.

Diversity -

•In addition to fluvio-lacustrine deposits (e.g., sinuous ridges), Holden crater ejecta and possible megabreccia related to the Eberswalde impact event occur. Some megabreccia may express veins related to hydrothermal activity. The materials in the ellipse and delta include clay minerals whose distribution is associated with different outcrop characteristics.

Preservation -

•Orbital detection of clay minerals near the bottom of the delta front, maybe in bottom set deposits, define a well-defined target for exploration. There are also potential lake deposits within the landing ellipse that offer exploration targets. On Earth, such deposits can concentrate and preserve organics and evidence for habitability and life.

Exploration Targets –

•Well-defined fluvial-deltaic-lacustrine and megabreccia targets coupled with mineralogical diversity within and outside of the ellipse defines a short and long term exploration strategy. Lacustrine sediments likely exposed in and near the ellipse and distribution is becoming well-mapped. Distribution of targets make exploration of the site a mix of land on and go to.

Remaining Uncertainties:

• Little evidence for shorelines corresponding to the elevation of the delta surface and the spillway to the eastern basin, though some aspects of the system (including the poorly defined shorelines) suggest it may have been ice-covered (though no deformation of delta as might be expected if it was). Predictions made enable this to be evaluated in situ.

• Delta emplacement might be consistent with delivery of water and sediment shortly after the Holden impact; this cannot be ruled out in advance of landing, but tests are proposed to resolve in situ. Sediment contributions to the delta from Holden ejecta are uncertain though mapping of tributaries and characteristics of incision will help resolve in advance of landing.

• Delta is no older than Early Hesperian and some investigators believe it may have been deposited as late as the Early Amazonian, but there is no consensus whether a post-Noachian age is of a concern for preserving organics or for preserving evidence for past habitability or life on Mars.

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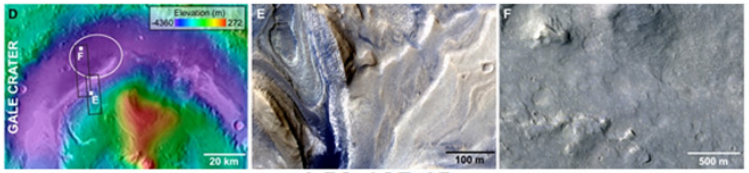
Gale Crater Site



4.5S, 137.4E

Overarching Hypothesis:

- Strata within the 5 km thick mound of layered sediments within Gale crater record a sequence of aqueous habitable environments over an extended period. These strata contain multiple hydrous minerals (sulfates, phyllosilicates) that indicate varying aqueous environmental conditions.

Possible Cons of Site:

• The original extent and timing of processes responsible for the present mound morphology needs better definition and the regional and global stratigraphic context of the mound is not firmly established and it is unlikely that all depositional aspects of the mound will be understood in advance of landing.
• Science in landing ellipse on and near an alluvial fan is secondary to that outside of the ellipse and observations within the ellipse may be encumbered by dust.

Specific Pros of Site:

Setting -
•Diverse stratigraphy in a 5 km mound within a 5 km deep Late Noachian crater. Stratigraphy includes well-defined beds of hydrated minerals and the lower mound includes contributions by fluvial processes and likely reflects deposition during changing and possibly global scale wetter-to-drier environmental conditions.
•Alluvial materials and inverted channels in the ellipse record hydrologic conditions when they were emplaced and provide the opportunity to sample materials weathered and eroded from the crater walls.

Diversity -
•Multiple mineralogical and stratigraphic units within the 5 km thick mound sequence with alternating inter-bedded phyllosilicate and sulfate bearing beds in the lower mound. Stratigraphy comprising the mound is continuous over many km and well characterized in places.
•Alluvium in the landing ellipse enables sampling crater rim materials that may record environmental conditions during their emplacement and from before the formation of the north-south dichotomy on Mars.

Preservation –
•The phyllosilicate-bearing units in the lower mound and moat include smectites that would help preserve organics if present. Biosignatures may be best preserved in the sulfate bearing strata in the mound.

Exploration Targets –
•The specific distribution of science targets within and outside of the ellipse is well defined. Preserved organics could occur in a high thermal inertia unit in fan in ellipse, in clay rich layers that may not have sulfates, and in the sulfates.

Remaining Uncertainties:

• Although several testable models for mound formation exist, uncertainty remains about the depositional setting for much of the stratigraphy despite a better understanding of the constituent mineralogy. Nevertheless, bed continuity and morphology implies origin of lower section involved deposition onto a wet surface or into standing water and there is evidence for fluvial redistribution of mound materials.
•The source of water associated with deposition remains uncertain, but if sediments were deposited in a lake, the relative paucity of associated valleys suggests groundwater as opposed to meteoric sources.
• The source of the lower mound sediments is unknown but likely from outside of the crater and it is uncertain whether the mound is part of a larger deposit (though it is morphologically similar to deposits seen elsewhere on Mars). Valleys breaching the rim at a stratigraphic level now lost to erosion may have contributed fill to the crater and/or in lake.
• Crater statistics suggest Gale is Late Noachian, whereas floor deposits onlapping the lower mound and including the fan in ellipse are interpreted to be Early Hesperian, thereby bracketing the age of the lower mound. Age of upper mound and total time recorded in the mound is uncertain.
•Preservation potential of organics in the sulfate units may be compromised by the known presence of iron oxides.

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Holden Crater Site

26S, 325E

Overarching Hypothesis:

- Holden crater preserves evidence of a closed fluvial-lacustrine system that provides the opportunity to apply a geomorphic systems approach to evaluating and preserving evidence for a sustained, habitable environment.

Specific Cons of Site:

- Origin of stratified light-toned materials as lacustrine versus alternate depositional processes remains uncertain, but in situ evaluation of bedding character and chemistry is likely to distinguish origin.
- Relatively limited variety of phyllosilicate minerals known to preserve organics detected from orbit.

Specific Pros of Site:

Setting -

•The bajada in the ellipse and light-toned layered materials comprise one of the largest and best preserved alluvial systems on Mars. The diverse and potentially weathered sediments likely record the environmental conditions responsible for their formation during the Hesperian perhaps into the Early Amazonian. This sequence is underlain by the light-toned layered deposits and overlying Uzboi flood deposits and enable the age of the target deposits to be related to global stratigraphy.

•Collectively, additional diverse and widespread megabreccias in and outside the ellipse and alluvial materials in the ellipse suggests sampling of rocks ranging in age from early crustal Noachian to perhaps into the Hesperian or even Early Amazonian.

Diversity -

•Diversity is represented by fan sediments, phyllosilicate-bearing light toned layered deposits, Uzboi flood deposits, and mega-breccias in the crater walls/floor.

•The mineralogical diversity in the light-toned layered deposits and crater walls/floor include both altered and primary compositions.

Preservation -

•Strata comprising the light-toned layered materials may be the equivalent of bottom set beds emplaced in a lacustrine setting, which might preserve organics for interrogation by the MSL.

Exploration Targets –

•Well-defined exploration targets exist within and outside the landing ellipse. Targets within the ellipse offer access to all major units for interrogation, though thicker sections of the light-toned layered materials and megabreccias occur farther to the south. Putative bottomset beds provide a target for evaluating any preserved organics

Remaining Uncertainties:

- There are no shorelines or stratal geometries and limited evidence for other properties associated with the light-toned layered deposits and fans that can be used to more confidently define their origin and genetic relationships.
- Diverse megabreccia occurrences within the ellipse, walls, and rims may include evidence that they supported an impact-induced hydrothermal system.
- Light-toned layers high on the west wall of Holden may relate to older beds excavated from the pre-existing Holden basin.
- Age of light-toned layered deposits and adjacent alluvial fan surfaces are no older than Early Hesperian and fans may be as young as Early Amazonian, though there is no consensus whether this is an issue for habitability and evaluating conditions for life.

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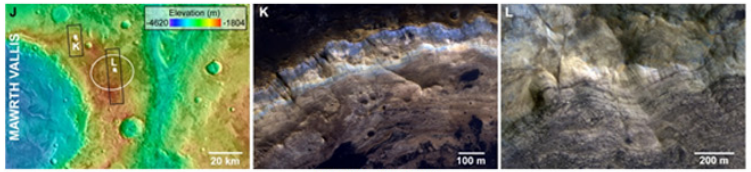
Mawrth Vallis Site



24N, 341E

Overarching Hypothesis:

- Mawrth Vallis records geologic processes during early Martian history, when aqueous phyllosilicate-forming processes were pervasive and persistent. This site provides the opportunity to understand the potential for early habitability on the planet and may be representative of global conditions on Mars.

Possible Cons of Site:

• There is no consensus on the depositional setting or the mechanisms for concentrating or preserving organics and it is unlikely that the depositional setting will be further refined prior to landing and in situ evaluation.
•Although textural and chemical characterization of the units using the MSL payload may distinguish between models for emplacement history, there is not a consensus that such an approach will be successful.

Specific Pros of Site:

Setting -
•Exposes the oldest preserved rocks of the four candidate sites and provides an opportunity to explore Noachian crust to seek and investigate information about the processes active on early Mars.
•The relative ages of exposed rocks are well constrained and suggests they are among the oldest preserved on Mars and might be from a period not recorded in the rock record on Earth.
•Hydrated minerals are present and modeled to contribute several tens of percent by volume to the rocks (most of any of the sites) that formed in aqueous environments. The section within and near the landing ellipse appears to be mineralogically representative of other Noachian crustal sections in Arabia Terra, thus allowing an understanding of what possibly were widespread processes on early Mars. Capping mesa-forming materials appear unaltered and may record changing conditions during the Hesperian and younger times.

Diversity –
•The ellipse and go to outcrops encompass a diverse, complex mineralogical and rock sequence that includes many of the hydrated minerals found on Mars (multiple phyllosilicates and sulfates) whose formation records varying aqueous environmental conditions and any changes in surface aqueous alteration environments. Rocks were likely emplaced by multiple geologic mechanisms that probably included diagenetic (e.g., for Al-phyllosilicates), impact, fluvial, and/or pedogenic processes, and remain in situ.

Preservation -
•Several locations in close proximity and within the ellipse may allow interrogation of a variety of rocks to help define the early period of time when water was present and determine whether the environment was habitable. The phyllosilicate-bearing units include smectites, suggesting they are well preserved and may contain/help preserve organics.

Exploration Targets –
•A good list of prioritized targets within the ellipse has been identified and targets outside the ellipse, including sulfates, are also well-defined. Both the Mg/Fe and Al- bearing phyllosilicate units need to be interrogated to assess the nature and distribution of any organics.

Remaining Uncertainties:

• The depositional setting(s) associated with emplacement of the rocks and mineralogic units at Mawrth remains uncertain, is unlikely to be resolved using existing orbital data sets, but may be resolved in situ.
• It is uncertain if the observed alteration record (i.e., represented by the Al-phyllosilicates) extends to the primary Fe/Mg smectite deposit and its potential organic record.
• It remains uncertain whether Oyama crater ejecta persists or which unit it might correspond to, though Al-phyllosilicates likely post-date Oyama.
•The amount, source, and duration of interaction with water in development of the units remains uncertain.