Mars Landing Site Selection Activities:

An Update on MSL and Future Missions

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MSL Project
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<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Define/Refine Constraints</td>
<td>(e.g., rock abundance)</td>
</tr>
<tr>
<td>2007</td>
<td>Consider constraints where possible</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Steering Comm. adds 7th Site</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Consider Engineering constraints</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Limited Ongoing Studies</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Mature Engineering constraints</td>
<td>(e.g., wheel actuators)</td>
</tr>
</tbody>
</table>
~50 Proposed MSL Landing Sites

Shaded areas are above +30°N, below -30°S, and above +1 km in elevation
Seven Downselected MSL Landing Sites:

Mawrth Vallis
Miyamoto Crater
Eberswalde Crater
Holden Crater

Seven Sites Receiving Highest Science Ranking:
Shaded areas above +30°N and -30°S, elevations >1 km
Green outlines denote final four sites based on science, engineering
Mars Landing Site Selection Activities

Four Sites: Mawrth, Gale, Eberswalde, Holden

Potential Sites: NE Syrtis, E Margaritifer
Final Four MSL Landing Ellipses

Eberswalde

Gale

Mawrth 2

Holden

25 km x 20 km Ellipses
## Final 4 MSL Landing Sites

<table>
<thead>
<tr>
<th>NAME</th>
<th>LOCATION</th>
<th>ELEVATION</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holden Crater</td>
<td>26.37°S, 325.10°E</td>
<td>-1940 m</td>
<td>Fluvial Layers, Phyllosilicates</td>
</tr>
<tr>
<td>Mawrth Vallis (2)</td>
<td>24.01°N, 341.03°E</td>
<td>-2246 m</td>
<td>Noachian Layered Phyllosilicates</td>
</tr>
<tr>
<td>Eberswalde Crater</td>
<td>23.86°S, 326.73°E</td>
<td>-1450 m</td>
<td>Delta, Phyllosilicate</td>
</tr>
<tr>
<td>Gale Crater</td>
<td>4.49°S, 137.42°E</td>
<td>-4451 m</td>
<td>Layered Sulfates, Phyllosilicates</td>
</tr>
</tbody>
</table>
HiRISE Coverage of Four MSL Landing Sites:
Stereo HiRISE Coverage of Four MSL Landing Sites:

- Holden Crater
- Eberswalde Crater
- Gale Crater
- Mawrth Vallis
Clay-Bearing Beds in Deltaic Setting:

- Strata exposed in meander bend dip outward, as expected for a point bar deposit (not simply erosional)

From Ralph Milliken
Mars Landing Site Selection Activities

Gale Crater: K. Edgett, B. Thomson, N. Bridges, R. Milliken

- High diversity of geologic materials with different compositions and depositional conditions
- This diversity is arranged in a stratigraphic context
- Stratigraphy records multiple early Mars environments in sequential order
- Gale is characteristic of a family of craters that were filled, buried, and exhumed, providing insights into an important martian process
Gale Crater
Holden Crater: J. Grant, R. Irwin, K. Whipple

PSP_001468_1535

100 m
Mars Landing Site Selection Activities

Holden Crater

DEM Provided by O. Aharonson
Mawrth Vallis: J-P Bibring, F. Poulet, J. Michalski, J. Bishop, E, Noe Dobra, J. Wray
Mawrth Vallis: Phyllosilicate-Bearing Stratigraphy within the Landing Ellipse:

- Red: Fe/Mg smectite (Fe³⁺)
- Green: ferrous phase (Fe²⁺)
- Blue: Al-phyllosilicate and/or hydrated silica

From Janice Bishop

From James Wray
Mars Landing Site Selection Activities

Potential New MSL Site Sites:

Taking Advantage of Launch Delay – Respond to New Discoveries/New Sites Identified by MRO

Call for new sites in August 2009

- Five Sites Met Criteria: Mineralologic/Morphologic Compelling; As safe as existing sites
  - Steering Committee, Project Review Dec. 11, 2009
    - Science and Safety
  - Strong Consensus NE Syrtis, E Margaritifer Potentially Compelling
    - NE Syrtis – Diverse Noachian Mineralogy (Phyllo, Serp, Carb)
    - E Margaritifer – Chlorides, Phllosilicates

MRO Imaging Mostly Complete

- Complete Stereo HiRISE Covergae of Ellipses
- Completing CRISM Covergae of Ellipses

Steering Committee & Project Review of Two Sites, early May 2010

- Science – Materials Available, Preservation Aqueous Environment
- Safety – Comparison to Existing 4 Landing Sites
- Recommend whether One Additional Site Should be Added
Newly Proposed Candidate MSL Landing Sites

Holden Crater
Eberswalde
Mawrth Vallis
Gale Crater
Nili Carbonate

NE Syrtis
Ladon - Chlorides
E Margaritifer Chlorides - Phyllo
Xanthe Terra fan delta
Mars Landing Site Selection Activities

New Proposed MSL Landing Sites

- 5.6S, 353.5E - 1.2 km E Margaritifer
- 18.8S, 332.5E - 2.1 km Ladon basin
- 21.7N, 78.8E - 1.5 km Nili Carbonate
- 16.7N, 76.9E - 2.6 km NE Syrtis
- 2.3N, 309E - 2.1 km Xanthe Terra crater

HiRISE Coverage Dec. 2009
A Thumbnail View of the Newly Proposed Sites:

- **East Margaritifer Chloride**
- **Ladon Basin Chloride**
- **Nili Carbonate**
- **NE Syrtis**
- **Xanthe Delta**
Mars Landing Site Selection Activities

Center Location 17.808 N, 77.076 E
Center elevation: -2033 m

HiRISE Coverage

CRISM Coverage

Center Location 5.644 S, 353.82 E
Center elevation: -1254 m

HiRISE Coverage

CRISM Coverage

Center Location 17.808 N, 77.076 E
Center elevation: -2033 m
Mars Landing Site Selection Activities


ABSTRACT
Surface characteristics at the five sites where spacecraft have successfully landed on Mars can be related favorably to their signatures in remotely sensed data from orbit and from the Earth. Comparisons of the rock abundance, types and coverage of soils (and their physical properties), thermal inertia, albedo, and topographic slope all agree with orbital remote-sensing estimates and show that the materials at the landing sites can be used as “ground truth” for the materials that make up most of the equatorial and mid-latitude regions of Mars. The five landing sites sample two of the three dominant global thermal inertia and albedo units that cover ~80% of the surface of Mars. The Viking landers 1 and 2, Spirit, and Mars Pathfinder landing sites are representative of the moderate-to-high thermal inertia and intermediate-to-high albedo unit that is dominated by crusty, doddly, and blocky soils (duricrust) with various abundances of rocks and bright dust. The Opportunity landing site is representative of the moderate-to-high thermal inertia and low-albedo surface unit that is relatively dust-free and composed of dark eolian sand and/or increased abundance of rocks. Interpretation of radar data confirms the presence of load bearing, relatively dense surfaces controlled by the soil type at the landing sites, regional rock populations from diffuse scattering similar to those observed directly at the sites, and root-mean-squared (RMS) slopes that compare favorably with 100 m scale topographic slopes extrapolated from altemetry profiles and meter scale slopes from high-resolution stereo images. The third global unit has very low thermal inertia and very high albedo, indicating that it is dominated by meter thick deposits of bright red atmospheric dust that may be neither load bearing nor trafficable. The landers have thus sampled the majority of likely safe and trafficable surfaces that cover most of Mars and shown that remote-sensing data can be used to infer the surface characteristics, slopes, and surface materials present at other locations.

21.1 INTRODUCTION
Understanding the relationship between orbital remote-sensing data and the surface is essential for safely landing spacecraft and for correctly interpreting the surfaces and materials globally present on Mars. Understanding the surfaces and materials globally present on Mars is also fundamentally important for inferring the erosional, weathering, and depositional processes that create and modify the Martian surface layer (Christensen and Moore, 1992). Although relatively thin, this surface layer or regolith, composed of rocks and soils, represents the key record of geologic processes that have shaped it, including the interaction of the surface and atmosphere through time via various chemical alteration, weathering, and eolian (wind-driven) processes.

Most of our detailed information about the specific materials that make up the Martian surface comes from the in situ investigations accomplished by the five successful landers. The first successful landings were the Viking landers in 1976, part of two orbiter/lander pairs that were launched in 1975 (Soffen and Young, 1972). Although the overriding impetus for the Viking landings was to determine if life existed on Mars, both stationary landers carried imagers, seismometers, atmospheric science packages, and magnetic and physical property experiments as well as the sophisticated life detection experiments. The Viking landers studied the landing sites, determined the chemistry of soils at the surface and in shallow trenches, and determined physical properties of surface materials by digging trenches with their sampling arms (Soffen, 1977).

The Mars Pathfinder (MPF) mission, launched 20 years later in 1996, was an engineering demonstration of a low-cost lander and small mobile rover (Golombek, 1997). The lander carried a stereooscopic color imager, which included a magnetic properties experiment and wind sock, and an atmospheric structure and meteorology experiment. The 10kg rover (Sojourner) carried engineering cameras, ten technology experiments, and an Alpha Proton X-ray Spectrometer for measuring the elemental composition of surface materials. The MPF rover traversed a about 100 m around the lander, exploring the landing site and characterizing surface materials in a few hundred square meter area (Golombek et al., 1999a; see also Chapters 3 and 12).

The Mars Exploration Rovers (MERs) Spirit and Opportunity landed twin moderate-sized rovers in early 2004 which have explored over 7 and 10km, respectively, of the surface at two locations. Each rover carries a payload that includes multiple imaging systems consisting of stereo Navigation Cameras (Navcam), the color stereo Panoramic Cameras (Pancam), and the Miniature Thermal Emission Spectrometer (Mini-TES), all on a 1.5m high mast. The rovers also carry an arm that can brush and grind a way the outer layer of rocks (the Rock Abrasion Tool or RAT) and can place an Alpha Particle X-ray Spectrometer (APXS), Surface Characteristics

Chapter from New Mars Book

Direct Relationship between Surface Characteristics at Landing Sites and Remote Sensing Signatures from Orbit

Surface - Cohesion, Particle Size of Fine Component and Rocks, topo maps
Orbit - Thermal Inertia, Albedo, Dust Index, Rock Abundance, Rocks, topo maps

Comparison & Data Improved Past 12 years Successful Prediction of MPF, MER, PHX Landing Sites
Site Characterization

Mars Landing Site Selection Activities

Extensive Acquisition & Analysis Orbiter Data

Create Data Products that Address Engineering Constraints
CDP Supports Generation of Data Products
HiRISE DTMs & Photoclinometry, Rock Maps, Thermal Inertia, MOLA Slopes, CTX DTMs, Radar Analysis

Support Engineering Landing Simulations & Safety Analysis

Engineering Constraints on Landing Sites
Latitude, Elevation, Ellipse Size, Slopes (many scales),
Rocks, Radar Reflectivity, Load Bearing (thermal inertia & albedo)

Greatest Concern is Slopes and Rocks at Rover Scale
Rocks - Safety Concern
Rocks >0.6 m high [1.2 m diameter] - landing stability and loads
m scale slopes concern - appears stable beyond 15° to 20-25°
km scale and 100 m slopes important for radar
May be less of a concern at these sites

Physical material properties will be important for trafficability analysis
Surface Characterization

3 Sites Relatively Dust Free; 4th Target Layers
Competent Load Bearing Surfaces, Radar Reflective

All Sites ~Meet 0.2-10 km Relief/Slope Constraint
   Rough Eberswalde, Gale, Mawrth, Holden Smooth

2-5 m Slopes:
   Rough Eberswalde, Gale, Mawrth, Holden Smooth

Rock Abundance
   Rocky Eberswalde, Gale, Mawrth, Holden Few Rocks

Combining Rocks & 2-5 m Slopes - Most Important Characteristics
   Rough/Rocky Eberswalde, Gale, Mawrth, Holden Smooth/Few Rocks

Additional Data Analysis & Landing Simulations
Will Determine Relative Safety
Traverse Requirements and Scenarios
Science versus Safety Trade

Landing Simulations - Determine Relative Safety of Sites
Example of Risk versus Reward Trade

*Eberswalde Concerns with 100 m & 2-5 m slopes and rocky, Southern latitude, well understood depositional environment, quiet water clay deposits, address MSL science objectives directly

*Gale some rock and slope concerns (edge of ellipse), target materials require traverse outside of ellipse, sulfates and phyllosilicate layers present, unknown depositional setting, with poor geologic context or age of materials

*Mawrth some slope concerns, non “go to” site, Fe & Al phyllosilicates of LN age present, but uncertain depositional and/or diagenetic setting

*Holden no safety concerns, target materials require traverse outside of ellipse, Southern latitude, layered phyllosilicates in lacustrine or fluvial setting, well understood geologic context
Future MSL Site Selection Activities

• E Margaritifer & NE Syrtis sites
  • Evaluated early May 2010
  • One may be added to list of four
• Fourth Community Workshop Sept. 27-29 near JPL
  • In depth discussion science merits and surface characteristics
• PSG Working Group - detailed look at sites
  • Science targets & traversability
  • Chaired by Ken Edgett & Dawn Sumner, involve community via site advocates
• Fifth Community Workshop in March/April 2011
  • Findings of PSG Working Group
  • Final discussion of science merits & surface characteristics
• Independent Peer Review
• Selection by HQ in April 2011
Planning Future Site Selection Activities:

Mars Landing Site Selection Activities

Future Mars Landing Site Selection Activities
Submitted to MEPAG: Planetary Science Decadal Planning Group, and NASA HQ
John Grant, Matt Golombek, Alfred McEwen, Scott Murdoch, Frank Seibert, John Mustard, David Vaniman, Ken Tanaka, Gian Omori, Nicolas Mangold, Kate Rubbo, Steve Ruff, Don Ban, Summer, Brad Jalil, and Ralph Harvey

Abstract: Mars landing site selection activities help define the science potential and engineering risks associated with landed missions and take advantage of existing orbital assets to make discoveries that shape the integrated program of Mars exploration over time. Currently, orbiting missions, including Mars Odyssey and Mars Reconnaissance Orbiter in particular, have proven outstanding in identifying and characterizing candidate landing sites for future missions. As demonstrated by the loss of Mars Global Surveyor, however, these orbiting spacecraft have finite lifetimes and there are currently no plans or resources available to replace them or their instruments. We recommend that a process for identifying and characterizing candidate landing sites for a range of future mission scenarios be undertaken as soon as possible. This process should be accompanied by creation of a dedicated pool of funding to support landing site characterization activities via the peer review process and that would allow proposals that include suggesting imaging targets and the use of unreleased data. NASA should also provide sufficient resources to existing missions to enable these activities, especially during periods of high data return from Mars. Finally, NASA should consider including instruments with site-characterization capabilities on future missions.

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Presented at last MEPAG; Unanimous Support; White paper to Decadal Survey

Orbital assets exist now that can provide data for a wide variety of candidate landing sites

These orbiters and instruments have finite capabilities and lifetime (MGS) and instruments with equivalent or better/unique capabilities might not fly before possible landings in 2018 and beyond

Solicit Candidate Landing Sites for Future Missions [All Missions and Concepts]

Begin Imaging to Support Investigations; MRO Agreed to 3-4 Targets per Cycle

Workshops to Discuss Merits of Sites; Steering Committee to Review, Prioritize Sites

Funding to Support Site Investigations
Future Landing Sites:

- Call for sites (for range of future missions) made late last year, resulted in 15 candidates
- Call for CDP, additional candidate sites (proposals submitted March 1st)
  - Expected to fund 5-10 proposals for 25K for 1 year
  - Possibility for renewal
- New sites reviewed by Steering Committee to assess merits and rank for imaging by MRO
- Steering Committee represents broad interests (Astrobiology to SR and others)
  - Steering Committee includes John Grant, Matt Golombek (co-chairs), Dave Des Marais, Brad Jolliff, Nicolas Mangold, Alfred McEwen, John Mustard, Gian Ori, Steve Ruff, and Ken Tanaka
  - Ellipses generally 10 km X 15 km (or 15 km), many focused on MAX-C but others specified by proposer
  - Steering Committee Chairs work with proposers to establish image footprints
### New Candidate Landing Sites Submitted:

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Elevation (MOLA)</th>
<th>Target</th>
<th>Mission, Ellipse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antoniadi Crater [Smith et al.]</td>
<td>20.34°N, 62.91°E</td>
<td>+0.1</td>
<td>Granitoid, phyllosilicates, zeolites</td>
<td>MAX-C 15 km Ellipse</td>
</tr>
<tr>
<td>Columbus crater [Wray et al.]</td>
<td>28.8°S, 194.0°E</td>
<td>+0.9</td>
<td>Intracraterr layers kaolinite, smectites, jarosite, mono- and polyhydrates sulfates</td>
<td>Rover 15 km ellipse, MAX-C</td>
</tr>
<tr>
<td>Vernal Crater [Oehler &amp; Allen]</td>
<td>4.25°N, 354.34°E</td>
<td>-1.98</td>
<td>Potential Spring Deposits</td>
<td>Rover 15 km ellipse</td>
</tr>
<tr>
<td>Acidalia Planitia [Oehler &amp; Allen]</td>
<td>40.16 N, 333.22 E</td>
<td>-4.5</td>
<td>Mounds Interpreted as Mud Volcanoes</td>
<td>Rover 15 km ellipse</td>
</tr>
<tr>
<td>Acidalia Mensa [Oehler &amp; Allen]</td>
<td>46.63 N, 331.35 E</td>
<td>-4.5</td>
<td>Mounds Interpreted as Mud Volcanoes</td>
<td>Rover 15 km ellipse</td>
</tr>
<tr>
<td>Avire Crater [Harrison]</td>
<td>4.125°S, 159.86°W</td>
<td>-0.77</td>
<td>Gullies, mid-latitude fill material, layered lobate features, dunes</td>
<td>Rover 15 km ellipse, MAX-C Special Region</td>
</tr>
<tr>
<td>Kamnik Crater [Harrison]</td>
<td>37.49°S, 161.87°W</td>
<td>+2.3</td>
<td>Gullies, mantling material, mid-latitude “fill”</td>
<td>Rover 1 km ellipse inside crater, or outside, Special Region</td>
</tr>
<tr>
<td>Naruko Crater [Harrison]</td>
<td>36.55°S, 161.80°W</td>
<td>+2.7</td>
<td>Gullies, mantling material, mid-latitude “fill”</td>
<td>Rover 1 km ellipse inside crater, or outside, Special Region</td>
</tr>
<tr>
<td>Terby Crater [Grotzinger et al.]</td>
<td>27.79°S, 74.17°E</td>
<td>-4.9</td>
<td>Layered mound, possible evaporates, phyllosilicates</td>
<td>Rover 15 km x 10 km ellipse</td>
</tr>
<tr>
<td>Melas Chasma [Grotzinger et al.]</td>
<td>9.806°S, 76.507°W</td>
<td>-1.7</td>
<td>Sublacustrine fans, clinoforms, folds, channels, opaline silica</td>
<td>Rover 15 km x 10 km ellipse</td>
</tr>
<tr>
<td>N Pole A [Milovich &amp; Hecht]</td>
<td>89.0°N, 280.0°E</td>
<td>-2.5</td>
<td>Polar layered deposits, ice</td>
<td>Mars Scout, thermal drill, 250 km x 25 km ellipse</td>
</tr>
<tr>
<td>N Pole B, The saddle [Milovich &amp; Hecht]</td>
<td>84.0°N, 34.0°E</td>
<td>-3.0</td>
<td>Polar layered deposits, ice</td>
<td>Mars Scout, thermal drill, 250 km x 25 km ellipse</td>
</tr>
<tr>
<td>Paleolake in Ismenius Cavus [Wray et al.]</td>
<td>33.5°N, 17.0°E</td>
<td>~3.0</td>
<td>Phyllosilicates in crater breached by Manners Vallis. Well formed delta on NE wall</td>
<td>Astobio/MAX-C, 15 X 15 km ellipse</td>
</tr>
<tr>
<td>Southern Meridiani [Wiseman and Arvidson]</td>
<td>3.2°S, 354.5°E</td>
<td>-1.5</td>
<td>Land on and traverse from sulfates to phyllosilicates in highlands</td>
<td>15 X 15 km ellipse, MAX-C</td>
</tr>
<tr>
<td>N Pole C, Gemini Lingula [Milovich &amp; Hecht]</td>
<td>82.2°N, 354.0°E</td>
<td>-3.3</td>
<td>Polar layered deposits, ice</td>
<td>Mars Scout, thermal drill, 250 km x 25 km ellipse</td>
</tr>
</tbody>
</table>
May Future Landing Sites

Be as Compelling as these for MSL