Spatial Analysis of the final four Mars Science Laboratory (MSL) landing sites

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Outline

1. Where on Mars can we land?
   - MSL Landing Constraints
2. What data do we have?
   - Spatial Data Products
3. Image Integration into a Geographic Information System (GIS)
   - Georeferencing and Rectification
   - Resolution Pyramid
4. The Future of Landing Site Spatial Analysis
   - Tactical and Strategic Planning
### Table 3. Summary of Final Landing Site Engineering Constraints

<table>
<thead>
<tr>
<th>Engineering Parameter</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>±30°</td>
<td>Thermal Management</td>
</tr>
<tr>
<td>Elevation</td>
<td>&lt;-1 km wrt MOLA geoid</td>
<td>Sufficient atmosphere to slow spacecraft</td>
</tr>
<tr>
<td>Ellipse dimension</td>
<td>25 km by 20 km, roughly E-W</td>
<td>Aero-maneuvering accuracy</td>
</tr>
<tr>
<td>Terrain relief 1-1000 m baselines</td>
<td>100-130 m</td>
<td>Control authority and sufficient fuel during powered descent</td>
</tr>
<tr>
<td>Slopes at 2-5 m length scale</td>
<td>&lt;30°</td>
<td>Rover stability at touchdown</td>
</tr>
<tr>
<td>Rock height and abundance</td>
<td>Less than 0.5% probability of at least one ≤0.55 m high rock in 4 m² area, Equivalent to rock abundance of &lt;8%</td>
<td>Impacting rover belly pan or inside of wheels during touchdown</td>
</tr>
<tr>
<td>Radar reflectivity</td>
<td>Ka band reflective with radar backscatter cross section between -20dB and 15 dB</td>
<td>Radar altimeter (TDS) returns during descent</td>
</tr>
<tr>
<td>Load bearing surface No thick dust deposits</td>
<td>Thermal inertia &gt;100 J m⁻² s⁻⁰.⁵ K⁻¹ and albedo &lt;0.25, Radar reflectivity &gt;0.01 for load bearing bulk density</td>
<td>Rover trafficability No sinkage during touchdown</td>
</tr>
</tbody>
</table>

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Latitude +-30 degrees
Elevation < -1 km
Thermal Inertia > 100 TIU
Figure 2. MOLA topographic map of Mars showing location of landing sites proposed for the Mars Science Laboratory at the first workshop (numbered in order of prioritization, Table 5). Revised engineering constraints later restricted landing sites to ±45° latitude and finally ±30°.
## Science Constraints

<table>
<thead>
<tr>
<th>Category</th>
<th>Miya</th>
<th>SMer</th>
<th>Nili</th>
<th>Hold</th>
<th>Ebers</th>
<th>Maw2</th>
<th>Gale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Multiple rock units obs. from orbit?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>2) Well-defined strat./X-cutting relations?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3) Diverse mineralogy / systematic trends?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>4) Diverse geomorphology / system. trends?</td>
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<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td><strong>Context</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5) Geologic framework before landing?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>6) Place MSL obs. into regional context?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>7) Well-resolved chronology of rock units?</td>
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<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<td><strong>Habitability</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8) Min./Geomorph. evidence?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>9) Indicators of water duration, pH, activity?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td><strong>Preservation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>10) Timing of minerals wrt sedimentation?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>11) Environment for preservation?</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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</tbody>
</table>

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Eberswalde Crater: MOLA

Legend
MOLA_grid1.img
Values:
- High: 1000
- Low: 1500

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Mawrth Vallis Site 2: MOLA
MOLA Relief <100m over 1km
Gale
Holden

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Eberswalde: HiRISE Footprints
Gale: HiRISE Footprints
Holden: HiRISE Footprints
Mawrth: HiRISE Footprints
Table 4. HiRISE stereo pairs and images* used to make DEMs, orthophotos, rock maps, terrain classification and traversability maps at the time of landing site selection

<table>
<thead>
<tr>
<th>Eberswalde Crater</th>
<th>Gale Crater</th>
<th>Holden Crater</th>
<th>Mawrth Vallis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSP_008272_1560</td>
<td>PSP_009149_1750</td>
<td>PSP_002088_1530</td>
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<td>ESP_019045_1530*</td>
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<td>ESP_019322_1530</td>
<td>ESP_016262_2040*</td>
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<td>ESP_020034_1560</td>
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<td>ESP_020324_1555*</td>
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<td>ESP_019823_1530*</td>
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<tr>
<td>ESP_020390_1555</td>
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<td>ESP_019889_1530</td>
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</tr>
</tbody>
</table>

Images with an asterisk denote those used for computing rock lists and their derived products: rock abundance, cumulative fractional area, and “additional strikes”.

*Calef – Spatial Analysis of MSL Landing Sites - 2011*
Orthophotos - Eberswalde

Area of the ellipse: 392.68 km²

Ortho Photo Coverage: 369.11 km² (94.00%)
Area of the ellipse: 392.68 km²
Ortho Photo Coverage: 312.19 km² (79.50%)
Area of the ellipse: 392.68 km²

Ortho Photo Coverage: 333.45 km² (84.92%)
Orthophotos - Mawrth

Area of the ellipse: 392.68 km²

Ortho Photo Coverage: 372.05 km² (94.75%)
Elevation Data Volume = 4 x MARS

Modified from Kirk et al. EPSC/DPS, 2011
Eberswalde

All ellipses are 20x25 km

Sites use same color scale for slopes, different for elevations

Modified from Kirk et al. EPSC/DPS, 2011
Gale

Modified from Kirk et al. EPSC/DPS, 2011
Holden

Modified from Kirk et al. EPSC/DPS, 2011
Mawrth

Modified from Kirk et al. EPSC/DPS, 2011
Adirectional Slope Distributions

Past and Candidate Landing Sites Compared

Cumulative Fraction of Area Below Slope vs. Adirectional Slope

- Eberswalde Total
- Eberswalde T Total
- Mawrth2 Total
- Gale Total
- Gale T1
- Holden Total
- Holden T Total
- Spirit
- Opportunity
- Phoenix

Randy Kirk et al. EPSC/DPS, Nantes 2011
GIS Integration and Georeferencing

Calef – Spatial Analysis of MSL Landing Sites - 2011
Image Georeferencing
Horizontal and Vertical Transformation Statistics

Randy Kirk et al. EPSC/DPS, Nantes 2011
Resolution Pyramid
HRSC (12.5m/pixel)
Resolution Pyramid
CTX (6m/pixel)
Resolution Pyramid
HiRISE (0.25 m/pixel)
Cumulative Fractional Area
Inescapable Hazard - Crater
(Barely) Escapable Hazard – ‘Mesa’
Traverse Hazards - Dunes
Maps show the probability of failure from rocks and slopes convolved with the probability of landing within each 150 m cell.
Future Tactical and Strategic Planning

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Gale

D = 45 m

Secondaries? Where from?

Isochrons from Calef et al., (2011)

LPSC XLII, #2717
Mineralogy across traverse routes

CRISM RGB mineral parameter maps (red = Fe-minerals, green = Fe/Mg-clay minerals, blue = sulfates) overlain on CTX mosaic.

Bright red regions correspond to olivine-bearing dunes, green regions contain nontronite, and dark blue regions contain sulfates. Orange and magenta regions contain sulfates and clay minerals in variable proportions.

Can get through mineral strata observed from orbit

Description and image taken from:
Cratered Plains – No obvious Mobility Concerns

Dark Dunes Appear Fresh
Many Exceed 30° Mobility Impediment

Sample Strata Here

Drive up Canyon Here

Can Access Mineral Strata in CRISM
Can drive up mound

Gale Crater

Gale Crater: CTX

Golombek et al., MSL Data Products
Thermal Inertia Maps

Fergason et al. (2006a)
Material Properties Map
Automated Texture Analysis to identify geologic features
Traverse Cost Maps
Traverse Cost Maps

Paolo Bellutta
‘Toe Dip’ to Targets

Rachael Hoover
Dunes? No Problem!

Rachael Hoover
Gale Traverse Planning

Paolo Bellutta
Where do you want to go?
Special Thanks to:
- Matthew Golombek
  - Paolo Bellutta
  - Andres Huertas
  - Devin Kipp
  - Randy Kirk
Questions?

SELECTION OF THE MARS SCIENCE LABORATORY LANDING SITE

Journal Geophysical Research, 2011

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