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Mineralogical characterization of Mars Science Laboratory candidate landing sites from THEMIS and TES data

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ABSTRACT

Data from the Mars Global Surveyor Thermal Emission Spectrometer (TES) and the Mars Odyssey Thermal Emission Imaging System (THEMIS) instruments are used to assess the mineralogic and dust cover characteristics of landing regions proposed for the Mars Science Laboratory (MSL) mission. Candidate regions examined in this study are Eberswalde crater, Gale crater, Holden crater, Mawrth Vallis, Miyamoto crater, Nili Fossae Trough, and south Meridiani Planum. Compositional units identified in each region from TES and THEMIS data are distinguished by variations in hematite, olivine, pyroxene and high-silica phase abundance, whereas no units are distinguished by elevated phyllosilicate or sulfate abundance. Though phyllosilicate minerals have been identified in all sites using near-infrared observations, these minerals are not unambiguously detected using either TES spectral index or deconvolution analysis methods. For some of the sites, small phyllosilicate outcrop sizes relative to the TES field of view likely hinder phyllosilicate mineral detection. Porous texture and/or small particle size (<∼60 μm) associated with the phyllosilicate-bearing surfaces may also contribute to non-detections in the thermal infrared data sets, in some areas. However, in Mawrth Vallis and Nili Fossae, low phyllosilicate abundance (<10–20 areal %, depending on the phyllosilicate composition) is the most likely explanation for non-detection. TES data over Mawrth Vallis indicate that phyllosilicate-bearing surfaces also contain significant concentrations (>15%, possibly up to ∼40%) of a high-silica phase such as amorphous silica or zeolite. High-silica phase abundance over phyllosilicate-bearing surfaces in Mawrth Vallis is higher than that of surrounding surfaces by 10–15%. With the exception of these high-silica surfaces in Mawrth Vallis, regions examined in this study exhibit similar bulk mineralogical compositions to that of most low-albedo regions on Mars; the MSL scientific payload will thus be able to provide important information on surface materials typical of low-albedo regions in addition to investigating the origin of phyllosilicate and/or sulfate deposits. With the exception of Gale crater, all of the landing sites have relatively low dust cover compared to classic high-albedo regions (Tharsis, Arabia and Elysium) and to previous landing sites in Gusev Crater, Utopia Planitia, and Chryse Planitia.

1. Introduction

The Mars Science Laboratory (MSL) is a roving robotic spacecraft planned for launch in 2011. MSL mission objectives are to locate and interpret evidence of the environmental history of a region of Mars, particularly with respect to characterizing past or present habitability. The design of MSL allows for considerably relaxed constraints on landing site selection compared to those for the Mars Exploration Rovers (Golombek et al., 2003), with an allowable latitude range of 45°S to 30°N, altitudes as high as 1 km above the areoid, and landing ellipses as small as 25 km along the major elliptical axis (http://marsoweb.nas.nasa.gov/landingsites/index.html). In early 2006, the Mars scientific community was solicited for candidate landing site suggestions. Since that time, more than 30 sites have been proposed in response to the initial call. During the course of three open workshops held in June 2006, October 2007, and September 2008, candidate landing site regions were prioritized and down-selected on the basis of (1) morphologic and spectroscopic evidence for aqueous activity and/or habitable environment from existing orbital data, (2) mineralogic diversity, (3) likelihood that surface materials encountered by MSL will be easily placed into a more regional context observed from orbit, and (4) potential for biosignature preservation (http://marsoweb.nas.nasa.gov/landingsites/msl2009/memoranda/sites_jul08/Discussion%20Points-Science%20Criteria.doc). At the conclusion of the September 2008 workshop, the final sites under consideration were: Eberswalde crater, Gale crater, Holden crater, Miyamoto crater, Nili Fossae Trough, south Meridiani Planum,

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and four separate locations in Mawrth Vallis (Table 1). In November 2008, the MSL landing site steering committee further reduced the list of candidate landing sites to Gale crater, Holden crater, Eberswalde crater, and ellipse number two in Mawrth Vallis. In the months leading up to the launch of MSL, a single landing region will be selected from these top four sites. A final landing site workshop will also be held to choose a specific landing ellipse location within that region (http://marsoweb.nas.nasa.gov/landingsites/index.html).

Our work uses data from the Mars Global Surveyor Thermal Emission Spectrometer (TES) and the Mars Odyssey Thermal Emission Imaging System (THEMIS) to assess the mineralogic characteristics and dust cover contribution for the top seven candidate landing regions reviewed at the September 2008 workshop. This work was carried out under directive from the MSL program to (1) facilitate selection of the site with the highest possible scientific potential by maximizing the mineralogical understanding of candidate regions, as well as to (2) provide context while the mission is in progress. These thermal infrared (TIR) analyses are highly complementary to ongoing near-infrared (NIR) measurements of each site from the Mars Express Observatoire pour la Minéralogie, l'Eau, les Glaces, et l'Activité (OMEGA) (Bibring et al., 2005) and Mars Reconnaissance Orbiter Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (Murchie et al., 2007) instruments. This paper does not address the detailed NIR spectral characteristics or thermophysical properties of the candidate sites; these aspects are the subjects of ongoing work by other researchers (Fergason, R., 2008. Thermal Inertia Maps of Candidate MSL Landing Sites, presentation at the 3rd MSL Landing Site Workshop, Monrovia, CA. Available from: <http://marsoweb.nas.nasa.gov/landingsites/msl2009/workshops/3rd_workshop/program.html/>; Seelos et al., 2008; Michalski and Fergason, 2009).

The data sets, processing, and analysis methods used in this work are described first below. Then for each site, a brief overview of the science rationale behind its candidacy and an analysis of the mineralogical and dust cover characteristics are given. Sites are presented in order of increasing east longitude. Data products generated for this work are currently available in raw format at http://faculty.washington.edu/joshband/cdp/index.html.

2. Data and methods

2.1. THEMIS and TES instrument descriptions

The THEMIS infrared subsystem is a multispectral imager with ~100 m/pixel spatial sampling and a swath width of ~32 km. The infrared imager measures radiation at nine wavelengths between ~6.8 and 14.9 μm, with an average bandwidth of ~1 μm for each channel (Christensen et al., 2004). For each site, spectral units are identified from THEMIS IR data and their distributions are mapped at full spatial resolution (Section 2.2). Detailed mineralogical information is then determined for each spectral unit using TES data (Section 2.3).

The TES instrument measures infrared radiation between ~6 and 50 μm (1700–200 cm^{-1}) with a selectable spectral sampling of 5 or 10 cm^{-1}. The TES instrument also contains a visible bolometer that measures lambert albedo between ~0.3 and 3.0 μm. Each detector footprint covers an area of ~3 × 8 km (Christensen et al., 1992, 2001). In this work, the TES data are used to perform quantitative mineralogical analyses (Section 2.3) and spectral feature mapping (Sections 2.4 and 2.5) for each site. The TES hyperspectral, low-spatial resolution data may be used in combination with THEMIS data to provide detailed mineralogic information at a high-spatial resolution.

2.2. Spectral unit maps

For each candidate site, THEMIS daytime radiance images with warm average surface temperatures (>245 K) are corrected for atmospheric dust and water ice contributions and converted to emissivity using the methods described by Bandfield et al. (2004). Atmospherically corrected THEMIS images are then mosaicked together, with a spatial resolution of 100 m per pixel. Decorrelation stretched (DCS) (Gillespie et al., 1986) emissivity images are used to identify spectral end-members within each candidate landing region. Average spectra from each end-member surface are extracted from each image in the mosaic. Those spectra are then normalized to the mean spectral contrast and averaged to obtain a representative spectral shape for that end-member surface. The normalization to average spectral contrast results in some surfaces exhibiting modeled concentrations greater than 1.0 in the spectral unit maps.

Once spectral end-members are identified, spectral unit maps are generated from surface emissivity mosaics using a spectral library that includes the end-members plus spectra appropriate for a given landing site (Sections 3–9). A linear least-squares fitting algorithm (Ramsey and Christensen, 1998) is used to model each THEMIS pixel using the spectral library (Bandfield et al., 2004), resulting in concentration distributions of each spectral unit. Unlike DCS mosaics, these maps provide quantitative information about the fractional contribution of each end-member to the surface emissivity on a pixel-by-pixel basis. In addition, information from the full spectral range is utilized and interfering atmospheric and temperature effects are minimized.

Table 1
Candidate MSL landing sites analyzed in this study.

Site name	Approximate center latitude/longitude coordinates of proposed landing ellipse(s)
Nili Fossae Trough	21.01°N, 74.45°E
Gale crater	4.49°S, 137.42°E
Holden crater	26.38°S, 325.08°E
Eberswalde crater	23.86°S, 326.73°E
Mawrth Vallis	24.65°N, 340.1°E, 23.99°N, 341.04°E, 23.21°N, 342.43°E, 24.85°N, 339.42°E
Miyamoto crater	3.51°S, 352.26°E
S. Meridiani Planum	3.05°S, 354.61°E

Table 2
TES data selection constraints.

	Surface emissivity derivation	Dust cover index
Target temperature, K	⩾255	⩾250
Emission angle	⩽30	⩽10
Orbit range[a]	1–5317	1–8504
Total ice extinction	⩽0.04	–
Total dust extinction	⩽0.15	–
Image motion compensation	None	None
Scan length (wave number spacing)	10	10
Quality: solar panel motion[b]	Unknown or <0.120 deg/s	None
Incidence angle	–	<80°

[a] MGS mapping phase orbit number. To convert to orbit counter keeper (OCK) number, add 1683.

[b] Additional quality and observational fields from the TES database used in this study: major_phase_inversion 0 0, algor_risk 0 0, spectral_mask 0 0 and detector_mask_problem 0 0. More information is available at http://pds-geosciences.wustl.edu/missions/mgs/tes.html.