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Extensive aqueous deposits at the base of the dichotomy boundary in Nilosyrtis Mensae, Mars

Joshua L. Bandfield[a,*], Elena S. Amador[b]

[a] Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, CO 80301, USA.
[b] Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA

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ABSTRACT

Thermal emission imaging system (THEMIS) and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectral datasets were used to identify high bulk SiO_2 and hydrated compositions throughout the Nilosyrtis Mensae region. Four isolated locations were identified across the region showing short wavelength silicate absorptions within the 8–12 μm spectral region, indicating surfaces dominated by high Si phases. Much more extensive exposures of hydrated compositions are present throughout the region, indicated by a spectral absorption near 1.9 μm in CRISM data. Although limited in spatial coverage, detailed spectral observations indicate that the hydrated materials contain Fe/Mg-smectites and hydrated silica along with minor exposures of Mg-carbonates and an unidentified hydrated phase. The high SiO_2 and hydrated materials are present in layered sediments near the base of topographic scarps at the hemispheric dichotomy boundary, typically near or within low albedo sand deposits. The source of the high SiO_2 and hydrated materials appears to be from groundwater discharge from Nili Fossae and Syrtis Major to the south, where there is evidence for extensive aqueous alteration of the subsurface. Although discontinuous, the exposures of high SiO_2 and hydrated materials span a wide area and are present in a similar geomorphological context to previously identified deposits in western Hellas Basin. These regional deposits may reflect aqueous conditions and alteration within the adjacent crust of the martian highlands.

1. Introduction

Spacecraft observations continue to reveal a wide variety of locations on Mars with evidence for past aqueous environments throughout its history. The increasingly detailed measurements and interpretations shed light on the specific conditions present at the time of formation. In particular, the identification of specific aqueous phases and their textural and morphological context can be used to determine specific environmental characteristics, such as the duration of exposure to water, pH, temperature, and chemical pathways. It is the combination of these factors that can be used to assess the potential for the development, sustenance, and preservation of life, in addition to assessing the geologic evolution of the planet.

Numerous exposures of aqueous phases have been identified across Mars (e.g., Christensen et al., 2001; Bandfield et al., 2003; Gendrin et al., 2005; Poulet et al., 2005; Milliken et al., 2008; Ehlmann et al., 2008; Bishop et al., 2008; Osterloo et al., 2008; Ehlmann et al., 2011; Carter et al., 2013). In addition, in situ observations have been used to identify strong evidence for past aqueous conditions in regions where evidence from orbital measurements is faint or non-existent (e.g., Ruff et al., 2011; Morris et al., 2010). In many cases, these numerous exposures less than a few kilometers in scale, typically may be 10′s or 100′s of kilometers removed from their source (Barnhart et al., 2011). In addition, with a few exceptions, the concentrations of the aqueous phases commonly appear to be low (<~10–15 areal %) based on near-infrared measurements and the lack of detection using orbital thermal infrared (TIR) spectral datasets (e.g., Viviano and Moersch, 2013; Poulet et al., 2014). The isolated and potentially reworked nature of these materials can make it difficult to fully understand the formation environment.

More extensive exposures of aqueous phases have been identified, however. Many of these include laterally extensive layered sequences of sulfates and hematite similar to those investigated by

* Corresponding author.
E-mail address: jbandfield@spacescience.org (J.L. Bandfield).

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Table 1
THEMIS spectral bands.

Band	Center wavelength (μm)	Width (μm) FWHM*
1	6.78	1.01
2	6.78	1.01
3	7.93	1.09
4	8.56	1.16
5	9.35	1.20
6	10.21	1.10
7	11.04	1.19
8	11.79	1.07
9	12.57	0.81
10	14.88	0.87

* Full width at half maximum transmission

the Mars Exploration Rover at Meridiani Planum (e.g., Christensen et al., 2001; Weitz et al., 2008; 2012). There are also several regions dominated by phyllosilicate and silica phases that include extended areas with high concentrations of materials (>∼10–15%) that appear to have formed in-place. Mawrth Vallis is perhaps the most prominent example, covering ∼10,000 km^2 with a range of phyllosilicate and silica compositions that indicate a variety of aqueous conditions (Loizeau et al., 2007; Bishop et al., 2008; McKeown et al., 2009; Farrand et al., 2009; Noe Dobrea et al., 2010; Michalski et al., 2013; Viviano and Moersch, 2013). Several extensive, but somewhat less prominent examples are also present on Mars. This includes Nili Fossae, where phases such as phyllosilicates and carbonates are exposed in bedrock units (e.g., Mangold et al., 2007; Mustard et al., 2009; Ehlmann et al., 2009; Viviano et al., 2013), and western Hellas Basin, where nearly pure hydrated silica is exposed sporadically along a 650 km stretch of the basin rim (Bandfield, 2008; Bandfield et al., 2013).

Here, we use infrared spectroscopic datasets to identify another extensive region of hydrated and high bulk silica compositions near the martian hemispheric dichotomy boundary in the Nilosyrtis Mensae region. This is one of the largest regions of aqueous compositions found on the planet, including numerous isolated exposures, and a region of nearly continuous hydrated compositions stretching for ∼300 km along the dichotomy boundary. The mineralogy and morphological context bears similarities to previously described regions in western Hellas Basin and nearby in Nili Fossae (Ehlmann et al., 2009; Mustard et al., 2009). Some of the surface compositions in this region have been described in previous work and Nilosyrtis Mensae has been proposed as a landing site because of its mineralogical diversity (e.g., *Summary Report for the First MSL Landing Site Workshop* available at http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/1st_workshop/docs/MSL_workshop_report.pdf). Despite this, the extensive nature and high concentrations of the exposures have only been briefly described to date (Poulet et al., 2008; Ehlmann et al., 2009).

2. Data and methods

2.1. THEMIS data

The thermal emission imaging system (THEMIS) consists of a 320 by 240 element uncooled microbolometer array with 9 spectral channels centered at wavelengths from ∼7 to 15 μm (Table 1) and a spatial sampling of 100 m/pixel. Multispectral images are collected in a pushbroom configuration with rows of detectors under each spectral filter co-added to increase the signal to noise ratio. Detailed descriptions of calibration methods and radiometric uncertainties are presented in Christensen et al. (2004), Bandfield et al. (2004a), and Edwards et al. (2011).

Our analyses used THEMIS data acquired at afternoon local times of ∼1400–1800 H and near-nadir observation geometries. We only examined images with full spectral coverage and an average temperature > 220 K for spectral diversity and features of interest. Using these criteria, all regions of interest investigated here (described in Section 3.1.1) have full surface coverage and many surfaces have repeat coverage. We did not place restrictions on atmospheric water ice or dust loading for THEMIS image selection, but the images used for detailed analyses all have 9 μm dust opacities of < 0.16 and 11 μm water ice opacities of < 0.05.

We employed several methods that use multispectral THEMIS images to identify surfaces with high bulk SiO_2 content. First, we used decorrelation stretch (DCS) images (Gillespie et al., 1986), to rapidly identify spectrally unique surfaces using calibrated radiance data without the need for the extensive processing typically required for producing atmospherically corrected surface emissivity (e.g., Hamilton and Christensen, 2005; Bandfield et al., 2004b; Rogers et al., 2005; Bandfield, 2008; Osterloo et al., 2008). The high bulk SiO_2 surfaces of interest to this study have relatively low emissivity values at wavelengths corresponding to THEMIS band 4 within the ∼8–12 μm Si–O asymmetric stretch Reststrahlen band. By contrast, basaltic and dusty surfaces have low emissivity values in THEMIS bands 6–8 and 2 respectively. These differences in emissivity result in color differences between the three compositional types. We constructed color DCS images from THEMIS band 6–4–2, 8–7–5, and 9–6–4 radiance images to cover a wide spectral range and distinguish between the different surface types. Using these three band combination images, the high SiO_2 surface types appear as magenta, yellow, and yellow respectively.

Although the DCS images are useful for the rapid identification of spectrally unique surfaces, we applied other techniques to the THEMIS data in order to confirm their presence and derive quantitative parameters from the data. We first correct the THEMIS data for atmospheric effects using the methods of Bandfield et al. (2004b) in order to derive surface emissivity. We used the surface emissivity data in two ways; 1) direct analysis of THEMIS surface emissivity spectra and comparison with previously described Mars thermal infrared (TIR) spectral types, and 2) production of weighted absorption center (WAC) images.

Surfaces with relatively low emissivity near 8 μm (THEMIS band 3) typically result in spectra with band 1–2 emissivity values greater than one. This is a result of our assumption that the maximum surface emissivity occurs in THEMIS bands 3–9, neglecting bands 1–2 for surface kinetic temperature determination. Although it is clear that this is can be an incorrect assumption, the measured radiance is typically low in these bands. Consequently, they have the potential to map significant inaccuracies in the other bands if they are used for surface temperature determination. A relatively low emissivity in band 3 compared to bands 1–2 can be inferred where the emissivity of THEMIS bands 1–2 is greater than one throughout this work, consistent with the presence of shorter wavelength absorptions.

The WAC images use the overall shape and position of the 8–12 μm Reststrahlen Si–O absorption present in THEMIS data to estimate the relative SiO_2 content of the surface materials. This technique takes advantage of the inverse correlation between the wavelength position of the Si–O absorption and SiO_2 content (Vincent and Thomson, 1972). Each WAC value is calculated from the integrated area of the spectral absorption present in the surface emissivity of THEMIS bands 3–9. The WAC wavelength is where half of the absorption area is present at longer wavelengths and half is present at shorter wavelengths. This technique is similar to that developed by Vincent and Thomson (1972) and has been applied previously to THEMIS surface emissivity data by Smith et al. (2013) and Amador and Bandfield (2015). This is also similar to the spline fit minimum emissivity technique of Pan et al. (2015) and Rogers and Nekvasil (2015). One advantage of this technique is that it reduces the THEMIS data to a single quantitative