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Comparison of the mineral composition of the sediment found in two Mars dunefields: Ogygis Undae and Gale crater – three distinct endmembers identified

Heather Charles [a,*], Timothy Titus [b], Rosalyn Hayward [b], Christopher Edwards [b], Caitlin Ahrens [c]

[a] USGS/NAU, United States
[b] USGS, United States
[c] University of Arkansas, United States

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ABSTRACT

The composition of two dune fields, Ogygis Undae and the NE–SW trending dune field in Gale crater (the "Bagnold Dune Field" and "Western Dune Field"), were analyzed using thermal emission spectra from the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) and the Mars Odyssey Thermal Emission Imaging System (THEMIS). The Gale crater dune field was used as a baseline as other orbital compositional analyses have been conducted, and *in situ* sampling results will soon be available.

Results from unmixing thermal emission spectra showed a spatial variation between feldspar mineral abundances and pyroxene mineral abundances in Ogygis Undae. Other datasets, including nighttime thermal inertia values, also showed variation throughout the dune field. One explanation proposed for this variation is a bimodal distribution of two sand populations. This distribution is seen in some terrestrial dune fields.

The two dune fields varied in both mineral types present and in uniformity of composition. These differences point to different source lithologies and different distances travelled from source material. Examining these differences further will allow for a greater understanding of aeolian processes on Mars.

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1. Introduction

Over the last half century, a fleet of spacecraft has visited Mars, ranging from the early flybys of the Mariner probes (e.g. Abelson, 1965; Steinbacher and Gunter, 1969; Leighton and Murray, 1971) to the exploration of the surface with landers and rovers (e.g. Soffen and Young, 1972; Soffen, 1977; Squyres et al., 2003; Grotzinger et al., 2012). The wealth of data returned by these spacecraft has revealed that the current surface of Mars is dominated by polar and aeolian processes (Greeley et al., 1992; Thomas et al., 1992). Aeolian processes, the focus of this paper, are important mechanisms in shaping geologic features on the Martian surface and are important in the generation of sediment on Mars. Analyzing the formation, composition, and distribution of mineral types in dune fields is key to the understanding of geologic and recent climatic processes on Mars, as it is these relatively long-baseline processes that erode rock into sediment. Two large dune fields, both located within the southern highlands, provide an opportunity for comparison of mineral composition. One dune field, Ogygis Undae, is located on the edge of Argyre Planitia while the other is located in Gale crater, near the dichotomy boundary (Figs. S1–S5).

The informally named "Bagnold dune field" is of timely scientific interest since Gale crater is currently being explored by the Mars Science Laboratory (MSL) "Curiosity" rover (Grotzinger et al., 2012) ("Bagnold" is part of a dune field identified in the Mars Global Digital Dune Database (MGD^3) as 1370-050 (Hayward et al., 2007a, 2007b). Due to morphological differences, 1370-050 is sometimes considered as two dune fields, "Bagnold" and "Western". For the purposes of this analysis the dune field will be considered as one, with two sections). In the research leading up to the MSL landing, the composition of the Gale crater dune fields was examined in detail (Rogers and Bandfield, 2009; Lane and Christensen, 2013; Seelos et al., 2014). Results from previous analyses can be compared to the abundances found here, which can then be compared to *in situ* sampling results performed by Curiosity (Bridges et al., 2015). Verifying that thermal emission data can determine mineral composition validates mineral com-

* Corresponding author.
E-mail address: hcharles@usgs.gov (H. Charles).

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position results for Ogygis Undae and other dune fields on Mars. Since most Martian dune fields will not be sampled by rovers in the near future, linking the orbital data to ground truth will be used to provide insight into the differences in methods and help constrain the composition of other dune fields.

1.1. Background and motivation

Thermal emission data from Ogygis Undae were analyzed to determine mineral composition and the distribution of the various mineral groups (Ahrens and Titus, 2014). The preliminary analysis of this dune field (Ahrens and Titus, 2014), identified as 2938-497 in the MGD[3], noted variation in the mineral abundances across the dune field from west to east. A follow-on study was conducted to validate the compositional variation by comparing spectral unmixing results using a suite of spectral libraries that systematically included or excluded certain mineral groups (Charles and Titus, 2015). The eight mineral groups used were feldspar, pyroxene (both high and low-calcium), high-silica phases, sulfate, hematite, quartz, carbonate, and olivine (Rogers and Fergason, 2011). Removing feldspar from the library did not remove variation in pyroxene, high-silica phases, or sulfate, and did not decrease the fit RMS error (Charles and Titus, 2015). Thermal inertia data from Ogygis Undae were also used to characterize the variability in grain size across the dune field.

2. Instruments

2.1. Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES)

The TES instrument package consists of a Michelson interferometer/spectrometer, a bore-sighted thermal bolometer, and a solar reflectance bolometer (Christensen et al., 2001). Six detector elements make observations of the surface; each set of six such observations are numbered using incremental counter keepers (ICKs). Each orbital track (one full orbit) is also numbered using orbital counter keepers (OCKs). As the average altitude of the MGS was 400 km during the mapping phase, the area covered by the detector array is approximately 9 km across the orbital track and 6 km along the track (∼9 km if the smear due to spacecraft motion is considered) (Christensen et al., 2001).

2.2. Mars Odyssey Thermal Emission Imaging System (THEMIS)

The THEMIS instrument package consists of both infrared (IR) and visible (VIS) light imagers. The thermal infrared microbolometer array captures infrared images in a pushbroom fashion over nine wavelengths, centered from 6.8 to 14.9 μm. The visible/near-infrared images are created using five bands centered from 0.42 to 0.86 μm. This instrument, which was part of the 2001 Mars Odyssey mission, was intended to be used in conjunction with TES data to determine the mineralogy of the Martian surface. Infrared images from THEMIS have 100 m/pixel resolution (Christensen et al., 2002).

3. Dune field sites

3.1. Dune field site 1: Ogygis Undae (293.8° E, −49.7° N)

The Ogygis Undae has the fourth largest area of dune fields listed in the equatorial region of the MGD[3] and is the sixth largest dune field by area outside the North polar erg (Hayward et al., 2007a, 2007b). This dune field contains barchan, barchanoid, transverse, dome, and star dunes (Silvestro et al., 2010), has a thermal inertia in the 300–400 $\mathrm{J\,m^{-2}\,s^{-0.5}\,K^{-1}}$ range, and is located west of Argyre Planitia. Multiple high quality TES observations from the interior of the dune field are available due to the area, location, and shape. Fig. S1 in the supplementary online material (SOM) shows Ogygis Undae in relation to Argyre Planitia. Fig. S2 shows the MGS OCKs used to determine mineral composition with TES as shown in the Java Mission-planning and Analysis for Remote Sensing (JMARS), a geographic information system developed by Arizona State University (ASU) (Gorelick et al., 2003).

3.2. Dune field site 2: Gale crater (137.0° E, −5.0° N)

The second region examined for mineral composition was Gale crater. Dune field 1370-050 occupies the western half of the crater and includes barchan, barchanoid, and linear dunes, as well as sand sheets (Figs. S3, S4). The proposed Gale crater dune field sampling site for MSL is located in the northern portion of the offshoot from dune field 1370-050 (Hayward et al., 2007b), informally known as the Bagnold Dunes. Fig. S3 shows the dune field in relation to Gale crater while a close-up of the proposed site may be seen in the High Resolution Imaging Science Experiment (HiRISE) images in Fig. S4. Due to the narrow shape of the Bagnold dune field, only the mineral composition of the main body (the Western dune field) was analyzed (see Fig. S5 to show the orbital tracks over the Gale crater dune fields).

4. Methods

4.1. TES

4.1.1. Data selection

We used JMARS to select daytime, warm surface (above 250 K), clear atmosphere (9 μm dust extinction less than 0.2 and 11 μm ice extinction less than 0.05) TES data with orbital track values above 1583 for both Ogygis Undae and the Gale crater dune field.

4.1.2. Spectral data processing

Both sets of data were analyzed by first deconvolving TES emissivity in DaVinci, a programming environment developed by ASU (e.g. Edwards et al., 2015), using the methods outlined by Rogers and Fergason (2011). After warm surface, high quality data were selected, we conducted a surface/atmosphere separation using derived atmospheric endmembers (Bandfield et al., 2000a). The atmosphere removed, surface spectra were then unmixed (Ramsey and Christensen, 1998; Rogers and Aharonson, 2008) using a non-negative least squares fitting routine and a mineral spectral library containing eight mineral groups (feldspar, high-silica phases, pyroxene, sulfate, olivine, hematite, carbonate, and quartz), comprised of a total of forty-four mineral endmembers, developed by Rogers and Fergason (2011). (For a complete list of endmembers by mineral group, see Table S1 in Rogers and Fergason, 2011.) The DaVinci deconvolution produces normalized mineral abundances, both by mineral group and by endmember, for each orbit.

The OCKs used in each dune field can be seen in Tables S1 and S2. Each of these OCKs was unmixed separately into its respective mineral groups and endmembers.

4.1.3. THEMIS

To confirm the TES compositional results found in both dune fields, THEMIS DCS radiance images were examined and compared to the unmixing results. The THEMIS DCS images were processed following the standard calibration, production, and noise removal procedures detailed in Edwards et al. (2011). The DCS images (Gillespie et al., 1986) shown in Fig. S6 and S7 are a variant on the standard DCS stretch and are designed to highlight relative compositional differences within an image Edwards et al. (2011). These specially stretched DCS data are widely used in investigations of Mars as they highlight small