BULK MINERALOGY OF THE NORTHWEST ISIDIS REGION OF MARS DERIVED THROUGH THERMAL INFRARED SPECTRAL ANALYSES.

M.R. Salvatore[1], T.A. Goudge[2], M.S. Bramble[3], C.S. Edwards[4], J.L. Bandfield[5], E.S. Amador[6], J.F. Mustard[3], and P.R. Christensen[7]. [1]University of Michigan-Dearborn, msalva@umich.edu, [2]University of Texas at Austin, [3]Brown University, [4]Northern Arizona University, [5]Space Science Institute, [6]University of Washington, [7]Arizona State University.

Introduction: The region to the northwest of the Isidis impact basin on Mars (herein referred to as “NW Isidis”) is home to the spectrally diverse Jezero crater and its watershed [1] in addition to the NE Syrtis region [2]. Visible/near-infrared (VNIR) spectral investigations have identified primary volcanic and mafic materials, phyllosilicates, carbonates, and sulfates [2-7], indicating a complex geologic history and a diversity of aqueous alteration environments. Despite this extraordinary diversity, few investigations of bulk mineral assemblages using thermal infrared (TIR) emissivity data have been performed.

In this study, we use TIR data from the Thermal Emission Spectrometer (TES) [8] and Thermal Emission Imaging System (THEMIS) [9] to quantitatively derive surface compositions of geomorphic units previously mapped by [1] and [7] in the Jezero crater watershed and NE Syrtis regions, respectively. This dual investigation is of particular importance because these regions host several candidate landing sites of interest for future robotic and human exploration of the martian surface [10]. *In situ* exploration can help to answer many important questions about the mineralogical and geomorphic character of this region that cannot be fully investigated from orbit (see below).

Methods: Our investigation of TES data utilizes a modified iterative linear unmixing method similar to that developed by [11] to statistically derive average surface compositions and to understand the influence of individual mineral phases on the unmixing results. High-quality TES data over Jezero crater, the Jezero paleolake watershed, and NE Syrtis were subset and averaged for mapped geomorphic units [1,7]. Atmospheric constituents were removed from these averaged spectra through a non-negative least-squares method using an atmospheric endmember library in addition to a comprehensive library of crystalline and amorphous geologic materials [12]. Once atmospherically corrected, spectra were iteratively unmixed using the same geologic endmember library. Each spectrum was unmixed 60,000 times with up to 10 endmembers randomly removed from each individual unmixing procedure. Unmixing results with root mean square (RMS) errors greater than 0.3% were excluded and re-run. This procedure results in a matrix of unmixing results, and statistics can be derived to compare the goodness of fit when individual phases are excluded versus when they are included in the unmixing model.

Three THEMIS 10-band daytime infrared scenes were atmospherically corrected [13] and analyzed over NW Isidis. Data were unmixed using a modified endmember library containing a combination of scene-derived endmembers and laboratory-derived olivine (Fo68, [14]) to determine the relative enrichments of olivine throughout the region [15]. The weighted absorption center (WAC) was also derived to estimate the relative silica abundance of different surface lithologies [16]. WAC values represent the mean central wavelength of an observed emissivity spectrum, which varies from lower wavelengths for higher silica contents to higher wavelengths for lower silica contents.

Results: In general and like most of the martian surface at the km-scale, NW Isidis is dominated by basaltic compositions with varying abundances of olivine, plagioclase, and alteration and/or amorphous phases (holistically referred to as “phyllosilicates, smectites, and amorphous phases,” or “PSAC”). In short, most units are successfully modeled with 15-30% plagioclase, 15-30% pyroxene (with a slight preference towards LCP-rich compositions), 5-15% olivine, and 15-30% PSAC. The iterative linear unmixing algorithm also allowed us to confidently model spectrally significant abundances of carbonate in the Mottled Terrain of the Jezero watershed as well as in the Fractured Unit of NE Syrtis, which were both identified as carbonate-bearing using VNIR spectroscopy [1,7]. In these units, significant abundances of carbonate were frequently modeled, with up to 16.5% areal abundance modeled in individual spectra (Fig. 1). Although the RMS error threshold for our iterative unmixing procedure had to be relaxed to 0.55% when modeling individual TES spectra, doing so allowed us to confidently model significant carbonate abundance within an individual spectrum.

THEMIS WAC analyses and linear unmixing confirmed our TES observations and provided a more local understanding of compositional variations. Local WAC values were modeled to generally vary between 9.8 µm and 10.4 µm, which correspond to laboratory-derived basalts and olivine-enriched basalts, respectively (Fig. 2). Based on the THEMIS linear unmixing results, localized areas mapped with the highest WAC wavelengths are best modeled with an additional 15% to 20% of the olivine endmember relative to other scene-derived basaltic signatures. Very low WAC wavelengths (~9.3 µm) were also identified in small (<1 km^2) exposures within the Jezero watershed (Fig. 2). These WAC wavelengths are consistent with quartz-rich terrestrial monzonites measured in a laboratory setting. These observations are also consistent with those of [16] who observe similarly low WAC locales north of our study area in the Nili Fossae region.

Discussion: While VNIR reflectance spectroscopy is unrivaled at identifying spectrally unique alteration

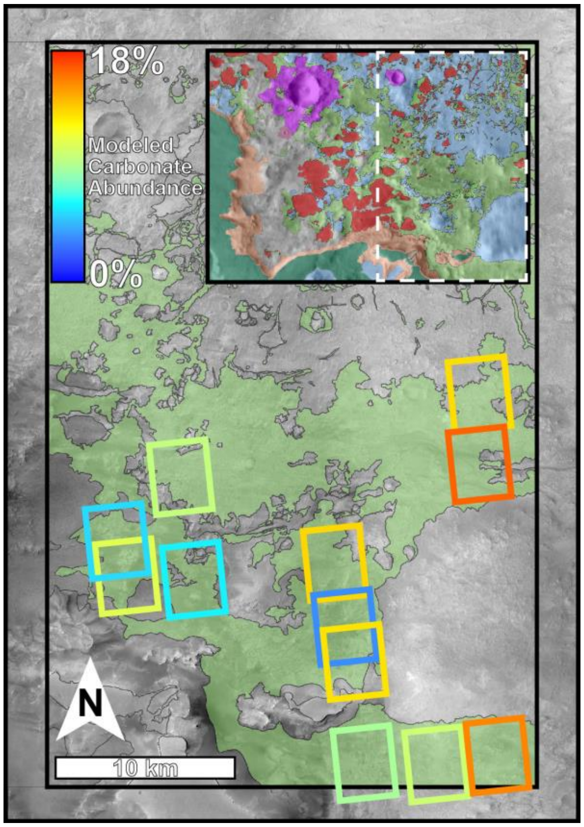

Fig. 1. Average modeled carbonate abundances in individual TES spectra within the Fractured Unit (green background) of NE Syrtis. Abundances were modeled using the iterative unmixing method of [11]. Geologic map modified from [7].

mineral phases, TIR emission spectroscopy is the only proven and validated means of remotely quantifying bulk mineralogy from orbit. In tandem, VNIR reflectance and TIR emission spectroscopy were used to characterize the full mineralogical diversity observed in the NW Isidis region. Most observed inconsistencies between mineral identifications in VNIR reflectance data and those in TIR emission data can be credited to differences in spatial resolution and the small spatial extents of the unique VNIR signatures.

From a bulk silica perspective, surface units within this study region vary from monzonitic to dunitic compositions, indicating a wide diversity of magma or melt evolution at the local (< 1 km^2) THEMIS scale. Such bulk compositional diversity is to be expected, given that the complex geologic history of this region is likely related to the formation of the Isidis impact basin, the associated impact melt formation and distribution, and subsequent high- and low-temperature aqueous alteration [1-7]. However, at the lower spatial resolutions of the TES instrument, most regional compositions are largely comparable to those of the nearby Syrtis Major basalts, indicating dominantly basaltic compositions with localized compositional heterogeneity causing the mineralogic variability observed with the higher spatial resolution datasets.

To relate the observed spectral signatures and mineralogical phases to formation mechanisms, *in situ* geologic investigations are a requirement. Understanding whether the identified alteration phases are detrital or authigenic in nature will help to determine the relative age of the formative alteration and sedimentary processes. Additionally, how did the carbonate-bearing materials form throughout this region, and what are the implications for atmospheric sequestration and early martian climate evolution?

Lastly, the nature of the geologic contacts observed throughout the NW Isidis region, particularly at the micro-scale, requires *in situ* investigation. For example, what is the nature of the relationship between the olivine- and carbonate-bearing units, and between the altered basement and the overlying carbonate- and sulfate-bearing lithologies? Is the olivine-enriched unit related to impact melt generated by the Isidis impact, or was subsequent volcanic or magmatic activity enriched in olivine? For these and other reasons, *in situ* investigation of this region is scientifically warranted.

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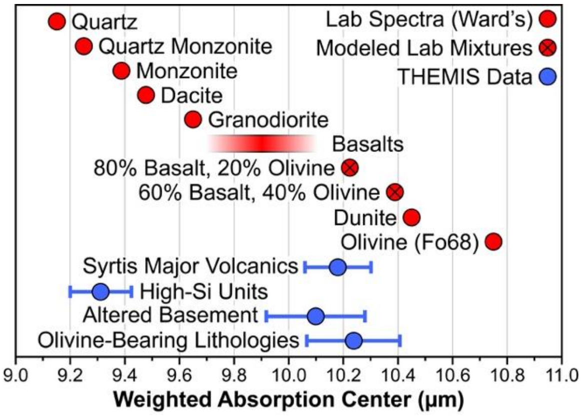

Fig. 2. Weighted absorption center (WAC) calculations for laboratory and orbitally derived spectra. Bars surrounding average THEMIS values (circles) represent minimum and maximum recorded WAC values.