SOURCES OF SAND IN MT. SHARP: POSSIBLE VOLCANIC LAYERS IN GALE CRATER, MARS.

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Introduction: The Murray formation at the base of Mt. Sharp in Gale crater was formed in a lacustrine environment more than three billion years ago, when liquid water flowed on the surface of Mars [1]. The duration of the lake is not yet constrained, and determining the origin of layers higher in Mt. Sharp is a key goal of the Mars Science Laboratory (MSL) mission. Within these higher layers, previous studies have identified "marker beds" [2] that produce sand and are dark-toned compared to surrounding light toned more recessive layers. This difference in properties indicates that the marker beds were deposited by different processes [3]. Understanding the origin of these maker beds could place better relative time constraints on geologic events within Gale crater and link them to events in the region, if these beds formed during large-scale events. The marker beds could also be useful for evaluating the lateral continuity of the Mt. Sharp stratigraphy.

In this study, we seek to determine the mineralogy, transport pathway, and source of mafic sediments in Mt. Sharp, with a focus on the marker beds. Understanding the primary mineralogy of the marker beds and other sediment sources in Mt. Sharp will provide context for results from MSL. MSL determined the mineralogy of active dunes in the northwest region of Mt. Sharp [5,6], but whether or not some of this sand was locally sourced from within Mt. Sharp is unclear [7]. Here we compare the spectral properties and inferred mineralogy of surface sediments to the dunes to determine whether or not the marker beds or other mafic units in Mt. Sharp could be a sediment source. Additionally, we propose that there are multiple packages of laterally continuous marker beds present throughout Mt. Sharp.

Methods: Visible/near-infrared (VNIR) hyperspectral images from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on MRO were used to create mineral maps of Mt. Sharp, starting in the well-understood northwestern region, and extending these maps to the rest of the mound. The CRISM analysis Toolkit (CAT) for ENVI was used to create a map focused on mafic minerals, specifically low-calcium pyroxene (LCPINDEX3), high-calcium pyroxene (HCPINDEX3), and ferrous minerals (OLINDEX3). To suppress atmospheric and surface dust and any remaining instrumental artifacts, each Map Projected Targeted Reduced Data Record (MTRDR) and Targeted Reduced Data Record version 3 (TRR3) cube was ratioed to a spectrally neutral spectrum, derived from each cube as an average of all (MTRDR) or in column (TRR3) spectrally neutral terrains, as defined based on the low values of key CRISM spectral parameters [8]. Channels with residual atmospheric bands near 2 μm were removed from the spectra. All spectra in each cube were continuum removed using a linear convex hull. Spectra were extracted based on the CRISM maps and used to infer mineralogy based on qualitative and quantitative comparison to lab spectra, including calculated center and shape of the 1 and 2 μm iron bands [9,10]. High-Resolution Imaging Science Experiment (HiRISE) images and terrain models of the region were used to visually relate stratigraphy and geomorphologic features to the mineral maps.

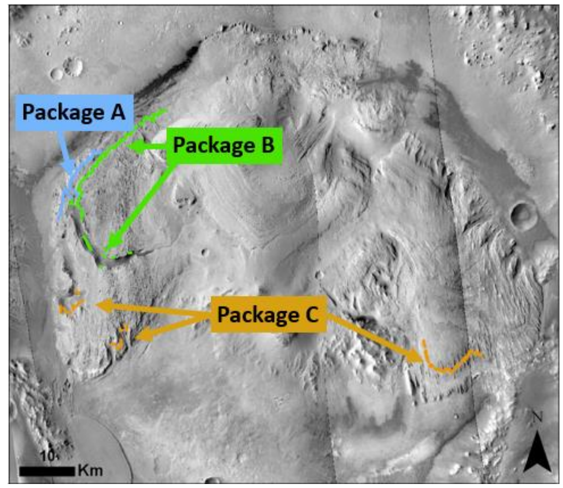

Figure 1. *CTX image of Mt. Sharp, Gale crater, Mars. Colored tracings signify marker bed packages. Blue is Package A, green is Package B, and goldenrod is Package C.*

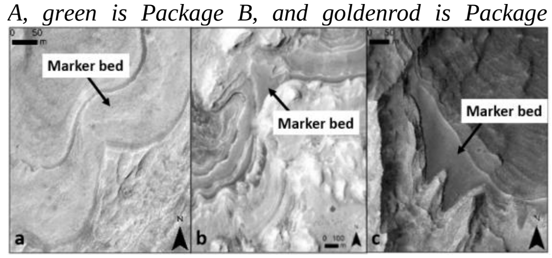

Figure 2. *HiRISE images of marker beds: (a) Package A, (b) Package B, and (c) Package C.*

Results: The marker beds have a lower albedo than the surrounding layers with a smoother appearance, and form distinct cliff-forming benches in outcrop (Fig. 1, 2). We have identified at least three separate packages (Packages A-C; Fig. 1, 2) composed of sequences of distinct marker beds in Mt. Sharp. Packages A and B occur in the NW/W regions, and Package C is in the SW and appears to continue around the southern mound into the SE region (Fig. 1). Each package is composed of one to three distinct layers (Fig. 1, 2). Package A has a higher albedo and has a rougher surface than Package B and C, but still forms a distinct cliff-forming bench in outcrop. The marker beds are laterally continuous over tens of kilometers and each package is at a different elevation. Package A is at an elevation range from -4150 m to -4000 m; Package B is at an elevation range from -3950 m to -3550 m; Package C is at an elevation range from -3150 m to -2600 m. The large elevation range within each package could indicate dipping of layers. We will conduct further analysis of the elevations and dips of the beds using HiRISE DTMs [11,12,13] to confirm the stratigraphy and continuity of the marker beds within Mt. Sharp.

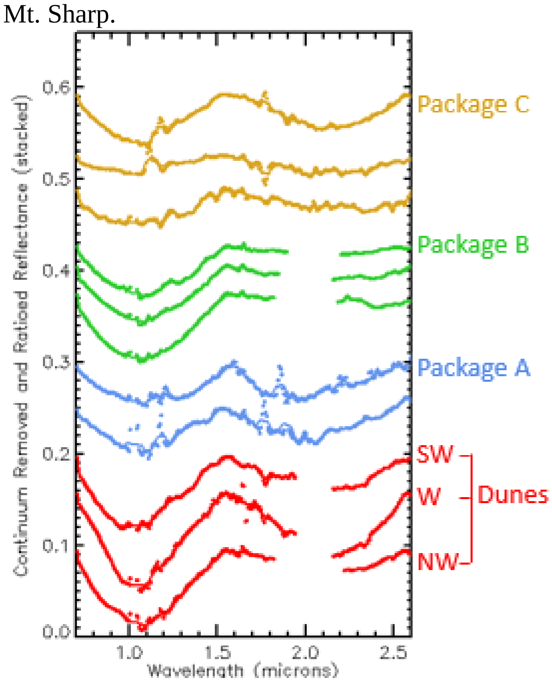

Figure 3. *Continuum-removed and stacked CRISM spectra for marker beds and nearby dunes on crater floor.*

CRISM spectra are shown in Fig 3. Package A exhibits a broad, asymmetric absorption band centered at 1.06 µm, consistent with high-Ca pyroxene (HCP), mixed with glass or olivine. A second broad band is centered at 1.95-2.00 µm, which is short for HCP, and is consistent with contribution from glass. The bands near 1 and 2 µm exhibit similar band depths, suggesting minimal spectral input from olivine and supporting a glass/ HCP mixture. Package A exhibits consistent spectral properties throughout the sampled layers. Package B CRISM spectra show a deep, broad, and asymmetric absorption band centered at 1.07 µm**,** consistent with olivine. A shallow, broad, and asymmetric absorption band is present in some spectra at ~2.20 µm, consistent with some contribution from HCP. All three marker beds in Package B exhibit nearly identical spectra, suggesting similar mineralogies. Package C CRISM spectra exhibit broad, shallow absorption bands at 1.01-1.05 µm and ~2.14 µm, consistent with HCP. Spectra were only gathered from a single layer in Package C and within that single layer, the spectra are more variable than Packages A and B, perhaps due to variable olivine.

The dunes in the northwest portion of the study region, which were sampled in situ by MSL, have similar spectral properties as the marker beds just upslope in Package B. These dunes also exhibit a deep, broad and asymmetric absorption band at 1.08 µm and a shallower absorption band at 2.15 µm, consistent with olivine mixed with HCP. The dunes in the western portion of the study region are similar to nearby marker beds in Package B. These dunes exhibit a deep, narrow, slightly asymmetric absorption band at 1.05 µm, and a similarly deep absorption band at 2.150 µm, consistent with HCP with minor olivine. The dunes in the southwestern portion of the study region are not clearly analogous to any of the marker bends sampled so far. The SW dunes exhibit a deep, broad, asymmetric absorption band centered at 1.01 µm, and a shallower absorption band is at 2.12 µm, consistent with HCP with some olivine.

Discussion: There are potentially three or more different packages of marker beds observed through Mt. Sharp composed of mafic minerals. The layers within these packages are spectrally similar and laterally continuous, indicating that each layer was deposited presumably from the same source, and likely by the same process. Variations both visually and spectrally between the different packages could indicate different sources or different grain size sorting during deposition. Our preliminary results show strong similarities between the spectra of the NW dunes and marker beds from Package B, suggesting that some of the olivine-bearing dune sediment sampled by MSL [5,7] could be sourced from the marker beds in Package B.

Because the marker bed spectra are not accompanied by clear alteration signatures, they likely indicate sediments from non-lacustrine processes, like volcanic, impact, or aeolian deposits. This also suggests that the marker beds have not been exposed to strong diagenetic processes, which may have had a major effect on the mineralogy of lower Mt. Sharp. The multiple repeating layers with similar spectra make impacts an unlikely source. However, differentiating whether the marker beds formed through volcanic activity or aeolian deposits will likely require in situ investigations by MSL.

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