DETERMINING GRAIN CHARACTERISTICS IN THE SHALER OUTCROP WITH CHEMCAM REMOTE MICRO-IMAGER MOSAICS.

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Introduction: The primary mission of the Curiosity rover is to characterize a habitable environment in Gale Crater, Mars. To identify an ancient habitable environment, the depositional and diagenetic environmental history must be interpreted from preserved geologic features. One of these ancient sedimentary features is the fluvial deposit "Shaler" [1, 2]. The Shaler outcrop in the Glenelg member of Yellowknife Bay formation [3, 4] is composed of trough cross-bedded coarse-grained sandstones, pebble beds and recessive finer-grained intervals. Seven distinct facies have been identified in the Shaler outcrop [5, 2]. To better characterize the facies of the Shaler outcrop, we conducted a survey of grain sizes using the ChemCam Remote Micro-Imager (RMI) located on the rover's mast. This study also evaluates the utility of the RMI camera as a tool to remotely characterize sedimentary deposits.

Data Collection Methods: To characterize the Shaler outcrop facies, a survey of grain sizes was conducted using high resolution mosaics from the RMI. ChemCam uses laser-induced breakdown spectroscopy (LIBS) to remotely determine the elemental composition of rock targets. The RMI is used to document the location of these laser pits for further analysis. RMI has an angular pixel size of 19.6 µrad [6, 7]. For well focused images, this corresponds to a theoretical maximum resolution (2 pixels) of ~80 microns (when observing at a distance of 2 m, 120 µm at 3 m, etc.) although the actual resolution is limited by optics [6, 7].

MAHLI (MArs Hand Lens Imager) images were compared to three companion RMI targets to evaluate grain sizes finer than those resolved by RMI. MAHLI's highest resolution at the Shaler outcrop ranged from ~20.2 µm/pixel (Aillik) to ~21 µm/pixel (Eqalulik).

Each target was evaluated to determine grain size, sorting, and areal distribution within the image. Grain size and area were measured using ImageJ software. Grain size was determined by measuring the longest axis (which may underestimate grain size if the long axis is not visible) [8] of every visible grain in the mosaic. Grain sizes were binned according to the Wentworth scale [9] (pebble=4-64 mm, granule=2-4 mm, very coarse sand=1-2 mm, coarse sand=0.5-1 mm).

Sorting and percent area distribution were calculated from these data. Sorting (σ), the spread in grain size data from the median grain size, was calculated using the method of [8], from [10]. Percent area distribution is defined as the percent of coarse sand and larger grain areas in a given surface area. The grains and surface area were measured from RMI images.

While measuring grain sizes, it is important to consider erratic grain size frequencies for small grains - edges can be blurred due to pixelation and grains smaller than the pixel size are unresolvable [11]. Research has shown that 2-D grain analysis overestimates particle size in small grains (35-140 µm/pixel) [12]. To overcome this issue, we followed the approach of [13] and required all measurable grains be composed of at least 5 pixels. For each image, resolution is determined by the distance to the target; therefore, we calculated the maximum grain size (in micrometers) that could be composed of 5 pixels in all of the targets. Calculated maximum sizes in most targets were ≤0.5 mm (except for Wishart, at 0.58 mm). Based on these results, we defined 0.5 mm (coarse sand boundary) as the resolvable grain limit in RMI mosaics at the Shaler outcrop.

Observations & Interpretations: We measured grain sizes in 27 ChemCam targets at the Shaler outcrop and applied the methodology of [8, 13] to estimate grain sorting and limitations on grain resolution. Grain sizes range from pebble to coarse sand, which is at the limit of RMI resolution. If grains <0.5 mm in diameter are excluded, the mosaics document a population that ranges from very well sorted (Menihek target) to poorly sorted (Eqalulik target), with σ ranging from 0.26 to 1.41. However, if the fine-grained population is included in the sorting calculation for each target, their inferred sorting will decrease. Seven distinct facies were defined in the Shaler outcrop [1, 2]. For more detail on the geochemistry and sedimentology of the facies, refer to [14] and [15], respectively. Facies 1 and 2 are not discussed because they are not observed by RMI at Shaler. Five of these facies were targeted with the RMI, and here we report the grain size distribution and sorting for each facies:

Facies 3 Light-toned cross-stratified fine-grained sandstones. These targets include Aillik, Fabricius_Cliffs, and Menihek, and are characterized by a fine-grained, uniform appearance. RMI resolvable grains in Fabricius_Cliffs and Menihek range from coarse sand to very coarse sand, and are on average 0.60 mm (coarse sand). On average, grains larger than medium sand are very well sorted (σ = 0.23, range 0.17 to 0.28). Target Aillik is documented in both RMI and MAHLI images. Although MAHLI Aillik images, at ~20.2 µm/pixel, can resolve grain diameters of 60 to 80 µm (~very fine sand size), the dusty target made this difficult. Grains observed with MAHLI were ~100-150 µm and no grains were resolved in the RMI mosaic. Fabricius_Cliffs grains finer than coarse sand compose ~98% of the target area. This facies is interpreted as finer-grained dunes [15].

Facies 4 Recessive, laminated sandstone with vertical fractures. These targets include Rusty_Shale and Rove and are characterized by vertical fractures and a recessive weathering style. RMI resolvable grains from all facies targets range from very coarse sand to pebble, and are on average 2.55 mm (granule). On average, grains larger than coarse sand are well sorted (σ = 0.49, range 0.45 to 0.52). This facies is interpreted to be the finer-grained top of a fining upward sequence at the more distal end of a fluvial fan [15].

Facies 5 Single set, cross-stratified pebbly sandstones. These targets include Camp_Island, Denault, Double_Mer, Gogebic, Michigamme, Montaigne, Piling, Port_Radium_1, Ramah, Reddick_Bight, Saglek, Stanbridge, Wakham_Bay, and Wishart, and are characterized by even lamination (~1.4 to 1.8 mm). Lamination does not correspond to grain size variation. RMI resolvable grains from all facies targets range from coarse to pebble, and are on average 1.37 mm (very coarse sand). On average, grains larger than medium sand are well sorted (σ = 0.45, range 0.32 to 0.59). All Wishart grains are sub-coarse, determined by the presence and resolvability of coarse sand and larger grains in the soil and lack of resolved grains in Wishart. Camp_Island, Ramah, Double_Mer, and Reddick_Bight grains finer than coarse sand compose ~ 97%, 87%, 81%, and 78% of the target area, respectively (Fig. 1). This analysis of percent finer grains is ongoing. This facies is interpreted as a series of migrating sandy bedforms [15].

Facies 6 Stacked planar- and trough cross-stratified pebbly sandstones. These targets include Cartwright, Eqalulik, Howells, Seal_Lake, and Steep_Rock, and have a rough, pitted texture that is predominantly composed of smaller sand grains with an irregular distribution of larger grains. RMI resolvable grains from all facies targets range from coarse to pebble, and are on average 1.23 mm (very coarse sand). On average, grains larger than medium sand are moderately sorted (σ = 0.77, range 0.43 to 1.41). Target Eqalulik is documented in both RMI and MAHLI images. Although MAHLI Eqalulik images, at ~21 µm/pixel, can resolve grain diameters of 60 to 80 µm (~very fine sand size), grains observed with MAHLI were ~100-335 µm. Eqalulik grains finer than coarse sand compose ~ 97% of the target area in RMI mosaic. No grains are resolved in Seal_Lake and no soil grains were present; therefore the grains are estimated to be sub-coarse. This facies is interpreted as part of the proximal end of a fluvial fan [15].

Facies 7A and B. Upper Shaler. A) coarse-grained cross-stratified facies, B) fine-grained well-laminated facies with occasional nodules. These targets include Chioak, Husky_Creek, and Mary_River, and are characterized by abundant pits and bumps. Only Mary River contained resolvable in-place grains, which ranged from very coarse sand to granule, and are on average 1.94 mm (very coarse sand). Grains in Mary River larger than medium sand are well sorted (σ = 0.38). All Chioak grains are sub-coarse, determined by the presence and resolvability of coarse sand and larger grains in the surrounding soil. No grains in Husky_Creek were resolved and no soil grains were present; therefore the grains are estimated to be sub-coarse based on comparisons with Chioak.

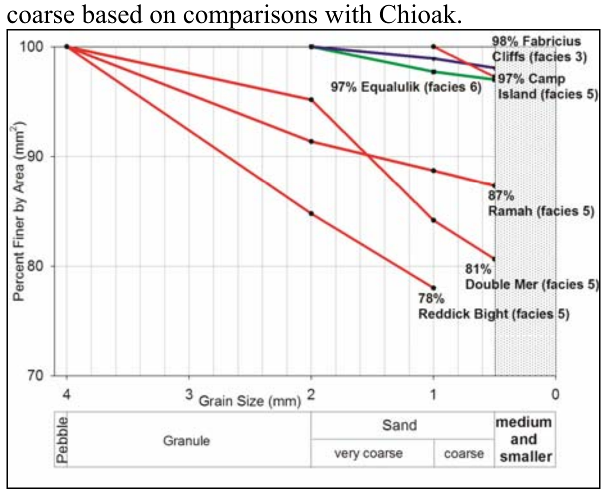

Figure 1. Clast distribution for select targets. Percentages listed indicate the fraction of grains that are finer than coarse sand.

Conclusions: The grain sizes and sorting in 27 ChemCam targets were assessed at the Shaler outcrop. Many targets are dusty and dominated by grains finer than coarse sizes (78% to 100%). RMI images indicate that in many facies, those grains larger than coarse are on average very coarse sized, except facies 4, which contains granule size grains. The grain sizes in targets with complementary MAHLI images (Aillik, Eqalulik, and Howells) are ~100 up to 335 µm.

RMI mosaics from the Shaler outcrop resolve grains down to coarse sand sizes (0.5mm) and better define variations in grain size and facies.

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