GRAIN SCALE ANALYSES OF THE MURRAY AND STIMSON FORMATIONS USING DATA FROM THE MARS SCIENCE LABORATORY MARS HAND LENS IMAGER AND THE CHEMCAM REMOTE MICRO IMAGER

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Introduction: The main goal of the Mars Science Laboratory (MSL) mission is to determine if habitable environments existed on Mars\textsuperscript{1}. Since landing in August 2012, the MSL Curiosity rover has been investigating ancient sedimentary environments in Gale crater. At sedimentary outcrops, analyses of the distribution of grain sizes and their sorting help infer the depositional environment. Onboard the rover, the two instruments best suited for grain size studies are the Mars Hand Lens Imager (MAHLI), located on the rover’s arm, and the ChemCam Remote Micro Imager (RMI), located on the rover’s mast. To improve our understanding of depositional environments in Gale crater, this study tested manual and automated grain size measurement methods using data from both cameras at a location informally known as Marias Pass. The grain size data was then used to test paleoenvironmental hypotheses. In addition to investigating variations in the datasets and methods at Mar’s Pass, this study builds on previous work by comparing results to other locations, informally known as Bridger Basin and Quela, to look for lateral and vertical grain-scale changes.

Geologic Background: For much of the past two years, Curiosity has been investigating two distinct geologic formations in Gale Crater: the Stimson formation sandstone and the Murray formation mudstone. The Stimson sandstone unconformably overlies the Murray mudstone. In the vicinity of Mariass Pass, the Murray formation mudstone is characterized by well-sorted, very fine sand-sized and smaller grains which are primarily unresolved in images. It is tan to gray with slight pock marks in the unprocessed MAHLI images used in this study. Due to its fine grain size, and abundant planar laminae, the Murray formation at this location is interpreted as a lacustrine deposit\textsuperscript{2-3}. The Stimson formation is characterized by meter-scale climbing-dune cross-stratification\textsuperscript{4-5}, and is often exposed in outcrops that are several meters thick. High-resolution imaging also reveals abundant pin-stripe lamination, a texture that forms from internal sorting of the grains. These sedimentary structures are suggestive of an aeolian depositional environment\textsuperscript{4-5}. The grain-scale data collected in this study supplement the above observations and test the plausibility of lacustrine and aeolian origins of the Murray and Stimson formations respectively, while also assessing variability within the Stimson formation.

Methods: At Marias Pass, Bridger Basin, and Quela, Curiosity used both the MAHLI and RMI cameras to image a total of 20 rock targets for grain-scale analyses. We used manual point-counts to measure mean grain size distributions at all targets.

Measurements from Marias Pass were used to compare the capabilities of the two cameras and of automated methods of determining mean grain size. To assess the imager abilities, a manual point-count distribution was obtained for each image, one from each camera, and the mean grain sizes compared. To test automated abilities, the same images were processed using pyDGS software\textsuperscript{6}. The code uses wavelets to identify the spatial patterns that dominate the image and uses that information to determine the distribution of grain sizes\textsuperscript{6}. We compared these values to the manual point count data to assess the software’s accuracy. We also examined grain-size distributions for depositional interpretations for the two formations.

Finally, we compared measurements from Marias Pass to the Bridger Basin and Quela locations to look for lateral and vertical variability. Mean values from manual point-counts at each location were compared. We looked for trends both laterally from location to location, and vertically within the formation by looking for correlations between distance from the contact, elevation, and mean grain size.

Results: Grain Size and Sorting: At Marias Pass, nine rock targets were imaged and then used for methods comparison and depositional environment analyses. Ronan, Seeley, Big Arm, Clark, and Lumpy sampled the Stimson formation while Wallace, Lamoosh/Frog, and Buckskin were Murray formation targets. Mean grain sizes and sorting for all targets are shown in Figure 1A.

Methods Comparison: Mean grain size, sorting, and skewness for MAHLI and RMI images show close correlation between the two datasets. We find that the measurements are relatively similar despite differences in resolution and in standoff distance. However, manual results compared to automated results show significant differences. The measurements for the DGS results are much coarser than the manual ones. The program treats unresolved grains as non-existent or part of a larger whole, rather than as very fine grains. To measure the discrepancy the smaller grains caused in the results, the point count data were recalculated to disregard unresolved grains and compared against the revised DGS data. The data were much more similar.
after the comparison (Figure 1B), suggesting that the pyDGS software is capable of detecting a large portion of the resolvable grains in the MAHLI and RMI images.

Depositional Interpretations: The Murray formation mudstone is interpreted to have been deposited in a lacustrine environment [2] and the very fine grain sizes found in this study support that interpretation. The Stimson formation targets in this study are primarily composed of fine-to-medium sand grains (capable of being moved by the wind), which is consistent with the interpretation that the Stimson formation represents an aeolian dune field [3].

It should be noted that at the bottom of the Stimson formation, near the contact with the underlying Murray formation, a number of larger grains are present and cross-stratification is less pronounced [6]. These larger grains may be rip-up clasts of the underlying Murray formation [3]. The larger grain sizes and lack of cross-bedding near the contact suggest that water may have been involved in the erosion and re-deposition in this lower part of the formation.

Lateral and Vertical Variability: The presence of rip-up clasts and poor sorting in the Stimson formation prompted further grain-scale analyses of the Stimson formation at Bridger Basin and Quela. Comparisons of mean grain size distributions across all three locations looked for lateral and vertical changes at the grain-scale. Both MAHLI and RMI images were used in the study. Initial results suggest locational variation in grain size. At Marias Pass, results show correlation between grain size and elevation. Mean grain size fines as elevation increases. In contrast, at Bridger Basin, elevation does not change, but mean grain size is varied. The Quela site lacks sufficient data to assess large-scale trends within the section. While there is notable variation in mean grain size within each site, comparison of data across all three sites does not reveal a significant trend.

While data from Quela was inconclusive, the presence of a fining-upward trend at Marias Pass and the lack thereof at Bridger Basin suggests possible minor differences in depositional processes at the Murray-Stimson contact. Although the dominant depositional environment for the Stimson formation is interpreted to be aeolian, local differences hint at more variability, including potentially subaqueous deposition.

Conclusions: Images from the MAHLI and the RMI provide comparable grain-scale measurements. pyDGS does not account for grains smaller than a few pixels, and therefore should be used with caution when assessing images with a large fraction of unresolved grains. Grain-size distributions are consistent with lacustrine and aeolian depositional interpretations for the Murray and Stimson formations respectively. Comparison of Stimson formation targets across sites shows some local variability and indicates minor differences in depositional processes at the Murray-Stimson contact.

Figure 1. A: Mean grain sizes for Marias Pass targets and their sorting measurements. Manual results are in blue (MAHLI) and red (RMI), while automated results are in green (MAHLI) and purple (RMI). B: Adjusted mean grain sizes for Marias Pass targets. Resolved manual results are in blue (MAHLI) and red (RMI), while recalculated automated results are in teal (MAHLI) and orange (RMI). Phi=−log₂(d) where d is diameter in millimeters. Error bars are one standard deviation.


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