GRAIN SIZE ANALYSIS WITH SIMULATION OF DIGITAL IMAGES FROM MARS SCIENCE LABORATORY TESTBED IMAGERS.
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Introduction: The Mars Science Laboratory (MSL) rover, Curiosity, landed on Mars in August 2012 with the goal of assessing the past or present habitability of an environment in Gale Crater. To assess the habitability of these modern and ancient environments, MSL carries a suite of instruments capable of exploring preserved geologic features that may represent habitable environments. This instrument suite contains several science camera systems which have been used to gain a better understanding of the depositional environments in Gale Crater. Recently, fluvial and lacustrine deposits on Mars have been identified as past habitable environments [1]. Part of this identification includes characterizing the distribution of grain sizes in sedimentary deposits, which informs the interpretation of the depositional environment. It is important to explore the limitations on grain size resolution with these cameras, as it directly affects the accurate measurement of grains and interpretation of depositional environments. This study determines the accuracy at which grains in terrestrial sedimentary rocks can be identified and measured under variable sun angles, and compares results to the resolution capability of the ChemCam remote micro-imager (RMI). Compared to the RMI camera, the remote cameras (Mast Camera and Navigation Camera) that are also used for grain analysis on the rover have a lower resolution. Previous studies have demonstrated that the RMI camera is a useful tool to remotely characterize sedimentary deposits [2].

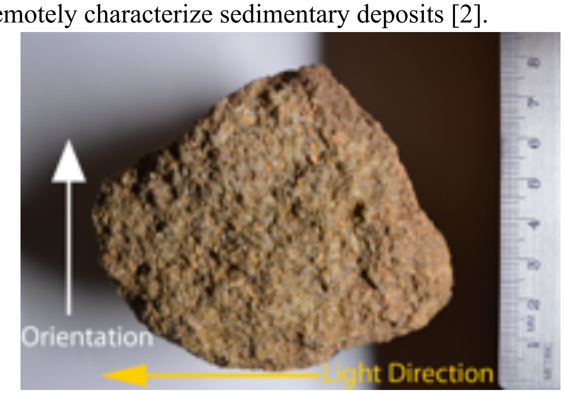

Fig. 1. Laboratory DSLR image of a coarse sandstone.

Data Collection Methods: Six samples from the Abo Formation were collected in New Mexico, USA. The Abo Formation is comprised of fluvial mudstones, sandstones, and conglomerates deposited in a low-gradient alluvial plain in the Permian [3]. Using a high resolution digital single-lens reflex (DSLR) camera (Nikon D3200 and a Nikkor 18-55 mm lens), images were acquired of each sample with simulated sun angles of 30º, 45º, and 60º. Grain size and area were measured using ImageJ software [4]. The area and length (longest visible axis) of each grain in a selected 500 mm^2 area were measured and recorded. Grain sizes were binned according to the Wentworth scale [5] (pebble=4-64 mm, granule=2-4 mm, very coarse sand=1-2 mm, coarse sand=0.5-1 mm, medium sand=0.25-0.5 mm, fine sand=0.625-0.25 mm, very fine sand=0.0625-0.625 mm, silt =0.0039-0.0625 mm). Accurate grain measurement can be difficult for very small grain sizes. Pixelation can blur grain edges and grains smaller than the pixel size are not resolvable [6]. Additionally, two dimensional grain analysis is known to overestimate particle size in small grains (35 - 140 µm/pixel; [7]). To reduce possible error in grain size measurements, we required measured grains in the study be composed of at least 5 pixels (as in [8]).

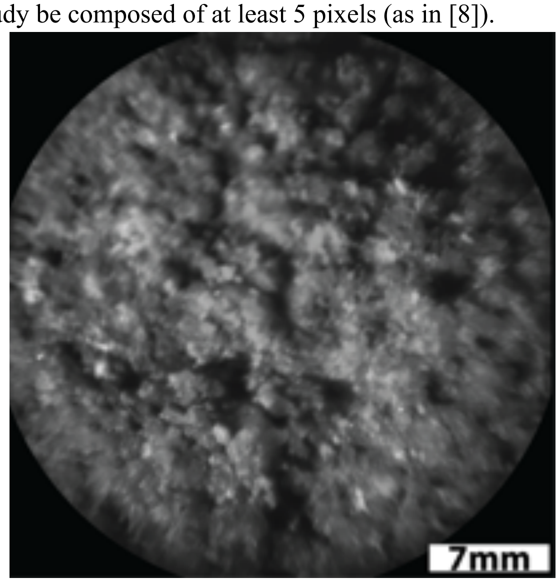

Fig. 2. Testbed RMI image of a coarse sandstone.

To simulate RMI imaging capabilities, two samples (Figs 1, 3) were imaged by the RMI testbed imager, an identical copy of the RMI on Mars, at the Institute for Research in Astrophysics and Planetology in Toulouse, France (Figs. 2, 4). The grains in these black and white images were measured for area and length, and compared to the DSLR color images. The RMI is used to document the location of ChemCam's laser-induced breakdown spectroscopy laser pits for further analysis. RMI has an angular pixel size of 19.6 µrad [9, 10]. 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 [9, 10].

Fig. 3. Laboratory DSLR image of a pebbly sandstone.

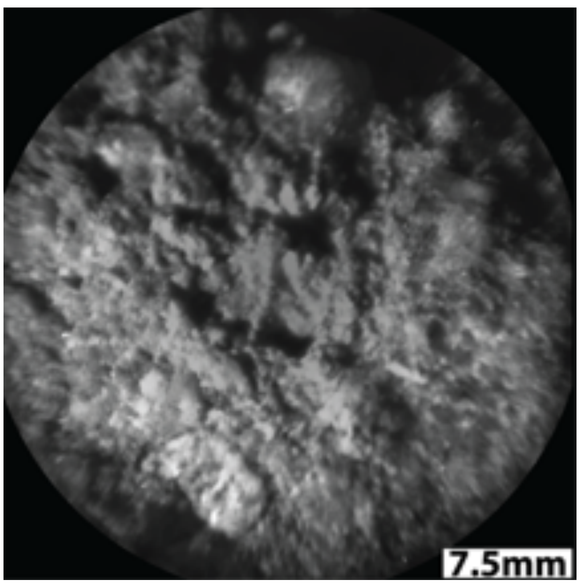

Fig. 4. Testbed RMI image of a pebbly sandstone.

Observations and Interpretations: Grain sizes were measured in six sedimentary rock samples using the methodology of [8, 11] to estimate grain size and limitations on grain resolution. Grain sizes ranged from pebble to silt sized particles. Lower angles of sunlight made shadows larger, which hid grains that may have been useful for analysis. However, high sunlight angles made grain boundaries less distinct. Precipitates, cementation, and oxidation of the minerals in the samples made it difficult to analyze all grains in the sample area.

The RMI images were not as sharp as the DSLR images because the RMI images were captured at a further distance than the DSLR images. The RMI in Fig. 2 was taken ~1.535 m from the sample and the RMI in Fig. 4 was taken at ~1.549 m from the sample. The DSLR image in Fig. 1 was taken at 0.380 m and the image in Fig. 3 was taken at 0.335 m. RMI image contrast was higher than the DSLR image contrast. The grain boundaries were less distinct in the RMI images than in the DSLR images. In the coarse sandstone sample, 59% of the grains resolved/measured in the DSRL image (sun angle 45º, Fig. 1) were also resolved in the RMI image (Fig. 2). In the pebbly sandstone, 26% of the grains measured in the DSLR image (sun angle 45º, Fig. 3) were also resolved in the RMI image (Fig. 4).

Conclusions: The grain size in the DLSR images had little effect on the accuracy of measurement, because most of the grains were composed of at least 5 pixels. In the RMI images, grains smaller than ~0.36 mm were difficult to measure if the grain and matrix were a similar color. Light colored grains were more easily resolved in the RMI images because of the high contrast. The lack of sharpness and color in RMI images makes the measurement of small grains difficult with this technique. However, using images captured at more than one sun angle provided more accuracy because the 30º and 45º angles of sunlight reveals grain boundaries that are otherwise unseen in the 60º angle of sunlight. The 60º angle of sunlight illuminated more grains and created fewer shadows, so more grains were measurable. Approximately 73% of grains resolved in the 60° sun angle were resolved in the 30° sun angle DSLR image, and ~90% of grains resolved in the 60° sun angle were resolved in the 45° sun angle. Using images captured at multiple angles also helped when identifying whether a grain was genuine or a diagenetic feature with contrasting color or brightness. Cement covered parts of grains, but it was not obvious unless a comparison of images at different sun angles was used. With different illumination angles, grain boundaries were easier to see and the precipitates and cements were more easily identified. This study has shown that using a set of images at different sunlight angles led to higher accuracy of grain measurement. For future work, capturing images at different perspectives could be useful as well, as the different faces of grains are shown when the orientation of the camera view is changed.

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