AEOLIAN SEDIMENTS AND FORMS ALONG THE OPPORTUNITY ROVER TRAVERSE

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Introduction: Studying aeolian sediments and forms is crucial to understand aeolian transport on Mars. Such studies require employing in situ data, as orbital images are not sufficient to determine small scale features and processes that happen at the planetary surface. Although currently we have very limited in situ data resources, we can establish some methodology allowing classification of forms and sediments, studying their spatial distribution and their evolution in time.

Up till know, Martian aeolian sediments on microscopic scale have been studied by three rovers: Curiosity, Opportunity and Spirit. In this work, we will focus on the Opportunity rover, as it travelled the longest distance (more than 45 km) and which location is unique. Meridiani Planum is a very flat region, covered by coarse-grained ripples of various sizes and densities. The only major landforms on the plains are impact craters. Meridiani Planum bedrock is made of sulfate-rich sandstones (the Burns Formation), from which hematite concretions are eroded. These concretions, called spherules, are a common constituent of Meridiani Planum sediments [1].

Methodology: To study sediments, we need granulometric and morphologic information. In order to obtain it, we used the PADM algorithm [2], a semi-automated method which employs three segmentation techniques, enabling determination of shape and size of individual grains. In comparison to manual methods, it is much faster, easier, and can very accurately define the shape of grains. To determine the shape of grains, we not only used aspect ratio and circularity, but also roundness defined by Wadell [3]. To calculate this parameter, we employed the computational geometry algorithm created by Zheng and Hryciw [4]. An example of grains' detection is shown in Fig 1.

To study aeolian sediments we used the MI and Pancam images taken by Opportunity. Bedform investigations was performed using the Navcam, Hazcam, and Pancam datasets, as well as the HiRISE images, covering the Opportunity traverse area. We also employed the HiRISE and MOLA HRSC DTMs to study local and regional topography.

For detailed geomorphological mapping we used objective classifiers, such as size, crestline length per area, height.

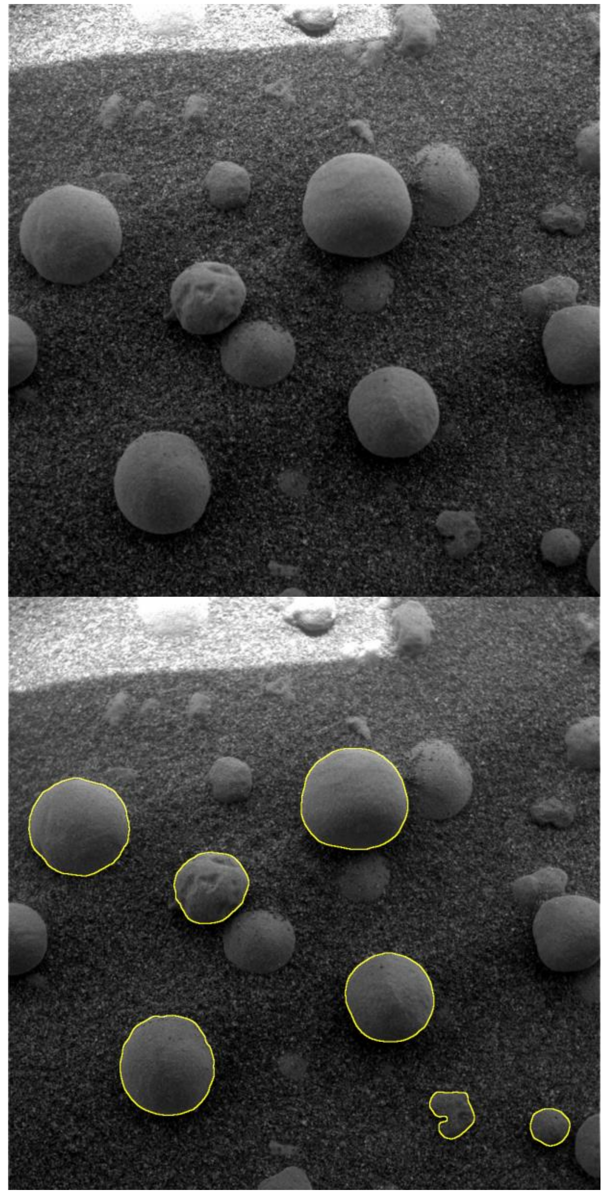

Figure 1. Detection of spherules. The algorithm detects automatically only particles that are not buried in sand or cut by the image border. In this image only 7 objects meet these criteria. One is not a spherule. The median diameter of 6 spherules is 4.97 mm. Their median roundness and circularity are 0.83 and 0.90, respectively.

Results: The PADM algorithm was firstly validated on 182 regolith images that were taken by the MI instrument. The validation indicated that the algorithm efficiency and accuracy within the dataset, composed of images of various illumination and types of sediments, is not worse than 84%. The implementation of the algorithm in Mathematica and Matlab allowed fast deletion of unwanted objects; therefore, it was easy to choose well-detected particles for further analysis.

We analyzed almost 300 images of sediments obtained along the traverse of the Opportunity rover. The morphological analysis was possible only for larger grains (diameter > 0.5 mm), as the resolution of MI images is ca. 31 um/px [5]. The granulometric analysis was done for grains larger than 5 px in diameter (d). The smaller grains (down to 5 px in area) were analyzed only when they were located on a plain background, like on the magnet arrays or smooth rock surfaces.

Sediments observed on Meridiani Planum are similar to each other with exception of these in the Endeavour Crater area, which is in a different geological unit than the Meridiani plains.

Spherules are common on the plains and are of great importance for aeolian transport as they made up lag deposit, which influences the roughness and hardness of the surface. The median spherules' diameter varies between different samples, which is probably related to changes in bedrock composition.

Sands composed of fine-grained particles (d < 300 µm), common on Meridiani Planum do not vary significantly (to the limits of the image resolution). They have a median diameter of 165 µm and a bimodal distribution with the higher mode at 130 µm and the lower at 170 µm.

As we are limited in this study to area of the Opportunity traverse, we focus on aeolian forms that were observed by the rover. These are mainly: normal and coarse-grained ripples, ripples convergence and divergence zones, wind streaks, sand shadows, lag deposit zones, ventifacts, linear structures transverse to the ripple field orientation. The orientation and/or superpositions of these forms indicate that they were shaped and reshaped by different winds, similarly to the observations of other authors [see e.g. 6,7].

The geomorphological mapping indicated that we have three main types of coarse-grained ripples. We called those ripples: small, medium and large.

The small ripples are few centimeters high; they are several centimeters wide, and their wavelength is of order of tens of centimeters. They are especially common in areas where aeolian deflation is dominant (e.g. near large non-eroded craters). The medium and large ripples' wavelengths are of order of meters, however large ripples are ca. 3 times higher (up to ca. 1 meter) than medium ripples and have different morphology. They are common in areas with alternating accumulation and deflation zones.

The coarse-grained sands are composed mostly of spherules' fragments [6]. The granulometric and morphological parameters of these sands taken from different types of coarse-grained ripples show some significant differences (Fig 2).

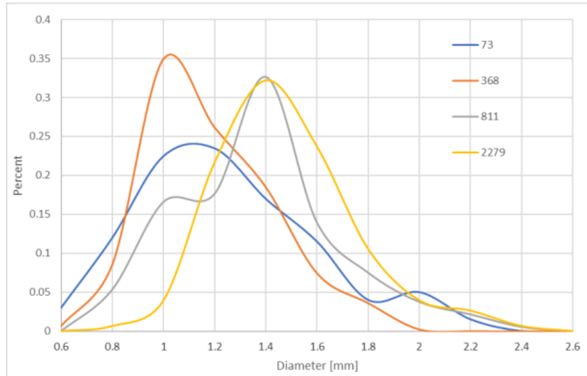

Figure 2. Granulometry curves for four samples: sol 73 – small ripple crest/slope, sol 368 – medium ripple crest, sol 811 – large ripple slope, sol 2279 – large ripple crest.

Further work: Having this ground truth analysis, we can move to approximated CTX/HiRISE mapping of the whole Meridiani Planum, based on the information acquired during this study and on the assumption that this region is geologically uniform. Meridian Planum is covered by CTX images almost entirely, and many HiRISE images are also available. Such mapping is, however, not possible without an automatic method for landform recognition and analysis, which is currently being developed. It is based on available techniques [see e.g. 8], and can be used to analyze large datasets, providing dedicated geoinformatic infrastructure.

Acknowledgments:

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References: [1] Squyres S.W., et al. (2004) Science, 306 (5702), 1709-1714. [2] Kozakiewicz J. (2018) *Earth Science Informatics*, 11, 257-272. [3] Wadell, H. (1933) *J. Geol.*, 41(3), 310–331. [4] Zheng J. and R.D. Hryciw (2016) *J. Comput. Civ. Eng.*, 30(6): 04016021 [5] Herkenhoff KE et al (2003) *J Geophys Res*. 108:8065. [6] Sullivan, R., et al., (2005) *Nature*, 436, 7047, 58-61. [7] Fenton L.K. et al. (2015) *Aeolian Research*, 16:76-99. [8] Foroutan, M., J. R. Zimbelman (2017) *Geomorphology*, 293, Part A, 156-166.