FRACTAL ANALYSIS OF THE MICROSTRUCTURE OF THE MARTIAN SOIL AT THE PHOENIX LANDING SITE.

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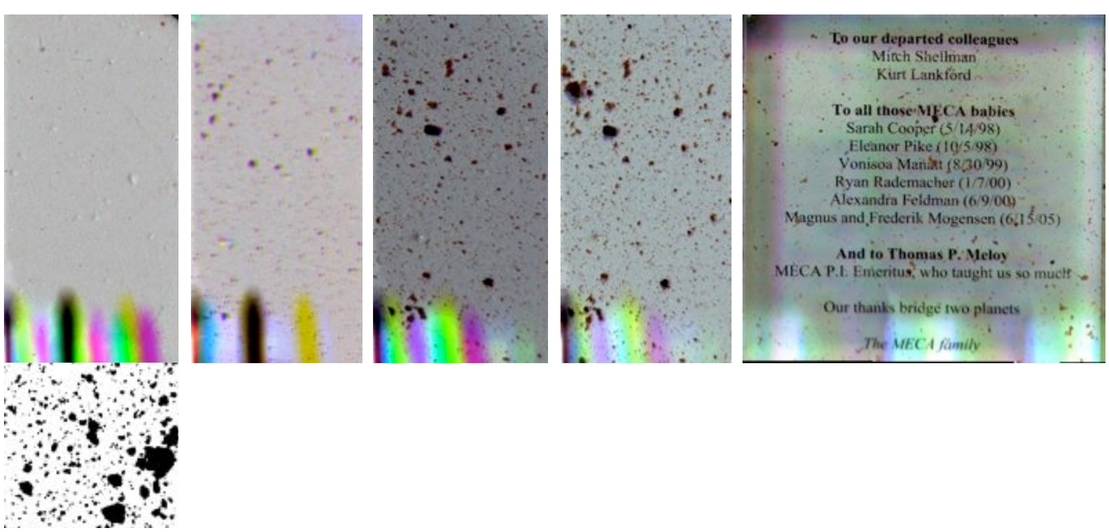
Introduction: The microscope station of the Phoenix Lander is able to image the dust and soil of Mars at unprecedented resolution, with a 4 µm resolution for the optical microsope and less than 100 nm with the atomic force microscope [1]. Soil was delivered by the robot-arm scoop of Phoenix to a series of substrates for imaging by the two microscopes. We present here an analysis of the particle sizes of material collected on substrates which were intentionally not loaded with soil, a white calibration standard and a stitching standard. These substrates passively collected material over the course of the mission which was mobilized within the microscope station enclosure. Hence the particle population represents a integrated sample from the dig volume of Phoenix [2] with the selection criteria of sufficient adhesion between the particles and the substrates to prevent removal either during the vibrations induced by rotations and translations of the sample wheel or by gravity as the substrates were imaged vertically.

The two substrates both accumulated particles between observations. A sequence of images from the white calibration substrate is shown in fig. 1(a - d) from which it is evident that once particles adhered, they remained on the substrate. Larger particles were able to stick to the rougher surface of the macor of white calibration standard compared to the quartz of the stitching standard. The particles show very little variation in coloration, with the most likely provenance being the dominant orange-brown segment of the soil seen in all samples from the landing site [3].

Particle size distributions: Particle size distributions were determined from images (d) and (e) using a variety of segmentation approaches. These were converted to plots of accumulated mass (in arbitrary units) against particle diameter, with the assumption that the density of the material was constant and the particles are approximately spherical. The former is justified by the even colouration which is independent of particle size, while images of the particles in profile at the edges of the substrates formed the basis for approximate sphericity. Fig. 2 shows such a plot for the Sol 137 image using different segmentation approaches. The data shows a break in slope at about 15 µm particle diameter.

Fractal analysis: Such plots can be interpreted in terms of the fractal dimension of the fragmentation of the soil [4]. The slope can vary between a value of 3 and zero, with the slope given by $3 - D$, where D is the fractal dimension of fragmentation. D is inversely related to the probability of fragmenation of a particle, with a high probability corresponding to an easily fragmented particle. Hence a steep slope corresponds to a size regime where the probability of particle fragmentation is low, while a shallow slope indicates that the particles easily break up in that size range. Breaks in the slope correspond to a change in the strength of the particles to fragmentation, for instance the transition from primary particles to agglomerates above a certain size. A good fit to the data is possible with the parameters as shown in fig. 2. corresponding to a fractal dimension of 0.23 for particles smaller than 15 µm and 1.71 for larger particles.

The very low value for the smaller particles, close



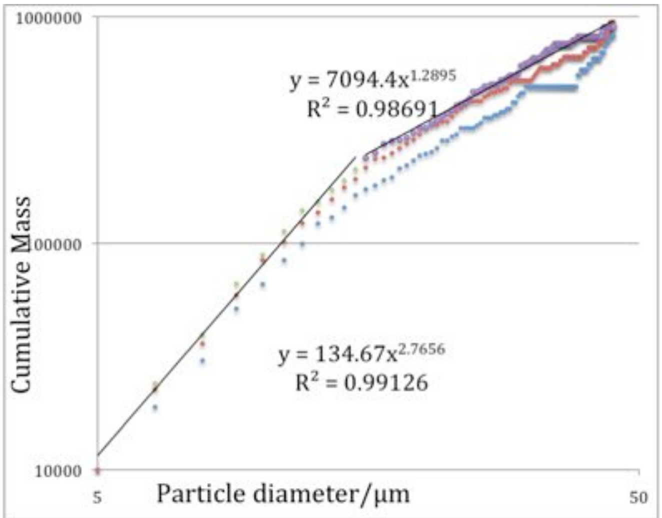


Fig. 2: Logarithmic plot of the cumulative mass with particle diameter. The three plots for different segmentations to produce the binary image.

to the theoretical minimum of zero, indicates that in this size regime fragmentation is rare: these particles are likely to be the primary particles of the soil at this site. In contrast the much larger value of 1.71 for particles greater than 15 µm across corresponds to weaker forces preventing fragmentation, with the most likely explanation being that these larger particles are agglomerates of the smaller, primary particles. This is confirmed by the profile of the larger particles in figure 1 which exhibit a more jagged shape.

Conclusions: On Earth, the largest primary particles are up to 0.5 µm in size, forming the clay fraction of the soil, with a fractal dimension of between about 0.2 and 1. This analysis of the soil at the Phoenix site indicates that the primary particles are both resistant to fragmentation and up to 30 times larger than terrestrial particles.

The agglomerates in the Phoenix soil, from 15 µm up, are very strongly bound. In comparison on Earth, bulk soil has a fractal dimension of 2.9 or above, while the lunar regolith has values ranging from 2.3 to 2.5. This regolith is seen as very cohesive, and if the fractal dimension of 1.7 extends upwards from the 50 µm seen here to the mm scale, it would be indicative of the extreme stickiness of the soil seen during Phoenix operations.

The microstructure of the soil of the Phoenix landing site is unlike any other soils so far studied on Earth and the Moon. Further work should extend this analysis to larger length scales and allow comparison with the soil properties at the imaging range of other locations on Mars.

References:

[1] Hecht et al. (2008) JGR, 113, E00A22. [2] Arvidson. et al. (2009) *LPSC XXXX*. [3] Goetz et al. (2009) *LPSC XXXX*. [4] H. Millán, *et al*, *Geoderma 117 (2003) 117–128*.