A MATHEMATICAL MORPHOLOGY APPROACH TO THE ANALYSIS OF MARTIAN SOIL SAMPLES. C. Lira, J. Saraiva, P. Pina, L. Bandeira and J. Antunes, CERENA, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal (cristina.lira@ist.utl.pt).

Introduction: The characteristics of Martian soils are a matter of clear importance when considering the problems that can arise for a rover traversing areas where loose particles are predominant – as Opportunity had the mischance to comprove by itself. The study of Martian surficial materials has been the subject of a number of works, mainly concerned with the texture, constitution, origin and sorting of the particles [1] [2] [3] and what that can tell us about the geologic history of the areas concerned [4] [5]. These studies are generally focused on the manual measurement of grain characteristics on images of soils, since it is not feasible to have a rover collecting and analyzing large numbers of samples.

However, a method to analyse the granulometry of Martian soils without physically collecting and handling samples can be attained through the application of image analysis techniques. The methodology we propose is based on mathematical morphology, and consists on the successive application of an operator (opening with reconstruction) that can give us a measure of the area that is occupied by different dimensional fractions of the particles present in an image.

Dataset: We collected a number of images of the Martian soil acquired by Opportunity's MI in different settings. Each of these images covers an area of 3.2x3.2 cm^2, and the particles present have dimensions in the order of mms (the grains), though they are embedded in a matrix of much smaller dimensions. These images were chosen because they were mentioned in a previous work [1], in which some data on the dimensions of the grains was presented; also because they were easy to procure and seemed to present a wide range of challenges, thus enabling us to begin developing a methodology for the automated processing of the soil scenes.

Methodology: The samples imaged by the MI show a number of characteristics that can be explored for the processing of the images with the aim of characterizing the soil in terms of the dimensions of the particles clearly discernible. Given the remote nature of the images, there are some issues that, in order to be solved, will need the input of physical information, that can be acquired only through the handling of the soil itself (namely, scooping the samples, or trenching the soil).

The operator chosen for the processing of the images, called opening, is a way to determine the volumetric granulometry of an image [6]. To clearly understand this, it must be taken into account that an image can be seen as a textured surface, with peaks and valleys according to the intensity values of each point. The morphological opening identifyies volumes under a given threshold (the size of the opening); these could be high thin peaks or comparatively low but large areas. The use of this operator can be justified by the fact that there is a relation (even though, for grey-level images, it is not simple) between the texture of the image given by its volumetric granulometry and the distribution of sizes of the particles present.

Results: We present and discuss below the results obtained for some of the images, along with some comments. The interpretation of the graphics demands the careful analysis of the images resulting from the successive application of the opening (with increasing argument).

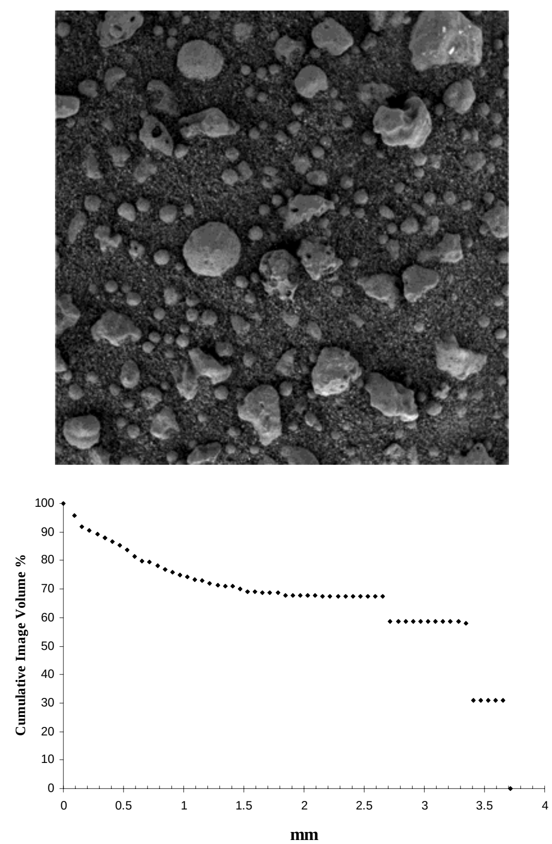

Figure 1. Soil sample from MI image 1M132896901 (MER Opportunity, NASA/JPL), 3.2 cm on a side, and respective volumetric granulometry, obtained by openings of increasing size.

Figure 1 shows a sample where particles of very diverse sizes can be seen; there is a fine matrix embedding larger grains whose size distribution is clearly discontinuous: some round spherules of small radius and larger, sometimes angular grains. On the graphic this situation can be related to a smooth decrease in the curve followed by three discontinuities, at 1.9, 2.7 and 3.3 mm, reflecting the fractionated nature of the grain size distribution. From this size on, the number of remaining pixels (that do not belong to grains) is very small, since all grains are already 'sieved'; thus, this part of the curve is irrelevant for the analysis.

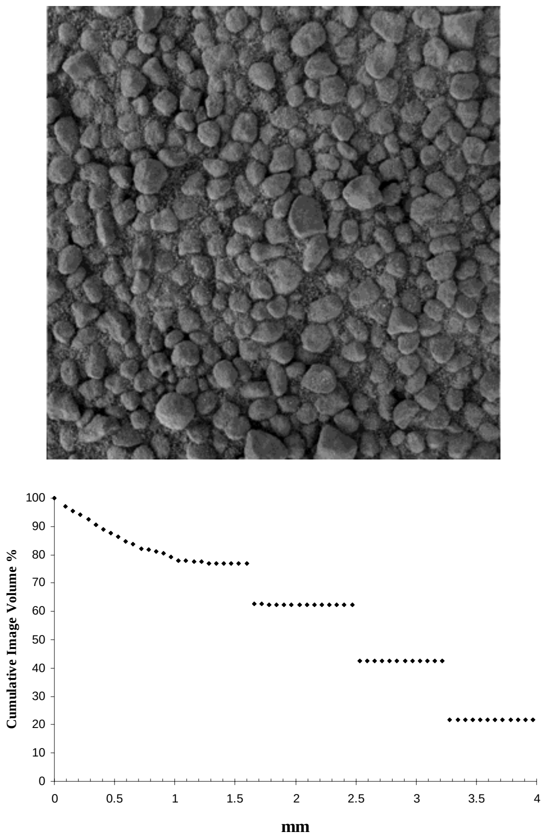

Figure 2. Soil sample from MI image 1M132808705 (MER Opportunity, NASA/JPL), 3.2 cm on a side, and respective volumetric granulometry, obtained by openings of increasing size.

Figure 2 shows another sample, apparently better sorted. Still, the graphic clearly demonstrates the discontinuity of the size distribution, with a group of grains around 1.6 mm and another, larger, around 2.5 mm. Again, from this point on, there are no more grains to be 'sieved'.

The differences between the values of grain sizes that we determined and those presented before [1] can be explained by the fact that we are measuring the extreme values of the granulometric fractions defined through the graphics, instead of mean values for a selected set of grains analyzed.

Future work: This methodology is still in the first steps of development, and there are a number of improvements that can lead to better results, easier to interpret in terms of the granulometry of particles present in soil samples. The segmentation of the particles will lead to a clear separation between background and grains, thus allowing for the determination not only of their dimensions but also their shape. Furthermore, the background can then be equated with the finer matrix present, giving better information on the distribution of different dimension fractions within a sample.

This technique can, of course, be tested and further developed on terrestrial soils, allowing for a validation of the results and the search for relation between what can be seen on a surficial image and the vertical structure of the soil in the first centimeters of depth.

Acknowledgements: This work was funded by FCT (Portugal), in the frame of research projects MAGIC (PDCTE/CTA/49724/2003) and TERPOLI (PTDC/CTE-SPA/65092/2006). FCT also funded CL (SFRH/BD/28229/2006), JS (SFRH/BD/37735/2007) and LB (SFRH/BD/40395/2007).

References: [1] Weitz et al. (2006) *JGR*, 111: E12S04. [2] Jerolmack et al. (2006) *JGR*, 111: E12S02. [3] Yingst et al. (2008) *JGR*, 113: E12S41. [4] Soderblom et al. (2004) *Science*, 306: 1723-1726. [5] Herkenhoff et al. (2004) *Science*, 305: 824-826.. [6] Soille (2003), Morphological Image Analysis, Springer.