The PHOENIX Microscopy Experiments

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Introduction: The PHOENIX mission to Mars has several geological goals, one of which aims at understanding the degree to which the origin of the soil at the landing site is linked to water based processes. In order to do so, PHOENIX features a suite of instruments that allows looking at the landing site at different length scales, addressing the whole geological context. The Mars descent imager (MARDI) will provide an overview of the site based on various aerial pictures taken at heights from about 1000m above ground to a few meters. This information shall allow assessing how representative the actual landing site is for the whole region. The surface stereo imager (SSI) will then take a look at the site as it would appear to a field geologist. Still, relatively large objects and form will be of major interest: What are the slopes, rock abundance, and size distribution at the boulder to cobble level? The robot arm camera (RAC) can inspect a smaller area at a higher magnification, which should reveal details down to the level of gravel (lower millimeter scale range). However, this area will be limited by the reach of the robotic arm. More important, RAC will take images of the trench that will be dug by the robot arm. Especially the trench sidewalls will be of interest for putting the samples for the microscopy station in a larger context.

Microscopy on Mars: The RAC will document the sample in the scoop prior to its delivery to the microscopy station of MECA (Microscopy, Electrochemistry and Conductivity Analyzer). This will be valuable information especially for interpreting size distribution analysis made by the MECA microscopes. The design of MECA "pre-selects" particles in the following way: A wheel, carrying different sets of substrates will be partially pushed through a slot in the MECA enclosure, exposing one set of 6 substrates onto which the samples will be poured. Pulling the sample-wheel back into the enclosure will wipe off a large amount of the soil sample, leaving a layer of about 200µm thickness on the substrates. Some of the substrates are so called "micro-buckets", small cups of about 3mm diameter and depth, where of course also particles larger than 200µm will be admitted. The set of samples will then be sequentially positioned in front of the microscopes, which involves tilting of the substrates to the vertical position. The sample-substrate interaction (adhesion) and intra-sample forces (cohesion) will select those particles which will be presented to the microscopy station for investigation. Substrates with specially structured surfaces were designed in order to control this interaction and to allow stabilizing the samples during AFM imaging. More information about these substrates will be given in an accompanying paper by W. T. Pike et al. (this volume).

MECA Microscopy will primarily address the following questions: what is the size and size distribution of soil particles, and what is their shape. These characteristics will indicate which processes have affected the particles and whether they were transported to the observation site. Well-sorted size distributions indicate fluid sediment sorting. Rounded particle forms indicate abrasion by fluid transport (air or water), and/or water-based chemical weathering in situ (diagenesis). Etch features on particle surfaces seen with AFM resolution also indicate water-based processes in the regolith. The presence of very fine clay mineral crystals would be additional evidence for aqueous weathering on Mars.

After in situ calibration of the instruments and sample delivery, optical microscopy (OM) images will be taken in a first analysis. The sample wheel can be moved through the focus of the OM such that 3D information can be gained. Figure 1a shows how a sample of red aeolian sand trapped in one of the micro-buckets as it might appear to the OM on Mars. The coloring will be achieved by LED based red, green, blue and UV illumination and subsequent superposition of the respective and individually acquired grayscale images.

The pixel size of the OM image is 8µm. Hence, particle sizes below about 20µm cannot be measured. For identifying particle shape, a particle must measure approximately 100-150µm, otherwise roundness and an-

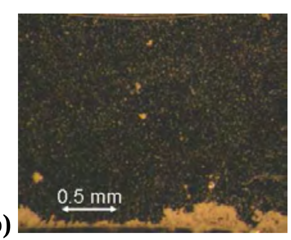
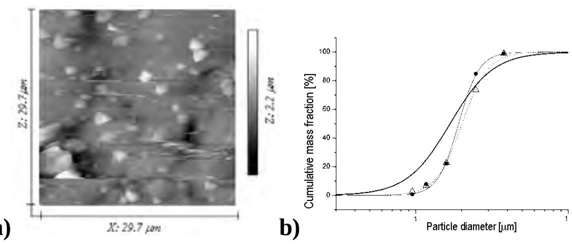
a)  **b)** 

Figure 1 **a)** Red aeolian sand in a micro bucket imaged with an OM. The field of view is about 1.5mm $\times$ 1.5mm. **b)** Crushed basalt (white particles) on a blank silicon substrate (black), imaged with a laboratory microscope at the field of view that the MECA OM has. It can be seen that most of the particles sled to the lower rim of the substrate.

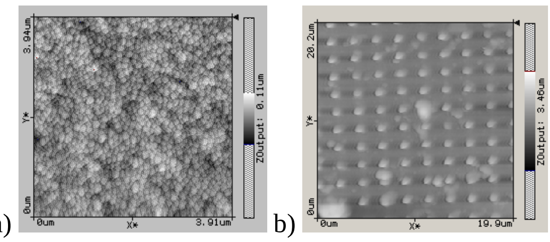


a) b)

Figure 2 **a)** Quartz particles imaged with an engineering model of the MECA AFM. The height information is indicated in grey level **b)** The cumulative mass (volume) fraction for the 69 particles measured in a) is indicated with triangles. The circles take additional experiments into. The solid line is a reference measurement made by laser scattering. The mean particle diameter was 1.28±0.41µm for a) and 1.47±0.54µm for all AFM measurements made during that campaign.

gularity cannot be distinguished. On the other hand, the atomic force microscope (AFM), which will be engaged after OM, has a field of view (FOV) of 40µm and can zoom-in to 5 µm FOV, at which scale the pixel size will be 10nm. This should allow characterizing particles down to the 100nm scale range. The AFM cannot reach the full FOV of the OM; access is limited to small band of about 56µm (corresponding to the diagonal of the FOV) in width in the lower half of the substrates. Up to now, AFM has rarely been used for particle analysis in geology. Figure 2, however, demonstrates that AFM measurements can indeed provide valuable information on particle size and size distribution at the 0.1 to 10µm scale range previously inaccessible on Mars. This range is also particularly important for analyzing dust particles from the atmosphere. Results of previous missions, based on fitting the particle radius to light scattering measurements, indicate a range between 0.2 and 4µm.[1] This was achieved assuming a certain dielectric constant and shape. Particle shape information will therefore improve the understanding of such light scattering experiments. Knowledge of the average dust particle size and shape will enable more accurate probing dust clouds by light scattering experiments. Airborne dust is expected to play an important role in the climate of Mars and in the H_2O sublimation cycle, and therefore, AFM will also contribute to investigating atmospheric science questions.

All previous Mars lander missions found that airborne dust contains magnetic particles. It is supposed that the mineral responsible for that property is maghemite, a Fe-III oxide, which could be formed from a Fe-II oxidation state in a wet, oxidizing atmosphere[2]. The microscopy station, therefore, also features in each set two magnetic substrates of different strengths, which will allow specific interrogation of those particles. More information about magnetic substrates and the scientific context of the corresponding experiments will



a) b)

Figure 3 **a)** 4µm×4µm AFM images of silica 100nm diameter spheres. **b)** AFM image of a pin-cushion calibration sample. The height information is indicated in grey levels.

be given in an accompanying paper by M.B. Madsen et al (this volume). The capability of measuring shape with FAMARS (as the MECA AFM is dubbed) has not yet been fully explored, in contrast to OM, where these kinds of measurements are well established. Corresponding characterization experiments with FAMARS are in progress. First results are shown in Figure 3a, where 100nm diameter silica spheres are imaged. The shape of the AFM probe may dilate the apparent object in the image and can influence the measured shape of particles. It needs therefore to be regularly assessed during the mission by means of retro imaging on a pin-cushion sample like the one shown in Figure 3b. Data processing with an “erosion algorithm” will allow afterwards correcting tip artifacts in the measurements.

Summary: First measurements show that FAMARS and the MECA OM, in combination with the delivery system of MECA, should allow characterizing Martian particles with high resolution. Context with larger scale measurements will be given by RAC SSI, and MARDI images. Future work will consist in characterizing MECA OM and FAMARS, cataloging OM and AFM measurements on Mars analogue samples and performing end-to-end tests on MECA test beds. The latter will be important to identify the biasing of size distribution results by the sample delivery chain.

Acknowledgements: Helpful discussions with P. Smith, U. Keller, M.B. Madsen, W. Markiewicz and other members of the Phoenix Science team are gratefully acknowledged. We thank N.F. de Rooij for his interest and support in this work. D. Brändlin-Müller, L. Howald, A. Tonin, H.R. Hidber, A. Mazer, L.E. Tatge, R. Tanner, H. Sykulska, and S. Vijendran are recognized for their contribution to the development and fabrication of the instruments. The work is financially supported by the Space Center at EPFL, the Wolfermann-Nägeli Foundation, the Canton et République de Neuchâtel and the PHOENIX Scout Mission of NASA.

[1] *for a summary see* S. Gautsch, PhD thesis Univ. Neuchâtel, UFO-Verlag, Allensbach (D), 2003 [ISBN 3-935511-24-8].
[2] P. Bertelsen et al. Science, **305**, 827 (2004)