AUSTRALIAN RED DUNE SAND: A POTENTIAL MARTIAN REGOLITH ANALOG

K. R. Kuhlman[1], J. Marshall[2], N. D. Evans[3], and A. Luttge[4] (1) Jet Propulsion Laboratory, MS 302-231, Pasadena, CA, 91109; kkuhlman@jpl.nasa.gov, (2) SETI Institute, NASA Ames, Moffett Field, CA, (3) Oak Ridge National Laboratory, Oak Ridge, TN, (4) Rice University, Houston, TX.

Introduction: To demonstrate the potential scientific and technical merits of *in situ* microscopy on Mars, we analyzed a possible Martian regolith analog -- an aeolian red dune sand from the central Australian desert (near Mt. Olga) [1]. This sand was chosen for its ubiquitous read coating and the desert environment in which is it found. Grains of this sand were analyzed using a variety of microanalytical techniques. A database of detailed studies of such terrestrial analogs would assist the study of geological and astrobiological specimens in future missions to Mars.

Potential instrument concepts for in situ deployment on Mars include local electrode atom probe nanoanalysis (LEAP), vertical scanning white light interferometry (VSWLI), scanning electron microscopies, energy dispersive x-ray microanalysis (EDX), atomic force microscopy (AFM) and X-ray diffraction (XRD). While *in situ* deployment of these techniques is many years away, ground-based studies using these analytical techniques extend our understanding of the data obtained from instruments to be flown in the near future.

Pseudoconfocal microscopy: Optical microscopy will be one of the first techniques used to observe Martian dust. However, optical microscopy suffers from narrow depths of field at high magnifications. Pseudoconfocal microscopy is a technique that takes advantage of this lack of depth of field to produce "in focus" optical images, such as shown in Figure 1. This image was produced using a stack of 32 images taken at a magnification of 100X and a depth of field of approximately 14 micrometers. The images were then deconvolved and combined using the Extended Focal Imaging (EFI) module in the analySIS® 3.1 software package from Soft Imaging System Corporation [4]. The image illustrates the ubiquity and non-uniformity of the red-orange coating on every grain.

Vertical scanning white light interferometry (VSWLI): A potential flight technique, VSWLI provides about 0.5 to 1.5 micrometer lateral resolution and vertical resolution on the order of two nanometers for surface features up to 100 microns high [2]. This technique complements the atomic force microscope (AFM) by providing a bridge between optical microscopy and the high-resolution measurement of surface morphology by the AFM. The three-dimensional image in Figure 2 illustrates the capabilities of this technique. This image also shows the difference in surface texture of one of the coated grains. Note the smooth texture on the left of the image and the rough texture on the right. This may indicate the difference between an abraded surface (left) and a surface that is coated (right). Pitting due to chemical weathering is also visible and quantifiable using VSWLI.

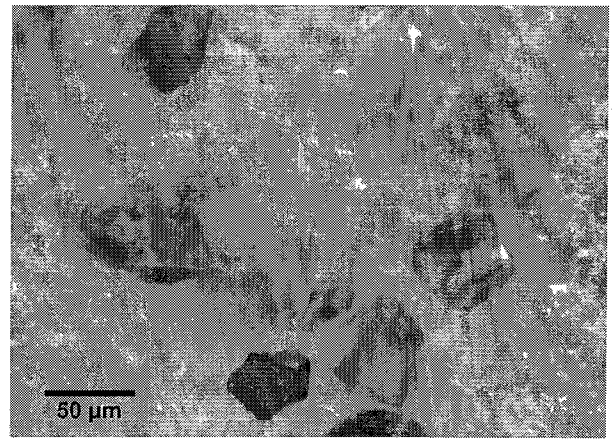

Figure 1: Pseudoconfocal optical image of red aeolian sand produced using a stack of 32 images. Magnification = 100 X. Background is frosted glass.

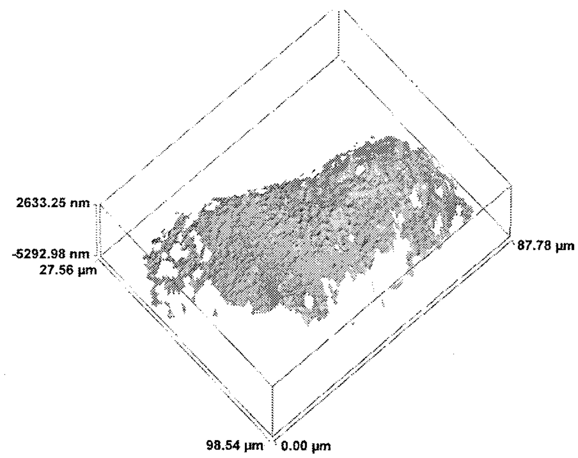

Figure 2: Vertical scanning white light interferometry (VSWLI) reconstruction of the surface of a coated grain.

Scanning electron microscopy (SEM): One of the analytical techniques that is often taken for granted on Earth, but extremely difficult to implement *in situ*, is SEM. When combined with an energy dispersive X-ray spectrometer (EDX), SEM can reveal surface morphology and chemical composition on the scale of micrometers. This technique is very important for understanding the deposition of these surface coatings and modification by chemical and aeolian processing (Figure 3). Surface weathering and the nature of the underlying particle can also be ascertained. Energy dispersive mapping of a cross-section shows that the coating (on the right of the back-scattered electron image in Figure 4) contains both iron and aluminum (Figure 5). This coating is likely an aluminum-rich sol-gel that originates from clays in the region. The clays may have been dissolved by water during brief periods of precipitation, and percolated through the sand leaving evaporites in the crevices of the particles. The EDX spectra also indicate the presence of O, K, P, Ca, Ti, Cr, Ni, Zn, Cu and Au.

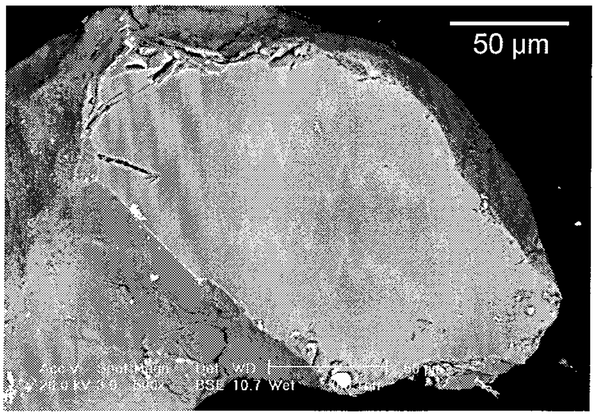

Figure 3: Backscattered electron image of the cross section of a grain showing fractures and cracking at the edges from aeolian transport.

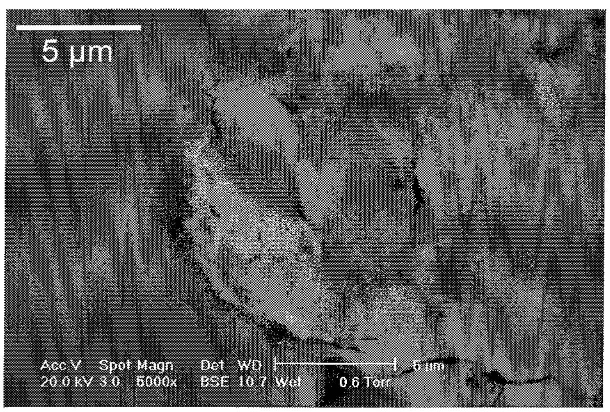

Figure 4: BSE of cross section showing texture of the coating. The polished cross-section of the quartz particle is on the left. Note the bright "grains" within the film that appear in the Fe image in Figure 5.

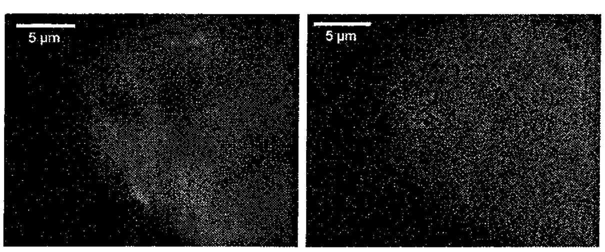

Figure 5: Iron (left) and aluminum (right) EDX maps of cross section in Figure 4. Note that the iron and aluminum coat the outer surface of the grain.

Transmission electron microscopy (TEM): Preliminary TEM of a cross-section of a particle of the red sand shows that the film is not uniform (Figure 6). In fact, the film appears to be composed of tiny crystalline grains within a non-crystalline matrix. These nanocrystals have a distinctively hexagonal shape (Figure 6), strongly indicating hematite. A very small amount of hematite nanocrystals could easily be responsible for the intense red color of the sand.

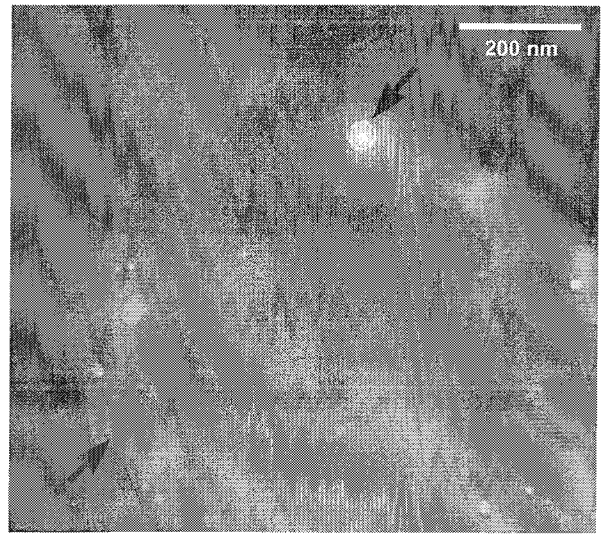

Figure 6: High-resolution TEM image of coating on a grain of Australian red sand. Note the hexagonal shape of the indicated nanocrystals.

Conclusions: Using this variety of techniques to examine the aeolian sample provided a robust set of data that enabled conclusions to be drawn about the origin of the red coating and environmental conditions in general. Our conclusions correlated well with what was actually known about the provenance of the sample and with reports of similar red sands in the literature. Studies of terrestrial analogs will further our understanding of the processes occurring on Mars. Work will continue with TEM, LEAP, AFM and XRD. Results provide us with incentive to miniaturize analytical instruments for *in situ* deployment and field equipment for future human explorers of extreme environments.

References: [1] Collected by Carol Breed, USGS, 1980, [2] Luttge, A. et al. (1999) *American Journal of Science*, **299**(7-9) 652-678, [3] http://www.soft-imaging.com/. [4] Kuhlman, K. R., R. L. Martens, T. F. Kelly, N. D. Evans and M. K. Miller (2001) "Field Ion Microscopy and Three-Dimensional Atom Probe Analysis of Metamorphic Magnetite Crystals," *Ultramicroscopy*, In Press.

Acknowledgements: Research at JPL and SETI was sponsored by NASA. Research at the ORNL SHaRE User Facility was sponsored by U.S. DOE, under contract DE-AC05-00OR22725 with UT-Battelle, LLC, and through the SHaRE Program under contract DE-AC05-76OR00033 with Oak Ridge Associated Universities.