AN ESEM/SEM STUDY OF LUNAR SOIL AND THE POTENTIAL FOR A MINIATURIZED VERSION ON THE MOON Kevin G. Thaisen[1], Lawrence A. Taylor[1], Jessica A. Gaskin[2], Greg Jerman[2],and Brian D. Ramsey[2]; [1]Planetary Geosciences Institute, Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996, (<kthaisen@utk.edu>), [2]NASA-Marshall Space Flight Center, Huntsville AL 35812.

Introduction: As NASA prepares for the return of humans to the Moon, it is imperative to address the science and engineering challenges that will be forthcoming. Innumerable insights into the origin and formation of the Moon, characterization of the lunar soil formation processes, and weathering on airless bodies have been made due to the study of the returned samples from Apollo and Luna missions; as well as the more recently found lunar meteorites.

Although considerable research has already been performed on the samples returned from the moon, these samples represent less than ten percent of the lunar surface area and are significantly biased toward equatorial latitudes. Also, due to collection methods and transportation back to the Earth, samples preserving the important fine- to coarse-particle layering which occurs at the actual lunar surface do not exist.

The successful realization of a lunar outpost will require substantial expansion of our knowledge relating to the lunar regolith. To obtain the morphological, compositional, chemical, and size distribution information that is going to be required, we have been working toward the development of a miniaturized Environmental Scanning Electron Microscope (mESEM) in conjunction with the Marshall Space Flight Center (MSFC), which is funded by the Planetary Instrument Definition and Development Program (PIDDP).

Objectives and current results: Our project involves miniaturization of an Environmental Scanning Electron Microscope (mESEM) with Energy Dispersive Spectroscopy (EDS). We are working toward developing a "point and shoot" mESEM, with a minimum of moving parts, which could be part of a Lunar Rover system. The benefits of having a mobile mESEM on the lunar surface are numerous and include the ability to determine particle size distribution (PSD), morphology, and composition at the micrometer scale. Experiments have been conducted at the University of Tennessee-Knoxville (UTK) and MSFC with SEM and ESEM on returned Apollo soil samples (varying sizes <1 mm) to aid in establishing desired mESEM capabilities and to set design parameters. We are studying the sample charging effects, loss of resolution, and capability to perform EDS under various SEM settings and sample preparations. Of primary concern is sample preparation. To minimize this, we have looked at uncoated lunar samples under vacuum versus with an environmental gas. We have established that an environmental gas in the sample chamber may not be necessary if a lower current is used [1]. This would greatly simplify the lunar mESEM design. As can be seen in Figure 1, sample imaging capability for this particular sample was not significantly reduced by a lack of a carbon or gold surface coating or environmental gas in the sample chamber. We have also performed imaging and EDS on samples which were adhered to carbon tape and samples that were electrostatically attached to larger grains. The results were mixed, in that the amount of sample charging was highly dependent on sample type and size. Future experiments with loose material will be required to determine whether or not any sample stabilization prior to imaging will be required.

Surface charging can develop during the electron current flow accompanying high magnification that is

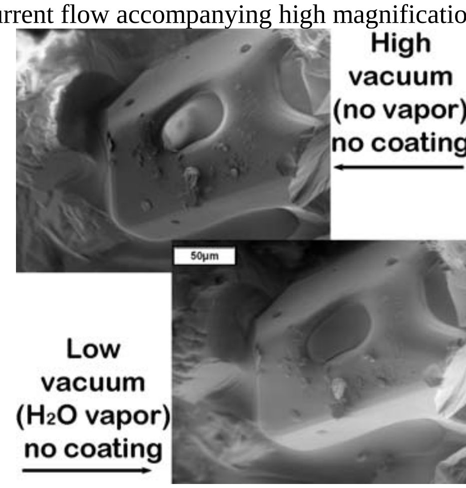

Figure 1. Imagery from a SEM (top) and ESEM (bottom) of uncoated sample under high vacuum and low vacuum with water vapor, respectively.

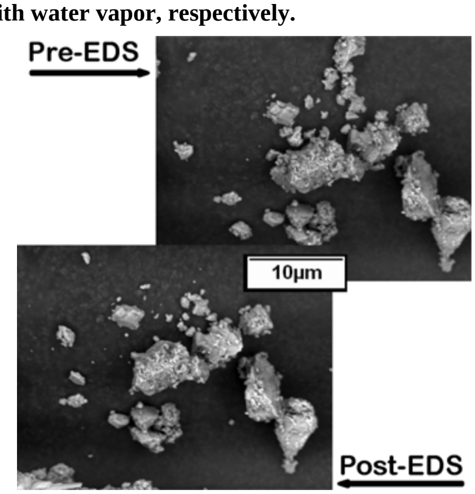

Figure 2. Movement of particles has occurred during EDS operations. Top image is before EDS and bottom is after.

sufficient to move smaller particles as can be seen in Figure 2. The use of EDS tends to charge samples more than during "normal" imaging operations due to longer dwell times of the electron beam, necessary to generate sufficient x-ray signal. This can cause the smaller, loose particles to move somewhat during analysis. However, we have found that satisfactory chemical analyses can be obtained, as seen in Figure 3 of a regolith particle collected by Apollo 17, and that EDS does not appear to be affected by these charging effects. In many cases, we were even able to obtain an elemental map of the area of interest. One drawback due to significant surface charging that may occur during EDS collection is that small particles can migrate out of the field of view of the scan, making results difficult to repeat.

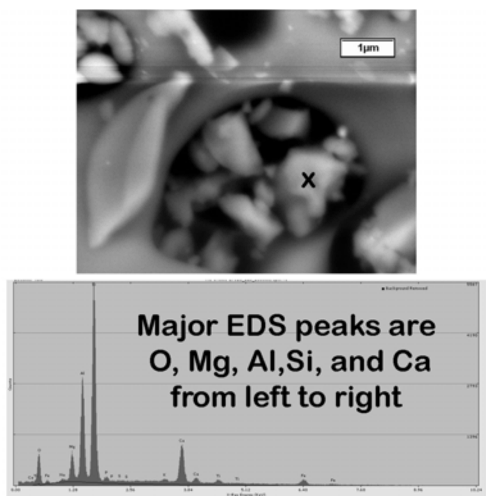

Figure 3. High resolution image (top) of dust within a vesicle of a regolith particle. EDS results from spot X (bottom).

Uses of a mESEM + EDS on the Moon: There is still a considerable amount of research which needs to be conducted on the Moon. This work will directly influence astronaut safety, our understanding of space weathering, and its influence on equipment, and the enigmatic problems of lunar volcanism.

Astronaut safety. There is significant interest in the characterization of lunar dust (<20 µm soil) within the medical community. This dust, particularly the <2 µm fraction, may present serious health problems during prolonged exposure, including potential for cornea and skin abrasion, or even the development of respiratory fibrosis and pulmonary problems. The dust will not just influence the biologic aspects of the mission, but will also negatively affect the equipment that astronauts use and need [2]. We have already determined the PSDs and morphologies of several lunar soils and their dust fractions [3-4]. However, these samples are highly compromised since the "rock boxes" did not completely seal on the Moon [2]. Early quantification of the amount and types of particles in this respiratory-dust size range will allow for the development of operational procedures to mitigate exposure.

Space weathering. The bombardment of micrometeorites (<1 mm) is the major cause of space weathering, but little is actually known of the processes involved, except that which can be discerned from the end-products – e.g., agglutinates. This major weathering process on all airless bodies is of major scientific importance in lunar soil formation, as well for its effects on reflectance spectroscopy. It was thought that *in-situ* evidence of space weathering, resembling sand-blasting, was present on the Surveyor 3 lander that was ~200 m from the Apollo 12 LM. With a piece of the lander retrieved for study on Earth, it was determined that the apparent space weathering was due to dust particles which were accelerated to high velocities during the Apollo 12 decent stage (Metzger, P. pers. comm.). There was obviously space weathering effects there also, but it was over-whelmingly camouflaged by the exhaust-generated effects.

If we are fortunate enough to land in the vicinity of an Apollo rover, or any other hardware left by previous missions, it should be possible to examine these, with our *in-situ* mESEM, for space weathering features (e.g., zap-pits). These could provide a direct dataset for the evaluation of the flux of micro-meteorites that produce the space weathering effects which are a few micrometers in size or less as documented by several investigations by McKay et al. at JSC.

Lunar volcanism. Many aspects of lunar volcanism still need to be addressed including the driving force for the pyroclastic effusives. Evidence for this is on the outer surfaces of the glass beads that are common in all lunar soils. Distinguishing between impact spheres and volcanic glass beads is important for the interpretation of pyroclastic deposits [5]. The distinction between these two lies in the vapor coatings present on the volcanic beads. Apollo 17 orange soil and Apollo 15 green glass (i.e., volcanic beads) have proven to be key to understanding the nature of the Moon's mantle, and hence a better understanding of all lunar igneous rocks. Besides this, the nature of the vapor coatings on the volcanic pyroclastic beads is a function of their origins and reflects the volatiles present during their formation. Volcanic pyroclastic beads are also of particular interest to in-situ resource utilization endeavors, where they may provide a feedstock for oxygen production.

References: [1] Callas, J.L. (2000) Appl. Phys. Lett.; [2] Taylor, L.A. et al. (2005) Proc. AIAA SEC I, #2510; [3] Liu, Y. et al (2008) Jour. Aerosp. Engr., 21, 272-279; [4] Park, J. et al. (2008) Jour. Aerosp. Engr., 21, 266-271; [5] Delano J.W. & Livi K. (1981) GCA 45, 2137-2149.