LUNAR DUST: CHEMISTRY AND PHYSICAL PROPERTIES AND IMPLICATIONS FOR TOXICITY.

Yand Liu[1] and Lawrence A. Taylor[1], [1]Planetary Geosciences Institute, Department of Earth and Planetary Institute, University of Tennessee, Knoxville, TN 37996.

Introduction: Lunar dust is an environmental hazard for activities on the Moon, with effects that range from the potential toxicity to astronauts to the degradation of machinery [1, 2]. Lunar dust is the <20 μm fraction of lunar regolith and consists of ~20 wt% of the bulk 'soil', and as such must be mitigated from its deleterious effects.

In order to develop any mitigation methods, studies have been conducted on lunar dust properties ranging from chemistry and mineralogy, particle size distribution, particle shape, magnetic susceptibility, and electrostatic properties. Here, we summarize our results on properties pertaining to toxicity studies initiated by the Lunar Airborne Dust Toxicity Advisory Group (LADTAG).

Chemistry and Mineralogy: Taylor et al. [3,4] investigated the chemical and mineralogical makeup of 20-45 μm, 10-20 μm, and <10 μm fractions of lunar mare and highland soils. Data on highland soils are accessable at http://web.utk.edu/~pgi. Besides contributions to the understanding of space weathering process on airless bodies, the data also provide us important information about the composition of lunar dust. Figure 1 shows the mineral constitutes of the nine mare soils. Both low-Ti and high-Ti mare soils show increasing abundances of agglutinate glasses with decreasing size. The increasing contents of agglutinitic glass are also accompanied by increasing I_s/FeO (maturity index and a measure of nanophase metallic iron content) [5,6]. and with soil maturity. Similar trend was found in highland soils [4]. Dust of mature soils (I_s/FeO≥60, [6]) contains generally more than 50 vol% of agglutinitic glass, and the <10 μm fraction contains up to 80 vol%. Based on these observed trends, we can infer that the < 2.5 μm fraction, which is roughly the respirable dust sized defined by OSHA (3.5 μm aerodynamic diameter), consists almost entirely of agglutinitic glass (>80 %), which itself contains high abundances of nanophase metallic iron (np-Fe^0).

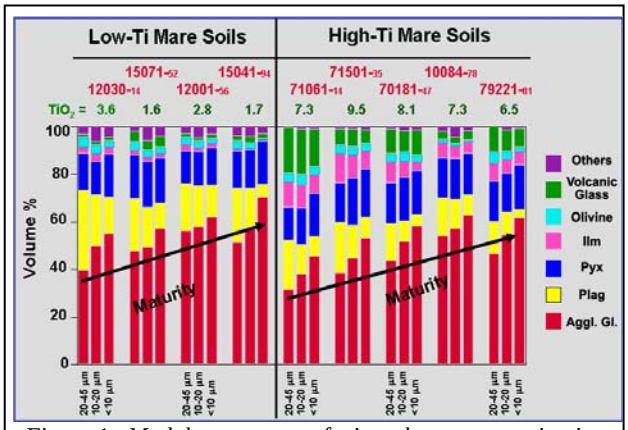

Figure 1. Modal percentage of mineral components in nine lunar soils. Aggl. Gl. stands for agglutinitic glass. For each group of soil, the sample is arranged in increasing maturity from left to right. Adapted from Taylor et al. [3]. The number after each sample number is maturity index (Is/FeO) from Morris [6].

Particle Size Distribution: One of the important properties affecting the toxicity of dust is the size distribution of the dust. Figure 2 shows three lunar samples (Apollo 11 mare 10084; Apollo 16 highland 64801; and Apollo 17 mare 70051) [7, 8]. All three samples contain a significant number of particles <2.5 μm. Because of the high abundances of these small particles and their unique chemistry (glass with np-Fe^0), these particles once in the respiratory system could remain in the lungs and cause severe lung fibrosis or other diseases, or for the <100 nm grains, they might even enter directly into the blood system, where the metallic np-Fe could interact to reduce the Fe^{3+} in the hemoglobin.

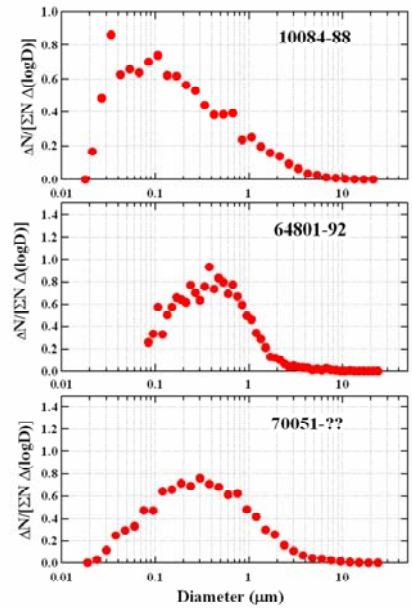

Figure 2. Particle size distribution of the <45 μm fraction of three lunar soils (Apollo 11 mare 10084, Apollo 16 highland 64801, and Apollo 17 mare 70051). The number after each sample number (e.g., -88) is the maturity index for the <45 μm fraction from Taylor et al. [3,4] and data on http://web.utk.edu/~pgi. For 70051, all that can be said is that it is Immature.

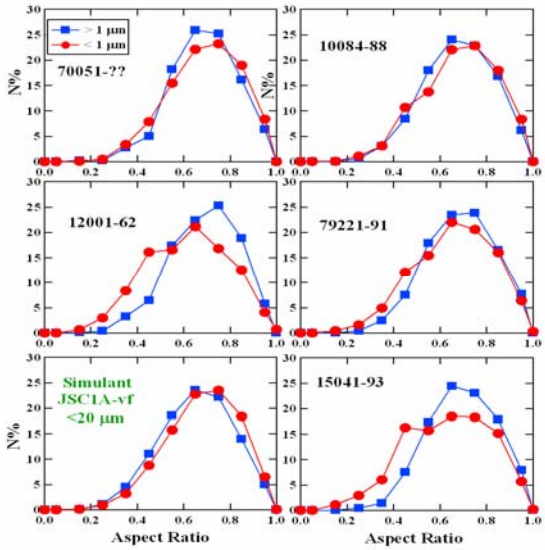

Figure 3. Aspect ratios of the <45 μm fraction of five lunar soils (mare soils: 10084, 12001, 15041, 70051 79221) and one simulant JSC1A-vf. The aspect ratio is defined as short/long axis and is a measure of elongation. Thousands of particles were measured for each sample. Modified from Liu et al. [9]. Sample notations are the same as in Figure 2.

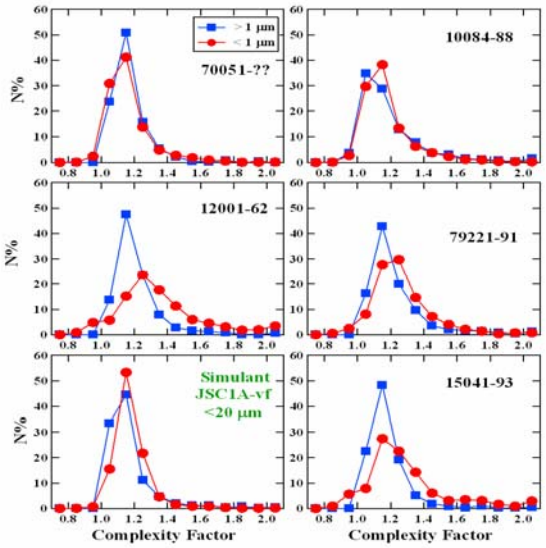

Figure 4. Complexity factor. For each particle, an ellipse was least-squares fitted to the measured area. The complexity factor is the measured perimeter divided by the calculated one of the fitted ellipse. Modified from Liu et al. [9].

Particle Shape and Morphology: The shape and morphology of dust particles are another important factor in determining the toxicity, as this directly relates to the reaction surface areas of the dust particles. Figures 3 and 4 plot the aspect ratios (short /long axis) and complexity factors (a measure of roughness) of five lunar soils and one simulant JSC1A-vf [9]. Lunar samples and simulant JSC1A-vf display a peak at an aspect ratio of ~0.7, with the distribution curve slightly skewed toward smaller numbers (~3-12% in numbers is <0.4). Complexity factors of all samples center around 1.25, but curves are skewed toward larger numbers, indicating a significant proportion of angular and jagged grains. The complexity factors are slightly larger for more mature samples (1.2-1.3 for 79221, 1.2 for 15041) than those of sub-mature (1.1-1.2 for 10084) or unmature samples (1.1-1.2 for 12001).

SEM images of individual grains show complex surface textures (vesicles, mounds, and folds, [9]), suggesting enhanced reactive surface area.

Discussions: Our results show that most lunar dust particles are fine, angular and jagged grains that are composed of impact-generated glass, containing nano-sized metallic Fe. The toxicity of the particles is related to the speed with which they are cleared from the lungs. Most of the large particles (>3 μm) deposited on trachea and primary bronchi will be trapped by mucus and cleared out by coughing. The remaining smaller particles (<~3 μm) are mainly removed through phagocytosis by airway and alveolar macrophages through dissolution, the later mainly for alveoli. Particles engulfed by macrophages are subjected to an acidic fluid (the lysosomal fluid) with PH = 4.5 [10]. This acidic fluid is able to dissolve the meta-stable glass. The complex features (vesicles and glass mounds) of lunar dust particles increase the reactive surface area of the particle, and thus, aid the dissolution rate of dust particles. During the dissolution processes, the large number of nanophase Fe^0 particles embedded in the glass may affect the fluid and cell chemistry, which are being investigated through medical tests (LADTAG). For particles of <100 nm size, sharp edges may aid their translocation from the alveolar region to the blood circulation. The near-neutral PH value of the blood [10] will make the dissolution of the dust particles more difficult. Similarly, the dissolution of dust materials or simulants with similar composition and shape need to be studied to determine the interaction of nanophase Fe^0 with blood, particularly with effects on Fe^{3+} and Fe^{2+}. Results from the studies outlined above have shown that lunar dust is a potential hazard to human health that must be dealt with by sufficient filtration methods [2].

References: [1] Gaier J. R. (2005) NASA, GRC. NASA/TM-2005-213610. [2] Taylor L. A. et al. (2005) *1st Space Explor. Conf., AIAA*. [3] Taylor L. A. et al. (2001) *JGR, 106*, 27985-27999. [4] Taylor L. A. et al. (2003) *LPS XXXIV*, Abstract # 1774. [5] Morris R. V. (1976) *LPSC VII*, 315-335. [6] Morris R. V. (1978) *LPSC IX*, 2287-2297. [7] Park J. S. et al. (2008) *JAE*, (accepted). [8] Schnare D. W. et al. (2008) *LPS XXXIX*, Abstract #1156. [9] Liu Y. et al. (2008) *JAE*, (accepted). [10] Plumlee G. S. et al. (2006) *Rev. Mineral.*, 64, 5-57.