THE NATURE OF SPACE WEATHERING EFFECTS RECORDED IN LUNAR MATERIALS. L. P. Keller[1], S. K. Noble[2], S. Zhang[1] and R. Christoffersen[3], [1]Mail Code KR, ARES, NASA/JSC, Houston, TX 77058, [2]Code 3Y55, NASA/HQ, Washington, D.C. 20062, [3]Code JE23, Jacobs Tech., Houston, TX 77058. (Lindsay.P.Keller@nasa.gov).

Introduction: On the Moon, the exposed surfaces of lunar soil grains and lunar rocks become modified over time through complex interactions with the lunar surface environment [1]. These interactions encompass many processes including micrometeorite impacts, vapor and melt deposition, and solar wind implantation/sputtering effects that collectively are referred to as "space weathering". A key product of these combined effects is the development of nm- to µm-scale coatings on the surfaces of both exposed rocks and lunar regolith grains. Studies of space weathering effects in lunar soils and rocks aid in understanding the origin and evolution of the lunar regolith as well as the interpretation of global chemical and mineralogical datasets obtained by remote-sensing missions. The interpretation of reflectance spectra obtained by these missions is complicated because the patina coatings obscure the underlying rock mineralogy and compositions. Space weathering effects collectively result in a reddened continuum slope, lowered albedo, and attenuated absorption features in reflectance spectra of lunar soils as compared to finely comminuted rocks from the same Apollo sites [2]. Understanding space weathering effects in fine-grained (<50 µm) fractions of lunar soils is important because they constitute the bulk of the surface area of lunar soils and reflectance spectra from this size fraction most closely approximates the spectra of the bulk soils.

Results and Discussion: The majority of space weathering effects are directly linked to the production of nanophase Fe metal in lunar materials [3]. Nanophase metal is produced in situ by the direct irradiation of Fe-bearing minerals, by condensation of impact-generated vapors, and within melt glass (agglutinitic glass). Size is important when it comes to nanophase Fe metal. The Fe grains observed in soil grain rims tend to be small (~3 nm) and are the major contributor to the reddening effect in soils whereas larger Fe grains tend to darken [4]. These effects were demonstrated quantitatively through a series of experiments utilizing silicas with known distributions and sizes on nanophase Fe metal [5] and feed directly into models to deconvolve space weathering effects from lunar reflectance data [6].

Surface alteration of lunar soil grains has been recognized since shortly after the return of the Apollo samples. Using analytical electron microscopy, Keller and McKay [7, 8] showed that amorphous rims on lunar soil grains are highly complex and span the range between erosional surfaces modified by solar wind irradiation to depositional surfaces modified by the condensation of sputtered ions and impact-generated vapors. Bulk measurements of certain rim elemental compositions allow the simple end member processes to be identified: irradiated rims are cation depleted due to preferential sputtering and show excess oxygen in chemical analyses due to the inferred presence of OH. Irradiated rims retain a chemical memory of their host grain. The vapor deposited rims contain species in reduced oxidation states (e.g. Fe, Si), are oxygen deficient, and are compositionally distinct from their substrates [8]. Subsequent work has confirmed the earlier results but has also identified complexities and additional important processes that are involved in space weathering on the Moon, especially melt addition to grain surfaces as a component of space weathering [e.g. 9-10] and post-depositional thermal processes [11].

Lunar soil grains have a typical lifetime of 10^4-10^5 years until they are destroyed, usually by impact processes, and this lifetime constrains the time-window for the accumulation of space weathering effects on individual grains. Studies of rock patinas extend this window of opportunity to longer exposure times. Recent studies have shown that rock patinas are much thicker than those on soil grains and display a complex stratigraphy that includes irradiated layers, vapor deposited layers, melt glass layers and entrained grains [9]. The thickness of rock patinas is dominated by melt layers that have accreted on the rock surfaces. The patina melts are compositionally heterogeneous and contain abundant nanophase Fe metal particles.

The processes involved in space weathering on the Moon are reasonably well understood but major unresolved questions exist regarding the rate at which these effects accumulate in the lunar regolith and the efficiency of nanophase Fe metal production by irradiation effects compared to condensation of impact generated vapors. Using solar flare track densities as a proxy for exposure time, [12] showed that the thickness of irradiated rims is positively correlated with exposure, whereas vapor-depositional effects are episodic and do not reflect a gradual accumulation of material with time. Efforts are focusing on quantifying irradiation effects through laboratory experimentation to determine the chemical effects due to sputtering and sputter deposition [13].

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