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Evaluation of Space Weathering and Surface Exposure Timescales for Lunar Soils in Apollo 17 Core Sample 73002 through Electron Microscopy

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Space weathering causes the surface soils on airless bodies like the Moon to be morphologically, microstructurally, and chemically altered due to micrometeoroid bombardment and solar wind irradiation [1]. Microstructural and chemical alterations accumulate in surface grains with continued exposure time on the planetary surface. One characteristic of space weathered samples is the presence of altered rims on regolith grains due to ion damage from solar wind and the recondensation of impact-generated vapor and melt deposits. Other space weathering features include solar flare tracks (SFT), which are nanoscale lineations formed by high-energy ions (predominantly Fe group nuclei) that originate from solar flares and penetrate millimeters into the surface [2]. Recent work has determined that the width of solar wind-damaged rims in anorthite ($CaAl_2Si_2O_8$) and olivine ($(Mg, Fe)_2SiO_4$) grains, and their respective SFT densities are correlated, and both characteristics are related to exposure timescale.

Core sample 73002 was collected on Apollo 17 and was recently released through the Apollo Next Generation Sample Analysis Program. The ~60 cm length core sampled a landslide originating from anorthosite-rich lunar highlands [4]. Visible-near infrared reflectance spectral profiles and ferromagnetic resonance measurements of bulk soils from the core indicate that grains in the upper 9.5 cm of regolith have characteristics consistent with longer durations of surface processing than samples deeper in the core [5,6]. Little work has been done, however, to stratigraphically study individual space weathered regolith grains in 73002 to further our understanding of lunar regolith mixing processes. Here we present observations of microstructural and chemical space weathering characteristics of grains in 73002 through transmission electron microscopy (TEM).

We were allocated samples from 15 intervals. We prepared the samples by dry sieving the soils into <20 μm size fractions and prepared electron transparent thin sections for TEM analysis using a Leica UC7 ultramicrotome. Bright field (BF) and dark field (DF) scanning TEM (STEM) images of solar flare tracks and space-weathered rims were acquired on a JEOL 2500SE TEM, equipped with a 60 mm^2 ultra-thin window silicon drift energy dispersive x-ray (EDX) spectrometer at NASA Johnson Space Center (JSC). Nanoscale compositional variations in grains were mapped by EDX compositional spectrum imaging.

SFT densities and amorphous rim thicknesses were measured on BF and DF images. In addition, an interval-by-interval modal analysis of grain mineralogy will be completed to better understand the compositional diversity of grains in the <20 μm size fraction compared to the bulk soil. Chemical maps will be produced for grains that are transected by the faces of the ultramicrotome bullets. This analysis will be performed with a JEOL 7900F SEM equipped with a 170 mm^2 SDD type EDX system located at JSC.

Most grains studied by TEM showed significant evidence of space weathering. STEM images and EDX measurements show splash-melt and vapor deposited rims on grain surfaces, some with embedded Fe-bearing nanoparticles ranging in size up to ~10 nm in diameter (Fig. 1). We observe solar-wind damaged rims extending below the vapor deposits, and SFTs present in grain interiors. The rim thicknesses and SFT densities were determined using [3]. We analyzed two olivine grains in Interval 1 and anorthite for all intervals.

A track production rate was calculated in [3] for surface exposed regolith grains and used to estimate the exposure timescales for the grains in this study which range between 1 - 5 MY range (Fig. 2). SFT densities were compared to amorphous or nano-crystalline rim thicknesses of their respective grains. Results show that rim thickness and SFT density is strongly correlated for both olivine and anorthite. As expected, olivine rim thickness increases much faster over the same track production timescale compared to anorthite [3]. Our results for olivine provide an opportunity to compare the relative effects of solar wind and solar flare exposure on both mineral types.

There is no measurable difference in the track density distributions between grains from intervals in the top 1.5 centimeters of 73002, implying that the soil has experienced effective regolith reworking at the uppermost surface. This result is within the 9.5 cm of mature soil depth concluded by [5,6]. These results are consistent with impact driven regolith mixing models. However, this core has been collected from an area which has undergone regolith overturn via landslide. Vertical regolith mixing subsequent to landslide

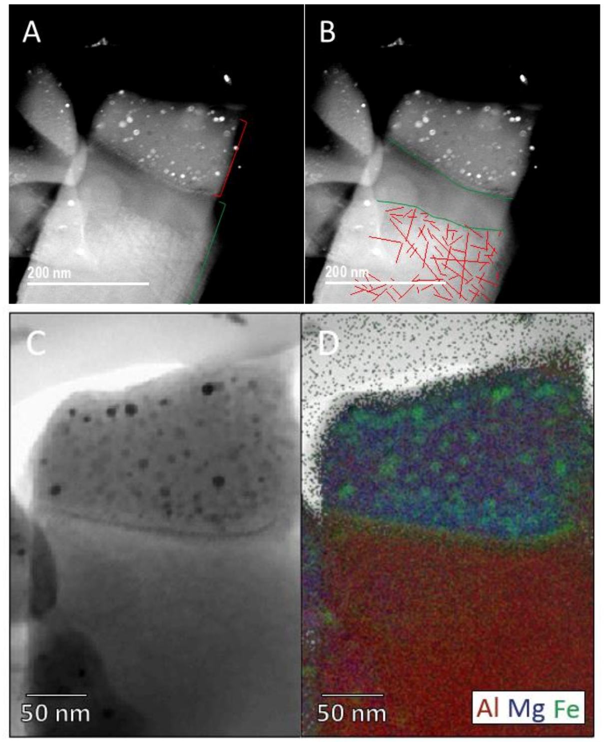

Figure 1. A) DF STEM image of a lunar anorthite rim with the red bracket identifying splash melt containing metallic Fe nanoparticles and the green bracket denoting the grain interior; B) the amorphous rim is bounded in green and SFTs traced in red. C) BF STEM of the same area; D) EDX chemical map showing Al rich grain interior, iron rich vapor deposited rim, and impact melt splash with npFe in a Mg rich matrix.

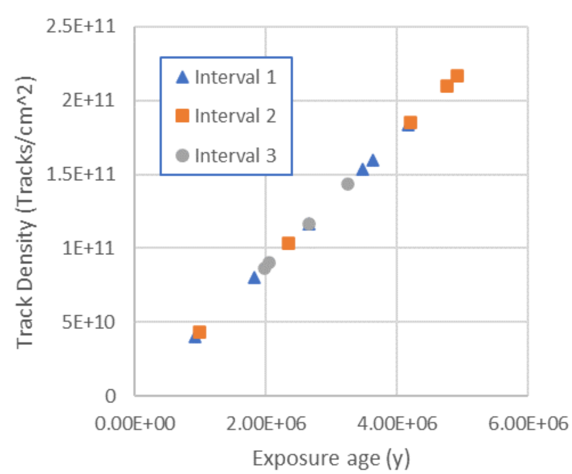

Figure 2. A) Distribution of SFT density with calculated exposure ages.

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emplacement may be representative of the space weathered grain distributions discussed in this paper. Lateral mixing may be better represented deeper within the core and analysis of deeper intervals will determine if evidence of lateral mixing is present in the core.

A maximum surface exposure age determined via SFT density is approximately 5 million years. This is consistent with the lower estimate of surface exposure ages of the light mantle determined in previous studies, ranging from 10s to over 100 Ma [4]. The limited number of analyzed grains restrict the implications that can be made regarding the history of the landslide deposit. Additional analysis will be performed for an additional 12 intervals in 73002 and the lower portion of the core (sample 73001) which is yet to be released.

References:

[1] CM Pieters and SK Noble, JGR: Planets **121** (2016), p. 1865.
[2] GE Blanford et al., Proc. LSC VI (1975), p. 3557.
[3] LP Keller et al., MPS **56** (2021), p. 1685.
[4] HH Schmitt et al. Icarus **298** (2017), p. 2.
[5] L Sun et al., MPS **56** (2021), p. 1574.
[6] Morris et al. 53rd LPSC (2022), Abstract 1849.

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