**DETERMINING SURFACE EXPOSURE AGES OF REGOLITH GRAINS IN LUNAR CORE SAMPLE 73002 BY INVESTIGATING SOLAR PARTICLE IRRADIATION DAMAGE.** J. A. McFadden[1], M. S. Thompson[1], L. P. Keller[2], R. Christoffersen[3], R. V. Morris[4], C. Shearer[5], and the ANGSA Science Team[6] [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, (mcfadde8@purdue.edu) [2]ARES, Code XI3, NASA/JSC, Houston, TX 77058 [3]Jacobs, NASA Johnson Space Center, Mail Code XI, Houston, TX 77058 [4]NASA-JSC, Houston, TX, USA [5]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131 [6]ANGSA Science Team list at https://www.lpi.usra.edu/ ANGSA /teams/. (cshearer@unm.edu).

**Introduction:** Space weathering causes the surface soils of airless bodies like the Moon to be microstructurally and chemically altered by exposure to micrometeoroid bombardment and solar wind irradiation [1]. These alterations accumulate in surface grains with continued residence in the uppermost millimeters of regolith. Low energy solar wind ions (largely $H^+$ and $He^+$) produce a layer of radiation damage as they become implanted in grain surfaces. Also present are solar energetic particle (SEP) tracks, which are nanoscale lineations within grain interiors formed by heavy, high-energy ions (mainly Fe group nuclei) penetrating up to millimeters below the surface [2]. Recent work has determined that the width of solar wind-damaged rims on anorthite and olivine, and their respective SEP track densities are correlated with each other and with grain surface exposure age [3].

Core sample 73002, recently released under the Apollo Next Generation Sample Analysis (ANGSA) Program, has provided an opportunity to study material collected from the light mantle formation in the Taurus-Littrow Valley during Apollo 17. The light mantle is thought to have been deposited via landslide originating from the neighboring South Massif [4]. Spectral analysis of bulk core soils found a plagioclase rich composition, confirming a highlands origin of the formation [5]. Spectral profiles and ferromagnetic resonance (FMR) measurements of bulk soils sampled at cm-intervals from 73002 indicate that regolith up to ~9.5 cm in depth have maturity indices consistent with longer durations of surface processing than samples deeper in the core. Thus, this upper ~9 cm layer likely represents the maximum extent of an *in-situ* reworking zone which may have persisted over 5 to 17 million years [5,6]. Here we present an analysis of grain exposure ages within the *in-situ* reworking zone of 73002 derived from SEP track density measurements via transmission electron microscopy.

**Methods:** Bulk samples of regolith from the first eight dissection intervals and every following fourth interval down the core were delivered to Purdue University as <45 μm size fractions. The first eight intervals, representing the top 4 centimeters of regolith, were individually dry sieved into <20 μm size fractions, and prepared by ultramicrotomy for analysis in a scanning transmission electron microscope (STEM). Bright field (BF) and dark field (DF) STEM images of SEP tracks and solar wind-damaged 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. Nanoscale compositional variations in grains were determined by EDX. SEP densities and solar wind irradiated rim thicknesses were measured in anorthite and olivine grains using BF and DF images.

**Results:** The majority of grains studied by STEM showed evidence of space weathering, including solar-wind damaged rims and SEP tracks present in grain interiors [Fig. 1]. The rim thicknesses and SEP track densities were determined using the methods of [3] for 98 grains spanning all eight intervals with 32 grains observed in Interval 1 and 18 grains in Interval 2. The remaining intervals contributed 4 to 10 grains each. Of the grains measured, 14 olivine grains scattered throughout the top 4 cm of 73002 were identified with the remainder being anorthite.

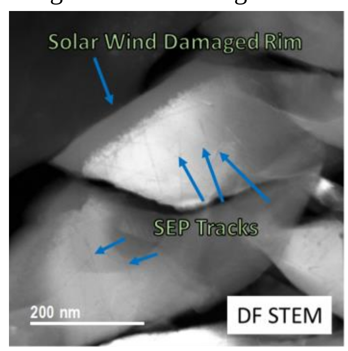

**Fig 1:** DF-STEM image exhibiting a solar wind damaged rim on crystalline anorthite with SEP tracks.

A track production rate of $4.4 \pm 0.4 \times 10^4$ tracks $cm^{-2}yr^{-1}$ was determined by [3] for individual surface exposed grains. This value was used to estimate the surface exposure timescales of the grains in this study. The mean exposure age for all intervals is $3.1 \times 10^6$ yr ($\sigma = 1.8 \times 10^6$) [Fig. 2]. Currently, it is difficult to assess stratigraphic variations in grain exposure age due to limited samples analyzed per interval. However, in Interval 1, we have an increased sample size and grains in this section have a mean exposure age of $3.3 \times 10^6$ yr ($\sigma = 2.0 \times 10^6$). Overall, the grain with the highest track density was $4.9 \times 10^{11}$ tracks $cm^{-2}$ corresponding to an exposure age of ~$11.1 \times 10^6$ yr found in Interval 1. The second highest exposed grain was found in In-

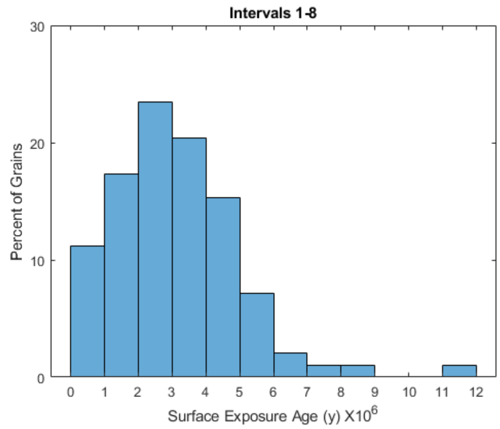


**Fig. 2:** Distribution of exposure ages found in the top 4 cm of core sample 73002.

terval 6 with a track density of $3.5 \times 10^{11}$ tracks $cm^{-2}$ corresponding to an exposure age of ~$8.0 \times 10^6$ yr. Track densities and solar wind damaged rim thickness distributions show no significant variation with interval depth.

SEP densities were compared to solar wind damaged rim thicknesses of their respective grains. Minimum and maximum rim thickness for anorthite were 10 nm and 155 nm, respectively. For olivine, the minimum and maximum thickness were 35 nm and 120 nm, respectively. Fig. 3 shows that rim thickness and SFT density is correlated for both olivine and anorthite grains, in agreement with [3].

**Discussion:** Our measurements were obtained primarily from anorthite grains with minor olivine grains (~14% of the total grains). The mean and standard deviation of SEP track derived surface exposure ages of individual grains found in Interval 1 is similar to those determined for the combined interval distribution. We also found that the majority of exposure ages range from 1 to 5 million years with very few residing on the surface for longer. This is likely due to high rates of regolith reworking at the uppermost surface suggested by modern regolith reworking models [7], producing the *in-situ* reworking zone after landslide deposition. This process is hypothesized to rapidly homogenize lunar regolith at the very surface. This likely explains the similarities between the distribution for Interval 1 and that for the combined intervals. The maximum exposure age was found to be ~11 million years which is within the *in-situ* reworking timescales suggested by [5-6]. It also suggests a minimum constraint for the landslide emplacement age.

While the intervals discussed here primarily provide information on regolith mixing due to high rates of vertical overturn subsequent to avalanche emplacement, we also plan to explore how distributions for space weathered regolith may have been altered during

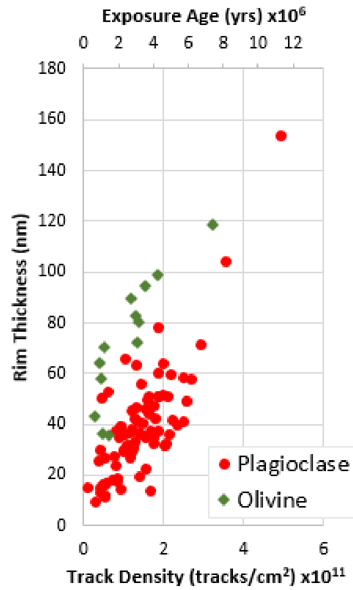


**Fig 3:** Distribution of solar wind damaged rim thickness with respect to SEP track density and surface exposure age for anorthite and olivine grains.

the landslide event. This unique process of regolith mixing may be better represented below the *in-situ* reworking zone and analysis of deeper intervals will be required to determine if such mechanisms should be considered. It is possible that an ejecta blanket originating from larger impacts may have inverted local stratigraphy after landslide emplacement. We intend to explore these potential reworking modes through the analysis of an additional 8 intervals in 73002 and the lower portion of the core (core section 73001).

**Conclusions:** SEP track densities and solar-wind damaged rim widths were measured in space weathered <20 μm sized anorthite and olivine grains within the first 4 cm of Apollo core sample 73002. The majority correspond to surface exposure ages ranging from approximately 1 to 5 million years. SEP track density variability with respect to grain depth suggests that these intervals are well mixed and is further evidence for an *in-situ* reworking zone in the upper regions of 73002. Additional grains will be analyzed to develop more in-depth conclusions regarding the nature of regolith mixing and possible discontinuities within the geologic context of the 73002 core.

**References:** [1] Pieters, C.M. and Noble, S.K. (2016) JGR: Planets 121, 1865-1884 [2] Blanford, G.E., et al. (1975) Proc. LSC VI, 3557-3576 [3] Keller, L.P., et al. (2021) MPS 56, 1685-1707 [4] Schmitt, H.H., et al. (2017) Icarus 298, 2-33 [5] Sun, L., et al. (2021) MPS 56, 1574-1584 [6] Morris et al. (2022) LPSC LIII, Abstract #1849 [7] Costello, E.S., et al. (2018) Icarus 314, 327-344 [8] Blanford, G.E., et al. (1979) Proc. LPSC X, 1333-1349.