EVALUATING SURFACE EXPOSURE TIMESCALES DERIVED FROM SOLAR ENERGETIC PARTICLE TRACK DENSITIES FOR GRAINS FROM APOLLO 17 CORE SAMPLE 73002. 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 morphologically, microstructurally, and chemically altered due to micrometeoroid bombardment and solar wind exposure [1]. These processes produce a multitude of microstructural and chemical changes that accumulate on individual soil grains that are continuously exposed on the surface. One characteristic is the formation of solar wind damaged rims on grains which develop from low energy solar wind particles penetrating <100 nm in depth. Also present are solar energetic particle (SEP) tracks, which are nanoscale streaks of irradiation damage in grain interiors formed by heavy, high energy ions (predominantly Fe group nuclei) originating from solar energetic particles (SEPs) that penetrate millimeters below the surface [2].

Previous track analysis techniques relied on a process known as chemical etching [3]. This technique broadened track widths to be observed via scanning electron microscopy. Unfortunately, this made analysis of grains with high track densities difficult as tracks would overlap each other. Recent work utilized modern TEM techniques to identify higher tracks densities and a track production rate was developed to relate the evolution of solar wind-damaged rim widths on anorthite and olivine, and their respective SEP track densities, with their exposure on the lunar surface [4].

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 explored in the Taurus-Littrow Valley by Apollo 17. The formation is thought to have been deposited via an avalanche originating from the neighboring South Massif [5]. Preliminary spectral profiles and ferromagnetic resonance measurements of bulk soils sampled at centimeter intervals from 73002 indicate that mature, space weathered regolith extends approximately 8 cm beneath the surface of 73002 corresponding to an *in situ* reworking zone that developed over ~17 MY [6,7]. Here we present the distribution of SEP track density-derived surface exposure ages for grains within the *in situ* reworking zone of 73002 via transmission electron microscopy (TEM)

Methods: Bulk samples of regolith from the first eight intervals and every following fourth interval down the core (dissection Pass 2) 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 sliced to 50 nm thick thin sections via ultramicrotomy for analysis in the scanning transmission electron microscope (STEM). Bright field (BF) and dark field (DF) STEM images of SEP tracks and solar wind damaged rims on olivine and anorthite grains were acquired with a 200 keV 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. Mineral types were determined using Cliff Lorimer method. The track production rate that was calculated in [4] for surface exposed regolith grains was used to estimate the surface exposure ages of the grains in this study.

Results: The majority of grains studied by TEM showed significant evidence of space weathering. BF and DF STEM images show splash-melt and vapor deposited rims on outermost grain margins with embedded Fe-bearing nanoparticles ranging in size up to ~10 nm in diameter (Fig. 1). Images also show solar-wind damaged rims below the vapor deposits, and SFT present in grain interiors. The rim thicknesses and SFT densities were determined using the methods of [4] for 30 grains in Interval 1, and 5 to 15 grains in intervals 2 through 8.

Track density distributions indicate that most exposure times are in the 1 - 5 MY range, with the greatest exposure age being ~11 MY found in Interval 1 and the

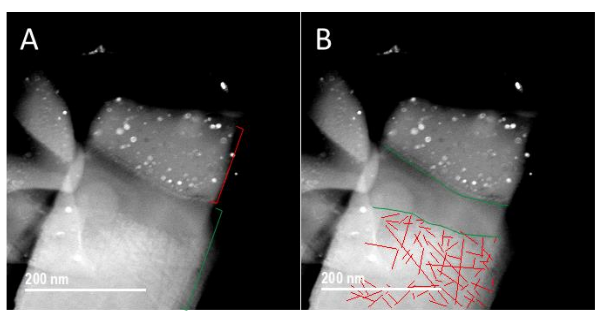
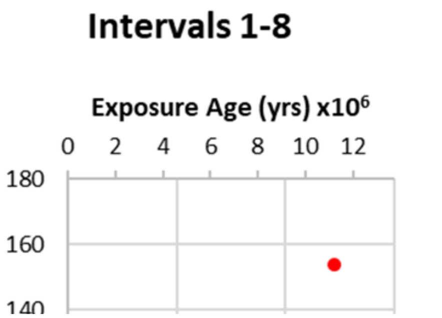


Figure 1: DF STEM images of A) a lunar anorthite rim with the red bracket identifying splash melt containing metallic Fe nanoparticles and the green bracket denoting the grain interior; B) the amorphous rim is bounded in green and SFTs traced in red.

second greatest exposure age being ~8 MY found in interval 6 [Fig. 2]. SEP track densities were compared to the solar wind damaged rim thickenesses of their respective grains. Fig. 2 shows that rim thickness and SEP track densities are correlated for both olivine and anorthite grains.

Discussion: The <20 µm size fraction of the top four cm of 73002 bulk soil composition is primarily anorthite, only exhibiting 11 olivine grains. This distribution is advantageous for our work as anorthite is the most well constrained mineral for analyzing solar flare tracks and solar wind damaged rims. The presence of both anorthite and olivine allows us to relate solar wind dam-



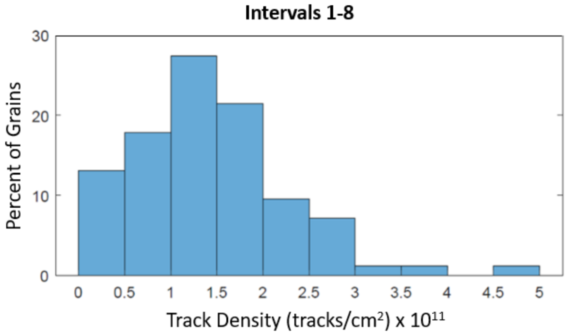


Figure 2: Track density distribution for grains in Intervals 1 – 8.

Figure 3: Solar wind damaged rim thickness and SEP track density in relationship to the exposure ages of anorthite and olivine grains

aged rim, SEP track density, and surface exposure ages estimations in 73002 to that of the results in [4].

The track density distribution for Interval 1 follows a normal distribution skewed left with a peak spanning 1 - 2 x 10^{11} tracks/cm^2. Combined Intervals 1-8 follows a similar distribution with a slight increase in abundance of grains with tracks ranging 2 – 2.5 x 10^{11} tracks/cm^2 [Fig. 3]. These densities correspond to surface exposure ages ranging from approximately 1 to 5 million years. Calculated exposure ages are within the bounds of space weathered soil depth concluded by [5,6] and modern regolith mixing models [8].

Spectral and FMR analysis performed by [6,7] concluded that the reworking zone of 73002 extends to ~8 cm beneath the surface which is beyond the depth of this study. With this in mind, we intend to analyze additional grains in Intervals 2 - 8. We will also perform similar analyses on grains below the *in situ* reworking zone in order to identify any grains that may have been exposed at the surface prior to landslide deposition.

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 of these values correspond to surface exposure ages ranging from approximately 1 to 5 MY. This age is substantially lower than the estimated reworking timescale indicated by [6], and implies that there is a high rate of mixing, on million year timescales, that forces space weathered grains to migrate downwards over time. The results of this work will be compared to modern regolith mixing models [8]. Additional grains will be analyzed to develop more in depth conclusions regarding the nature of regolith overturn both within the *in situ* reworking zone and landslide related modes of regolith mixing.

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