SURFACE EXOSURE TIMESCALES OF APOLLO CORE SAMPLE 73002 SPACE WEATHERED GRAINS.

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Introduction: Space weathering causes the surface regolith on airless bodies like the Moon to be morphologically, microstructurally, and chemically altered due to micrometeoroid bombardment and solar wind irradiation [1]. These processes produce a multitude of microstructural and chemical changes in individual soil grains that accumulate as grains are exposed on the surface over time. One microstructural feature produced by exposure to the solar wind is the development of ion-damaged rims on regolith grains via H^+ and He^+ ion irradiation. Also present are solar energetic particle (SEP) tracks, which are nanoscale lineations of ionization damage within grain interiors formed by high energy solar flare ions (primarily Fe group nuclei) which penetrate millimeters below the surface [2]. Recent work has confirmed that the thickness of solar wind-damaged amorphous rims on anorthite grains, nanocrystalline rims on olivine grains, and their respective SEP track densities are correlated with their surface exposure ages [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 during Apollo 17. The light mantle is thought to have been deposited via a landslide originating from the neighboring South Massif [4]. Spectral profiles and ferromagnetic resonance measurements of bulk soils sampled at cm-intervals from 73002 indicate the existence of mature regolith extending ~8 cm below the surface, suggesting the presence of an in-situ reworking zone in the core [5,6]. Here we present the distribution of SEP track densities, solar wind damaged rim widths, and the corresponding surface exposure ages of grains residing in the proposed in-situ reworking zone of core 73002.

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 0.5 cm intervals, representing the top 4 cm of regolith, were individually dry sieved to a <20 µm size fraction, and grains were prepared by ultramicrotomy for analysis in the scanning transmission electron microscope (STEM). Bright field (BF) and dark field (DF) STEM images of solar flare 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. Grain compositions were determined by EDX compositional spectrum imaging. SEP track densities and amorphous rim thicknesses were measured on BF and DF images.

Results: The fraction of grains with discernable space weathering features decreased with depth, with 100% in the first interval exhibiting space weathering features as opposed to ~60% in Interval 8. 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. Images also show solar-wind damaged rims below the vapor deposits, and SEP tracks present in grain interiors. The rim thicknesses and SEP track densities were determined using the methods of [3] for 54 grains spanning the top 4 cm. ~80% of the grains analyzed were anorthite and ~20% were olivine.

The track production rate from [3] was used to estimate the surface exposure times of the grains in this study. The majority of exposure times are in the 1 - 5 MY range for all intervals. The lowest value was 3.8×10^{-5} years in Interval 8 and the highest value was 1.1×10^7 years in Interval 6. Grains with the highest solar wind damage rim thicknesses and SEP track densities are found in Interval 6. The highest rim thickness and track density observed for anorthite is 126.5 nm and 4.7×10^{11} tracks/cm^2, while for olivine they are 98.6 nm and 1.83×10^{11} tracks/cm^2, respectively.

Discussion: Intervals from the top 4 cm of 73002 show similar SEP track density and solar wind damaged rim thickness distributions. Spectral and ferromagnetic resonance measurements of 73002 indicate an in-situ reworking zone up to ~8 cm below the surface [5,6]. The depth analyzed in this work is within the core's uppermost in-situ reworking zone and may serve as an explanation to the homogenous distribution of exposure ages. The decreasing abundance of space weathered features with depth is consistent with regolith mixing models showing an exponential decay in regolith maturity with depth over time [7]. A maximum surface exposure age determined via SEP track density is approximately 10 million years. This timescale is consistent with the lower estimate of surface exposure ages of the light mantle determined in previous studies, which can range from 10s to over 100 Ma [4]. It also falls within the core regolith reworking development timescale of ~17 Ma [5,6]. Additional analysis will be performed for a further seven intervals in 73002.

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