UPDATE ON COSMOGENIC RADIONUCLIDE DEPTH PROFILES IN LUNAR CORE 73002/01 AS PART OF THE ANGSA PROGRAM. K. C. Welten[1], M. W. Caffee[2], J. Masarik[3], K. Nishiizumi[1], ANGSA Science Team[4]; [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA (kcwelten@berkeley.edu; kuni@berkeley.edu), [2]Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA (mcaffee@purdue.edu), [3]Dept. of Nuclear Physics and Biophysics, Comenius University, Bratislava, Slovakia, [4]ANGSA Science Team list at https:/www/lpi.usra.edu/ANGSA /teams/.

Introduction: The nature and evolution of the lunar regolith has been a major topic of research since the Apollo program brought lunar samples to Earth. Our understanding of lunar regolith mixing is still evolving, as recent studies of small impacts on the lunar surface observed in images from the Lunar Reconnaissance Orbiter Camera suggest a higher turnover rate of the lunar regolith than has been previously assumed. Our goal is to understand the long term, million years, history of the lunar surface utilizing radionuclides (^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca) produced by cosmic rays, both galactic (GCR) and solar (SCR). With half-lives ranging from 0.1 to 1.36 x 10^6 yr these cosmogenic nuclides provide information on lunar surface processes on a timescale of 10^5 to 10^7 yr. The measurement of multiple nuclides with different half-lives and different production mechanisms provides a framework to address the mixing rate of the lunar regolith and possible disturbances caused during collection of the core on the Moon, and subsequent transport and handling of the core in the lab. We measured the concentrations of ^{10}Be ($t_{1/2}$ = 1.36 x 10^6 yr), ^{26}Al (7.05 x 10^5 yr), and ^{36}Cl (3.01 x 10^5 yr) in Apollo 17 core 73002/01, which is one of the targets of the Apollo Next Generation Sample Analysis (ANGSA) initiative [1,2]. Partial depth profiles in the top core (73002) were reported previously [3]. Here we report updates on the depth profiles in core 73002 and 73001.

Sample Description: Double drive tube (DDT) 73002/01 was collected by the Apollo 17 astronauts near Station 3. The X-ray images of the top segment, 73002, show that the top 3 cm had a partial void that was compressed during extrusion of the core [4]. The extrusion process has reduced the length of core 73002 from ~23 cm to 18.5 cm [5]. The average density of core 73002 after extrusion is 1.726 g/cm^3. Core 73001, the bottom segment, has a length of 33.1 cm and an average density of 1.809 g/cm^3. During collection of the core on the Moon, several cm of material spilled from the bottom of core 73002, so there may be a gap between core 73002 and 73001. We assume for now that ~3 cm of material (5 g/cm^2) was lost, but will verify this based on the radionuclide depth profiles. We selected 14 samples from core 73002 and 8 from core 73001. All samples represent <1 mm size fraction of 5 mm dissection intervals with a resolution increasing from 5 mm in the top part of 73002 to ~5 cm at the bottom of 73001.

Experimental Procedures: Approximately 50 mg of each sample was dissolved in a HF/HNO_3 mixture along with Be and Cl carriers. Small aliquots of the dissolved samples were taken for chemical analysis by ICP-OES, while the majority of the sample was used for radionuclide analysis. Beryllium, Al, Ca, and Cl were separated and purified for analysis by accelerator mass spectrometry (AMS). The ^{10}Be/Be, ^{26}Al/Al and ^{36}Cl/Cl ratios were measured by AMS at PRIME Lab, Purdue University [6]. The measured ratios were normalized to AMS standards [7-9] and converted to activities in disintegrations per minute per kg (dpm/kg). The measured depth profiles of ^{10}Be, ^{26}Al and ^{36}Cl in core 73002/01 (Fig. 1) are compared with expected GCR production rates from model calculations [10] after minor adjustments to match measured depth profiles in the Apollo 15 deep drill core [11,12]. Figure 1 also shows measured depth profiles in three relatively undisturbed cores 15008/07, 15009 and 68002/01 [13-16]. The ^{26}Al depth profiles of the three other cores were normalized to the chemical composition of 73002 taking into account the Al concentrations of 9.7% for 15008, 8.7% for 15009 and 13.8% for 68002, respectively. The measured ^{36}Cl concentrations are normalized to the measured chemical composition of the samples, assuming relative production rates from the main targets elements, K:Ca:Ti:Fe of 24:10:3:1 [16]. All depth profiles are plotted as a function of effective shielding depth (in g/cm^2) to account for differences in density of the cores.

Results and Discussion: The average chemical composition of the 8 sub-samples of 73001 is 5.7% Mg, 11.0% Al, 0.14% K, 9.3% Ca, 0.9% Ti, 0.09 % Mn, and 6.2% Fe, almost identical to the composition of 73002 [3]. We assume constant O and Si concentrations of 44.5% and 21.5%, respectively, similar to values measured for nearby lunar soils 73221-73281 [17].

The ^{10}Be depth profile in core 73002/01 agrees within experimental uncertainty with those of other Apollo cores and with the expected GCR depth profile. The ^{26}Al depth profile in 73002/01 at depths >20 g/cm^2 also agrees with the expected GCR depth profile, while the near-surface samples show a significant SCR component. However, the SCR-produced ^{26}Al component in the top 1 cm of 73002 is significantly lower than in nearby trench soils 73221 [18,19], indicating that the top 1 cm of 73002 was either lost or mixed with deeper materials.

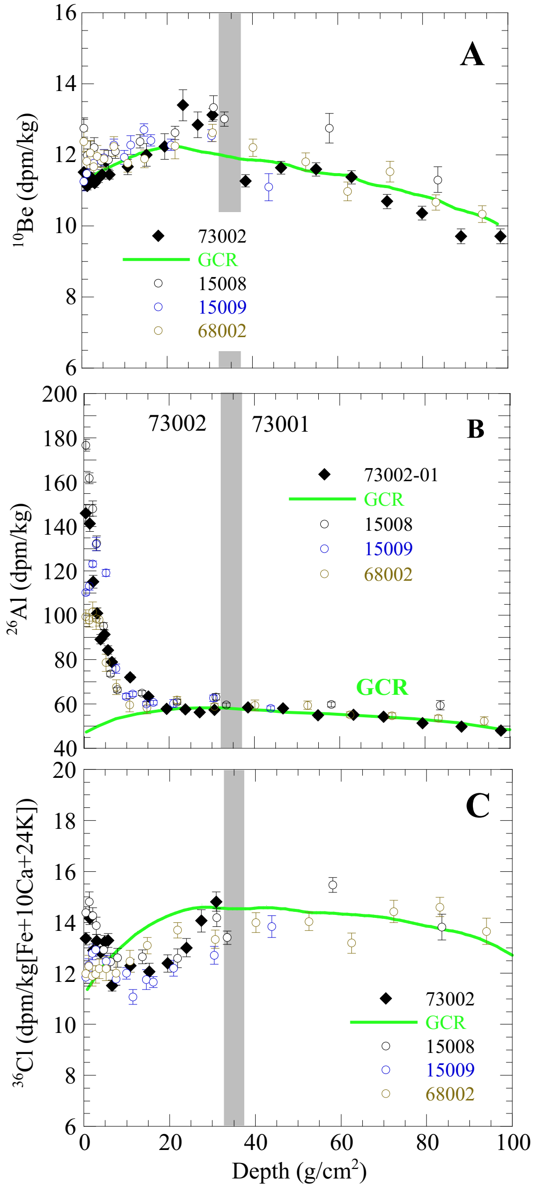

Figure 1. Measured depth profiles of ^{10}Be (A), ^{26}Al (B) and ^{36}Cl (C) in DDT 73002/01 in comparison with those measured in 15008, 15009 and 68002. The green curves represent expected GCR production rates from GCR [11-13].

The ^{36}Cl depth profile in core 73002 shows good agreement with those measured in other lunar cores, but all ^{36}Cl depth profiles (normalized to the main target elements) deviate from the expected GCR depth profile between 10-30 g/cm^2. It is not clear if the observed deviations are due to inadequacies in the model calculations and/or indicate significant contributions of neutron-capture ^{36}Cl (which are not included in the GCR depth profile). The increase of ^{36}Cl in 73002 from 10 to 30 g/cm^2 seems larger than in other cores. If this is due to neutron-capture on ^{35}Cl, it would require a Cl concentration of several tens of ppm. In this scenario, the ^{36}Cl depth profile in core 73001, which will be measured soon, is expected to further increase with depth. We are also performing model calculations of the ^{36}Cl depth profile from spallation as well as neutron-capture reactions.

Missing material. Since the depth profiles of ^{10}Be and ^{26}Al are relatively flat between 30-50 g/cm^2, these nuclides are not very sensitive to constrain the amount of missing material from the bottom of core 73002. While the measured depth profiles (Fig. 1A, 1B) do not show evidence for a large gap, they only constrain the loss to <10 cm. Since the depth profile of neutron-capture ^{41}Ca in lunar cores increases with depth up to ~100 g/cm^2, the ^{41}Ca depth profile in core 73002/01 should help to better constrain the amount of lost material from 73002.

Conclusions. Although the depth profile of ^{10}Be in core 73002/01 indicates that it is the least disturbed one among the Apollo 17 cores, the ^{26}Al depth profile shows evidence for recent mixing of the top ~9 cm of 73002. This disturbance in the stratigraphy of the top of core 73002 is consistent with other studies of this core [5,20,21] and may be related to the large void near the top that was filled up before/during extrusion of the core. Measurements of ^{36}Cl in core 73001 will show whether the neutron-capture ^{36}Cl component in this core is higher than in other Apollo cores, while measurements of ^{41}Ca in 73002/01 will help to constrain how much material was lost from the bottom of core 73002 during collection on the lunar surface.

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