

**COSMOGENIC RADIONUCLIDES IN LUNAR CORE 73002/01: COSMIC-RAY EXPOSURE HISTORY AND REGOLITH MIXING OF THE LUNAR SURFACE.** K. C. Welten<sup>1</sup>, M. W. Caffee<sup>2</sup>, K. Nishiizumi<sup>1</sup>, ANGSA Science Team<sup>3</sup>; <sup>1</sup>Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA ([kcwelten@berkeley.edu](mailto:kcwelten@berkeley.edu); [kuni@berkeley.edu](mailto:kuni@berkeley.edu)), <sup>2</sup>Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907-2036, USA ([mcaffee@purdue.edu](mailto:mcaffee@purdue.edu)), <sup>3</sup>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 return of the Apollo samples. 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 (<sup>10</sup>Be, <sup>26</sup>Al, <sup>36</sup>Cl, <sup>41</sup>Ca) produced by cosmic rays, both galactic (GCR) and solar (SCR). With half-lives ranging from 0.1 to 1.36 x 10<sup>6</sup> yr these cosmogenic nuclides provide information on lunar surface processes on a timescale of 10<sup>5</sup> to 10<sup>7</sup> 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 extrusion of the core in the lab. We measured the concentrations of <sup>10</sup>Be ( $t_{1/2} = 1.36 \times 10^6$  yr), <sup>26</sup>Al (7.05 x 10<sup>5</sup> yr), and <sup>36</sup>Cl (3.01 x 10<sup>5</sup> 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 for <sup>10</sup>Be and <sup>36</sup>Cl and a complete depth profile for <sup>26</sup>Al in core 73002 were reported at LPSC [3]. Here we report updates on the <sup>10</sup>Be and <sup>36</sup>Cl depth profiles in core 73002, while measurements of <sup>10</sup>Be, <sup>26</sup>Al and <sup>36</sup>Cl in core 73001 are still in progress.

**Sample Description:** Double drive tube 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 1.74 g/cm<sup>3</sup>, which is used to convert absolute depth to effective shielding depth in g/cm<sup>2</sup>. Core 73001, the bottom segment, has a length of 33 cm and an average density of 1.83 g/cm<sup>2</sup>. During collection of the core, several cm of material spilled from the bottom of core 73002, so there may be a gap between core 73002 and 73001. We selected 14 sieved samples (<1 mm fraction) from core 73002 to investigate the exposure and regolith mixing history. The samples represent 5 mm intervals of the top 4 cm of

the core 73002 (dissection pass 1), and 2-3 cm intervals of the remaining 14 cm of the core (pass 2). For core 73001 we selected 8 sieved samples (<1 mm) representing 5 mm intervals at 4-5 cm resolution.

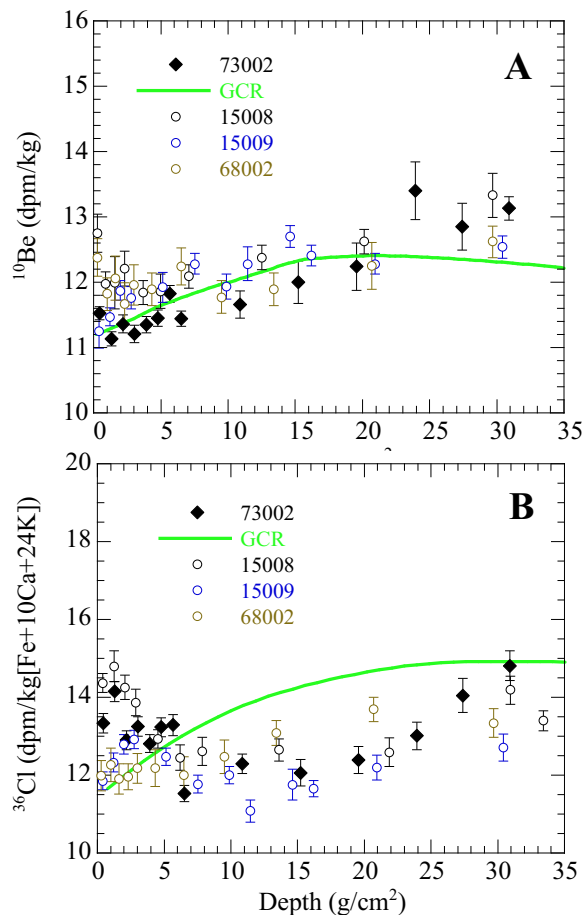
**Experimental Procedures:** Approximately 50 mg of each sample was dissolved in a HF/HNO<sub>3</sub> mixture along with Be and Cl carriers. Aliquots of the dissolved samples were taken for chemical analysis by ICP-OES. Beryllium, Al, Ca, and Cl were separated and purified for analysis by accelerator mass spectrometry (AMS). The <sup>10</sup>Be/Be, <sup>26</sup>Al/Al and <sup>36</sup>Cl/Cl ratios were measured by AMS at PRIME Lab, Purdue University [6]. The measured ratios were normalized to AMS standards [7-9] and the radionuclide concentrations (atoms/g) were converted to disintegrations per minute per kg (dpm/kg). The measured <sup>10</sup>Be and <sup>36</sup>Cl depth profiles in core 73002 (Figure 1) are compared and with expected production rates from GCR [10-13] and with measured depth profiles in several Apollo 15 and 16 cores [14-17]. The measured <sup>36</sup>Cl concentrations in core 73002 are normalized to the measured chemical composition of the samples, assuming relative production rates from the main target elements, K:Ca:Ti:Fe of 24:10:3:1, while no normalization is needed for <sup>10</sup>Be [3]. The GCR depth profiles shown in Fig. 1 are based on elemental production rates of [13] with minor adjustments to match the GCR depth profile of the Apollo 15 deep drill core [11].

**Results and Discussion:** The average chemical composition of the 14 sub-samples of 73002 is 5.7% Mg, 10.9% Al, 0.13% K, 9.0% Ca, 1.0% Ti, 0.09 % Mn, and 6.3% Fe, while those of core 73001 are almost identical. We assume constant O and Si concentrations of 44.5% and 21.5%, respectively, similar to values measured for nearby lunar soils 73221-73281 [18].

The flat <sup>10</sup>Be depth profile in the top few cm of 73002 agrees with the expected GCR depth profile (Figure 1A). While some other Apollo cores (15008, 68002) show a small excess (up to ~1 dpm/kg) of SCR produced <sup>10</sup>Be near the surface, SCR produced <sup>10</sup>Be in the top of 73002 is negligible (less than 0.5 dpm/kg). This is consistent with the conclusion from [3] that the surface of 73002 shows some evidence of recent mixing. The <sup>10</sup>Be concentrations in the remaining part of core 73002 agree within experimental uncertainty with those of other Apollo cores and with the expected

GCR depth profile. However, all cores seem to show slightly elevated  $^{10}\text{Be}$  levels at depths of 20–35 g/cm<sup>2</sup>. This cannot be explained by disturbances of the core, but is consistent with previous conclusions of Binnie et al. [16] that the  $^{10}\text{Be}$  production rate probably needs some adjustment.

The  $^{36}\text{Cl}$  in the top few g/cm<sup>2</sup> of 73002 indicate a small SCR  $^{36}\text{Cl}$  component of ~2 dpm/kg (Fig 1B). However, unlike the  $^{36}\text{Cl}$  profile of undisturbed core 15008 [15], the  $^{36}\text{Cl}$  profile of 73002 shows some evidence of recent mixing in the top few cm, as was also concluded from the  $^{26}\text{Al}$  results [3]. The  $^{36}\text{Cl}$  depth profile in the deeper portion of core 73002 shows good agreement with those measured in other lunar cores, but all  $^{36}\text{Cl}$  depth profiles (normalized to the main target elements) deviate from expected GCR production rates.



**Figure 1.** Measured depth profiles of  $^{10}\text{Be}$  (A), and  $^{36}\text{Cl}$  (B) in 73002 in comparison with those measured in Apollo cores 15008, 15009 and 68002. The green curves represent expected production rates from GCR based on model calculations and the depth profile in Apollo 15 deep drill core [11, 13].

**Conclusions.** Concentrations of cosmogenic  $^{10}\text{Be}$ ,  $^{26}\text{Al}$  and  $^{36}\text{Cl}$  in core 73002 indicate that it is one of the least disturbed ones among the Apollo 17 cores. Nevertheless, the  $^{26}\text{Al}$  depth profile shows evidence for some degree of mixing of the top ~9 cm. This disturbance in the stratigraphy of the top few cm may have occurred during the extrusion of the core, when the large void near the surface was filled up by material from somewhat deeper. This interpretation also seems consistent with other studies of this core, which show surprising heterogeneity in cohesiveness, reflectance and maturity within each 5 mm interval of the top 5 cm of the core [5, 19, 20].

Finally, the observed deviations of the measured  $^{10}\text{Be}$  and  $^{36}\text{Cl}$  concentrations in core 73002 (and other lunar cores) between 10–35 g/cm<sup>2</sup> from expected GCR depth profiles (from model calculations) suggest that the calculated production rates need some adjustment.

Future work will include measurements of  $^{10}\text{Be}$ ,  $^{26}\text{Al}$  and  $^{36}\text{Cl}$  in core 73001 (in progress), as well as measurement of neutron-capture produced  $^{41}\text{Ca}$  in 73002/73001. The latter will help to constrain how much material was lost from the bottom of core 73002 during collection on the lunar surface. Finally, we will reevaluate the GCR production rates of  $^{10}\text{Be}$ ,  $^{26}\text{Al}$  and  $^{36}\text{Cl}$  in the lunar surface.

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