**SEARCHING FOR THE MISSING TOP FEW MM OF THE UPPERMOST LUNAR SURFACE USING COSMOGENIC RADIONUCLIDES.**
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**Introduction:** Lunar surface materials, the regolith and rocks residing on the surface, archive implantation of solar wind, irradiation by solar cosmic rays (SCR), and bombardment of micrometeorites and meteorites. Together, these processes produce space weathering, erosion of rock surfaces, and vertical/horizontal transportation of lunar regolith.

We have determined erosion rates by micrometeorite impacts of lunar surface rocks, 68815 and 64455, and past SCR flux and energy spectrum by measuring detailed depth profiles of cosmogenic nuclide concentrations, especially SCR produced $^{53}$Mn ($t_{1/2}$ = 3.7x$10^6$ yr) and $^{26}$Al (7.05x$10^5$ yr) [e.g., 1, 2]. Lunar regolith gardening histories were also studied by comparing measurements of SCR-produced cosmogenic nuclides in lunar surface cores with steady state production depth profiles [e.g., 3].

Individual rocks record cosmogenic $^{26}$Al production by SCRs. Based on the measured depth profiles of 64455 we calculated an integrated $^{26}$Al production rate of ~560 atom/min/kg for 0-1 mm, ~380 atom/min/kg for 0-5 mm, and ~300 atom/min/kg for 0-1 cm depth of Apollo 16 soil (assuming density is 1.6 g/cm$^3$). Surprisingly, lunar cores and soils do not have high $^{26}$Al activity. The highest $^{26}$Al activities are 246±69 dpm/kg [4] and 230±18 dpm/kg [5] for the Apollo 12 core 12025 at the 0-5 mm interval. Core 12025 contains also the highest $^{53}$Mn activity [6]. The tops of these $^{26}$Al profiles are flatter and have lower activities than predicted. The discrepancies could either be due to a physical process, *e.g.,* gardening, or they could be the result of sample handling. To investigate the properties of the uppermost lunar surface regolith, and investigate the production profiles, we measured cosmogenic $^{10}$Be, $^{26}$Al, and $^{36}$Cl in Apollo 16 special sample 69004 (velvet cloth) as well as some other lunar surface soils.

**Sample Description:** Two Contact Soil Sampling Devices (CSSD) were deployed on the lunar surface by the Apollo 16 mission. These were used to collect the uppermost regolith layer at station 9 [7]. The CSSD is an aluminum-box in which an aluminum collector pad is inserted. For 69004, the pad is covered with nylon velvet cloth. The velvet cloth sampler was designed to sample the uppermost 0.5 mm of lunar regolith [8]. Little material was collected due to sampling difficulty. We received 3 samples of 69004. Fine loose powder 69004,5 was sieved with 63 µm mesh with ethanol in an ultrasonic bath. 69004,28 was classified “magnetic” but most particles are silicate. The chemical composition of 69004,28 is similar to that of 69004,5 but has ~20 % higher Fe concentration. The typical grain size of 69004,28 was smaller than 100µm. A small piece, 2.5x2.5 cm, of velvet cloth was also received. Most lunar soil had already fallen off from the cloth and separated but a small amount of soil was observed under the microscope. After the cloth was tapped from behind, a small amount of soil as well as glue from backside of the cloth and a few velvet cloth materials were obtained. After separating glue and cloth using 180 µm mesh sieve 0.56 mg of soil was obtained.

The maximum depth of skim soil 69921 is estimated at 5 mm. We measured two split samples to investigate heterogeneity. Shaded soil 69961 was collected under 0.5 m boulder after it had been rolled over [7]. The sample must have been shielded from SCR exposure by the boulder. 69921 was collected adjacent to the boulder. Both 69921 and 69961 were collected adjacent to 69004.

A mature surface soil 68821 was collected adjacent to boulder 68815 for which detailed depth profiles of cosmogenic nuclides were measured [1]. We sieved the sample and divided into 4 size fractions and measured cosmogenic nuclides in each fraction.

Surface soil 73210 was collected ~18 m from core 73002/1. The depth of skim samples 73221 is about 1 cm. The depth of trench soil 73241 is upper 5 cm. The depths of trench soils 73261 and 73281 are 5-10 cm from regolith surface. All 4 samples are <1 mm size and collected about 15 m from core 73002/1.

**Experimental Procedures:** Each sample was dissolved with a $HF/HNO_3$ mixture along with Be and Cl carriers. Beryllium, Al, and Cl were separated and purified for accelerator mass spectrometry (AMS) using anion-, cation-chromatography, and solvent extraction. AMS was performed at PRIME Lab, Purdue University [9]. Major chemical compositions of each dissolved sample were measured by ICP-OES.

**Results and Discussion:** Cosmogenic $^{10}$Be, $^{26}$Al, and $^{36}$Cl concentrations of Apollo 16 special samples are shown in Table 1 and that of Apollo 17 soil samples are shown in Table 2.

*Apollo 16 special samples.* Sample 69004 was not studied extensively because of the scarcity of sample available. Only analysis of noble gases was reported [10]. As expected, noble gases in 69004 are dominated by implanted solar wind noble gases. The measured $^{26}$Al activities of 69004,5 and ,28 are the highest among any lunar regolith samples measured to date. However, the $^{26}$Al concentration is near half the predicted integral production rate between 0-1 mm of surface soil and the observed activity is close to integrated activity between 0-1 cm. The $^{26}$Al concentration of skim soil 69921 that was collected adjacent to 69004 is near the integrated activity between 0-1.5 cm compared to collected depth of 0-0.5 cm. Mature soil 68821 also contains equivalent to depth of 0-1.5 cm of integrated $^{26}$Al activity. Boulder 68815 that was collected adjacent to 68821 is 2.0 Myr age of South Ray Crater ejecta. However, saturated $^{10}$Be concentrations of 68821 as well as core 68002 [11] indicate that surface soil at station 8 is not South Ray Crater ejecta.

Table 1. Cosmogenic radionuclide concentrations (dpm/kg) in Apollo 16 special samples

| Sample grain size | Mass (mg) | $^{10}$Be | $^{26}$Al | $^{36}$Cl |
|---|---|---|---|---|
| 69004 from cloth | 0.56 | 9.18 ±0.30 | 184.3 ±6.8 | |
| 69004,5 <63 µm | 1.00 | 10.42 ±0.25 | 264.5 ±8.0 | |
| 69004,5 >63 µm | 0.96 | 11.05 ±0.25 | 271.9 ±9.1 | |
| 69004,28 magnetic | 0.68 | 10.81 ±0.40 | 282.4 ±9.4 | |
| 69921,36A | 7.90 | 10.69 ±0.10 | 256.5 ±5.3 | 16.38 ±0.25 |
| 69921,36B | 5.47 | 10.92 ±0.11 | 260.8 ±5.7 | 16.75 ±0.30 |
| 69961,38 | 16.51 | 12.14 ±0.10 | 73.1 ±1.7 | 16.73 ±0.23 |
| 68821,31 <63 µm | 4.92 | 11.14 ±0.31 | 243.2 ±7.0 | |
| 68821,31 63> >180 µm | 11.75 | 11.56 ±0.12 | 251.6 ±6.8 | |
| 68821,31 >180 µm | 2.51 | 10.26 ±0.18 | 230.3 ±6.6 | |
| 68821,31 300-1000 µm | 2.52 | 8.81 ±0.12 | 222.2 ±6.3 | |

*Skim soils vs. double drive tube core 73002/1.* Two skim samples 73211 and 73221 were collected 15-18 m from double drive tube core 73002/1. Chemical composition of both skim samples and 73002/1 are near identical. High $^{26}$Al concentrations of both skim samples are close to the predicted SCR production of $^{26}$Al at 0-1.5 cm depth interval. On the other hand, $^{26}$Al concentrations of 6 subsamples of 73002 at 0-1 cm interval are ~150 dpm/kg [12], > 35 % lower than that of skim samples. We conclude that the top 1 cm of 73002 was lost during coring or capping on the Moon and subsequently mixed with near surface sample and void space at transportation and core processing time.

Table 2. Cosmogenic radionuclide concentrations (dpm/kg) in Apollo 17 skim/trench samples

| Sample depth | Mass (mg) | $^{10}$Be | $^{26}$Al | $^{36}$Cl |
|---|---|---|---|---|
| 73211,3 <1 cm | 65.8 | 11.90 ±0.41 | 211.4 ±1.9 | 13.98 ±0.25 |
| 73221,17 <1 cm | 68.6 | 12.28 ±0.23 | 241.6 ±2.3 | 14.35 ±0.26 |
| 73241,94 <5 cm | 60.6 | 11.61 ±0.18 | 108.5 ±1.2 | 14.30 ±0.25 |
| 73261,75 5-10 cm | 64.0 | 11.38 ±0.18 | 67.6 ±0.9 | 11.51 ±0.27 |
| 73281,75 5-10 cm | 69.2 | 11.35 ±0.30 | 59.0 ±0.6 | 12.01 ±0.26 |

*Vertical mixing vs. missing top layer of lunar surface.* Aluminum-26 concentrations of top 0.5 mm (69004), 5 mm (69921) and 1 cm (73211 and 73221) are very similar and close to predicted integrated activity at 0-1.5 cm. None of the lunar surface soils and core samples shows as high a surface activity as predicted by theoretical SCR $^{53}$Mn or $^{26}$Al production profiles. One possible explanation is that all these sites have been gardened to a depth of at least 1-3 cm in the last a few Myr, although there could be other explanations. The depth profiles of top layers of rock samples are slightly flattened compared to theoretical profiles, which could be due to surface erosion by micrometeorites [e.g., 1]. The flattened profiles observed in lunar surface regolith might be explained by erosion loss of lunar surface materials from the Moon. McCoy [13] estimated the rate of $4x10^7$ kg/yr material loss from the Moon by electrostatic suspension. This translates to a loss rate of 1 g/cm$^2$/Myr, which is identical to the observed erosion rate of lunar surface rocks. A better understanding of the processes leading to lunar dust transport (and loss) requires further studies.

**Acknowledgments:** We thank NASA/JSC Curation for providing lunar samples. This work was supported by NASA's LARS and Cosmochemistry programs.

**References:** [1] Kohl C. P. *et al.* (1978) *PLPSC 9,* 2299-2310. [2] Nishiizumi K. *et al.* (2009) *GCA 73,* 2163-2176. [3] Langevin Y. *et al.* (1982) *JGR 87,* 6681-6691. [4] Rancitelli L. A. *et al.* (1971) *PLSC. 2,* 1757-1772. [5] Fimiani L. *et al.* (2012) *LPS XLIII,* #1279. [6] Nishiizumi K. *et al.* (1979) *EPSL 44,* 409-419. [7] Hörz F. *et al.* (1972) NASA SP-315. [8] Allton J. H. (1989) JSC-23454. [9] Sharma P. *et al.* (2000) *NIM B172,* 112-123. [10] Kirsten T. and Dominik B. (1977) *Meteoritics 12,* 278-279. [11] Binnie S. A. *et al.* (2019) *GCA 244,* 336-351. [12] Welten K. C. *et al.* (2022) *LPS LIII,* 2389. [13] McCoy J. E. (1976) *PLSC 7,* 1087-1112.