**LUNAR REGOLITH DYNAMICS INFERRED FROM COSMOGENIC RADIONUCLIDES $^{10}$Be AND $^{36}$Cl IN CORE 68002/68001.** S. A. Binnie[1], K. Nishiizumi[1], K. C. Welten[1] and M. W. Caffee[2]. [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (sbinnie@ssl.berkeley.edu), [2]PRIME Lab., Purdue University, West Lafayette, IN 47907-1306, USA.

**Introduction:** The processes of lunar regolith mixing and the rates and depths at which they operate are poorly understood. Here we present cosmic-ray-produced $^{10}$Be ($t_{1/2}$ = 1.36 Myr) and $^{36}$Cl (0.301 Myr) measurements from the little studied Apollo 16 double drive tube core 68002/68001 in order to investigate regolith activity. We compare our findings to the radionuclide production rate profile and published $I_s$/FeO maturity indices, and deviations from a stable regolith profile are considered in relation to processes of regolith transport and reworking.

**Core Descriptions:** Taken at Geological station 8, core 68002/68001 is 3.5 km away from the 2.0 Myr old, ~700 m diameter South Ray Crater. The motivation for taking this core was the expectation that it would collect South Ray Crater ejecta, identified as high albedo rays extending outwards from the impact site. However, the astronauts did not observe a color change at the surface but instead noted the prevalence of large clast and boulder deposits [1]. The core sampled a regolith surface that was relatively level but pitted with many small craters ~0.5 m in diameter. The site is around 2 m from the rim of a 10-15 m diameter crater and the configuration of coarse and fine clasts found at the site suggests the surface material may be ejecta from this event [2]. The extracted core lengths were 26.7 cm (68002, upper part of the core, [3]) and 34.1 cm (68001, lower part of the core, [4]), with respective densities of 1.59 and 1.80 g/cm$^3$ and an overall recovery of 91%. Upon extraction, loose material and a void were found in the top 4 cm of core 68002, and a void in the top 1.5 cm of 68001. Based on X-radiography, Hörz et al. [3] tentatively assigned the 68002/68001 core 11 discreet units. Upon examination, Schwarz [3,4] and Korotev et al. [1] both find around 5 compositionally distinct units, although the positions of their respective layer boundaries differ in some cases. Korotev et al. [1] also propose variable layer maturity based on $I_s$/FeO data (fig. 1C).

**Experimental Procedure:** We prepared splits of samples (65-102 mg) from along the lengths of the cores according to [5], and measured cosmogenic radionuclides by AMS at Prime-Lab, Purdue University. To allow comparisons between measured radionuclide profiles and steady-state production rate profiles we normalize the $^{10}$Be and $^{36}$Cl results of the Apollo 15 deep drill core and core 15008 to the data from 68002/68001, following [5, 6]. These Apollo 15 cores are considered to have been collected from a stable non-mixed regolith, and so provide the best estimates for the $^{10}$Be and $^{36}$Cl production rate profiles. For the $^{36}$Cl production rate profile we incorporate the results from [7] to estimate the contribution from solar cosmic rays (SCR). We also normalize the 68002/68001 data for the slight elemental variations along its length. The mean concentrations of the main target elements in 68002/68001 are Fe = 4.3%; Ca = 10.7%; K = 0.1%; Si = 21.0%; Al = 14.0%; Mg = 3.7% and O = 43.1%. Our results are shown in figures 1A and 1B alongside the production profiles based on Apollo 15 data.

**Discussion:** The $^{10}$Be and $^{36}$Cl concentrations in 68002/68001 are fairly uniform along the lengths of the cores, particularly the top 10 - 20 g/cm$^2$ where results vary by only a few percent. Both $^{10}$Be and $^{36}$Cl results are near saturation. This indicates that there is no South Ray Crater ejecta in this core since the South Ray Crater is 2.0 Myr old and the $^{10}$Be would only be 64 % of saturation after 2.0 Myr exposure. Similar conclusions are reached using $^{53}$Mn ($t_{1/2}$ = 3.7 Myr) in core 64002/64001 from station 4 [8]. This result supports the suggestion of [1], that only coarse ejecta from the South Ray Crater impact reached station 8. On the other hand, there is no sign of an expected SCR contribution [7] to $^{36}$Cl production near the surface ($\leq$5 g/cm$^2$). One explanation is the loss of the top few g/cm$^2$ of regolith during coring, as occurred with the Apollo 15 drill core. Unfortunately, it is too late to measure SCR produced $^{22}$Na ($t_{1/2}$ = 2.6 yr). South Ray Crater ejecta at station 8 would be a layer ~2.5 cm thick [1], so it may be that evidence for the impact has been lost if it was present at the surface. Below ~30 g/cm$^2$ the $^{36}$Cl profiles are in fairly good agreement with production profiles based on Apollo 15 drill core data [5], though our measurements tend to be slightly higher. All of our $^{10}$Be measurements are higher than the Apollo 15 estimates. One minor inflection we observe in both the $^{10}$Be and $^{36}$Cl profiles at ~60 g/cm$^2$ is at a similar depth to an anomalously low set of $I_s$/FeO values, which [1] suggests are representative a submature-immature regolith heated by an impact event (fig. 1C). However, the reductions in the radionuclide profiles are too slight to infer a meaningful relationship with soil maturity.

While many of the general profile characteristics apparent in the $^{36}$Cl data mimic those in the $^{10}$Be profile there is a conspicuous difference between the two datasets at ~22 g/cm$^2$, where the $^{36}$Cl concentration is around 20-30 % lower than would be expected from the trend of the data. There are no variations in the target element chemistry of this sample that could explain this anomalously low result. A reduction in $^{36}Cl$ concentrations without a corresponding reduction in $^{10}Be$ can be explained if the regolith residing at this depth has experienced a complex exposure history. More rapid decay of $^{36}Cl$ in relation to $^{10}Be$ means that previously exposed regolith grains, which are subsequently buried at depths sufficient to reduce production will decay $^{36}Cl$ more rapidly than $^{10}Be$. If this packet of regolith is returned to the near-surface both radionuclides will eventually recover to their pre-burial concentrations, each requirng a different amount of time to do so. In the case of core 68001/68002, burial of previously saturated regolith at depths able to reduce production rates to ~10% of the surface rate for ~150 kyr, followed by emplacement at 22 g/cm$^2$ for ~100 kyr could produce the pattern we see; as could a situation where burial reduces production to ~50% for ~300 kyr, followed by emplacement at the current depth ~50 kyr ago. All possible scenarios must account for the difference of the $^{36}Cl/^{10}Be$ ratio in this sample as compared to the surrounding profile, meaning the material at this depth must have been transported to the site from a different location than the rest of the regolith sampled. However, compromises between the timing and depth of burial and post-burial exposure make the solution non-unique with only two nuclides, while sensitivity to the production rates used and the requirement for rapid deposition of regolith with material much closer to saturation than the material currently at 22 g/cm$^2$ makes these explanations tentative. Furthermore, near similar maturity of $I_s$/FeO [1] to depths of ~60 g/cm$^2$ indicates such recent complex exposure is unlikely (Fig 1C). Another possible cause for the relative concentrations found at 22 g/cm$^2$ is that an impact generated heating event caused loss of $^{36}Cl$ but not $^{10}Be$. This heat may have been generated during formation of the, aforementioned, nearby 10-15 m diameter impact crater, which could have caused synchronous loss of $^{36}Cl$ and burial at 22 g/cm$^2$. This hypothesis would require the impact to be younger than 600 kyr, but it is supported by the abundance of friable soil clods found between 9.5-14.5 cm depth [3]. However, visual analyses of the sample from ~ 22 g/cm$^2$ did not show an anomalous composition.

Disturbances of the lunar regolith up to 19 g/cm$^2$ have been recorded in Apollo 16 cores from $^{53}Mn$ data, a depth significantly greater than is predicted by meteorite impact gardening models over <10 Myr timescales [9, 10]. The low $^{36}Cl$ measurement at 22 g/cm$^2$ suggests reworking of material to this depth over the last several 100 kyr. However, the notion of recent regolith activity is at odds with the finding of [1], that the top ~60 g/cm$^2$ of the core is composed of a single, mature unit. The results of $^{26}Al$ ($t_{1/2}$= 0.705 Myr) and $^{41}Ca$ (0.104 Myr) measurements on our samples are pending and will help clarify our findings. In addition we will measure and compare radionuclide concentrations in other Apollo 16 cores.

**References:** [1] Korotev R. L. et al. (1997) *GCA, 61*, 2989–3002. [2] Hörz F. et al. (1972) *Apollo 16 Preliminary Science Report, NASA SP-315*, 7-24–7-28. [3] Schwarz C. (1993) *Lunar News, 55*, 10-11. [4] Schwarz C. (1994) *Lunar News, 57*, 16-19. [5] Nishiizumi K. et al. (1984) *EPSL, 70*, 157-163. [6] Nishiizumi K. et al. (1989) *LPS XIX*, 305-312. [7] Nishiizumi K. et al. (2008) *GCA, 73*, 2163-2176. [8] Nishiizumi K. et al. (1982) *LPS XIII*, 596-597. [9] Nishiizumi K. et al. (1979) *EPSL, 44*, 409-419, [10] Arnold J. R. (1975) *Moon, 13*, 159–172.

Figures 1A and 1B show $^{10}Be$ and $^{36}Cl$ results alongside production profiles. Figure 1C, adapted from [1], shows regolith maturity inferred from $I_s$/FeO data (grey line), and the average value for each regolith unit defined by [1] given as black lines (labeled a - e).