DYNAMICAL MOVEMENT PROCESSES OF INDIVIDUAL LUNAR SURFACE GRAINS. K. Nishiizumi[1] and M. W. Caffee[2], [1]Space Sciences Laboratory, University of California Berkeley, CA 94720-7450, USA (e-mail: kuni@ssl.berkeley.edu), [2]Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907-2036, USA (mcaffee@purdue.edu).

Introduction: Individual particles collected from the same location on the surface of Itokawa indicate noble gas cosmic ray exposure (CRE) ages that are discordant by more than tens of Myr [e.g., 1-5]. Evidently, the use of single-grain CRE is not a robust indicator of the surface exposure age or the erosion rate. But what about the individual grains' CREs in aggregate? Do the individual CRE ages taken together represent the average evolutional history of Itokawa surface or do they indicate independent histories for each particle, histories that are different from the average surface history? To answer these questions we measured cosmogenic radionuclides in individual lunar surface grains. The lunar surface in some ways our Rosetta Stone for regolith processes and our goal is to compare the individual lunar grains CREs to the bulk lunar soil, and by extension ultimately be able to relate the individual Itokawa grains' CREs to the bulk regolith.

Our immediate goal is to understand the evolutionary history of lunar regolith and to obtain surface mixing rates, or escape rates of dust from the lunar surface. We measure cosmogenic nuclides in surface materials taken from lunar surface cores for which we know the surface history. These cores represent the ground-truth for a regolith exposed directly to space, with no intervening atmosphere.

All previous studies of lunar surface regolith mixing were based on measurements of ^{53}Mn and ^{26}Al in bulk soils. In general, 50-100 mg of bulk soil was used for ^{53}Mn and ≥1 g of bulk soil was used for ^{26}Al nondestructive gamma-ray measurements or 50-100 mg of bulk soils for ^{26}Al accelerator mass spectrometry (AMS) measurements. Cosmogenic radionuclide depth profiles of lunar surface bulk soils show smooth profiles [e.g., 6] but each rocklet in the same soil shows a very different exposure history [7, 8]. To study the gardening processes on a grain-by-grain basis, the ^{53}Mn activities in individual rock fragments or "rocklets" from core 60010 were measured [7]. The rocklets ranged in size from 2 to 4 mm or 8 to 26 mg. The ^{53}Mn activities in the individual rocklets scatter widely compared to the bulk soil, suggesting that in many cases the rocklets have a different exposure history than the surrounding soil. Subsequent measurements of ^{53}Mn, ^{26}Al, and ^{10}Be in 18 individual rocklets taken from lunar core 15011 show even greater effects than those measured in the 60010 samples [8]. These results also clearly show that individual rocklets and bulk soil have different regolith histories. Although in the case of core 15011, activities of the larger rocklets differ the most from those of the bulk soils, we don't know if individual grains show the same evolutional history as bulk soils or show wide scatter like the individual rocklets.

Sample Descriptions and Methods: To further investigate movement of individual lunar surface grains, we selected 20 lunar grains from the top layers of two lunar cores, 15008 and 76001. The double drive tube 15008/7 was collected from rim (in the ejecta blanket) of a 10 m shallow crater on the highest point on the Apennine Front between Elbow and St. George Craters. The ^{26}Al measurements from depth profile samples indicates that this is one of the most undisturbed lunar cores (Fig. 1). The single drive tube 76001 was collected from the bottom of the slope of the North Massif on an 11˚ slope and shown slightly disturbed ^{26}Al profile at the surface (Fig. 2) and undersaturated ^{53}Mn down to ~2 g/cm^2 [9]. We picked 10 grains (210-560 µm or 18-157 µg) from the same depth (0-5 mm) of surface soil 15008,207 and 10 grains (485-1040 µm or 126-566 µg) from the same depth (0-5 mm) of surface soil 76001,385. The individual masses of these grains are nearly 3 orders of magnitude smaller than those of previous radionuclide measurements in rocklets of core 15011 and 60010 but 10-100 times larger than individual large Itokawa grains.

After SEM analysis and weighing, each grain was dissolved with an HF/HNO_3/$HClO_4$ mixture. Be, Al, and Mn carriers were added, followed by chemical separation and purification. Aliquots of the solution were used for ICP-OES and ICP-MS analyses. ^{10}Be and ^{26}Al in each grain were measured by AMS at Purdue University [10].

Results and Discussions: Figures 3 and 4 shows the ^{10}Be and ^{26}Al activities, respectively, in individual grains vs. mean grain size, along with the ^{10}Be and the ^{26}Al activities in the bulk samples (60-80 mg) at the equivalent depth of the individual grains, 0-5 mm. In both cores, the measured ^{10}Be activities in 20-30 % of the individual lunar grains differ dramatically from those of the bulk soils, from which the individual grains were extracted. The deviations, which are much larger than we expected, are not correlated to the size of the grains. The ^{26}Al activities of nearly half of individual grains differ greatly from that of the bulk soil for both cores. The lower activities indicate residence time at a location deeper than their current location with the upper 5 mm of the core. Based on ^{10}Be-^{26}Al activities, several of the grains came from greater than ~200 g/cm^2 (~1.3 m) depth to the present depth within the last 0.1-0.2 Myr. Higher ^{26}Al activities in individual grains might be explained by solar cosmic ray (SCR) irradiation near surface (see production profiles in Fig. 1 and 2), but lower activities, ~120 dpm/kg (for 15008) or ~150 (for 76001), are not easily explained. The previously suggested model of continuous infilling of near surface materials by downslope creeping is inadequate for our measurements [e.g., 9, 11, 12]. As yet we do not have a model that explains why many individual grains show such wide scatter in exposure history compared to that of individual rocklets. The answer may ultimately be applicable to Itokawa though.

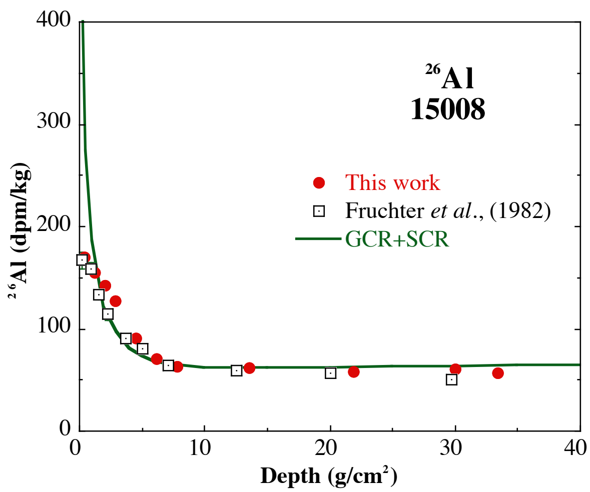

Fig. 1. ^{26}Al depth profiles of 15008 bulk soil.

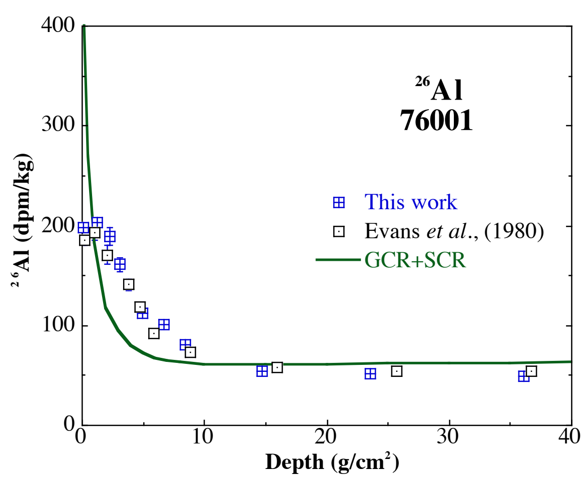

Fig. 2. ^{26}Al depth profiles of 76001 bulk soil.

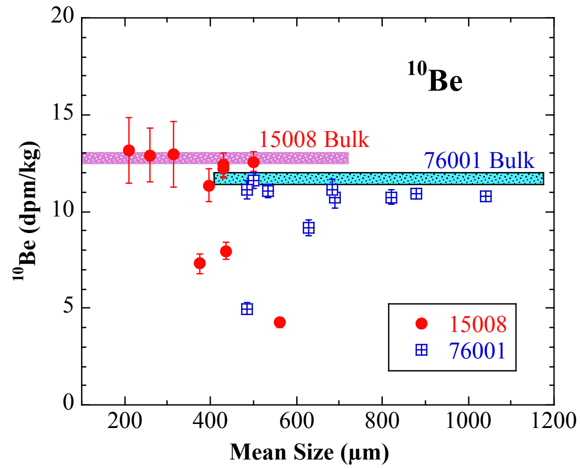

Fig. 3. ^{10}Be concentration vs. grain size of individual lunar grains from same depth (0-5 mm) of 15008 and 76001 soils.

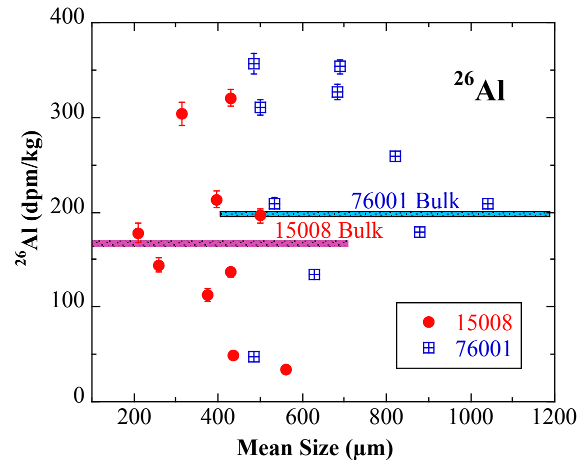

Fig. 4. ^{26}Al concentration vs. grain size of individual lunar grains from same depth (0-5 mm) of 15008 and 76001 soils.

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

References: [1] Nagao K. et al. (2011) *Science, 333,* 1128-1131. [2] Nagao K. et al. (2013) *LPS XLIV, Abstract* #1976. [3] Busemann H. et al. (2014) *Meteoritics & Planet. Sci., 49,* #5362. [4] Busemann H. et al. (2015) *LPS XLVI, Abstract* #2113. [5] Meier M. M. M. et al. (2014) *LPS XLV, Abstract* #1247. [6] Langevin Y. et al. (1982) *JGR, 87,* 6681-6691. [7] Nishiizumi K. et al. (1980) *LPS XI,* 818-820. [8] Nishiizumi K. et al. (1985) *LPS XVI,* 620-621. [9] Nishiizumi K. et al. (1990) *LPS XXI,* 895-896. [10] Sharma P. et al. (2000) *NIM, B172,* 112-123. [11] Evans J. C. et al. (1980) *PLSC, 11,* 1497-1509. [12] Nagle J. S. (1979) *PLSC. 10,* 1385-1399.