EXPOSURE AND TERRESTRIAL HISTORIES OF LUNAR METEORITES LAP 02205/02224/02226/02436, MET 01210, AND PCA 02007. K. Nishiizumi[1], D. J. Hillegonds[2], and K. C. Welten[1], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [2]CAMS, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Summary: We measured the cosmogenic radionuclide concentrations in new lunar meteorites, LAP 02205/02224/02226/02436, MET 01210, and PCA 02007. All meteorites contain solar cosmic ray produced ^{26}Al indicating a small preatmospheric radius.

Introduction: Cosmogenic nuclide studies of lunar meteorites have contributed significantly to our understanding of these objects. By measuring a combination of cosmogenic stable- and radionuclides, it is possible to determine a number of important properties of these meteorites. Most lunar meteorites have complex cosmic ray exposure histories, having been exposed both at some depth on the lunar surface (2π irradiation) before their ejection and as small bodies in space (4π irradiation) during transport from the Moon to the Earth. These exposures were then followed by residence on Earth's surface, a time commonly referred to as the terrestrial age. In addition to their complement of galactic cosmic ray (GCR) produced nuclides some lunar meteorites contain nuclides, produced by solar cosmic rays (SCR). Unraveling the complex history of these objects requires the measurement of at least four cosmogenic nuclides. The specific goals of these measurements are to constrain the following shielding or exposure parameters: (1) the depth of the sample at the time of ejection from the Moon; (2) the transit time (4π exposure age) from ejection off the lunar surface to the time of capture by the Earth; and (3) and terrestrial residence time. The sum of the transit time and residence time yields an ejection age, which is critical for lunar launch pairing. The ejection age, in conjunction with the sample depth on the Moon, can then be used to model impact and ejection mechanisms.

We report here preliminary results for the cosmogenic radionuclides in new lunar meteorites, LAP 02205/02224/02226/02436, MET 01210, and PCA 02007.

Experimental Procedures and Results: We received exterior and interior chips from each meteorite in order to investigate SCR effects. Exterior chips were further identified by distance from the surface of the fusion crust. Each sample was then dissolved in an HF-HNO_3 mixture along with Be and Cl carriers. The accelerator mass spectrometry (AMS) measurements were performed at Lawrence Livermore National Laboratory. Preliminary results of ^{10}Be (half-life=1.5x10^6 yr), ^{26}Al (7.05x10^5 yr), ^{36}Cl (3.01x10^5 yr), and ^{41}Ca (1.04x10^5 yr) concentrations in new lunar meteorites are shown in Table 1. The cosmogenic nuclide concentrations in Asuka 881757, NWA 032, and Yamato 793169 are shown in the table for comparison. Although results are still preliminary, exposure and terrestrial histories of each meteorite could be constrained as following.

LAP 02205/02224/02226/02436. Five LaPaz meteorites, LAP 02205, 02224, 02226, 02436, and 03632 are low-Ti crystalline mare basalts [1]. The recovered masses are 1226, 253, 244, 59, and 93 g, respectively. Since all meteorites contain fusion crust, we measured cosmogenic nuclides in exterior and interior samples to investigate SCR effects. Measurements of LAP 03632 are in progress. Nearly identical cosmogenic nuclide concentrations in these four meteorites as well as similarities of bulk chemical composition [2], petrography, and mineral chemistry [3] clearly indicate pairing. The wider range of ^{26}Al activities in individual samples indicates SCR production for near-surface specimens, especially LAP 02205,15 and 02224,8 that contain 50-70% higher ^{26}Al than the others. Since measured ^{41}Ca concentrations are higher than the 4π production rate, a significant portion of activities were produced on the Moon before launch and experienced negligible decay. We compared our cosmogenic radionuclide data to that of the Apollo 15 drill core depth profiles and 4π production rates for moderately sized meteorites, adjusting target element composition and macroscopic neutron cross section to that of the Apollo 15 core. The best scenario that fits our results is that the LAP lunar meteorite was ejected from ~700 g/cm^2 on the Moon 55±5 kyr ago and fell on Antarctica 20±5 kyr ago. The transition time from the Moon to the Earth, 4π exposure age, was 35±5 kyr. The saturation activities of SCR produced ^{26}Al in surface samples was ~100 dpm/kg, indicating an ablation depth of less than a few mm. Although Mikouchi et al., [4] concluded that LAP 02205 is clearly different from NWA 032, Jolliff et al. [1] suggested LAP 02205 was launch paired with NWA 032 based on bulk chemical and mineral compositions. Nyquist et al., [5] also concluded that the Ar-Ar age of LAP 02205 is similar to the total Ar ages of NWA 032. The ejection age of NWA 032 based on cosmogenic radionuclides [6] was 47±10 kyr and is indistinguishable from that of the LAP meteorites. These two lunar meteorites are thus consistent with the same ejection event.

MET 01210. The recovered mass of basaltic regolith breccia Meteorite Hills, MET 01210 is 22.8 g. 30% of this meteorite is covered by fusion crust. The exterior sample, MET 01210,11 was chipped from the fusion crust. The interior sample, MET 01210,12 was obtained 5-7 mm from fusion crust. The ^{10}Be and ^{36}Cl 4π exposure ages were very consistent: 0.95±0.13 and 0.90±0.18 Myr, respectively. The ejection depth was >1,000 g/cm^2. The terrestrial age is less than 20 kyr based on the ^{41}Ca concentration. Excess ^{26}Al in the surface sample clearly indicates SCR production of this nuclide. Even a small portion of ^{26}Al in the interior sample could have been produced by SCR. The preatmospheric radius was 3 cm or less. Arai et al., [7] proposed that MET 01210 is launch paired with Asuka 881757 (and probably Yamato 793169) based on close similarities of bulk composition, texture, and pyroxene composition. The ^{10}Be ejection ages of Asuka 881757 (0.8±0.2 Myr) and Yamato 793169 (0.9±0.2 Myr) [8] are consistent with proposed launch pairing of MET 01210 in light of our new results.

PCA 02003. The recovered mass of a feldspathic regolith breccia, Pecora Escarpment, PCA 02007 is 22.4 g. The ^{10}Be 4π exposure age is 0.95±0.11 Myr and terrestrial age is less than 30 kyr. The high ^{26}Al in PCA 02003,10 indicates SCR production. The highest activity of ^{26}Al was found in a sample 5-7 mm from the "surface." Since no fusion crust was observed in our piece, the sample might have come from close to the pre-atmospheric surface. The combination of four cosmogenic nuclides can be also explained by ~3 Myr exposure on the lunar surface (< 1 cm) before ejection and a short Moon-Earth transit time. However, only 4 nuclides cannot solve such a complex exposure history. Zeigler et al., [9] proposed that PCA 02007 is launch paired with Yamato 791197 based on petrographic similarity. The ejection age of Yamato 791197 is <0.1 Myr, so it is unlikely to match that of PCA 02007 [10].

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Table 1. Cosmogenic radionuclide concentrations in lunar and Martian meteorites (dpm/kg meteorite)

	^{10}Be	^{26}Al	^{36}Cl	^{41}Ca	Reference
LAP 02205,15 (0-2 mm)	0.687 ± 0.013	7.07 ± 0.21	2.034 ± 0.033	5.8 ± 1.0	This work
LAP 02205,17 (interior)	0.628 ± 0.014	5.43 ± 0.20	1.984 ± 0.033	4.9 ± 1.0	This work
LAP 02205,22 (0-1 mm)	0.771 ± 0.026	4.89 ± 0.19	1.836 ± 0.031	5.4 ± 0.8	This work
LAP 02205,22 (3-4 mm)	0.670 ± 0.019	4.80 ± 0.17	1.934 ± 0.032	5.4 ± 0.8	This work
LAP 02224.8 (0-1 mm)	0.682 ± 0.019	8.14 ± 0.26	2.034 ± 0.034	5.4 ± 0.7	This work
LAP 02224.8 (4-6 mm)	0.621 ± 0.014	7.04 ± 0.27	1.996 ± 0.041	6.5 ± 1.7	This work
LAP 02226,11 (0-1 mm)	1.010 ± 0.022	5.12 ± 0.22	1.866 ± 0.052	7.4 ± 0.9	This work
LAP 02436,6 (0-1 mm)	0.690 ± 0.015	6.13 ± 0.28	2.010 ± 0.055	6.6 ± 1.9	This work
NWA 032 (exterior)	*0.400 ± 0.105*	*4.42 ± 0.33*	*1.389 ± 0.045*	*3.2 ± 2.7*	*[6]*
NWA 032 (interior)	*0.318 ± 0.066*	*2.94 ± 0.26*	*1.303 ± 0.040*	*2.8 ± 1.4*	*[6]*
MET 01210,11 (0-1 mm)	8.39 ± 0.08	91.9 ± 1.7	14.23 ± 0.39	4.6 ± 0.8	This work
MET 01210,12 (5-7 mm)	7.96 ± 0.07	83.7 ± 2.2	14.13 ± 0.18	3.6 ± 0.7	This work
Asuka 881757,105	*7.19 ± 0.12*	*48.8 ± 2.6*	*16.31 ± 0.38*	*6.6 ± 0.9*	*[8]*
Y-793169,55	*7.87 ± 0.14*	*87.4 ± 2.0*	*18.32 ± 0.24*	*8.4 ± 2.8*	*[8]*
PCA 02007,10 (0-1 mm)	8.15 ± 0.07	166 ± 3	12.76 ± 0.15	5.0 ± 0.9	This work
PCA 02007,10 (5-7 mm)	8.82 ± 0.08	233 ± 5	13.48 ± 0.27	9.6 ± 1.1	This work
PCA 02007,15 (interior)	7.78 ± 0.07	136 ± 3	14.15 ± 0.17	5.4 ± 1.1	This work