EXPOSURE AND TERRESTRIAL HISTORIES OF NEW LUNAR AND MARTIAN METEORITES.

K. Nishiizumi[1], D. J. Hillegonds[2], L. R. McHargue[3] and A. J. T. Jull[3], [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 (hillegonds1@llnl.gov), [3]NSF Arizona AMS Facility, University of Arizona, Tucson, AZ 85721, USA (jull@u.arizona.edu)

Introduction: Cosmogenic nuclide studies of lunar and Martian meteorites have contributed significantly to our understanding of these objects. By measuring a combination of cosmogenic stable- and radionuclides, we can determine a number of important properties of those 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. On the other hand, we have not observed evidence of complex exposure history for any Martian meteorites, so far. 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 and Martian 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 or set limits on the following shielding or exposure parameters: (1) the depth of the sample at the time of ejection from the Moon or Mars; (2) the transit time (4π exposure age) from ejection off the lunar or Martian surface to the time of capture by the Earth and (3) the terrestrial residence time. The sum of the transit time and residence time yield an ejection age. The ejection age, in conjunction with the sample depth on the Moon or Mars, can then be used to model impact and ejection mechanisms.

We report here preliminary results for the cosmogenic radionuclides, ^{10}Be (half-life=1.5x10^6 yr), ^{41}Ca (1.04x10^5 yr), and ^{14}C (5,730 yr) in new lunar meteorites, Dhofar 280, 489, NWA 773 and Martian meteorites, NWA 998, 1068, 1110, 1195, and 1460. Measurements of ^{26}Al (7.05x10^5 yr) and ^{36}Cl (3.01x10^5 yr) are in progress.

Experimental Procedures and Results:

^{10}Be, ^{26}Al, ^{36}Cl, and ^{41}Ca measurements. We received exterior and interior chips from each meteorite in order to investigate SCR effects. Only interior chips were obtained for NWA 1068 and 1110. To eliminate weathering products, each sample was etched once or twice with 0.2 N HNO_3 solution in an ultrasonic bath for 10 minutes. The weight loss was found to be between 0 and 15%. Each sample was then dissolved in an HF-HNO_3 mixture along with Be and Al carriers. The AMS measurements were performed at the Lawrence Livermore National Laboratory.

^{14}C measurements. Interior samples of NWA 773, 998, 1110, and 1195 were used for the ^{14}C measurements. Samples were pretreated with 85-100% H_3PO_4 to remove weathering products. These weathering products are typical of meteorites recovered in this environment. The residue was then washed and dried before melting the sample in a flow of oxygen to recover $^{14}CO_2$ in presence of a carrier. The AMS measurements were performed at the University of Arizona NSF-AMS facility [1].

Results and Discussion: Preliminary results of ^{10}Be, ^{41}Ca, and ^{14}C concentrations in new lunar and Martian meteorites are shown in Table 1. The cosmogenic nuclide concentrations in Dhofar 026, 081, and DaG 476/489/670/735 are also shown in the table for comparison. Although ^{26}Al and ^{36}Cl measurements are not completed at this writing time, we could determined the following exposure and terrestrial histories of each meteorite.

Dhofar 280. Anorthositic fragmental breccia Dhofar 280 was found about 200 m apart from Dhofar 081. Mineralogy and petrography of Dhofar 280 is very similar to Dhofar 081 [2]. ^{10}Be and ^{41}Ca concentrations in Dhofar 081 are also identical to Dhofar 081 [3]. Two meteorites are most likely pair. Dhofar 081/280 was ejected at the depth of 200-230 g/cm^2 on the Moon at 40±20 kyr ago. The transition time from the Moon to the earth was much shorter than 10 kyr. The terrestrial age is 40±20 kyr.

Dhofar 489. A crystalline matrix feldspathic breccia Dhofar 489 is mineralogically different from other known Dhofar lunar meteorites [4]. Very low ^{10}Be and ^{41}Ca concentrations are similar to that of Dhofar 026 [5] which was found 80 km apart. The ejection depth was more than 1100 g/cm2 on the Moon. The transition time was 6±2 kyr.

NWA 773. The low levels of ^{10}Be and ^{41}Ca suggest two scenarios. The low ^{10}Be was also confirmed by a separate measurement at Arizona. One scenario is that the meteorite was ejected about 800 g/cm^2 on the Moon and the transition time was ~1 kyr. Another scenario is that the meteorite was ejected deeper than 1000 g/cm^2 on the Moon and the transition time was 30±3 kyr with large preatmospheric size (≥30 cm radius). The ^{14}C terrestrial age is 17±1 kyr for the latter case.

NWA 998. The ^{14}C terrestrial age of Nakhlite NWA 998 is 6±1 kyr.

NWA 1068 and 1110. Mineral composition indicates basaltic shergottite NWA 1110 is paired with NWA 1068 [6]. ^{10}Be and ^{41}Ca concentrations also support pairing of these objects. The ^{14}C terrestrial age of NWA 1110 is >40 kyr. The exposure age is 2.2-3 Myr based on only ^{10}Be result.

NWA 1195. Cosmogenic radionuclide concentrations of olivine-rhyric basaltic shergottite NWA 1195 are very similar to that of DaG 476/489/670/735 [7]. Mineral compositions of NWA 1195 is also similar to DaG 476/670 [8]. The ^{10}Be exposure age of NWA 1195 is 1.1±0.2 Myr and the terrestrial age is >37 kyr.

NWA 1460. The textures, mineralogy and mineral compositions of basaltic shergottite NWA 1460 are essentially identical to that of NWA 480 [9]. The exposure age is 2.2-3 Myr based on the ^{10}Be result alone.

Acknowledgment. We thank Jean-Alix Barrat, Adam Hupe, Greg Hupe, Marvin Killgore, Mikhail Nazarov, Nelson Oakes, and National Science Museum in Tokyo for providing meteorite samples. This work was supported by NASA grants NAG5-12846 and NAG5-11979, and under the auspices of the DOE by LLNL under contract W-7405-ENG-48.

References: [1] Jull A. J. T., et al. (1998) *Geochim. Cosmochim. Acta, 62,* 3025-3036. [2] Anand M., et al. (2002) *Lunar Planet. Sci., XXXIII,* CD-ROM, #1653. [3] Nishiizumi K. and Caffee M. W. (2001) *Lunar Planet. Sci., XXXII,* CD-ROM, #2101. [4] Takeda H., et al. (2003) *Lunar Planet. Sci., 34,* CD-ROM, #1284. [5] Nishiizumi K. and Caffee M. W. (2001) *Meteorit. Planet. Sci., 36,* A148-149. [6] Goodrich C. A., et al. (2003) *Lunar Planet. Sci., XXXIV,* CD-Rom, #1266. [7] Nishiizumi K., et al. (2001) *Lunar Planet. Sci., XXXII,* CD ROM, #2117. [8] Irving A. J., et al. (2002) *Meteorit. Planet. Sci., 37,* A69. [9] Irving A. J. and S. M. Kuehner. (2003) *Lunar Planet. Sci., XXXIV,* CD-ROM, #1503.

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

	^{10}Be	^{26}Al	^{36}Cl	^{41}Ca	^{14}C	Reference
Lunar meteorites						
Dhofar 280 (exterior)	5.58±0.07			221±7		This work
Dhofar 280 (interior)	5.43±0.06			217±8		This work
Dhofar 081 (exterior)	*5.38±0.10*	*31.2±0.8*	*7.16±0.11*	*201±18*		*[3]*
Dhofar 081 (interior)	*5.18±0.09*	*31.9±0.9*	*7.40±0.12*	*215±13*		*[3]*
Dhofar 489 (0-2 mm)	0.07±0.01			0.9±0.2		This work
Dhofar 489 (interior)	0.04±0.01			0.1±0.3		This work
Dhofar 026 (exterior)	*0.05±0.01*	*0.13±0.03*	*0.12±0.02*	*1.8±1.0*		*[5]*
Dhofar 026 (interior)	*0.03±0.01*	*0.17±0.04*	*0.02±0.00*	*1.2±0.6*		*[5]*
NWA 773 (exterior)	0.29±0.02			5.3±1.1		This work
NWA 773 (interior[a])	0.25±0.01			3.3±0.7		This work
NWA 773 (interior[b])	0.34±0.04				8.8 ± 0.2	This work
Martian meteorites						
NWA 998 (exterior)	20.1±0.4			4.4±0.6		This work
NWA 998 (exterior-2)	20.2±0.3			7.8±1.0		This work
NWA 998 (interior)	19.3±0.3			9.2±0.9	25.3±0.9	This work
NWA 1068	12.6±0.2			4.4±0.7		This work
NWA 1110	13.5±0.2			4.4±1.0	0.4±0.4	This work
NWA 1195 (exterior)	7.9±0.2			1.1±0.3		This work
NWA 1195 (interior)	7.3±0.1			2.9±0.5	<0.6	This work
DaG 476/489/670/735	*7.9 – 9.6*	*36 - 47*	*7.2-10.3*	*1.5 - 3.4*	*<0.3*	*[7]*
NWA 1460 (0-2 mm)	13.4±0.3			6.4±0.8		This work
NWA 1460 (interior)	14.3±0.2			5.2±0.6		This work

a. LLNL measurements.
b. Arizona measurements.