EXPOSURE HISTORY OF LUNAR METEORITE QUE93069: K. Nishiizumi, Space Sciences Laboratory, University of California, Berkeley, CA 94720, M. W. Caffee, R. C. Finkel, CAMS, Lawrence Livermore National Lab., Livermore, CA 94551, R. C. Reedy, NIS-2, Los Alamos National Lab., Los Alamos, NM 87545

Most lunar meteorites have complex cosmic ray exposure histories [1, 2]. They have been exposed both at some depth on the moon (2π irradiation) before their ejection and as small bodies in space (4π irradiation) during transport from the moon to the earth. As is the case for many other meteorites found in Antarctica, their terrestrial ages can be long. Measurement of cosmogenic radio- and stable nuclides can constrain these ages and help to unravel the complex histories of these objects. To unravel the complex history of these objects requires measurement of four or more cosmogenic nuclides in the same sample. We report here cosmogenic 36Cl (t(1/2) = 3.0 x 10^5 years), 26Al (7.05 x 10^5 years), and 10Be (1.5 x 10^6 years) results for a new lunar meteorite QUE93069.

Anorthositic breccia QUE93069 was collected in the Queen Alexandra Range, Antarctica. The recovered size is 5.0 x 2.2 x 2.3 cm and 21.4 g in weight. The object has a thick fusion crust on the top and a thin fusion crust on the bottom. Some lunar meteorites, such as Calcocoon Creek, Yamato 791197, and Yamato 793169, contain SCR (solar cosmic ray) produced nuclides, which indicate low ablation during atmospheric entry. To investigate SCR effects in QUE93069, we measured cosmogenic nuclides in 4 sub-samples with different shielding depths. QUE93069,14 was chipped into 3 portions; thick fusion crust (0-1 mm from recovered surface), 1-4 mm, and 5-9 mm. The interior sample, QUE93069,13 was collected at 8-11 mm from the surface. Be, Al, and Cl were chemically separated from each sample. 10Be, 26Al, and 36Cl were measured by AMS at Lawrence Livermore National Lab [3]. The concentrations of target elements, Mg, Al, K, Ca, Mn, and Fe, were determined by atomic absorption spectrometry. The results of 10Be, 26Al, and 36Cl concentration in QUE93069 are shown in Table 1.

Our chemical analysis indicates that major target elements in each sub-sample are homogenous within 1-3 % except K, which is enriched in the fusion crust by ~25 %. This difference is not significant for the 36Cl production rate since the K concentration is 360 times lower than that of Ca in this meteorite. The 10Be and 36Cl concentrations in 4 samples are nearly identical except that 36Cl is low in the thick fusion crust. The low 36Cl in the fusion crust is presumably due to loss of Cl by volatilization. The same trend for 36Cl was observed in the thick fusion crust on the Salem meteorite. 26Al values in exterior samples were 7-9 % higher than interior samples. If the excess of 26Al was produced by SCR bombardment, the gradient of SCR contribution was ~6 dpm/5 mm. Although three nuclides do not provide enough information to fully explain the complex history of the lunar meteorite, our results do constrain the system. The production rates of cosmogenic nuclides for 2π and 4π exposure geometry are relatively well known [4]. The following two exposure scenarios are illustrative.

4π model: The meteorite was ejected from greater than several meters depth in the moon and all cosmogenic radionuclides were produced in space. The small gradient of SCR produced 26Al indicates a shielding depth greater than 5 g/cm^2 in space. The preatmospheric radius was probably larger than 10 g/cm^2. The estimated saturation activities of 36Cl and 10Be are 20-25 dpm/kg and 21-24 dpm/kg, respectively. Based on 36Cl concentrations, the terrestrial age is calculated to be 0.18 ± 0.05 My. Based on 10Be concentrations, this meteorite was exposed to cosmic rays 1.9 ± 0.4 My. This implies that QUE93069 was ejected from the moon 2.1 ± 0.5 My ago. The 26Al concentration at the time of fall was 90-120 dpm/kg and suggests a pre-atmospheric radius of 10-20 g/cm^2.

2π model: This model assumes most of the cosmogenic radionuclides were produced on the moon. Based on the 10Be concentrations, this meteorite was exposed to cosmic rays at a depth of 5-50 g/cm^2 on the moon. Since the production rate of 36Cl at the depth of 5-50 g/cm^2 is 13-17 atom/kg-min, the maximum terrestrial age is <0.07 My. The predicted 26Al production rate is 70-90 atom/kg-min at this depth. A shallow ejection depth, 5-10 g/cm^2, better fits the observed 26Al. Slightly high 26Al in exterior samples could be produced at shallow depth on the moon or during a short transition time (<0.1 My) from the moon to the earth.

According to the Antarctic Meteorite Newsletter, the thin section of QUE93069 is very similar to MAC88105. Our chemical analysis also indicates very similar chemical composition except that Mg is slightly high QUE93069. These two lunar meteorites were collected 40-45 km apart. However, the cosmogenic radionuclide concentrations are very different. We found 3.42 dpm/kg of 36Cl, 17.5 dpm/kg of 26Al, and 2.26 dpm/kg of 10Be in MAC88105/88104 [2]. We concluded that the MAC88105 was ejected from a depth of 360-400 g/cm^2 on the
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The meteorite was exposed to cosmic rays as a small body in space for about 0.04-0.05 My, the transition time. The terrestrial age of the meteorite is 0.21-0.25 My. High $^{36}$Cl in QUE93069 eliminates the possibility that these two objects are from the same fall. However, if the QUE93069 was ejected from a depth of 5-20 g/cm$^2$ on the moon 0.25-0.3 My ago, and exposed to cosmic rays as a small body in space for about 0.16-0.2 My, and had 0.05-0.1 My terrestrial age, the observed three cosmogenic radionuclide concentrations are consistent with same impact event as MAC88105.

Although a variety of combinations of the $2\pi$ and $4\pi$ models are possible for QUE93069, further useful discussions are not possible until other cosmogenic nuclides such as $^{41}$Ca, $^{53}$Mn, and noble gases have been determined.

The exposure histories of 13 lunar meteorites (10 independent cases) have been studied. Fig. 1 illustrates ejection ages and terrestrial ages of all lunar meteorites that we have studied.

**Table 1. Cosmogenic radionuclide concentration in QUE93069**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth from surface</th>
<th>$^{36}$Cl (dpm/kg meteorite)</th>
<th>$^{26}$Al (dpm/kg meteorite)</th>
<th>$^{10}$Be (dpm/kg meteorite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUE93069,14</td>
<td>0-1 mm</td>
<td>12.93 ± 0.21</td>
<td>74.0 ± 1.6</td>
<td>11.42 ± 0.25</td>
</tr>
<tr>
<td>QUE93069,14</td>
<td>1-4 mm</td>
<td>14.52 ± 0.48</td>
<td>74.8 ± 2.3</td>
<td>12.02 ± 0.27</td>
</tr>
<tr>
<td>QUE93069,14</td>
<td>5-9 mm</td>
<td>14.80 ± 0.15</td>
<td>68.4 ± 1.5</td>
<td>12.38 ± 0.26</td>
</tr>
<tr>
<td>QUE93069,13</td>
<td>8-11 mm</td>
<td>14.62 ± 0.25</td>
<td>68.8 ± 1.4</td>
<td>11.95 ± 0.25</td>
</tr>
</tbody>
</table>

**Figure 1. Ejection ages and terrestrial ages of lunar meteorites**

References: