GEOCHEMISTRY OF LUNAR HIGHLAND METEORITES MIL 090034, 090036 AND 090070.

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Introduction: Apollo and Luna samples were collected from a restricted area on the near side of the Moon, while the source craters of the lunar meteorites are randomly distributed. For example, Takeda et al. [1] and Yamaguchi et al. [2] found a variety of lithic clasts in Dho 489 and Y 86032 which were not represented by Apollo samples, and some of these clasts have lower rare earth elements (REE) and FeO abundances than Apollo anorthosites, respectively. Takeda et al. [1] and Yamaguchi et al. [2] concluded that Dho 489 and Y 86032 originated from the lunar farside. Therefore, lunar meteorites provides an opportunity to study lunar surface rocks from areas not sampled by Apollo and Luna missions.

Three lunar anorthitic breccias (MIL 090034, 090036 and 090070) were found on the Miller Range Ice Field in Antarctica during the 2009-2010 ANSMET season [3]. In this study, we determined elemental abudnances for MIL 090034, 090036 and 090070 by using INAA and aimed to characterize these meteorites in chemical compositions in comparison with those for other lunar meteorites and Apollo samples.

Analytical method: Three lunar highland meteorite samples (MIL 090034, 090036 and 090070) were received as chips from the Meteorite Working Group (NASA/Johnson Space Center) and ground to powder in clean agate mortars. Portions of these samples were irradiated two times with different irradiation periods. The neutron irradiation was carried out at Kyoto University Research Reactor Institute (KURRI).

Results and Discussions: *Chemical characteristics of MIL 090034, 090036 and 090070.* Aluminium oxide abundances for MIL 090034 (30.3 %) and MIL 090070 (29.8 %) are higher than that for MIL 090036 (26.3 %). MIL 090034 and MIL 090070 have the highest Al_2O_3 abundances among other lunar highland meteorites, indicating that these two meteorites have the largest modal abundances of plagioclase relative to other lunar meteorites. This observation can also be recognized when Sc and Cr abundances are taken in account (Fig. 1). Figure 1 compares Cr and Sc abundances for lunar highland meteorites. This is quite reasonable in consideration that Cr and Sc are mostly hosted by pyroxene but not by plagioclase. As shown in Fig. 1, there is a positive correlation between Sc and Cr abudnances. This trend indicates that lunar highland meteorites having higher Sc and Cr abundances contain higher mafic components than those with lower abundances of these elements. MIL 090034 and MIL 090070 have lower Sc and Cr abundances than those for almost all lunar highland meteorites and have similar these elements abundances to those for Dho 081, Dho 489 and Dho 733, implying that MIL 090034 and 090070 are less affected by the contribution of mafic components. MIL 090036 is intermediate in Sc and Cr abundnances.

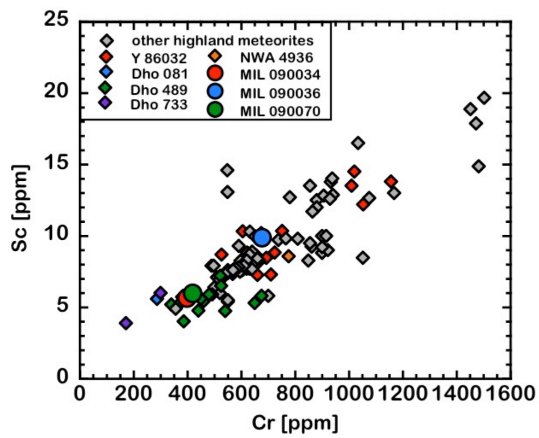

Fig. 1. Cr vs. Sc abundances for lunar highland meteorites.

In addition to higher Al_2O_3 abundances for MIL 090034 and MIL 090070, these two lunar highland meteorites have the lowest mg numbers (molar Mg/(Fe+Mg) ratios) among lunar highland meteorites. Mg numbers are plotted against Sc abundances in Fig. 2. MIL 090034 and MIL 090070 have similar mg numbers to that for Dho 081. As shown in Fig. 2, mg numbers and Sc abundances for almost all lunar highland meteorites can be produced by mixing of lunar highland meteorites (represented by Dho 489) with high mg number and mare basalts with low mg number, except for MIL 090034, 090070 and Dho 081. These three lunar highland meteorites are chemically different from other lunar highland meteorites.

Compared to lunar meteorites, MIL 090036 is unusual among lunar meteorites, in having high incompatible elements abundances (e.g., REE). CI chondrite-normalized REE abundance patterns of lunar meteorites including MIL 090036 are illustrated in Fig. 3. As shown in Fig. 3, REE abundances and their abundances pattern for MIL 090036 are significantly different from those for lunar meteorites except for NWA 4936. Almost all lunar meteorites including MIL 090034 and 090070 have relatively light-REE (LREE) enriched patterns with positive Eu anomalies. Although MIL 090036 and NWA 4936 are also slightly enriched in LREE, these two meteorites have negative Eu anomalies. As suggested by Korotev et al. [4], REE abundances and their abundance patterns for MIL 090036 and NWA 4936 are similar to those for samples from Apollo 16. The observed differences between MIL 090036 and NWA 4936, and other lunar highland meteorites are reflected by the degree for contribution of PKT components. Figure 4 shows Sc abundances plotted against Sm abundances for lunar meteorites including mingled and mare meteorites. MIL 090036 and NWA 4936 are plotted on the line represented by mixing of FHT with PKT. Therefore, MIL 090036 and NWA 4936 contain higher amounts of KREEPy components than most other lunar highland meteorites.

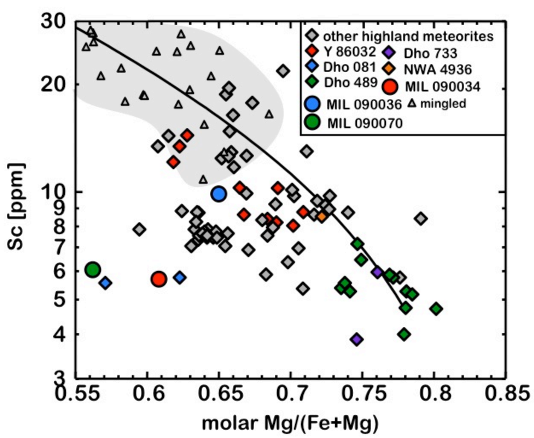

Fig. 2. An mg number vs. Sc abundances for lunar highland meteorites. Line represents mixing line of lunar highland meteorites (Dho 489 [1]) and mare basalt (Y 793169 [5]).

Pairing of MIL 090034, 090036 and MIL 090070. MIL 090034, 090036 and 090070 are chemically different from almost all known lunar highland meteorites. MIL 090034 and 090070 have less mafic components and the lowest mg number. These two meteorites have very similar chemical composition to Dho 081, indicating that the possibility of a source crater pairing of these lunar highland meteorites. The source area of these three meteorites is highland terrain rich in feldspathic components, with a significant distance separating it from craters connected with mafic and KREEPy components. Compared to MIL 090034 and 090070, MIL 090036 has higher amounts of mafic and KREEPy components. The REE abundances and their abundances patterns for MIL 090036 are similar to those for NWA 4936 and samples from Apollo 16. In terms of chemical compositions, MIL 090036 could be paired with NWA 4936 and they likely originated close to the Apollo 16 site.

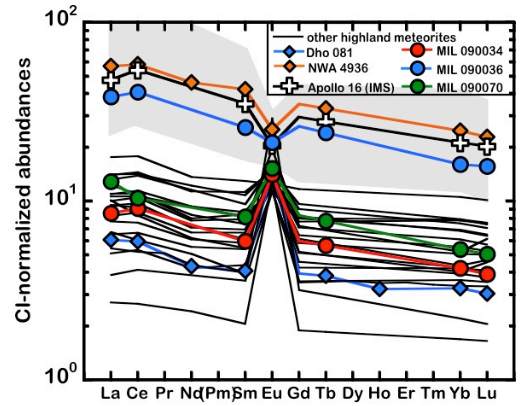

Fig. 3. CI-normalized rare earth elements abudnances for lunar highland meteorites and imact melt splashes from Apollo 16. Light dark shaded regions represent compositional ranges of impact melt splashes from Apollo 16 [6].

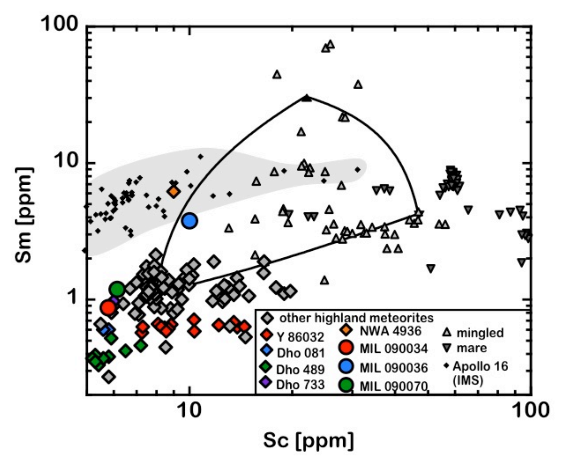

Fig. 4. Sc vs. Sm abundances for lunar highland, mingled and mare meteorites. Lines represent mixing line of FHT, PKT and maria. Data of FHT, PKT and maria, and imact melt splashes from Apollo 16 are taken from Korotev et al. [4] and Morris et al. [6].

References: [1] Takeda H. et al. (2006) *Earth Planet. Sci.*, 247, 171-184. [2] Yamaguchi A. et al. (2010) *Geochim. Cosmochim. Acta*, 74, 4507-4530. [3] Righter K. *Ant. Met. News Lett*. (2010) 33 (2). [4] Korotev R. L. et al. (2009) *Meteoritics & Planet. Sci.*, 44, 1287-1322. [5] Warren P. H. and Kallemeyn G. W. (1993) *Proc. NIPR Symp. Antarct. Meteorites*, 6, 35-57. [6] Morris R. V. et al. (1986) *J. Geophys. Res.*, 91, E21-E42.