

BEHAVIOR OF MAGNESIUM ISOTOPES DURING LUNAR MAGMATIC DIFFERENTIATION. F. Sedaghatpour¹, F.-Z. Teng¹, Y. Liu², D. W. G. Sears³, and L. A. Taylor². ¹Isotope laboratory, Department of Geosciences and Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, U.S.A. (fsedagh@uark.edu), ²Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA, ³NASA Ames Research Center, MS 245-3, Moffett Field, Mountain View, California 94035, USA.

Introduction: Knowledge of Mg isotopic compositions of terrestrial and extraterrestrial materials can be used to identify the origin of the building blocks of the planets and the processes that contributed to the formation and differentiation of planetary objects [1-4]. Magnesium isotope fractionations can occur at high temperatures during condensation and evaporation processes around the Sun, producing the calcium-aluminum rich inclusions (CAIs) [1, 5] and chondrules [6, 7].

Compared to the Earth [e.g., 4, 8-11], there are limited studies of Mg isotopic compositions of the Moon with discrepant results [2, 12-14]. Analyses of lunar mare basalts, glasses, and impact melts with uncertainties of $\sim\pm 0.2\%$ (2SD) reveal a limited Mg isotopic variation among these samples similar to that for chondrites [2, 12]. By contrast, using higher-precision analysis of Mg isotopes, Wiechert and Halliday [13] reported a heterogeneous non-chondritic composition for Mg isotopes of the Moon. Recently, Chakrabarti and Jacobsen [14] suggested an identical chondritic Mg isotopic composition of the Earth and Moon, but is questionable since the $\delta^{26}\text{Mg}$ values of terrestrial samples reported by them are different from those reported in other studies [4, 8-11]. Many the discrepancies in the previous studies can be ascribed to inter-laboratory bias.

In order to provide an internally consistent estimate of the Mg isotopic composition of the Moon, we studied 47 well-characterized lunar samples from all major types of lunar rocks, including mare basalts, highland impact melts, mare breccias and regolith samples.

Analytical methods: A small-volume (~ 2 ml) ion exchange column, packed with pre-cleaned Bio-Rad 200-400 mesh AG 1-X8 resin, was used as a primary column to remove Ti from the samples. In a second step, cation-exchange chromatography, following a similar procedure described by Teng et al. [4, 8], was used to separate Mg. Magnesium isotopic analyses were done by the standard bracketing method, using a Nu Plasma MC-ICPMS at the Isotope Laboratory of the University of Arkansas.

To evaluate the precision and accuracy of our data, full-procedural replicate analyses of two synthetic solutions (IL-granite and IL-lunar), an in-house

Kilbourne Hole (KH) olivine and pure Mg standards, were performed. The in-run precision on the $^{26}\text{Mg}/^{24}\text{Mg}$ value for a single measurement of one block of 40 ratios is less than $\pm 0.020\%$ (2SD). The internal precision on the measured $^{26}\text{Mg}/^{24}\text{Mg}$ value is $\leq \pm 0.090\%$ (2SD), based on 4 repeat runs of the same sample solutions during a single analytical session. IL-granite and IL-lunar yielded an average $\delta^{26}\text{Mg}$ value of $-0.034 \pm 0.059\%$ (2SD) and $-0.024 \pm 0.055\%$ (2SD) respectively, which are identical to the expected true value of 0. The olivine KH-1 yielded an average $\delta^{26}\text{Mg}$ value of $-0.302 \pm 0.047\%$ (2SD), which is in agreement with the one reported by Teng et al. [4] ($\delta^{26}\text{Mg} = -0.27 \pm 0.07\%$; 2SD, n=16). The results of standard solutions; therefore, confirm the accuracy of our data during this course of analysis.

Results: The lunar samples analyzed here fall on a single mass-dependent fractionation line with a slope of 0.505, which is consistent with that reported in literatures [4, 8]. $\delta^{26}\text{Mg}$ values range from -0.608% to -0.017% in mare basalts, from -0.334% to -0.148% in highland impact melts, from -0.328% to -0.155% in mare breccias, and from -0.410% to -0.140% in lunar regolith (Fig.1). These values fall within the range previously reported for lunar samples by Wiechert and Halliday [13]. Chakrabarti and Jacobsen [14] have reported an overall lighter $\delta^{26}\text{Mg}$ compared to our data and that of others. The cause of this discrepancy is not clear yet [14].

Discussion and conclusions: Lunar regolith, mare breccias, and highland impact melts display identical Mg isotopic compositions, agreeing within uncertainties $\pm 0.090\%$ (Fig. 1). This result indicates that the surface processes on the Moon (e.g. solar wind, cosmic rays, micro-meteorite bombardment, and etc.) did not fractionate Mg isotopes in these samples significantly.

A significant Mg isotope fractionation ($\sim -0.230\%$) is observed between the average $\delta^{26}\text{Mg}$ values of low-Ti ($-0.250 \pm 0.091\%$) and high-Ti ($-0.479 \pm 0.135\%$) basalts (Fig. 1). This variation is significantly outside the analytical uncertainties $\pm 0.090\%$. The variations of $\delta^{26}\text{Mg}$ within the low- and high-Ti basalts could have been produced by source heterogeneity, crystal fractionation, partial melting and/or magma assimilation and mixing.

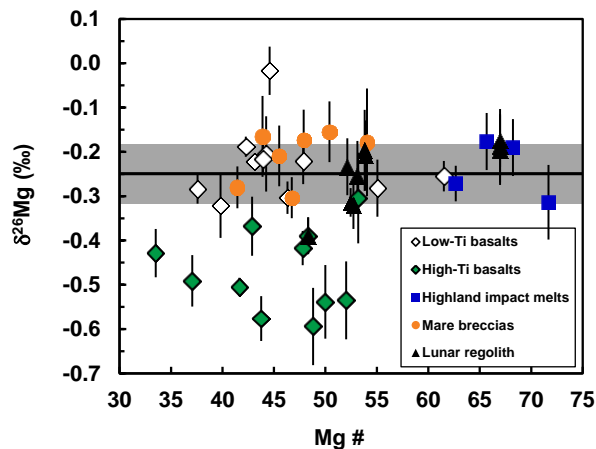


Fig. 1 Variation of $\delta^{26}\text{Mg}$ versus $\text{Mg}\#$ for lunar mare basalts, highland impact melts, mare breccias and regolith studied here. The solid line is the average $\delta^{26}\text{Mg}$ (-0.25‰) for the Earth [4] with $\pm 2\text{SD}$ (0.07‰) indicated by grey bar.

Magnesium isotopic fractionation during crystal fractionation and partial melting is small as shown by studies of terrestrial samples [8-11]. Magnesium isotope compositions of lunar basalts are not correlated with $\text{Mg}\#$, suggesting the insignificant Mg isotope fractionation during the crystal fractionation. Polybaric partial melting models with preferable consumption of ilmenite have been suggested as possible sources of O [e.g., 15] and Fe [16] isotope fractionation in mare basalts. The partial melting of ilmenite may cause Mg isotope variations within lunar basalts, if only ilmenite plays an important role as Mg budget in high-Ti basalts. Although there is a significant variation between $\delta^{26}\text{Mg}$ and TiO_2 in lunar basalts, the parallel trends in $\delta^{26}\text{Mg}$ versus $\text{Mg}\#$ and Al_2O_3 are against a simple magma mixing origin for low- and high-Ti basalts.

High- and low-Ti basalts are derived from different mineralogical sources produced during the crystallization of a lunar magma ocean (e.g., 17). The source for high-Ti basalts is ilmenite-rich cumulates, whereas the source for low-Ti basalts is dominantly lherzolitic. With the above discussion on negligible effects on magnesium isotope fractionation by partial melting and crystal fractionation, Mg isotopic variations among lunar basalts likely reflects their source heterogeneity. Using the estimated proportion of low- and high-Ti mantle sources and their average $\delta^{26}\text{Mg}$ values, the weighted average value of lunar upper mantle is estimated to be -0.273‰ . The average $\delta^{26}\text{Mg}$ value of the most primitive basalts is also $-0.275 \pm 0.101\text{‰}$ (2SD, $n = 3$). These values are

indistinguishable from those of the Earth ($\delta^{26}\text{Mg} = -0.25 \pm 0.07\text{‰}$) and the chondrites ($\delta^{26}\text{Mg} = -0.28 \pm 0.06\text{‰}$) [4]. Such homogeneity among solar system objects may suggest a homogenous nebular reservoir for these planetary objects in the solar system, which is well mixed in Mg isotopes on large scale.

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