Solidification of the lunar magma ocean suggested by composition of the highland crust

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Introduction: Previously we reported that highland materials with higher Mg# (Mg/[Mg+Fe] in mole percent in mafic minerals) (up to 80) than those on the lunar nearside were found on the lunar farside [1]. The observed higher Mg# on the lunar farside indicates that the farside crust consists of rocks that crystallized from less-evolved magma than the nearside crust. One of the other key parameters for evaluating solidification of the lunar magma ocean is Th abundance. Th is an incompatible element and concentrates in the liquidus phase when magma cools, therefore highland material that solidified earlier must have lower Th abundance than the highland material that solidified later. Th abundance distribution and its dichotomic nature were found to be lower on the farside than on the nearside [2].

If the dichotomic distribution of lunar highland Mg# and the Th abundance were formed by lunar magma ocean solidification, as the solidification proceeds, Mg# will decrease while Th abundance will increase, giving the two parameters a negative correlation. This study investigated the correlation of the two observed parameters of the lunar highland to validate the magma ocean origin of Mg# and Th abundance distribution on the lunar surface. We also tried to estimate the chemical composition of the lunar magma ocean by combining two remote-sensing data sets.

Method: Using Kaguya gamma-ray data, we derived the relative Th abundance (count of the observed gamma-ray data) map of the Moon as gridded data. We then derived the Mg# map of the lunar highland so that it had the same grid as the Th abundance map. For comparison with the derived Mg# and Th abundance correlation trend, we calculated the Mg# of the lunar magma ocean starting with different bulk chemical compositions by using the MELTS program [3]. The calculated starting magmatic compositions were bulk silicate Earth and bulk lunar magma ocean.

Results: The derived Mg# and Th concentration ratio of the same location indicates a negative correlation of the two parameters. In addition to the negative correlation, another interesting feature is that there seems to be two separate trends with lower and higher Th concentration ratios. Comparison of the observed Mg# and Th concentration ratio trend with that of the model calculation suggests that the observed data of the lower Th concentration ratio group matches the bulk silicate Earth composition better than the lunar magma ocean.

Discussion: The negative correlation of observed Mg# and Th concentration ratio suggests that current values of these parameters on the lunar surface are likely due to cooling of the lunar magma ocean as each location crystallized at a different solidification stage though the origin of the two apparent sets of the observed trends is not clear. The fact that the observed data of the lower Th concentration ratio group matches the bulk silicate Earth model better may imply that the chemical composition of the lunar magma ocean needs to re-evaluated and that the Mg# of the actual bulk lunar magma ocean may be higher than previously estimated although we need to further evaluate the effect of calculation conditions. The possibly higher Mg# of the bulk lunar magma ocean agrees with the reported higher Mg# (up to 80) in the farside highland than previously estimated based on the nearside sampled FAN compositions.

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