

論文の内容の要旨

**Bulk composition of the Moon constrained
by the conditions of anorthosite crust formation**

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A basic understanding of inner structure, chemical composition and thermal history for the Moon have been provided from the extensive explorations, including remote sensing and analysis of Apollo samples and lunar meteorites. In particular, the crust of the Moon has been investigated in detail; the lunar highland is estimated to be the ancient anorthosite crust with 35–55 km thickness. The lunar anorthositic crust is thought to have formed by large-scale differentiation of a totally molten Moon, which was later named as the lunar magma ocean (LMO). The existence of LMO suggests the giant impact theory of the origin of the Moon that is a giant impact of a Mars-sized body on the young Earth and formation of the Moon from the ejecta. Although there is a framework for the origin and evolution of the Moon as mentioned above, the geophysical and geochemical process still remain unknown, such as the chemical evolution during the lunar formation and the efficiency of the crystal separation in the cooling LMO. The major cause is derived from the large uncertainty of the bulk composition of the Moon. Previous workers have disputed whether the chemical

composition of the bulk Moon is similar to or richer FeO and/or Al₂O₃ contents than those of the Earth because of the enormous difficulties for the estimates of inner structure of an extra-terrestrial planet and for the estimates of the bulk composition using the local and trace information. In this study, we will estimate the bulk composition of the Moon by developing a differentiation model for the conditions of anorthite flotation in the LMO to satisfy both physical and chemical constraints for anorthosite crust formation through thermodynamic and fluid dynamic consideration on anorthite flotation and accumulation in the LMO.

We have constructed the polybaric incremental fractionation model for the differentiation of the LMO with various the initial compositions and the efficiency of crystal separation as parameters, and calculated the compositions of residual melt and crystallizing phases with MELTS/pMELTS program. The results of thermodynamic calculation were evaluated for the following observations; (1) the amount of anorthite, which crystallized from the residual melt, is abundant enough to form the lunar crust, (2) composition of the orthopyroxene coexisting with anorthite is consistent with that of lunar highland rocks, (3) anorthite separated from the turbulent LMO, and (4) the rare earth elements (REE) composition of the LMO is consistent with that observed in the parent magma of the lunar highland rocks. The allowable values of FeO and Al₂O₃ content of the bulk LMO is successfully constrained in a narrow region that is FeO-rich and BSE-like Al₂O₃ contents. This lower limit of the initial FeO content is constrained to be ~1.3 xBSE from the condition of the anorthite separation from the turbulent LMO. The upper limit of the initial FeO content is constrained to be less than 1.9 xBSE for any values of the initial Al₂O₃ and X_{scft} from the condition of the maximum Mg# of orthopyroxene in FAN. The lower limit of the initial Al₂O₃ of the LMO is constrained to be more than 0.8 xBSE in order to reproduce the observed lunar crustal thickness. The upper limit of the initial Al₂O₃ content is constrained to be less than 1.1 xBSE from the condition of the REE pattern of the parent melt of FAN rocks. The FeO content is constrained to be more than 1.3 xBSE and less than 1.8 xBSE, if the Al₂O₃ content of the Moon is comparable to that of the Earth. These upper and lower limits of the FeO contents are positively correlated with X_{scft} .

In summary, the range of the FeO and Al₂O₃ content of the LMO constrained in this study is 1.2–1.8 xBSE for FeO and 0.8–1.1 xBSE for Al₂O₃ and lies between that of the Earth and Mars. This emphasizes an importance of simultaneous estimation of the bulk abundances of FeO and Al₂O₃, significance of which has been overlooked in most of the previous studies. The bulk composition of the Moon constrained in our study may provide the possibility of the estimate for the orbit of the impactor that collided the proto–Earth at the last stage of the planet formation.

