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Calcium Isotopic Compositions of Lunar Anorthosites

WENKE WANG, XIN LI, FANG LIU, YAJUN AN AND ZHAOFENG ZHANG

Research Center for Planetary Science, College of Earth and Planetary Sciences, Chengdu University of Technology

Anorthosite is an igneous rock with more than 90% plagioclase content, widely distributed in the lunar highlands. The study of anorthosites is of significant importance for understanding the early formation of the lunar crust and the lunar evolutionary history. Typically, four models for the formation of lunar anorthosites have been proposed: (1) magma ocean crystallization; (2) mantle hybridization; (3) localized melting and KREEP redistribution; (4) multi-stage synthesis, integrating initial crystallization, mantle-crust interactions, late-stage KREEP assimilation. Recently, theoretical models (including thermal diffusion dynamics, top-down solidification, three-end-member mixing, and KREEP material assimilation) and radiogenic Sr-Nd isotopes suggest that the formation of lunar anorthosites is likely controlled by complex, multi-stage, and multi-source magmatic process. Furthermore, the existence of An-rich (An>90) plagioclases and the inconsistency of anorthosite ages constraints understanding on the Lunar Magma Ocean model.

Anorthosites are predominantly composed of anorthite and that calcium isotopes ($\delta^{44/40}$Ca) possess advantages such as wide distribution and sensitivity to early planetary differentiation. To better understand the formation of anorthosites, we obtained the Ca isotopic compositions of 14 anorthite single minerals (>90% plagioclase), 26 anorthosite clasts (>10% mafic minerals), and 13 feldspathic matrix from 13 lunar feldspathic breccia meteorites systematically. The $\delta^{44/40}$Ca values of anorthite single minerals ranged from 0.68‰ ~ 0.94‰ (mean: 0.78 ± 0.15‰, 2SD, n=18), consistent with our previous study (0.75 ± 0.13‰, n=4). The $\delta^{44/40}$Ca values of anorthosite clasts ranged from 0.59‰ ~ 0.99‰ (mean: 0.78 ± 0.21‰, 2SD, n=26), showing no correlation with the content of mafic minerals (olivine, pyroxene, ilmenite). Some clasts exhibit $\delta^{44/40}$Ca > 0.90‰, indicating the existence of isotopic heterogeneity. The $\delta^{44/40}$Ca values of the feldspathic matrix ranged from 0.56‰ ~ 0.95‰ (mean: 0.79 ± 0.27‰, 2SD, n=13), which is comparable to the variation range observed in anorthosite clasts, with also approximately 0.4‰ fractionation. In general, the Ca isotopic composition of anorthosite clasts and feldspathic matrix is similar and has a fractionation of about 0.4‰, indicating that the important value of calcium isotopes in exploring the formation of lunar anorthosites.