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A Fresh Look at an Old Moon: Magnesium Isotope Constraints on Lunar Differentiation from Previously Unstudied Lunar Meteorites

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Stable isotope systems have been used in lunar samples to constrain the origin and evolution of the Moon, evaluate genetic relationships with Earth, and to understand the effects of high-temperature processes such as the giant impact and lunar magma ocean (LMO) crystallization [1-4]. These studies have provided insight into volatile loss, mixing between the proto-Earth and the giant impactor, and the origins of the Moon. Yet many questions remain regarding the relationships between lunar crustal rocks and the evolving compositions of lunar mantle sources from which they derive.

Stable calcium isotopes ($\delta^{44}Ca$) are a useful tool for understanding the petrogenesis of lunar igneous rocks and their sources because of their well-understood magmatic fractionation behavior and resistance to devolatilization processes. Lunar samples analyzed thus far (n = 33) have $\delta^{44}Ca$ variations consistent with predictions for isotopic equilibrium [5-7], with anorthosites ($\delta^{44}Ca_{BSE}$ = -0.19 ± 0.10‰, n = 11) having lower $\delta^{44}Ca_{BSE}$ than basalts (-0.10 ± 0.10‰, n = 20). Equilibrium predictions for mineral-melt fractionation have thus been combined with LMO crystallization models to (i) constrain the mineralogy of LMO cumulates, (ii) conclude that lunar $\delta^{44}Ca$ is indistinguishable from that of bulk Earth, and (iii) establish a relative chronology for lunar differentiation events [5-7]. Open questions remain, however, regarding the extents of $\delta^{44}Ca$ variability, the significance of $\delta^{44}Ca$ variations between lunar rock types, and the parameters relating $\delta^{44}Ca$ of samples back to those of the LMO and the Earth.

We present new Ca isotope and major/trace element data (alongside full-slab micro-XRF element maps) on a suite of ten lunar meteorites that include anorthosites, troctolites, basalts, norites, and breccias. New and existing $\delta^{44}Ca$ data will be discussed in the context of lunar magma ocean cumulates, magmatic differentiation, and lunar evolution models to better understand the timing and significance of Ca isotope variability between lunar lithologies and their mantle sources.

[1] Wiechert et al. (2001) *Science*; [2] Fischer *et al.* (2024) *PNAS*; [3] Paniello et al. (2012) *Nature*; [4] Millet *et al.* (2016) *EPSL*; [5] Fu et al. (2023) *Commun Earth Environ*; [6] Klaver *et al.* (2021) *EPSL*; [7] Wu et al. (2020) *GCA*