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Ce-Nd-Sr Isotope Systematics of Lunar Samples and Origin of Ce Anomalies on the Moon

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Cerium is one of the rare earth elements, but sometimes, it's behaviour is different and is known as Ce anomaly. Distinct physical or chemical property of Ce^{4+} from other trivalent REE ions, i.e. high volatility of Ce^{4+} or low solubility of CeO_2 in aqueous environment, causes the positive or negative Ce anomalies. The difference in volatility is closely related to the condensation process from the solar nebula, and some chondrites are known to exhibit distinct Ce anomalies. Masuda et al. (1972) pointed out the existence of positive Ce anomalies in some lunar highland samples. The positive Ce anomalies are also reported in lunar meteorites (e.g. Takahashi and Masuda, 1994; Kagi and Takahashi, 1998). ^{138}La is one of the long-lived radioactive nuclides which decays to ^{138}Ce by β^- decay. Therefore, this decay scheme is useful to understand the origin of these Ce anomalies. Here, La-Ce, Sm-Nd and Rb-Sr isotope systematics of lunar samples were investigated with a newly developed Ce isotope measurement technique and the decay constant (Tanimizu, 2000).

Investigated samples were as follows: high-Ti basalt (10017, 75015), KREEPy basalt (14310, 65015), high Al basalt (14321). ^{138}Ce/^{142}Ce, ^{143}Nd/^{144}Nd and ^{87}Sr/^{86}Sr isotope ratios were measured with a TIMS, VG Sector 54-30. The concentrations of LREE (La, Ce, Nd, Sm), Rb and Sr were determined by the conventional isotope dilution mass spectrometry. Rb-Sr mineral ages were also determined for 10017, 14310, 14321 and 65015.

The Rb-Sr ages were almost consistent with previous studies (3.57 ± 0.03 Ga for 10017, 3.84 ± 0.11 Ga for 14310, 4.22 ± 0.23 Ga with an initial ^{87}Sr/^{86}Sr ratio of 0.6996 ± 0.0008 for 14321 and 3.90 ± 0.06 Ga for 65015); λ_{Rb} = 1.42x10^{-11}/yr). Among the investigated five samples, the LREE enriched and high REE abundance samples (like the REE pattern of KREEP), 14310, 14321, 65015 have slight positive Ce anomalies. The present εCe and εNd values were calculated and plotted on the εCe-εNd diagram. The εCe-εNd diagram is useful to trace the evolution of rocks through LREE. A schematic figure (Fig. 1) explains the relation between the LREE patterns of rocks which derived from CHUR and the directions of their isotopic growth through time on the εCe-εNd diagram. Lunar sample 10017 and 75015 must be depleted in LREE and the other samples must have totally LREE enriched patterns (Masuda et al., 1972) more than 3 Ga because of the well defined Rb-Sr ages. Therefore, the former two samples are expected to be plotted in the second quadrant and the latter plotted in the fourth. The latter samples, however, are in fact plotted in the third quadrant. This is due to the positive Ce anomalies. If the Ce anomalies were caused by some present or recent event, it also should be plotted in the forth quadrant. We can conclude that the Ce anomalies of the three samples are certainly recognized, and they are not the result of recent metamorphic events. Their εCe and εNd values at their Rb-Sr ages were still plotted on the third quadrant. The possible origin of the Ce anomalies will be discussed with data of lunar soil samples.

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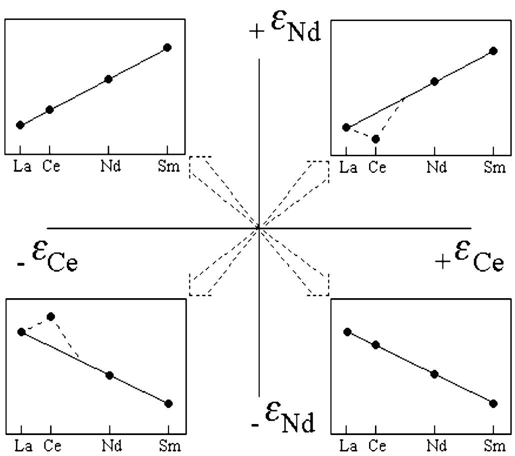

Figure 1: A schematic figure which explains the relation between the LREE pattern and the direction of their isotopic growth with time on the εCe-εNd diagram.

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