Systematic REE Isotopic Analyses for Cosmochemistry

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The data of a series of the elemental abundances of rare earth elements (REE) in planetary materials (REE abundance pattern) have been widely used to understand the geochemical evolution processes of the materials since the pioneering work (Masuda and Matsui, 1966), because REE have several similarities of physicochemical properties due to their electron configurations of the atomic structures. Furthermore, isotopic compositions of some REE are variable, because they include radiogenic components derived from the decay systems of ^{138}La-^{138}Ce ($t_{1/2}$=1.05×10^{11} yrs), ^{146}Sm-^{142}Nd ($t_{1/2}$=6.8×10^{7} yrs), and ^{147}Sm-^{143}Nd ($t_{1/2}$=1.07×10^{11} yrs) and nucleogenic components in Sm, Gd, Dy, Er and Yb isotopes produced by neutron capture and spallation reactions caused by cosmic-ray irradiation. Here in this talk, I would like to introduce my recent work on systematic REE isotopic analyses of meteorites and lunar samples.

Neodymium has two radiogenic isotopes, ^{142}Nd and ^{143}Nd, that are decayed from ^{146}Sm and ^{147}Sm, respectively. ^{147}Sm-^{143}Nd chronometry has been traditionaly applied for the determination of the formation ages of planetary materials. On the other hand, ^{146}Sm-^{142}Nd chronometry, consisting of a presently extinct radionuclide ^{146}Sm with a half life of 68 Ma, has been recently used to better understand the early differentiation processes of the solar planets (Boyet and Carlson, 2005; Boyet et al., 2010; Bouvier et al., 2015). In this study, I also performed high-precision isotopic analyses of Nd in eucrites for the development to consider the early evolutional processes of the solar planets from a chronological point of view, and to confirm of isotopic homogeneity of eucritic materials after the early differentiation events. The data set of ^{147}Sm/^{144}Nd-^{143}Nd/^{144}Nd from eight eucrites lie on a single isochron of ^{147}Sm-^{143}Nd isotopic systematic with a slope of 4.56 Ga. On the other hand, their isotopic deviations of ^{142}Nd show slightly negative to zero values relative to terrestrial standard materials (ε^{142}Nd=-0.2 to 0), and no positive values which are observed in typical non-cumulate eucrites having high Sm/Nd elemental ratios. These results are consistent with previous studies (Boyet and Carlson, 2005; Boyet et al., 2010).

Cerium has Ce has four stable isotopes with mass number 136, 138, 140 and 142. Of the four isotopes, ^{138}Ce isotope includes radiogenic component decayed from ^{138}La with a half-life of 1.05×10^{11} years. The Ce isotopic studies once developed for the application of ^{138}La-^{138}Ce chronometry (Tanaka and Masuda, 1982). ^{138}La-^{138}Ce decay system can be one of chronometers for understanding the formation and the evolution processes of solar planetary materials. Since ^{138}Ce isotopic excesses of eucrites correlate with their La/Ce elemental ratios, these excesses are identified to be the decay product from ^{138}La. However, the La/Ce elemental ratios of eucrites and diogenites show in a narrow range (^{138}La/^{142}Ce= 0.00317 to 0.00322), and it is difficult to make their whole rock isochron only from our data. In this study, our data are compared with previous studies to confirm the consistency between our results and previous results (Makishima and Masuda, 1992)

Besides the chronological studies based on the decay systems of La-Ce and Sm-Nd, Sm and Gd isotopic measurements were also taken in the same samples to understand the cosmic-ray exposure histories of individual samples, because significant isotopic shifts of ^{149}Sm-^{150}Sm and ^{157}Gd-^{158}Gd are expected from the neutron capture reactions by ^{149}Sm(n,γ)^{150}Sm and ^{157}Gd(n,γ)^{158}Gd, respectively, in association with cosmic-ray irradiation. In particular, ^{149}Sm and ^{157}Gd are very sensitive to thermal neutrons. Since ^{149}Sm, ^{155}Gd and ^{157}Gd have very large thermal neutron capture cross sections, their isotopic variations induced from the neutron capture reactions of ^{149}Sm(n,γ)^{150}Sm, ^{155}Gd(n,γ)^{156}Gd and ^{157}Gd(n,γ)^{158}Gd can be useful indicators to understand thermalized degree of the arising neutrons (Russ et al., 1972; Hidaka et al., 2000). On the other hand, ^{161}Dy, ^{164}Dy, ^{167}Er and ^{168}Yb are sensitively react with epithermal neutrons, because they have significant resonance integrals in the energy range above thermal energies (E>0.1 eV). Recent isotopic studies suggest that the neutron energy spectrum on the lunar surface is richer in high-energy region than that proposed by previous study (Albalat et al., 2012; Krujier et al., 2013). Isotopic analyses of Sm, Gd, Dy, Er and Yb in a series of lunar surface materials provide a useful informaation to reconstruct a neutron energy spectrum on the lunar surface.

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