Nucleosynthetic isotope anomalies of trans-iron elements in meteorites: implication for the origin of terrestrial planets

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The chemical composition of the Earth has been a matter of debate for more than several decades. Classical models assumed that the bulk Earth had CI chondrite-like relative abundances for refractory elements. This view has been challenged by the discovery of nucleosynthetic isotope anomalies in bulk aliquots of meteorites; a series of studies on high precision isotope analysis of meteorites concluded that carbonaceous chondrites (CCs) and ordinary chondrites (OCs) have stable isotope compositions resolvable from those of the Earth for a variety of lithophile and siderophile elements (e.g., Ti, Cr, Mo, Ru) [1-3]. By contrast, enstatite chondrites (ECs) have stable isotopic compositions similar to those of the Earth for the same elements. Such observations suggest that a large fraction of the building blocks of the Earth is composed of enstatite chondrite-like materials rather than the other chondrites including CI [4].

Our recent high precision isotope analyses on chondritic and non-chondritic (NC) meteorites for some trans-iron elements (e.g., Sr, Mo, Nd) support this interpretation [5-7]. In the most cases, the extent of isotope anomaly is in the order of Earth ˜ NC ˜ EC < OC < CC, which generally corresponds to the current location of meteorite parent bodies in the asteroid belt as a function of heliocentric distance [8]. This implies that stable isotopes of these elements were nearly homogeneously distributed in the feeding zone of the Earth where parent bodies of ECs and some NCs have formed, whereas distinct isotopic compositions for the same elements are observed in the outer asteroid belt where parent bodies of CCs are located. Unlike this observation, however, some refractory heavy elements (Hf, W, and Os) have uniform stable isotope compositions across all classes of meteorites [9-11], indicating that stable isotopes of these elements were homogeneously distributed from the Earth (1 AU) toward the outer part of the asteroid belt (˜ 5 AU).

The origin of heterogeneous/homogeneous distribution of stable isotopes for the above-mentioned elements within the inner solar system (< ˜5 AU) is poorly constrained. Two contrasting models have been proposed so far to account for the observed isotope variabilities in meteorites. The first model advocates that late injection of a nearby supernova sprinkled isotopically anomalous grains into the protoplanetary disk, followed by aerodynamic sorting of grains in different sizes that resulted in planetary scale isotope heterogeneities [12]. However, recent theoretical studies argue that ccSNe generate only low-mass r-nuclides (A< 130), which contradicts the observed isotope anomalies in Ba, Sm, and Nd. Alternatively, the second model postulates that nebular thermal processing caused selective volatilization of isotopically anomalous components from presolar grains, associated with physical separation of gas and remaining solid [1,13-14]. In this case, isotope anomalies can be observed for elements with intermediate 50% condensation temperature (˜1000 K < $T_{50\%}$ < ˜1600 K), because ultra-refractory and moderately volatile elements are preferentially distributed into the solid and gas phases during the heating event, respectively. Therefore, isotope anomalies in meteorites would be useful for tracking the thermal history of dust grains in the solar nebula, which ultimately provide important clues for understanding the origin of terrestrial planets.

References: [1] Trinquier, A. et al. (2009) *Science* **324**, 374. [2] Burkhardt, C. et al. (2011) *EPSL* **312**, 390.

[3] Fischer-Gödde, M. et al. (2015) *GCA* **168**, 151. [4] Dauphas, N., et al. (2014) *EPSL* **407**, 96. [5] Yokoyama, T. et al. (2015) *EPSL* **416**, 46. [6] Nagai, Y. and Yokoyama, T. (2016) *Goldschmidt conf.* [7] Fukai, R. and Yokoyama, T. (2016) *Goldschmidt conf.* [8] DeMeo, F.E. and Carry, B. (2014). *Nature* **505**, 629. [9] Sprung, P. et al. (2010). *EPSL* **295**, 1. [10] Kleine, T.et al. (2004). *GCA* **68**, 2935. [11] Yokoyama, T. et al. (2010) *EPSL* **291**, 48. [12] Dauphas, N. et al. (2010) *ApJ* **720**, 1577. [13] Burkhardt, C. et al. (2012) *EPSL* **357-358**, 298. [14] Yokoyama, T. and Walker, R.J. (2016) *RiMG* **81**, 107.

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