DOES THE EARTH HAVE A SUPERCHONDRITIC Sm/Nd Ratio? S. Huang[1], S. B. Jacobsen[1] and S. Mukhopadhyay[1], [1]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St. Cambridge, MA 02138 (huang17@fas.harvard.edu)

Introduction: In most models for the Earth's composition, it is assumed that the refractory elements are present in chondritic proportions relative to each other [e.g., 1]. This assumption is now challenged by recent ε^{142}Nd studies [2-4]. Specifically, Boyet and Carlson [2] found that the ε^{142}Nd of the Earth is ~20 ppm higher than that of the ordinary chondrites. There are three possible interpretations [5]: (**I**) The Bulk Silicate Earth (BSE) has a chondritic Sm/Nd ratio, and the high ε^{142}Nd of terrestrial samples are balanced by an inaccessible enriched reservoir, either hidden at the base of the mantle [2, 4] or lost to the space by impact erosion [6]. That is, the accessible portion of the Earth has a superchondritic Sm/Nd ratio; (**II**) The ε^{142}Nd difference implies that BSE might have a Sm/Nd ratio 6% higher than chondrites, i.e., the BSE is superchondritic [3, 7-8]. This has led to the proposal that the present-day ε^{143}Nd of BSE is +7, similar to that of some deep mantle plumes, rather than chondrites [8-9]; (**III**) The ~20 ppm ε^{142}Nd difference between the Earth and ordinary chondrites could be of a nucleosynthetic origin [10, 11]. Here we evaluate whether the Earth, or the accessible portion of the Earth under the "hidden reservoir" hypothesis [2], has a chondritic Sm/Nd ratio.

Discussion: *Homogeneity of the Chondritic Reservoir.* Chondrites have nearly the same Sm/Nd, with a very narrow range (±2%) [2, 12]. In contrast, several studies have revealed ~50 ppm ε^{142}Nd variation in chondrites, and correlations of ε^{142}Nd with ε^{144}Sm (a p-process only isotope), ε^{148}Nd (a r-process dominated isotope) and ε^{135}Ba (Fig. 1). Importantly, the Earth plots on the chondrite trends, overlapping with enstatite chondrites. In addition to the ^{142}Nd similarity, Earth and enstatite chondrites have the same isotopic compositions of O, Ca, Ti and Cr, elements that show substantial isotopic variations among different chondrite groups [13-14]. The ~50 ppm ε^{142}Nd variation in chondrites is most likely of a nucleosynthetic origin [10-11], resulting from small variations in the distribution of different nucleosynthetic components in the solar nebula. To summarize, there are several tens of ppm level nucleosynthetic anomalies in Ba, Nd and Sm isotopes in chondrites, implying that the chondritic reservoir is not homogeneous at this level. *It is inappropriate to claim that Earth and the chondritic reservoir have ~20 ppm ε^{142}Nd difference.*
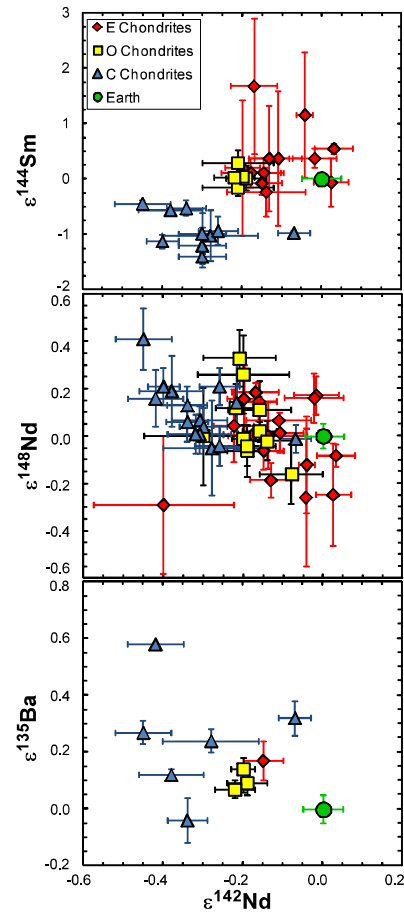

Fig. 1 Sm, Nd and Ba isotopic anomalies in chondrites.

Formation of a superchondritic nebular reservoir. The ~20 ppm ε^{142}Nd enrichment in terrestrial samples was interpreted to reflect a superchondritic Earth, with a Sm/Nd ratio ~6% higher than the chondritic value [3, 7-9, 15]. Specifically, Allègre et al. [15] suggested that a superchondritic nebular reservoir could form from volatility fractionation because Sm is more volatile than Nd under reducing environment. The most pronounced signature of volatility fractionation of rare earth elements (REE) occurred in natural samples is the Group II REE pattern, characterized by a positive Tm anomaly and nearly flat LREE pattern [e.g., 16]. However, compared to CI chondrites, the Earth does not have a measurable Tm anomaly [e.g., 1].

Volatility fractioanation of REE is also coupled with fractionation of Ca isotopes. During a $CaTiO_3$ evaporation experiment, Sm/Nd increased by 12% [17] and $^{44}Ca/^{40}Ca$ increased by 104‰ [18] in an evapo-

rated residue that had lost 83.4% of its initial mass. So a nebular reservoir, where volatility fractionation produced a Sm/Nd ratio ~6% higher than the chondritic value, would be expected to have $^{44}Ca/^{40}Ca$ ratio several tens of per mil higher than the chondritic value. However, the $^{44}Ca/^{40}Ca$ variation of all chondrites and Earth is less than 1‰ [19-20].

In summary, *it is unlikely that the Earth attained a superchondritic Sm/Nd ratio via nebular REE fractionation.*

Sm/Nd ratio of the Earth: Constraints from the long-lived ^{147}Sm-^{144}Nd system. The long-lived ^{147}Sm-^{143}Nd system is not very sensitive to small nucleosynthetic anomalies because of much larger ^{143}Nd variation due to radioactive decay (many ε units, compared to ppm level variations in ^{142}Nd). We use the ^{147}Sm-^{143}Nd isotopic systematics of MORBs and continental crust (CC) to test whether the BSE could have a superchondritic $^{147}Sm/^{144}Nd$ with a present-day $ε_{Nd}$ of +7, or higher.

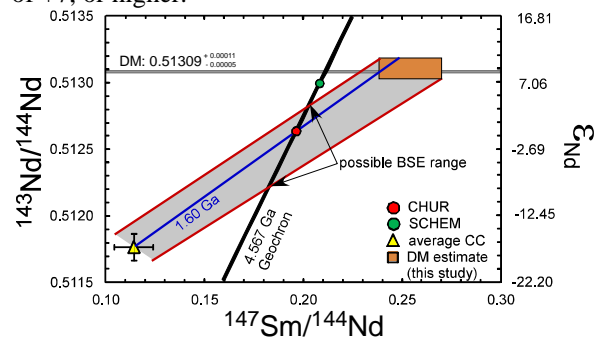Fig. 2 $^{143}Nd/^{144}Nd$ vs $^{147}Sm/^{144}Nd$ systematics of major reservoirs in the Earth. SCHEM (Superchondritic Earth Model) and CHUR are from [7, 12], average CC is from [21], and DM estimates are from Fig. 3.

Since CC formation is the only major event depleting the mantle, the depleted mantle (DM), which is the source of MORBs, is complementary to the CC. In a $^{143}Nd/^{144}Nd$ vs. $^{147}Sm/^{144}Nd$ plot, the BSE is constrained at the intersection of the CC-DM tie line with the 4.567 Ga Geochron (Fig. 2). We estimated the DM composition using MORB data downloaded from PetDB database. MORB $^{143}Nd/^{144}Nd$ variation reflects the DM value, but $^{147}Sm/^{144}Nd$ variation in MORB reflects both source heterogeneiry and partial melting process. We considered two end-member scenarios, and found that all DM estimates are higher than that required by SCHEM, but match that required by a chondritic Earth model (Fig. 3). Therefore, the result that $^{147}Sm/^{144}Nd$ of DM inferred from MORB data is higher than that required by SCHEM is robust, and not dependent on model details.

Conclusion: The ~50 ppm $ε^{142}Nd$ variation in Earth and chondrites results from variations in the mixing proportions of different nucleosynthetic components. It is unlikely to form a nebular reservoir with a superchondritic Sm/Nd ratio, from which the Earth accreted. The ^{147}Sm-^{143}Nd isotope systematics of CC and DM imply that the BSE has a near-chondritic $^{147}Sm/^{144}Nd$ ratio.

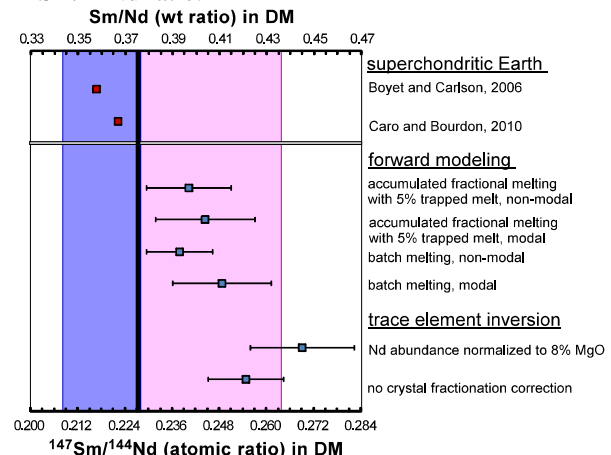Fig. 3 $^{147}Sm/^{144}Nd$ of DM estimated by various approaches. The pale blue area represents the possible range for $^{147}Sm/^{144}Nd$ of DM under SCHEM, and the pink area represents the possible range for $^{147}Sm/^{144}Nd$ of DM under a chondritic Earth model.

References:
[1] McDonough W. F. & Sun S. S. (1995) CG 120, 223-253; [2] Boyet M. & Carlson R. W. (2005) Science 214, 427-442; [3] Caro et al. (2008) Nature 452, 336-339; [4] Gannoun A. et al. (2011) PNAS 108, 7693-7697; [5] Jacobsen S. B. et al. (2008) PTRS 366, 4129-4162; [6] Campbell I. H. & O'Neill H. St C. (2012) Nature 483, 553-558; [7] Caro G. & Bourdon B. (2010) GCA 74, 3333-3349; [8] Jackson M. G. et al. (2010) Nature 466, 853-856; [9] Jackson M. G. & Carlson R. W. (2011) Nature 476, 316-319; [10] Ranen M. C. & Jacobsen S. B. (2006) Science 314, 809-812; [11] Andreasen R. & Sharman M. (2006) Science 314, 806-809; [12] Jacobsen S. B. & Wasserburg G. J. (1984) EPSL 67, 137-150; [13] Trinquier A. et al. (2009) Science 324, 374-376; [14] Zhang J. et al. (2012) Nature Geosci 5, 251-255; [15] Allègre C. J. et al. (2008) EOS 89(53) V11E-01; [16] MacPherson G. J. (2004) Treaties on Geochemistry 1, 201-246; [17] Davis A. M. et al. (1995) LPS 26, 317-318; [18] Zhang J. et al. (2012) LPS 43, #2132; [19] Simon J. I. & DePaolo D. J. (2010) EPSL 289, 457-466; [20] Huang S. & Jacobsen S. B. (2012) LPS 43, #1334; [21] Goldstein S. J. & Jacobsen S. B. (1988) EPSL 87, 249-265.