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Superchondritic Mantle Is Partially Depleted Mantle; and Quantification of the Spidergram Sequence

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1 Introduction

Prior to 2005, the composition of the bulk silicate Earth was conventionally assumed to be "chondritic", meaning that the refractory and lithophile elements (Al, Ca, Sc, Ti, Sr, Y, Zr, Nb, Ba, REE, Hf, Ta, Th, and U) are present in the BSE in the same ratios as in chondrites. This assumption has been used to determine and compile the composition of BSE [e.g., 1-3]. Boyet and Carlson [4-5] discovered that terrestrial rocks have higher $^{142}Nd/^{144}Nd$ compared to chondrites by 0.2±0.1 epsilon units. Because ^{142}Nd is from the decay of the extinct nuclide ^{146}Sm (half-life 106 million years), the result suggests either the Earth accreted with higher Sm/Nd ratio (superchondritic Earth), or measured samples all come from the part of the Earth that has been depleted before ^{146}Sm has decayed away.

Since the work of Boyet and Carlson [4-5], the paradigm of "chondritic" mantle has been shifting to a superchondritic mantle [6-8]. Assuming a superchondritic mantle would mean that the bulk silicate Earth composition obtained in previous studies and applied to make many inferences about mantle depletion and igneous rock petrogenesis have to be assessed, and there is no easy way to obtain the refractory lithophile element concentrations in BSE unless it can be specified how the superchondritic composition was derived and how the concentrations of the refractory lithophile elements are related.

In this work, I examine whether the superchondritic mantle composition can be related to normal mantle depletion.

2 Methods

The approach is to compare the best estimates of the superchondritic mantle composition in Sm/Nd (from ^{147}Sm-^{143}Nd systematics), Lu/Hf (from Hf-Nd isotopic mantle array and ^{176}Lu-^{176}Hf systematics), and Rb/Sr (from Sr-Nd isotopic mantle array and ^{87}Rb-^{87}Sr systematics) [7] with the expected depletion by mantle partial melting. The U-Th-Pb system does not provide much constraint because Pb isotopic ratio spans a large range at the superchondritic $^{143}Nd/^{144}Nd$ ratio. The expected depletion of the mantle residue or the elemental abundance in mantle-derived melts are often graphically examined using the so-called spidergram, in which elemental abundances relative to chondrites or BSE are plotted in a sequence in which the elements are arranged from the most incompatible elements in the left to the least incompatible elements in the right. The spidergram is the expanded version of the REE plot (La is the most incompatible and Lu is the least incompatible). Although the sequence is fairly well known and widely used, it has not been quantified on the extent of fractionation from one element to the next. For example, in one version of the spidergram ([9] by adding the missing REE elements), the elemental sequences are: Cs ≈ Rb ≈ Ba ≈ W > Th ≈ Nb ≈ Ta ≈ K > La > Ce ≈ Pb > Pr ≈ Mo ≈ Sr > P ≈ Nd > F ≈ (Pm) > Zr ≈ Hf ≈ Sm > Eu ≈ Sn ≈ Sb ≈ Ti > Gd > Tb > Dy ≈ Li > Ho ≈ Y > Er > Tb > Yb > Lu. According to this qualitative sequence, Nd is more incompatible than Sm by 2 units, Hf is more incompatible than Lu by 9 units, and Rb is more incompatible than Sr by 4 units. However, the elements are not necessarily equally spaced in terms of incompatibility. Hence, a quantitative way to arrange the incompatible elements is necessary.

In order to quantify roughly the degree of incompatibility, we compare the composition of BSE [2] and that of depleted MORB mantle (DMM) [10], because the latter is often pinned to the former. For each incompatible element, the concentration in DMM is divided by that in BSE, and then taken the logarithm. The quantified relative incompatibility of the elements is listed below (zero means no differentiation; a more negative

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value means more incompatible):

Cs: -2.77
Rb: -1.92
Th: -1.76
Ba: -1.70
U: -1.46
K: -1.39
La: -1.02
Ce: -0.77
Sr: -0.71
Pr: -0.66
Nd: -0.56
Ti: -0.41
Sm: -0.41
Eu: -0.36
Hf: -0.35
Gd: -0.32
Tb: -0.28
Dy: -0.24
Ho: -0.20
Tm: -0.125
Yb: -0.095
Lu: -0.069

From the quantification, one can see that the incompatibility varies a lot from La to Ce (0.25 units), but not much from Yb to Lu (0.026 units). The very small degree of depletion for Yb and Lu does seem problematic and may indicate possible systematic error in the treatment by [2] or [10]. Nonetheless, we will use the results to quantify the incompatibility sequence. For the ^{147}Sm-^{143}Nd system, Sm is less incompatible by 0.15 units than Nd. For the ^{176}Lu-^{176}Hf system, Lu is less incompatible by 0.28 units than Hf. For the ^{87}Rb-^{87}Sr system, Rb is more incompatible than Sr by 1.21 units.

3 Results

With this rough quantification of the incompatibility sequence, the inferred enrichment of Sm/Nd and Lu/Hf ratios, and depletion of Rb/Sr ratio in the superchondritic mantle can be plotted against the enrichment or depletion in MORB mantle (Fig. 1). The plot shows excellent correlation between the "superchondritic" mantle and MORB mantle. Roughly, the "superchondritic mantle is depleted one third of the way compared to MORB mantle. Note that if we instead use the qualitative incompatibility sequence, the difference between Lu and Hf would be largest, which would not generate a good trend. Hence, the quantification does help to reveal the relation shown in Fig. 1.

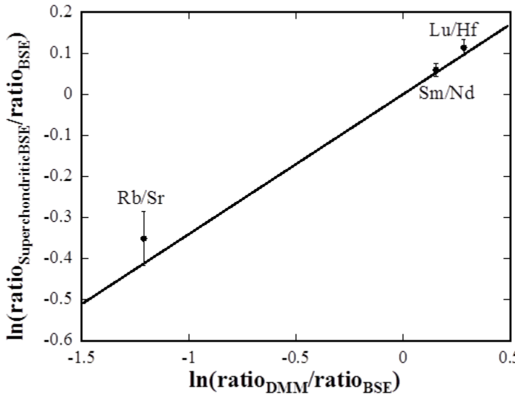

Fig. 1. Depletion factor for the "superchondritic" mantle compared to the depletion factor for MORB mantle (DMM).

4 Discussion

The so-called superchondritic mantle is consistent with a partially depleted mantle in terms of Sm/Nd, Lu/Hf, and Rb/Sr ratios. The antiquity of the superchondritic mantle based on ^{142}Nd/^{144}Nd isotopic ratios demonstrates the antiquity of mantle depletion. The similarity with Earth mantle depletion suggests that the process that generated the high ^{142}Nd/^{144}Nd ratio (by about 0.2 epsilon units) occurred in Earth, rather than in planetesimals or in the solar nebula. For example, the high ^{142}Nd/^{144}Nd ratio in most terrestrial samples may be modeled either by continuous depletion of the mantle or by a two-stage mantle depletion. There is still a need to find Hadean crustal reservoirs (>4.4 Ga) with low ^{142}Nd/^{144}Nd ratio. Such crustal materials might be in the lower crust, or might be recycled, or might be stripped off Earth by giant impacts.

References

Hart and Zindler, 1986, *Chem. Geol.*, 57, 247-267.
McDonough and Sun, 1995, *Chem. Geol.*, 120, 223-253.
Palme and O'Neill, 2004, *Treatise of Geochem.*, 2, 1-38.
Boyet and Carlson, 2005, Science, 209, 576-581.
Boyet and Carlson, 2006, *EPSL*, 250, 254-268.
Caro et al., 2008, *Nature*, 452, 336-339.
Caro and Bourdon, 2010, *GCA*, 74, 3333-3349.
Campbell and O'Neill, 2012, Nature, 483, 553-558.
Sun and McDonough, 1989, *Geol. Soc. London Special Publ.*, 42, 313-345.
Salters and Stracke, 2004, *Geochem. Geophys. Geosys.*, 5, Q05004.