COLLISIONAL EROSION AND BULK SILICATE EARTH REFRACTORY LITHOPHILE ELEMENT BUDGETS. R. M. G. Armytage and A. D. Brandon, University of Houston, Department of Earth and Atmospheric Sciences, 312 Science and Research 1, Houston, TX, 77204, USA. (rarmytage@uh.edu)

Introduction: A standard assumption of compositional models of bulk silicate Earth (BSE) is that the refractory lithophile elements (RLE) are present in chondritic relative proportions [e.g. 1-2]. High precision measurements of ^{142}Nd/^{144}Nd challenge this assumption. There is an offset of approximately 20ppm in ^{142}Nd/^{144}Nd between average chondrites and the Earth's modern convecting mantle [3], where ^{142}Nd is the daughter isotope of ^{146}Sm with $T_{1/2}$ of 103 Myr (λ^{146}=6.730×10^{-3} Myr^{-1}) [4], or 68 Myr (λ^{146}=1.019×10^{-2} Myr^{-1}) [5]. The three most plausible interpretations of the data are (i) nucleosynthetic variation of initial ^{146}Sm/^{144}Sm or ^{142}Nd/^{144}Nd in the solar nebula [e.g. 6-7]; (ii) early differentiation of BSE with a chondritic Sm/Nd while ^{146}Sm was still live, with only the depleted reservoir sampled as yet [3]; (iii) BSE has a superchondritic Sm/Nd ratio [8-11].

The current precision and sample size of chondritic data cannot currently determine the validity of (i). The existence of a BSE early enriched reservoir (required by (ii)) that complements the modern accessible mantle's ^{142}Nd/^{144}Nd is hard to test for directly. The preferential removal of early-formed planetesimal crusts via collisional erosion, increasing the Sm/Nd of the growing planet, is a mechanism that has been proposed to generate a superchondritic BSE [12]. The feasibility of this, and hence (iii), can be assessed, using the Moon to constrain the composition of the proto-Earth.

For a number of elements such as Ti [13], W [14], Cr [15] and Si [16], the isotopic composition of the Earth and Moon are identical and unique among solar system bodies. The simplest interpretation is that the Moon formed from mantle material of the proto-Earth, rather than the impactor as required in the standard smoothed particle hydrodynamic (SPH) models [e.g. 17]. Newer models of the Giant Impact [18-19] generate scenarios that are consistent with the isotopic constraints, allowing for the use of lunar data to constrain the composition of the proto-Earth.

In this study we build on previously presented work [20], and incorporate new lunar basalt ^{142}Nd data [21] to assess the viability of collisional erosion in generating a superchondritic BSE Sm/Nd ratio and the implications for the RLE budgets of the BSE.

Method: The simple multi-stage coupled ε^{143}Nd-μ^{142}Nd source model used in this study has been adapted from earlier work [e.g. 22, 23 R, V, me]. The new lunar Nd isotope basalt data from [21] fall, along with the previous data [24-25], on a straight line when corrected for neutron fluence and crystallization age. In coupled ε^{143}Nd-μ^{142}Nd space, such a straight line can be interpreted as an isochron, and its intersection with a multi-stage Nd isotope evolution model can constrain bulk ^{147}Sm/^{144}Nd ratio of the Moon and hence BSE. The slope and intercept of the isochron are used to find the unique ^{147}Sm/^{144}Nd for a given time of fractionation, t_1. The range in possible ^{147}Sm/^{144}Nd ratios can be further constrained assuming that the bulk composition of the Moon is identical to the BSE, restricting μ^{142}Nd to 0±3. The derived maximum and minimum Sm/Nd ratios can be used to constrain the collisional erosion parameters F_{pc} (mass fraction of proto-crust), f_{cr} (mass fraction of proto-crust eroded), and mass fraction of melt residue eroded, f_{res}, based on the simple mass balance of [12]. A range of possible BSE RLE budgets from collisional erosion can be calculated.

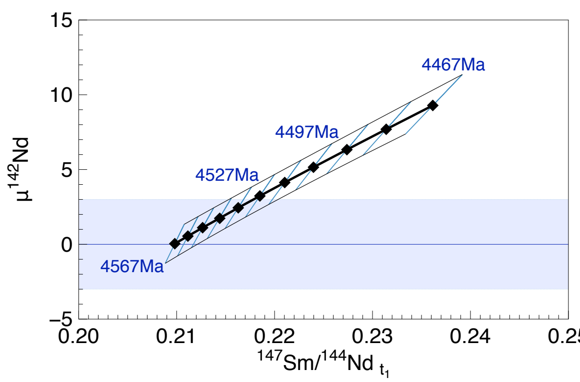

Fig. 1 μ^{142}Nd vs ^{147}Sm/^{144}Nd of the source (thick black line). This is calculated using $t_{1/2}$ =103 Myr for ^{146}Sm. The black diamonds mark the ages of fractionation (t_1) at 10 Ma intervals. The thinner black lines are the maximum and minimum ^{147}Sm/^{144}Nd based on 95% confidence intervals from the linear regression through the lunar basalt data. The blue curves are lines of equal t_1. The lilac band is the BSE μ^{142}Nd=0 at the current precision possible, which is ±3ppm

Results and Discussion: Figure 1 shows the range in ^{147}Sm/^{144}Nd$_{t1}$ versus μ^{142}Nd contoured for t_1. With the assumption of bulk silicate Earth μ^{142}Nd=0±3ppm, for λ^{146}=1.019×10^{-2} Myr^{-1}, ^{147}Sm/^{144}Nd$_{t1}$=0.2088-0.2198, corresponding to t_1= 0-40Myr$_{ONC}$ (ONC = onset of nebular condensation). For the longer half-life (λ^{146}=6.730×10^{-3} Myr^{-1}), ^{147}Sm/^{144}Nd$_{t1}$=0.2088-0.2205, and t_1=0-64Myr$_{ONC}$. Therefore, this collisional erosion process has to have occurred during the early accretional history of the Earth, and if it did happen in the Giant Impact as proposed previously [20], the Moon must have a young formation age (i.e. <64Myr$_{ONC}$).

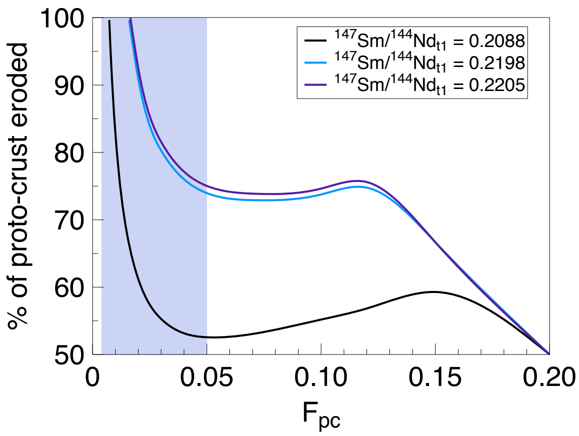

Fig. 2 Constraints from coupled Nd source models on proto-crust formation in a collisional erosion scenario. Percentage of proto-crust eroded is calculated from f_{cr}/F_{pc} for a given F_{pc}. Black line is the minimum Sm/Nd (i.e. ^{147}Sm/^{144}Nd at t_1 = 4567Ma), blue line is maximum Sm/Nd for ^{146}Sm $t_{1/2}$ = 68 Myr, purple line is maximum Sm/Nd for ^{146}Sm $t_{1/2}$ = 103 Myr. The lilac band is a range in planetary crust mass fractions from Earth (0.4%) to Moon (5%).

These limits on the Sm/Nd ratio resulting from an early fractionation event can be applied to constrain the collisional erosion parameters. Figure 2 plots the percentage of proto-crust that must be eroded as the function of the initial mass fraction of proto-crust formed (F_{pc}). The two main conclusions are that a minimum of 50% of the proto-crust (at likely F_{pc}'s) must be eroded based on the Nd isotopic constraints, and that F_{pc} must be greater than at least the crust mass fraction of the Earth (0.004), for the modeled collisional erosion scenario to be viable.

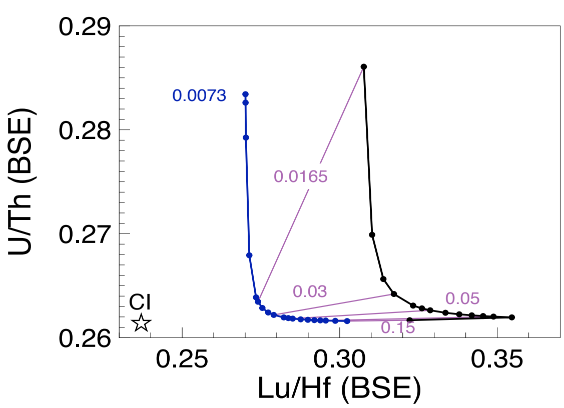

Fig. 3 BSE U/Th vs Lu/Hf resulting from collisional erosion based on constraints from ^{142}Nd isotopic systematics. The blue line corresponds to the minimum Sm/Nd ratio (t_1=4567Ma) and the black line is the maximum Sm/Nd (t_1=4503 Ma). The solid circles represent different F_{pc} fractions. The purple traces are lines of equal F_{pc}. The minimum possible fraction of proto-crust (F_{pc}) is 0.0073, labeled in blue. The star is the CI chondrite ratio from [2]

Figure 3 shows the RLE ratios Lu/Hf and U/Th for a range of F_{pc}'s based on the maximum and minimum Sm/Nd discussed above. The U/Th ratio is always within 10% of the chondritic ratio, whereas the Lu/Hf can deviate from chondritic by up to 50%. This variation is due to the difference in bulk partition coefficients for Lu and Hf (D_{Lu}=0.12, D_{Hf}=0.35 [26]) in contrast to the similar behavior during mantle melting of U and Th (D_U=0.0011, D_{Th}=0.001 [26]). Both of these ratios in this modeled collisional erosion scenario are well below those proposed for DMM (depleted MORB mantle) by [26] of Lu/Hf = 0.369 and U/Th = 0.405.

Any modification of the RLE budget of the BSE will have implications for heat and ^{4}He fluxes from the mantle due to radiogenic decay from U and Th. This provides another potential avenue of constraints that can be applied to refine this collisional erosional model based on ^{142}Nd systematics. The effect of collisional erosion on more volatile lithophile elements such as K, which also affects the heat budget of the Earth and noble gas budgets, also needs to be considered.

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