A NON-CHONDRITIC EARTH AS THE RESULT OF COLLISIONAL EROSION IN THE GIANT IMPACT: CONSTRAINTS FROM EXISTING LUNAR ^{142}Nd DATA. R. M. G. Armytage and A. Brandon, University of Houston, Department of Earth and Atmospheric Sciences, 312 Science and Research 1, Houston, TX, 77204, USA. (rarmytage@uh.edu)

Introduction: A growing body of evidence suggests that the isotopic composition of the Earth and Moon are identical and unique among solar system bodies. [1-5]. For many of the isotope systems (e.g. Ti, W, Cr) it is unlikely that their signatures have been homogenized across a post-Giant Impact disk, as has been proposed to explain the oxygen isotope anomalies [6]. It is being considered more and more likely that the Moon formed from material from the proto-Earth, rather that the impactor Theia. Newer models of the Giant Impact [7-8] have sought to address these isotopic constraints, where previous smoothed particle hydrodynamic (SPH) models required the majority of the Moon forming material to derive from Theia [e.g. 9]. If composed of material from the proto-Earth then the Moon can provide a snapshot at the time of the Giant Impact, providing constraints on the early Bulk Silicate Earth (BSE).

One key question is whether BSE is chondritic in its lithophile element ratios. One approach to constrain this is by utilizing the ^{146}Sm-^{142}Nd system, where ^{142}Nd is the daughter isotope of ^{146}Sm with a half-life of 68Myr [10] There is an offset of appromiately 20ppm in ^{142}Nd/^{144}Nd between average chondrites and the Earth's modern convecting mantle [11]. If representative of BSE, this offset implies a larger Sm/Nd ratio than observed in average chondrites. Two of the strongest contenders to explain superchondritic Sm/Nd in the Earth's modern convecting mantle are: a) that BSE differentiated early, while ^{146}Sm was still live, with measured modern terrestrial samples representing a depleted reservoir and with an as yet unsampled enriched reservoir balancing Earth to a chondritic composition or b) that the bulk Earth has a superchondritic Sm/Nd ratio [11-15]. One way to generate a superchondritic BSE is the process of collisional erosion, where planetesimals form proto-crusts, which are then preferentially removed during accretion, increasing the Sm/Nd of the planetesimals that accrete to form Earth [16]. It could easily be imagined that the Moon forming Giant Impact could be one such erosional event.

In this study we assess if collisional erosion during the Giant Impact could result in a BSE with a superchondritic Sm/Nd. Lunar basalt ^{142}Nd data are used as ky constraints, and it is assumed that the bulk Moon reflects the composition of the proto-silicate Earth with only minimal contribution from the impactor.

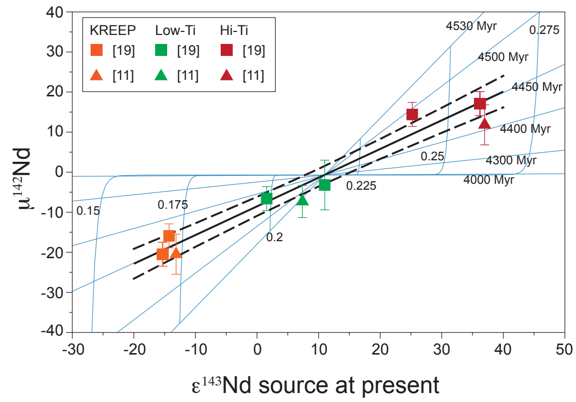

Fig. 1. Coupled ε^{143}Nd-μ^{142}Nd source model for t_1=4530Myr and $(^{147}Sm/^{144}Nd)_{t1}$ =0.2151 as an example. The straight blue lines are isochrons for reservoir closure times (t_2). The curved lines are for constant source ^{147}Sm/^{144}Nd. The black line is the regression line through the lunar data, and the dashed lines are the 95% confidence error envelope. The regression line is consistent with an isochron at 4450 Myr or 117 Myr after the onset of nebular condensation.

Method: Our simple model for a multi-stage Nd isotopic evolution has been adapted from earlier works [17-18] and is as follows. There are four stages: t_0 is 4567 Myr, the onset of nebular condensation (ONC), t_1 is the time of differentiation (here taken to be collisional erosion at the time of the Giant Impact), t_2 is closure age of source regions on the Moon and t_3 is the crystallization age of the lunar basalts. Each stage has an associated ^{147}Sm/^{144}Nd. To account for their different crystallization ages, all the lunar ε^{143}Nd data have been recalculated to a common source age (today) based on the measured ^{147}Sm/^{144}Nd for each sample. The lunar data used are the multi-static and multi-dynamic Nd data of [11,19], consisting of 11 lunar basalts evaluated for accuracy and neutron fluence corrections by [19]. The original calculations of collisional erosion [16] modeled BSE using ^{142}Nd data as one of the constraints. However, these models do not consider the timing of the process, which is key when using Sm-Nd systematics as one of the constraints. The assumptions built into our models are as follows: 1) The bulk Moon is identical to the proto-silicate Earth at the time of the Giant Impact. 2) The Nd isotope data for the Moon fall on a regression line, which represents an isochron (Fig 1). This isochron is thought to represent a common closure time for the different lunar reservoirs [19] at time t_2. 3) In ε^{143}Nd-μ^{142}Nd space this isochron will intersect with the common tie point for a multi-stage Sm-Nd differentiation model (Fig. 1). The coordinates of this tie point (i.e. ε^{143}Nd and μ^{142}Nd) will vary based on t_1 and ^{147}Sm/^{144}Nd. The tie point represents the bulk lunar (or BSE based on assumption 1) ε^{143}Nd and μ^{142}Nd, prior to differentiation into the source regions for the lunar basalts. 4) This tie-point has to have μ^{142}Nd=0 based on assumption 1.

With these assumptions, the slope and intercept of the isochron are used to find a unique ^{147}Sm/^{144}Nd for a given t_1 using the multi-stage Nd isotopic evolution equations of [17-18]. The resulting ^{147}Sm/^{144}Nd ratios are then fed into the collisional erosion equations of [16], and the resulting amounts of crustal differentiation and erosion necessary can be evaluated for their feasibility.

Results and Discussion: The first step was to determine the range in ^{147}Sm/^{144}Nd and t_1 consistent with the above assumptions. Figure 2 shows the range in μ^{142}Nd and ^{147}Sm/^{144}Nd for different differentiation times.

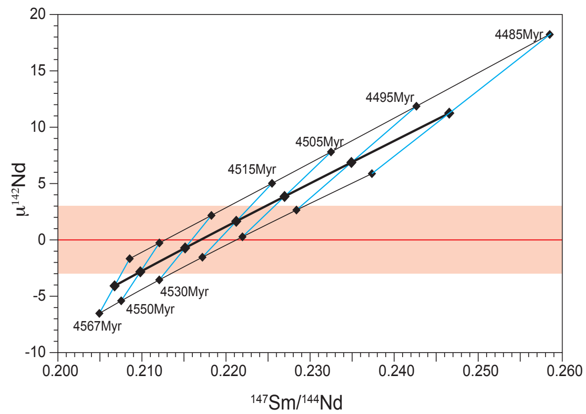

Fig. 2. μ^{142}Nd vs ^{147}Sm/^{144}Nd of source (thick black line). The thinner black lines are the 95% confidence intervals from the linear regression through the lunar data. The black diamonds are the ages of fractionation (t_1) and the blue curves are lines of equal t_1. The assumption is μ^{142}Nd=0 (red line), and the current precision possible is ±3ppm (pink rectangle).

The constraints provided by the precision on μ^{142}Nd and the previously stated assumption that μ^{142}Nd = 0 limits the range in (^{147}Sm/^{144}Nd)$_{t1}$ to 0.2075-0.229, with the concomitant range in t_1 being 4567-4494 Myr. The model limits the maximum age of the Giant Impact, assuming it is associated with a differentiation event, to ~70Myr after ONC with the final closure of the lunar reservoirs at ~120Myr$_{ONC}$.

The second step in the models was to address whether the half-life for ^{146}Sm coupled with the lunar data could put further constraints on possible collisional erosion scenarios. The equations [16], express the concentrations of elements in the BSE relative to chondritic abundances (C_{BSE}/C_0) as a function of the partition coefficient, the mass fraction of the protocrust formed (f^1), mass fraction of this crust that is removed (f^2), and the mass mantle residue that is also removed (f^r). With the range of Sm/Nd (calculated from ^{147}Sm/^{144}Nd) in Fig. 2, there are a number of plausible combinations of f^1, f^2 and f^r that satisfy the results from the first step in the models. In essence, the findings are no different than earlier works [12], but do confirm that collisional erosion during the Giant Impact could have generated a BSE with a superchondritic Sm/Nd.

We addressed the data in another way and calculated f^1, f^2 and f^r for Sm and Nd individually. To obtain C_{BSE} for Sm and Nd from the ^{147}Sm/^{144}Nd ratios from our models we used the intersections of the Sm/Nd ratios with the terrestrial mantle depletion array of [20]. The lowest permissible Sm/Nd ratio intersected the mantle depletion array within 5% of the Sm and Nd concentrations proposed for PUM (primitive upper mantle) [21]. The highest ratio intersects half-way between PUM and DMM (depleted MORB mantle) [20]. Hence this model does not permit a bulk Moon of DMM composition. However, finding valid f^1,f^2 and f^r values for Sm and Nd individually rather than as a Sm/Nd ratio is not possible with the equations from [16] when using chondritic concentrations for C_0. It is not yet clear whether this points to multiple stages of the process to generate a non-chondritic "C_0" or whether there are flaws in the current conception of collisional erosion.

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