CRUSTAL STRIPPING AND CHEMICAL EVOLUTION OF THE PROTO-EARTH DURING ACCRETION

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Introduction: Superchondritic Sm/Nd (Samarium/Neodymium) ratio has been evidenced in Earth's mantle rocks [1]. This observation is at odds with the canonical view of planetary accretion from chondritic building blocks, leading to chondritic ratios of lithophile (i.e. rock loving elements) and refractory elements in the silicate Earth. During the last stage of planetary accretion, planets grow from collisions with other embryos and with a remnant planetesimals population. During this process, relative abundances of lithophile and refractory elements may be affected by impact events. Especially, it has been suggested that the superchondritic Sm/Nd ratio could be inherited from collisional stripping of the Earth's early crust. Here, we quantify the influence of collisional erosion during accretion on the budget of lithophile and refractory elements such as Sm and Nd to evaluate the efficiency of this scenario.

Methods: The evolution of the Sm/Nd ratio with respect to eroded and accreted masses during the late-stage growth of Earth analogs is computed using a combination of analytical modeling [2, 3], N-body numerical simulations [4] and a geochemical modeling of mass balance. The eroded and accreted masses are estimated using scaling laws of rocky targets [2, 3].

Several type of accretional histories are tested (with and without Grand-Tack, different orbits for Jupiter and Saturn and different values for the disk surface density [4]). Additionnally, the contribution of small impactors is taken into account following a size-frequency distribution. The distribution of impactors follows the power law $\frac{dN_{sfd}}{dr} = -Kr^{-\alpha}$, with r the radius of the impactor and N_{sfd} the corresponding number of impactors.

The final Sm/Nd ratio of the bulk silicate Earth (i.e. primitive mantle) is determined under 3 sets of end-member scenarii: (1) The mantle and crust fully reequilibrate after each impact; (2) The accreted material merges with the crust only and the mantle does not reequilibrate with the crust (3) Full equilibration between the crust and mantle only occurs with giant impacts. Embryos are always assumed to be differentiated while planetesimals are assumed not differentiated. The escaped mass has a crustal composition when the excavation depth is lower than the crustal depth. The eroded material is made of both crust and mantle when the excavation depth is higher. Accreted mass is assumed to have a chondritic composition.

In this study, the fractionation of the Sm/Nd ratio is followed with time by computing ε_i for each embryo defined as:

$$\varepsilon_i = \frac{\left(\frac{Sm}{Nd}\right)_{BSS}^{end} - \left(\frac{Sm}{Nd}\right)_{BSS}^{ini}}{\left(\frac{Sm}{Nd}\right)_{BSS}^{ini}},$$

with BSS denoting the "Bulk Silicate Shell" of a given embryo i (i.e. its crust and mantle together).

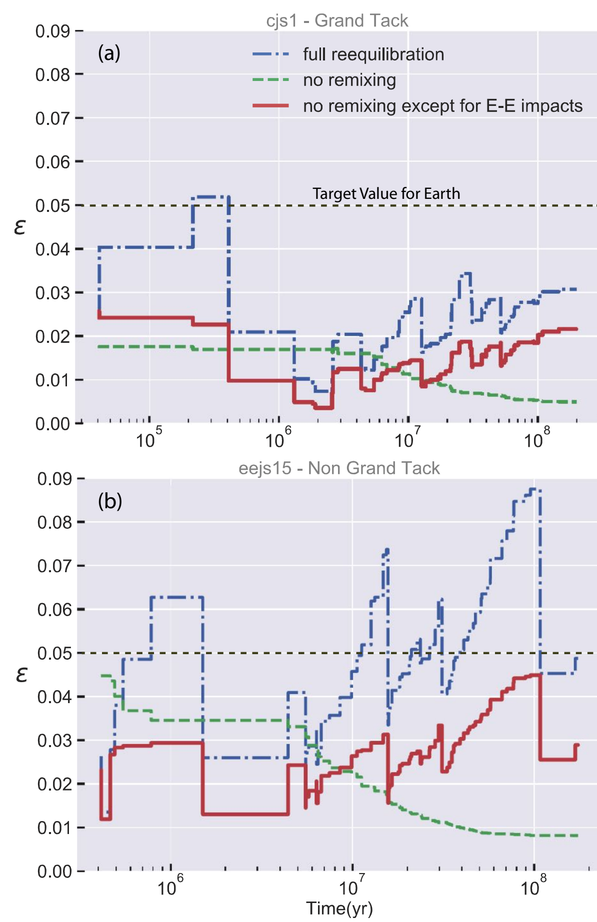

Figure 1. Evolution of the ε value (fractionation of the Sm/Nd ratio with respect to chondritic value) over time for two representative embryos (a) for a non grand tack scenario and b) a grand tack scenario.

Results & Discussion: The evolution over time of the ε value is shown in figure 1a and figure 1b for two given embryos and for two accretion scenarii (fig. 1a and fig. 1b show results for models with and without Grand-tack scenario respectively [4]).

At the end of N-body numerical simulations, averaged Sm/Nd ratio are computed for a population of embryos similar to the Earth. The final results are represented in figure 2.

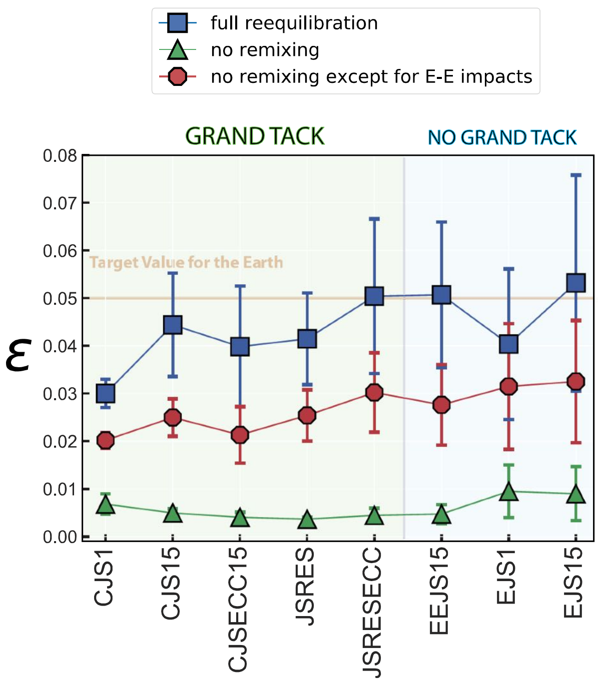

Figure 2. Mean values of ε for Earth analogs taken in different dynamical scenario [4] (with and without Grand-Tack scenario). Error bars correspond to the standard deviation. Blue squares correspond to scenario 1, for which a full reequilibration between crust and mantle is assumed for each impact event. Green triangles denote the scenario for which there is no reequilibration at all. For small impacts, only crust mass and composition are affected. Giant impacts are not considered. Red circles correspond to a more realistic case where only giant impacts lead to full re-equilibration.

We show that the crust is preferentially lost with respect to the mantle during accretion of terrestrial planets. Crustal erosion is more efficient for smaller embryos (i.e. during the earliest stage of embryos' growth) and for high impact velocities. Planetesimal impacts play a dominant role in determining the Sm/Nd ratio due to the efficiency of crustal erosion. The average and standard deviation of ε decrease for larger embryo final mass. It appears unlikely that collisional erosion only could explain the observed Sm/Nd ratio of the bulk silicate Earth (BSE). Indeed, the actual BSE Sm/Nd ratio is reached only for the full reequilibration scenario and only for few cases (figure 2). In addition, as we neglect re-accretion of ejected material, our results represent an upper estimate of the Sm/Nd fractionation.

Nucleosynthetic anomalies provide a potential explanation for non-chondritic Sm/Nd [5, 6] if the dynamical evolution of the disk is mostly non-erosive (i.e. Grand-Tack with a shallow surface density disk).

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