

HF/W ISOTOPIC EVOLUTION FOR POST LAST-GIANT-IMPACT EARTHS AND MOONS IN GRAND TACK ACCRETION SIMULATIONS. N. G. Zube¹, F. Nimmo¹, R. A. Fischer², S. A. Jacobson³, ¹Department of Earth and Planetary Sciences, University of California Santa Cruz (1156 High St., Santa Cruz, CA 95064, USA, nzube@ucsc.edu, fnimmo@es.ucsc.edu), ²Harvard University (20 Oxford St., Cambridge, MA 02138, USA, rebecca-fischer@g.harvard.edu), ³Northwestern University, Technological Institute (2145 Sheridan Road, Evanston, IL 60208, USA, seth.jacobson@earth.northwestern.edu).

Introduction: The decay of lithophile ^{182}Hf into siderophile ^{182}W with a half-life of 9 My can provide constraints on the timescales of planetary core formation and accretion. Classical accretion scenarios have produced planets with tungsten isotopic values like those measured presently on the Earth [2,3]. In Grand Tack accretion simulations [4,5] terrestrial planet formation occurs more rapidly, and reproducing the observed tungsten isotopic anomaly for Earth's mantle requires nearly complete equilibration between impactor core and target mantle [6]. Another observational constraint arises from the nearly indistinguishable W isotope anomalies measured for the terrestrial and lunar mantles [7]. Though it has been shown in models that moon-forming impactors are statistically unlikely to be isotopically similar to Earths in the Hf/W system [6,8], the post last-giant-impact (LGI) Hf/W evolution of the Earth and Moon complicates the comparison. To this end, we will evolve post-LGI, differentiated Earths and Moons in Grand Tack simulations through time to the present to determine the likelihood of reproducing the observed match in lunar and terrestrial ^{182}W .

Methods: We model Hf-W evolution for growing planets in 141 N-body simulations in the Grand Tack scenario. Partition coefficients are assumed constant throughout a model run. During collisions, the re-equilibration of elements between the core and mantle is calculated following [2]. For each set of models, we vary the equilibration factor during collisions—the fraction of impactor core that experiences re-equilibration with the entire target mantle—in steps ranging from none (cores merging) to complete equilibration. The LGI is modeled assuming the canonical scenario where the Moon is built from mostly impactor mantle (no mixing with Earth material) [9]. Pre-impact isotopic values for the Earth and Theia are compared.

Discussion: For Earth-like and Mars-like surviving planets, we find that cases with a high equilibration factor ($k > 0.7$) were most frequently able to approximate the observed W measurements for Earth and Mars (Fig. 1). This may be compared with classical scenarios in which an equilibration factor $k \sim 0.5$ is typically found [2, 3, 10]. The necessity of high equilibration for Grand Tack models is explained by the faster accretion timescales compared to classical scenarios.

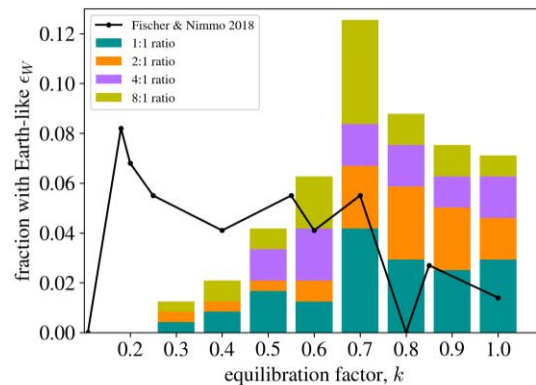


Fig 1. Fraction of total Earth-like bodies that match the pre-late veneer terrestrial tungsten anomaly ($\epsilon_W = 2.2 \pm 0.15$), divided among groups with varying initial embryo:planetesimal mass ratio. The solid line shows results from Classical accretion scenarios in [10].

For model moons made entirely of mantle material from Earth's last giant impactor (Theia), the probability of an Earth-Theia pair achieving a ^{182}W anomaly difference $\Delta\epsilon_W < 0.3$ when the model Earth ϵ_W value resembles the measured value is 8% across all Grand Tack simulations (Fig. 2).

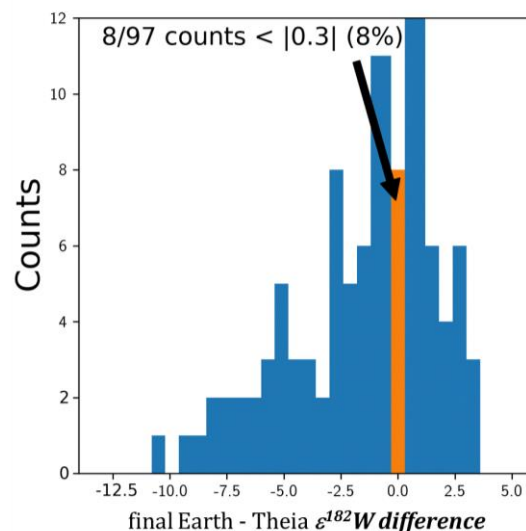


Fig. 2. Counts of ϵ_W difference in Earth-Theia pairs for cases when the model Earth matches the measured value, $\epsilon_W = 2.2 \pm 0.15$ (this value strips out the effect of the subsequent late veneer [11]).

A comparison of final time-evolved moons and Earths will also be presented. In this set of models, *both* post-LGI bodies experience differentiation and core formation, and ^{182}Hf decay is evolved to the present for the moon. The low likelihood of Earth-Moon ϵ_{W} similarity in the canonical LGI model indicates that a scenario where the Moon isotopically equilibrated with the Earth's mantle after the impact [12] may be required to explain the measured values.

References: [1] Kleine T. et al. (2009), *GCA*, 73, 5150-5188. [2] Nimmo F. et al. (2010), *EPSL*, 292, 363-370. [3] Rudge J. F. et al. (2010), *Nat. Geosci.*, 3, 439-443. [4] Walsh K. J. et al. (2011) *Nat.*, 475, 206-209. [5] Jacobson et al. (2014) *Nat.*, 508, 84-87. [6] Zube N. et al. (2017) *AGU 50*, Abstract P53F-05. [7] Touboul M. et al. (2007) *Nat.*, 450, 1206-1209. [8] Kruijer T. S. and Kleine T. (2017) *EPSL*, 475, 15-24. [9] Canup R. M. and Asphaug E. (2001) *Nat.*, 412, 708-712. [10] Fischer R. A. and Nimmo F. (2018) *EPSL*, 499, 257-265. [11] Kruijer T. S. et al. (2015) *Nat.*, 520, 534-537. [12] Pahlevan K. and Stevenson D. J. (2007) *EPSL*, 262, 438.