MAKING THE MOON FROM THE EARTH'S MANTLE - THE GEOCHEMICAL PERSPECTIVE.

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Introduction: The formation of the Moon from a circum-terrestrial disk ejected in a collision between the proto-Earth and a roughly Mars-sized impactor (a.k.a. the Giant Impact or GI Hypothesis [1]) is widely accepted today. However, the close geochemical similarity of lunar rocks and Earth's mantle has posed a serious problem for the hypothesis, as simulations of the GI consistently [1] had the Moon forming predominantly (~80%) from impactor material. In view of large isotopic and elemental inhomogeneities in different solar system objects, e.g. in O, Si, Cr and W isotopic ratios, or Mg/Cr and Hf/W elemental ratios, it seems unlikely that the impactor had a composition closely matching that of the Earth. Similarity in W isotopes and Hf/W ratios further implies that proto-Earth and impactor must have formed their cores at the same time. A post-impact re-equilibration model has been proposed to account for the similarity in O isotopes [2], but so far, no complete, quantitative model of this exists [3]. It therefore remains unclear at this stage whether this re-equilibration model can satisfy all geochemical constraints. Recently, a modified GI scenario with new parameters was presented, where a steep, high-velocity collision yields an iron-depleted disk mainly derived from terrestrial (or “target”) material and a reasonable Earth-Moon angular momentum [4]. Here, we compare the predictions from this model with constraints from the above-mentioned geochemical systems.

Results & Discussion: The geochemical similarity of Earth and Moon can be expressed in a factor $\delta f_T = (M_{target} / M_{total})_{disk} / (M_{target} / M_{total})_{post\text{-}impact\ Earth} - 1$, reflecting the depletion of terrestrial material in the Moon-forming disk. Since both Earth and Moon incorporate significant amounts of impactor material, it is this difference in relative contributions that has to approach zero to satisfy geochemical constraints. The exact value of δf_T depends on the composition of proto-Earth and impactor, but also on their initial mass and the mass lost from the system. Typical values for δf_T in the “canonical” model [1] do not exceed -66%, incompatible with geochemical constraints. For an impactor that resembles Mars in O, Si and Cr isotopic composition, δf_T should exceed -5%, -59% and -45%, respectively. A typical outcome of the new high-velocity GI model is a δf_T of -34%, compatible with these constraints except for O. However, O may be a special case, as there are at least three different solar system materials (Earth, E- and CI-chondrites) that plot on the terrestrial fractionation line, possibly because they all sample the same reservoir, from which also the impactor could have been derived. Alternatively, post-impact re-equilibration as proposed by [2][3] may have erased any remaining isotopic differences.

Conclusions: The high-velocity GI model [4] can satisfy the known geochemical constraints. A possible exception is O, if the impactor is as different in O isotope composition as Mars. In this case, post-impact re-equilibration [2] is still needed, for which our model constitutes a new starting point, as the high-velocity GI model also predicts a much hotter early Earth. This may have implications for geophysics and the formation of the atmosphere.

References: [1] Canup et al., 2001, *Nature* 412, p. 708. [2] Pahlevan & Stevenson, 2007, *Earth and Planetary Science Letters* 262, p. 438. [3] Pahlevan et al., 2011, *Earth and Planetary Science Letters* 301, p. 433. [4] Reufer et al., 2011, *Lunar and Planetary Science Conference* 42, abs. 1136.