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Improving the understanding of Hf-W and U-Pb systematics in the Earth-Moon system

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Traditionally, Hf-W and U-Pb systematics of the Earth's mantle have been interpreted as dating the age of Earth's core formation. Single-stage core formation models yielded a maximum Hf-W age of ca. 30 Myrs after ss formation (e.g., [1]), whereas the U-Pb system yielded somewhat older ages (ca. 100 Myrs, [2]). To resolve this discrepancy, two-stage models suggested a late stage addition of Pb to the Earth's metal core via sulfide melts [3]. Experimental evidence, however, showed that Pb is not sufficently chalcophile enough to validate such models [4]. The subsequent finding that Pb is in fact strongly siderophile [5,6] spurred models trying to reconcile the Hf-W and U-Pb age constraints, leading to the view that core formation on Earth is a rather late event that has occurred not until ca. 100 Myrs after ss formation [7]. In these models, the excess ^{182}W in the silicate Earth may be inherited from differentiated planetesimals. As for the Moon, it was recently found that the Moon exhibits identical ^{182}W abundances than the Earth [8]. By using the apparently different Hf/W ratios of the silicate Earth and the silicate Moon the age for the Moon-forming giant impact event has been estimated to >50Myrs after solar system formation [8]. Solidification of the lunar magma ocean has been estimated to >60 Myrs [8].

Based on high precision W data, the silicate Earth has recently been shown to exhibit a Hf/W ratio that is indistinguishable from that of the silicate Moon [9,10]. As the Hf/W as well as the ^{182}W composition in both bodies overlap, a maximum age of the Moon-forming giant impact can no longer be estimated. The similar Hf/W ratios strongly suggest that the Moon forming giant impact might have triggered an efficient metal-silicate re-equilibration on Earth. Radiogenic ingrowth of excess ^{182}W in the terrestrial and lunar mantle should then have largely occurred after the impact event and is no vestige of older planetesimals. Likely, the single-stage model age for core formation on Earth (now ca. 35 Myrs) may in fact date the Moon forming giant impact. Likewise, solidification of the lunar magma ocean may have occurred much earlier (as early as 50 Myrs after ss formation), as arrays defined by lunar samples in ^{182}Hf-$^{182}W (and^{146}$Sm-^{142}Nd) isochron space may possibly constitute mixing lines [10].

Using newly available sets of experimental data [5,6], trace element modelling can also cast doubt on the significance of the U-Pb age of the silicate Earth. At conditions prevailing in a deep terrestrial magma ocean, ratios of lithophile to siderophile elements such as Rb/Pb would be magnitudes higher in the terrestrial mantle than acually observed. As an inevitable consequence, most the Earth's volatile inventory must have accreted after core formation was virtually complete. The Earth's U/Pb ratio can be explained by replenishing an initially volatile depleted Earth with a high U/Pb ratio, similar to that of the Moon, by 1-3 percent of a volatile-rich late veneer component. This can explain the elemental U/Pb and Rb/Pb ratios as well as the unique Pb isotope composition of the silicate Earth. Therefore, the U-Pb system provides little information on the age of core formation.

References: [1] Kleine et al. 2002 Nature 418 [2] Allègre et al. 1995 GCA 59 (8) [3] Wood and Halliday 2005 Nature 437 [4] Lagos et al. 2008 Nature 456 [5] Wood and Halliday 2010 Nature 465 [6] Ballhaus et al. 2011 Mineralogical Magazine 35 (3) [7] Rudge et al. 2010 Nature Geoscience 3 (6) [8] Touboul et al. 2007 Nature 450 [9] König et al. 2011 GCA 75 [10] Münker 2010 GCA 74.