The lunar Hf/W budget and the age of the Moon

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At the low fO_2 of the Moon, W behaves more compatibly than on Earth [1,2]. To better understand W behavior on the Moon, we have extended existing high-precision High Field Strength Element (HFSE) [3] and Hf-Nd isotope datasets [4] to comprehend the petrogenesis of major lunar rock types and to assess implications for terrestrial and lunar ^{182}W systematics.

Our data for low-Ti mare basalts fall within loose ranges (U/W between 1.6 to 2.6, measured Hf/W between 30 to 50). Individual groups (such as Apollo 15 qtz-normative, Apollo 15 ol-normative, Apollo 12 ilmenite basalts) are fairly uniform (U/W generally varies by 0.1, measured Hf/W by ca. 5). In contrast, Apollo 17 high-Ti mare basalts show variable Hf/W up to 150 and correlated U/W up to 2.3, clearly distinct from both A11 high-Ti basalts (Hf/W of 40 to 60 and U/W between 1.5 and 2.2) and all low-Ti basalts. Melting models (continuous & fractional melting, ±residual metal) and the striking homogeneity of low-Ti mare basalts imply degrees of melting at which melt and source compositions for U,Th, and W are virtually identical. In keeping with Hf-Nd isotope evidence [4], however, different groups of low-Ti mare basalts came from mantle sources having distinct isotopic and extended HFSE features. A unique A17 high-Ti mantle source as implied by Hf-Nd isotopes [4] is also in line with variable Hf/W and U/W of A17 basalts, given the presence of residual oxides and metal [1,2].

Collectively, W was less incompatible than Hf during formation of the lunar magma ocean cumulates that likely made up the source of low-Ti mare basalts [1,2,4]. The Hf/W of low-Ti mare basalts thus constrain the Hf/W of the bulk silicate Moon to be at least ca. 15% above the Bulk Silicate Earth (BSE) value. The ^{182}W excess of lunar rocks compared to BSE [5,6] thus likely reflects radiogenic ^{182}W ingrowth the formation of both bodies in the first 60 Myr of the solar system, and an only minor importance of late accretion.

[1] Fonseca *et al*. (2014) EPSL 404 [2] Leitzke *et al*. (2016) Chem. Geol. 440 [3] Münker, C. (2010) GCA 74 [4] Sprung *et al*. (2013) EPSL 380 [5] Kruijer *et al.* (2015) Nature 520 [6] Touboul *et al*., (2015) Nature 520