NEW CONSTRAINTS ON EARLY LUNAR EVOLUTION FROM HIGH PRECISION MEASUREMENTS OF HIGH FIELD STRENGTH ELEMENTS IN LUNAR ROCKS

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Introduction: The compositional diversity of lunar rocks is commonly explained by melting of fossil cumulate layers formed during crystallisation of a lunar magma ocean (LMO). Lunar mare basalts are inferred to tap trace element depleted cumulate layers formed at the base of the LMO. The petrogenesis of high-Ti mare basalts is explained by direct melting of or, alternatively, by assimilation of late stage ilmenite-rich cumulate layers. Trace element enriched KREEP rocks tap mantle layers representing the final stages of LMO crystallisation. Based on measurements of ^{182}W [1] and ^{142}Nd compositions [e.g., 2] of lunar samples, it has been proposed that crystallisation of the LMO did not occur until 60 Ma after solar system formation and possibly lasted until 250 Ma. High precision isotope dilution measurements of HFS elements (W-Nb-Ta-Zr-Hf) and REE (Sm-Nd-Lu) on a representative suite of lunar rocks can now provide new insights into the processes active during the petrogenesis of lunar rocks. The data can also provide new insights into the significance of lunar ^{182}Hf-^{182}W and ^{146}Sm-^{142}Nd data.

Results: As expected from previous models, KREEP-rich and mare basalts display complementary Sm/Nd, Nb/Ta and Zr/Hf ratios, confirming the presence of complementary enriched and depleted reservoirs in the lunar mantle. Notably, high-Ti mare basalts display the lowest Nb/Ta and Zr/Hf and some of the highest Sm/Nd of all lunar rocks analysed, although they tend to exhibit higher concentrations of many incompatible trace elements. The high-Ti mare basalts analysed also exhibit tightly correlated Ta/W and Hf/W (up to values of 23 and 136, respectively), in marked contrast to terrestrial MORB (near constant Ta/W). A literature survey can extend this lunar array to even higher values (Ta/W up to 50 and Hf/W up to 298, [3]).

Discussion: Trace element modelling indicates that the strong (and coupled) increase of Ta/W, Hf/W and Sm/Nd in the high-Ti basalts can be best explained via assimilation of up to ca. 25% of ilmenite- and clinopyroxene-rich LMO cumulates by more depleted melts from the lower lunar mantle. During this assimilation process, the ^{182}W and ^{142}Nd isotope signatures of the hybrid magmas get decoupled from the Hf/W and Sm/Nd ratios as Hf and Sm are much more enriched than W and Nd, respectively. These observations have important implications for the interpretation of Sm-Nd and Hf-W systematics in lunar rocks. Together with a compilation of existing W/Th data for lunar rocks, the new Hf/W and Ta/W data indicate that the terrestrial and lunar mantles are indistinguishable in their Hf/W, explaining the similar ^{182}W abundance in both bodies and also arguing for a strong temporal link between the final stage of core formation on Earth and the Moon forming giant impact event. Moreover, the co-variations of lunar samples in ^{182}W vs. Hf/W and ^{142}Nd vs. Sm/Nd spaces, previously been interpreted as isochrons might eventually constitute mixing lines. Employing combined trace element and isotope modelling, the lunar Hf-W and Sm-Nd data would then be fully consistent with an "early" crystallisation age of the LMO (as early as 50 Myrs after solar system formation).

References: [1] Touboul, M. et al. 2007. *Nature 450*, 1206-1209. [2] Boyet, M. and Carlson, R.W. 2007. *EPSL 262*, 505-516. [3] Neal, C. 2001. *JGR 106*: 27865-27885.