Age and nature of meteoritic components on the Moon

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Osmium isotopes and highly siderophile elements (HSE: Re, Os, Ir, Ru, Pt, Rh, Pd, Au) in ancient lunar impact rocks provide further constraints on ages and compositions of meteoritic materials accreted to the early Earth-Moon system. We report the first Re-Os isochron age on a lunar impact melt rock from Apollo 16 (67935, 4.21±0.13 Ga). The Re-Os age together with recent age data underscores the significance of pre 4.0 Ga basin forming impacts on the Moon. The new HSE data will be discussed along with previous precise data sets to identify specific impactor compositions and to evaluate mixing processes in ancient lunar impact rocks. Granulites from Apollo 16 and 17 (67915, 67955, 79215) display HSE ratios and $^{187}Os/^{188}Os$ largely similar to volatile element depleted carbonaceous chondrites. Apollo 16 impact melt rocks 60315 and 67935 show strongly fractionated HSE compositions with subchondritic Os/Ir, chondritic Re/Ir, and suprachondritic $^{187}Os/^{188}Os$, Ru/Ir, Pt/Ir, Rh/Ir, Pd/Ir and Au/Ir, similar to some IVA iron meteorites. Slightly suprachondritic ratios of $^{187}Os/^{188}Os$, Ru/Ir, Pt/Ir, Pd/Ir observed for Apollo 14 sample 14310 are similar to ratios observed for other Apollo 14 and and Apollo 17 poikilitic impact melt rocks. The Re-Os age of 4.2 Ga obtained on 67935 in combination with a previously reported Sm-Nd recrystallization age of 4.2 Ga for 67955, support previous notions that significant contributions of meteoritic material were supplied to the lunar surface before the 3.9-3.8 Ga basin forming era. Similar ages, but different HSE compositions of the meteoritic components in 67935 (iron meteorite-like) and 67955 (carbonaceous chondrite-like) indicate two different impact events on the Moon at ≥4.2 Ga. The occurence of granulites with similar composition at Apollo 15, 16 and 17, and the iron meteorite signature at Apollo 14, 15 and 16 suggests a wide dispersal of these compositions over the lunar nearside. Following this reasoning, the slightly subchondritic Os/Ir and slightly suprachondritic $^{187}Os/^{188}Os$, Ru/Ir, Pt/Ir and Pd/Ir of poikilitic Apollo 17 and Apollo 14 impact melt rocks may be explained by mixing 80-95% of a carbonaceous chondrite-like HSE end-member composition as indicated by the granulitic impact rocks (e.g. 67955) with 5-20% of a fractionated iron meteorite-like impactor composition as inferred from 67935 and 60315.

Silicon isotope evidence against an Enstatite Chondrite Earth

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Enstatite chondrites are undifferentiated meteorites which formed at particularly reducing conditions as testified by the presence of Si in the metal phase. Enstatite chondrites are striking in having terrestrial compositions for several isotope systems such as O, Cr, Ti, and several others. Javoy *et al.* [1] interpreted these similarities as evidence for the Earth to be made of these chondrites. Silicon is particularly difficult to reconcile with this interpretation since it requires 28 wt% Si to be incorporated into the core which is way above the maximum Si core content (~7wt%). To get around this problem, a layered model with a Si-enriched hidden reservoir was proposed [1].

The silicon isotope compositions of enstatite chondrites and aubrites were measured on the MC-ICPMS Nu1700 at ETH Zurich. Bulk meteorites and separate enstatite minerals of the same meteorite were analyzed. The heaviest Si isotope composition was measured in an enstatite separate of an EH3 chondrite and gave $\delta^{30}Si$=-0.38 ± 0.03‰. Even in an extreme scenario of Earth's core formation in which (i) the accreting material is assumed to have a composition $\delta^{30}Si_{sil}$=-0.38‰ for its silicate phase (which is unlikely given that most bodies experienced thermal metamorphism or even metal-silicate differentiation, which would both give a lighter $\delta^{30}Si_{sil}$ ([2]; this study)) and (ii) there is no equilibration between metal and silicate during core merging of an impactor with the proto-Earth's core (e.g. [3]) (which is also unlikely given that it was shown that more than 36% of equilibration is necessary to account for both siderophile element abundances in the Earth's mantle and Hf-W data [4]), the resulting $\delta^{30}Si_{BSE}$ would never exceed -0.38‰. This is significantly lighter than the now agreed Si isotope composition of the Bulk Silicate Earth (BSE) $\delta^{30}Si_{BSE}$=-0.28‰ ± 0.03‰ [2; 5-6]. Therefore, while being quite intriguing meteorites from their similarities with the Earth, enstatite chondrites or aubrites cannot have been the material accreting the Earth.

[1] Javoy *et al.*, *EPSL*, 2010; [2] Ziegler *et al.*, *EPSL*, 2010; [3] Canup, *EPSL*, 2004; [4] Rudge *et al.*, *Nature Geosci.*, 2010; [5] Fitoussi *et al.*, EPSL, 2009; [6] Savage *et al.*, *EPSL*, 2010.