Origin of the late veneer inferred from Ru isotope systematics

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Elevated abundances of the highly siderophile elements (HSE) in the Earth's mantle are commonly explained by the addition of a chondritic late veneer after cessation of core formation [*e.g.*, 1]. Identifying the source and type of the late accreted material is a particular important issue, because the late veneer may have delivered considerable amounts of volatiles to Earth. Relative HSE abundances and Os isotope compositions of mantle materials are largely similar to those of chondrites, yet establishing a direct link of the late accreted material to a particular type of meteorite has proven difficult [2]. Ruthenium is a HSE and exhibits nucleosynthetic isotope anomalies at the bulk meteorite scale [3]. This makes Ru isotopes a promising new tool for identifying the source of the late accreted material, because the Ru isotope composition of Earth's mantle can be directly compared to that of meteorites.

We have precisely measured Ru isotopic compositions for a wide range of chondrites and iron meteorites, using the Neptune *Plus* MC-ICPMS at the University of Münster. All investigated meteorites, except the IAB irons but including several carbonaceous and ordinary chondrites are characterized by a deficit in *s*-process Ru relative to the Earth. Consequently, none of the meteorites nor a combination thereof can be the source of the late veneer. Our new Ru data in combination with previously published Mo isotope data for the same samples [4] show that all meteorites define a Ru *vs*. Mo isotope correlation [5]. This Ru-Mo correlation passes through the composition of Earth's mantle, implying that the late veneer derives from the same Ru-Mo isotopic reservoir and, hence, from the same type of material as the main building blocks of the Earth. This is because Mo, a moderately siderophile element, was delivered during the main stages of accretion, whereas the HSE Ru was mainly added by the late veneer. The Mo-Ru isotope systematics, therefore, seem to rule out an exotic outer solar system source for the late veneer, but strongly suggest an origin from the same type of inner solar system material that built Earth. The late accreted material thus may simply constitute the 'exponential tail' of accretion.

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Earth and Mars building blocks

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CI chondrites, which have the closest elemental composition to the solar photosphere, have often been chosen as the reference composition for the Bulk Earth [1,2]. However, from the viewpoint of isotope compositions (e.g. Cr isotopes), it is not plausible for the Bulk Earth to have a CI chondrite composition. Another approach based on isotopic similarities between Earth and enstatite chondrites proposed that these meteorites best represented the Bulk Earth [3]. However, based on silicon isotopes, it was recently shown that enstatite chondrites cannot represent more that 15% of the Earth's mass [4]. In addition, several chemical characteristics of enstatite chondrites are distinct from those of the Earth.

Rports of nucleosynthetic and non-mass dependent isotope anomalies have shown that there is a heterogeneous distribution of isotope compositions in the nebula, and these systems (e.g. O, Cr isotopes) have even become a reliable classifying tool for various meteorite groups [5,6]. We have been looking for possible building blocks of the Earth and Mars, using these isotopic signatures in meteorites.

As target values of our model, we used the Earth and Mars compositions of measured terrestrial samples and SNC (Shergottites, Nakhlites, Chassignites) martian meteorites samples, respectively.

We propose a model that accounts for (i) all isotopic compositions of the Earth and Mars; (ii) the refractory lithophile element enrichment of the Earth compared to CI chondrites, which is one specific characteristic of the composition of our planet [e.g. 7]; (iii) the volatile element budget in Mars, which has been difficult to match, as discussed in previous models of the bulk composition of Mars [8-9]. We will discuss these results with regards to implications on the scenarios for the formation of terrestrial planets.

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