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Ru isotope anomalies in meteorites

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Nucleosynthetic isotope anomalies in bulk meteorites have been reported for some siderophile elements (e.g., Ni, Ru, Mo) [1-4] but seem to be absent for others (e.g. Os) [5]. The contrasting isotope systematics of these chemically similar elements may place important constraints on the extent and efficiency of mixing processes as well as pathways of material transport within the early solar nebula. So far, only a limited number of samples have been investigated for Ru and nucleosynthetic anomalies were mainly reported for magmatic iron meteorites [3]. These Ru isotope anomalies correlate with those in Mo exactly as predicted from s-process nucleosynthetic theory, indicating a heterogeneous distribution of at least one s-process carrier at the bulk meteorite scale [1,4]. To further investigate the extent of Ru isotope anomalies in meteorites and to evaluate the significance of the cosmic Mo-Ru correlation we developed new analytical techniques for precise Ru isotope measurements by multicollector inductively coupled mass spectrometry (MC-ICPMS).
We present new Ru isotope data for IVB iron meteorites, the ungrouped iron Chinga, and the carbonaceous chondrites Allende (CV) Gujba (CB) and Tafassasset (CR-an). Ruthenium isotope compositions were measured using the ThermoScientific Neptune Plus at the University of Münster and are reported in εiRu-deviation from terrestrial Ru. For mass bias correction relative to 99Ru/101Ru all samples show well resolved negative anomalies in ε100Ru, consistent with previous data for IVB irons [3]. All samples show small negative anomalies in ε102Ru, but these are not unambiguously resolved yet. Slightly positive anomalies in ε96Ru and ε98Ru are also not clearly resolved yet. When normalized to 99Ru/100Ru all samples show resolvable deficits ε96Ru and ε98Ru, and large enrichments in ε101Ru, ε102Ru and ε104Ru.
The observed Ru isotope patterns are in excellent agreement with anomalies predicted for a deficit in s-process isotopes according to the stellar model of nucleosynthesis [6]. The carbonaceous chondrites Gujba and Tafassasset, together with magmatic iron meteorites plot on the Mo-Ru mixing line between an presumed s-process carrier and terrestrial Mo and Ru, indicating that the cosmic Mo-Ru correlation also extends to relatively young carbonaceous chondrites. In contrast to the well-resolved Ru and Mo isotope anomalies observed for bulk meteorites, no such anomalies seem to exist for Os and Pt [5,7], which is surprising, because Ru, Pt and Os all are refractory highly siderophile elements and most likely reside in the same carrier phases. The generation or preservation of nucleosynthetic anomalies may thus be related to processes within the solar nebula, rather than reflecting primordial heterogeneity in the distribution of presolar dust [8].
The Ru isotope data for meteorites may provide important constraints regarding the nature and origin of the material accreted to the Earth. The isotopic composition of highly siderophile Ru in the silicate Earth was set by the late veneer, whereas that of Mo, a moderately siderophile element, mainly reflects the isotopic composition of Earth's precursor bodies. The observation that the silicate Earth plots on the Mo-Ru correlation defined by meteorites thus indicates that the material added to the Earth as a late veneer after cessation of core formation derives from the same Mo-Ru isotopic reservoir than the bulk Earth [9]. Thus, the feeding zones of Earth's precursor bodies were the same than those of the late accreted material. The Ru isotope data may ultimately allow identifying the type of material constituting the late veneer. For instance, in a recent study it was proposed that the late veneer consisted of a mixture of 80% carbonaceous chondrites and 20% iron meteorites [10]. This model can be tested once a comprehensive Ru isotope data set for chondrites and iron meteorites is available.

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