

## Ruthenium isotope fractionation in partially differentiated meteorites

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**Introduction:** The transformation of undifferentiated solar nebula aggregates into fully differentiated planetary bodies consisting of metallic cores surrounding by silicate mantles is one of the most fundamental processes occurring in the early solar system. The earliest stages of differentiation have been preserved in meteorites derived from partially differentiated parent bodies. These meteorites are sometimes referred to as ‘primitive achondrites’ and include, among others, acapulcoites-lodranites, brachinites, and ureilites [1]. The petrology and geochemistry of these samples suggest they derive from sources that underwent segregation of partial silicate and S-rich metallic melts [e.g., 2-4]. In detail, however, uncertainties exist regarding the nature and extent of these processes. For instance, highly variable and fractionated abundances of highly siderophile element (HSE) abundances in partially differentiated meteorites seem to indicate large variation and sometimes unrealistically high degrees of melting and FeS melt extraction [e.g., 5]. This renders it difficult to use the HSE systematics of partially differentiated meteorites for assessing as to whether they were all affected by similar or different processes during differentiation.

Here we use an alternative approach that relies on mass-dependent Ru isotope fractionations between and among solids and melts during planetary differentiation. Ruthenium isotopes are well suited to examine melt segregation during planetary differentiation, because Ru isotope fractionation has been demonstrated between solid and liquid metal [6], but does not seem to occur during solar nebula processes, as is evident from homogeneous mass-dependent signatures of chondrites [7]. We obtained mass-dependent Ru isotopic data for ureilites, acapulcoite-lodranites and brachinites, with the ultimate goal to investigate the processes of metallic melt formation and segregation in partially differentiated meteorite parent bodies.

**Samples and Methods:** Mass-dependent Ru isotopic compositions of seven ureilites, three acapulcoite-lodranites, and one brachinite were determined using a <sup>98</sup>Ru-<sup>101</sup>Ru double spike for the precise measurement of mass-dependent Ru isotope variations [8]. To obtain the true mass-dependent Ru isotopic compositions, nucleosynthetic Ru isotope anomalies [9,10] and mass-dependent Ru isotopic compositions were determined on the same digestions or sample powder. In brief, meteorite samples (0.25 - 0.5 g) were digested inside Carius tubes (at 220°C for 48 hours). After digestion, the sample solution was split into two aliquots, one of which was spiked with a <sup>98</sup>Ru-<sup>101</sup>Ru double spike. Ruthenium was separated from the samples using a three-stage ion exchange chromatography [7], and the Ru isotope measurements of both spiked and unspiked samples were conducted using the Neptune *Plus* MC-ICPMS at Münster.

**Results:** Except for a transitional acapulcoite-lodranite, all investigated samples have heavy Ru isotopic compositions relative to chondrites. In spite of the different degrees of melting and melt segregation inferred from their trace element composition, all samples have indistinguishable Ru isotopic compositions. Moreover, the mass-dependent Ru isotopic signatures are not correlated with the Ru content of the samples.

**Discussion:** The indistinguishable mass-dependent Ru isotopic signatures of ureilites, acapulcoite-lodranites and brachinites indicates that the process resulting in Ru isotope fractionation were similar for all samples. The most plausible process that can account for the observed heavier Ru isotopic compositions and that is common to the parent bodies of ureilites, acapulcoite-lodranites and brachinites, is the separation of a FeS melt from either solid or liquid Fe metal [e.g., 2-4]. Mass balance considerations combined with the lack of any obvious correlation between Ru isotope fractionation and Ru content indicate that the resulting Ru isotope fractionation would vary with the degree of melting and melt extraction. Thus, the uniform mass-dependent Ru isotopic composition of the investigated samples indicates that all samples derive from sources with similar degrees of melt extraction. As such, we propose that the Ru isotope fractionation results from the separation of FeS and Fe melts during the early stages of differentiation. Whereas the FeS melt has been removed, the Fe melt only partially migrated, resulting in a heterogeneous distribution of this melt in the source regions of partially differentiated meteorites. High and low abundances of this metal then is responsible for the large variations in Ru contents among and between the partially differentiated meteorites. However, as the Fe metal is the major host of Ru in these meteorites, a heterogeneous distribution of the metal has no effect on their mass-dependent Ru isotopic compositions.

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