Isotopic complementarity of chondrules and matrix

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Chondrules and matrix are the major constituents of chondrites, but both the origin of chondrules and the genetic relationship between chondrules and matrix are poorly understood. To address these questions, we obtained W and Mo isotopic data for several chondrule and matrix fractions separated from the Allende CV3 chondrite. Our data show that chondrules and matrix have large and complementary nucleosynthetic W and Mo isotope anomalies resulting from the uneven distribution of stellar-derived dust. For Mo, chondrules and matrix show the characteristic *w*- and *m*-shaped patterns, indicative for the heterogeneous distribution of *s*-process matter, where the matrix is enriched in an *s*-process carrier over chondrules. The nature of this carrier is not well constrained, but the combined W and Mo isotope data are best explained by the heterogeneous distribution of a metal component enriched in *s*-process Mo and W.

The presence of complementary nucleosynthetic isotope anomalies in chondrules and matrix refutes an origin of chondrules in protoplanetary collisions and, instead, indicates that chondrules and matrix formed together from a common reservoir of nebular dust. This is consistent with prior conclusions based on the chemical complementarity of chondrules and matrix [1]. Of note, bulk Allende (like other bulk meteorites and inner solar system planets) shows no or only very small nucleosynthetic W isotope anomalies. Thus, after their formation, no or only very minor amounts of chondrules or matrix were lost, because otherwise bulk meteorites would show significant nucleosynthetic W isotope anomalies. To prevent this loss in a turbulent solar nebula, both chondrules and matrix must have accreted rapidly to a parent body, suggesting that chondrule formation was a critical step toward the formation of planetesimals [2]. Moreover, the need for rapid accretion of chondrules and matrix indicates that chondrules from a given chondrite group should exhibit very similar formation ages [2]. For the Allende chondrules we obtained a Hf-W age of 2.2±0.8 Ma after CAI formation, which given the large number of chondrules analyzed (~5,000), corresponds to the time at which most Allende chondrules formed.

[1] Palme *et al*. (2015) *EPSL* **411**, 11-19. [2] Budde *et al*. (2016) *PNAS* (in press).