Hf-W CHRONOLOGY OF CHONDRULES AND METAL FROM CR CHONDRITES.

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Introduction: Understanding the age and origin of chondrules is key for constraining the processes affecting solid material in the solar nebula, ultimately leading to the formation of planetesimals. However, the timing and duration of chondrule formation are debated. While most chondrules seem to have formed at ~2 Ma after CAI formation, chondrules from CR (Renazzo-type) carbonaceous chondrites may be ~1 Ma younger [1]. However, although CR chondrites largely escaped thermal metamorphism on their parent body, they were affected by aqueous alteration. As such, the young ages from chondrules from CR chondrites may also reflect disturbance or resetting by parent body processes. To address this issue and to better constrain the chronology of chondrule formation, we applied the ^{182}Hf-^{182}W system ($t_{1/2}$ = 8.9 Ma) to CR chondrites. These chondrites can be well-dated using the Hf-W system, because they contain abundant Fe-Ni metal, facilitating the direct measurement of the initial W isotopic composition for each sample. Moreover, the silicate fractions should have high Hf/W and, hence, radiogenic ^{182}W, making it possible to obtain precise internal isochrons.

Methods: So far we have analyzed pure metal fractions and different silicate fractions from three CR2 chondrites (NWA 801, Acfer 097, NWA 1180). Methods for sample digestion, the separation of W by anion exchange chromatography, the Hf and W concentration measurements by isotope dilution, and the W isotope measurements using the Neptune *Plus* MC-ICP-MS at Münster followed [2]. The W isotope data are normalized to either ^{186}W/^{183}W ('6/3') or ^{186}W/^{184}W ('6/4') and are reported as ε-unit deviations (i.e., 0.01%) relative to the bracketing solution standards. Repeated analyses of terrestrial rock and metal standards (BHVO-2, NIST 129c), which were digested, processed through the full chemical separation, and analyzed together with each set of samples, yield an external reproducibility (2 s.d.) of ±0.1 ε-units for ~30 ng W consumed per analysis.

Results: The metal fractions of the three CR chondrites have indistinguishable ε^{182}W values, but for each sample there is a small difference between the ε^{182}W (6/4) and ε^{182}W (6/3) values. This discrepancy is attributable to small but resolved nucleosynthetic anomalies in the CR metal, as is evident from slightly elevated ε^{183}W for the metals. After correction for these nucleosynthetic anomalies using the ε^{183}W of each sample, both ε^{182}W values agree. Note that the correction is negligible (<0.02ε) for the ^{186}W/^{183}W-normalized data of the CR metal [2]. These data, therefore, provide robust constraints on the timing of CR metal formation. The silicate fractions analyzed so far have only modestly elevated ^{180}Hf/^{184}W ratios of up to ~1.8 and show small radiogenic ε^{182}W excesses. These samples display clearly resolved nucleosynthetic anomalies that are larger than those of the metals.

Discussion: The Hf-W model age of all three CR metals is ~3.2 Ma after CAI formation. Although the overall spread in ε^{182}W and ^{180}Hf/^{184}W among the investigated fractions is too small to calculate precise isochrons, the Hf-W data for the silicate fractions (after correction for nucleosynthetic anomalies [2]) are nevertheless in good agreement with the model age defined by the metal fractions. An isochron regression of all analyzed samples yields an Hf-W age of 2.7±1.2 Ma after CAI formation. This Hf-W age for CR metal formation is in good agreement with Al-Mg ages of CR chondrules (~2.8 Ma for chondrules with resolvable ^{26}Mg excesses) [1] and also is in reasonable agreement with a Pb-Pb age of 3.6±0.7 Ma (corrected to ^{238}U/^{235}U = 137.786) obtained for a chondrule from Acfer 059 (CR2) [3], which is paired with Acfer 097 investigated in the present study [4]. We are currently analyzing additional samples, including high-Hf/W fractions and pure chondrule separates, with the ultimate goal to obtain precise internal isochrons for all three investigated CR chondrites. These new data will be presented at the conference and will make it possible to determine the timing of CR chondrite formation more precisely.

The metal and silicate fractions analyzed so far show different nucleosynthetic W isotope anomalies, indicating that silicates in CR chondrites are characterized by a deficit in *s*-process W relative to the metal. These anomalies are reminiscent to those observed previously for chondrules and matrix from the CV3 chondrite Allende [2] and are probably caused by the heterogeneous distribution of a single presolar carrier. If this is correct, then chondrules and metal in CR chondrites formed from a single reservoir, which would be consistent with the chemical complementarity between these two components observed for siderophile elements [5]. Either way, the presence of nucleosynthetic isotope anomalies in chondrules in CV and CR chondrites mandates formation within the solar nebula and rules out an origin of chondrules by protoplanetary impacts.

References: [1] Nagashima K. et al. 2014. *Geochemical Journal* 48:561–570. [2] Budde G. et al. 2016. *Proceedings of the National Academy of Sciences USA* 113:2886–2891. [3] Amelin Y. et al. 2002. *Science* 297:1678–1683. [4] Bischoff A. et al. 1993. *Geochimica et Cosmochimica Acta* 57:1587–1603. [5] Kong P. et al. 1999. *Geochimica et Cosmochimica Acta* 63:2637–2652.