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Incomplete condensation of volatile elements as the cause for volatile depletion in carbonaceous chondrites

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Volatile element depletion (relative to bulk solar composition) is a universal feature of rocky planetary bodies, but the causes for that are unclear. Carbonaceous chondrites (CCs), which are considered as primitive building blocks of rocky planets, are also volatile depleted. To investigate what processes caused volatile depletion in CCs, we measured isotopic compositions of Rb and K, as the two are both moderately volatile elements (MVEs) and their isotopes are very diagnostic of volatile depletion processes.

Our results show isotopic correlations between Rb and K, and between them and other MVEs such as Te [1] and Zn [2]. Correlations were also observed for each element between elemental concentrations in bulk CCs, mass fractions of fine-grained matrix, and isotopic compositions. These correlations indicate a binary mixing between a chondrule reservoir and a matrix reservoir. Using the correlations, we constrained the elemental and isotopic compositions of MVEs in the chondrule and the matrix reservoirs. Compared to the matrix reservoir (a proxy for chondrule precursor compositions), the chondrule reservoir is volatile depleted and isotopically light, suggesting an incomplete condensation of MVEs into chondrules. Based on the isotopic compositions of Rb and K in the chondrule reservoir, we calculated the average chondrule cooling rate, using a simple condensation model, to be ~540±170 K/hour. This cooling rate is consistent with the chondrule cooling rates (10–1000 K/hour) constrained based on chondrule textures.

The study suggests that the isotopic compositions of MVEs in bulk CCs record a two-stage chondrite formation process, with the first stage being chondrule formation involving incomplete condensation of MVEs into chondrule melts during chondrule cooling, causing volatile depletion and isotopic fractionation in chondrules, and the second stage being mixing between the chondrules and matrix, which led to the observed isotopic correlations between MVEs. Unlike volatile depletion in the Moon, which was caused by partial evaporation of volatile elements in the protolunar disk [3], this study presents the first evidence that incompletion condensation played a role in volatile depletion in some planetary bodies.

[1] Hellmann et al. (2020) EPSL549, 116508. [2] Pringle et al. (2017) EPSL468, 62–71. [3] Nie and Dauphas (2019) ApJL884,