Constraining the kinship between CB and CH chondrites and the formation of CB chondrules using Cr isotopes

K. Zhu (朱柯)[1,2]*, H. Becker[1], Y. Jiang[3], P. Koefoed[4], K. Wang (王昆)[4] [1]Institut für Geologische Wissenschaften, Freie Universität Berlin, 12249 Berlin, Germany, [2]Bristol Isotope Group, School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK (*ke.zhu@bristol.ac.uk), [3]CAS Key Laboratory of Planetary Sciences, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, China. [4]McDonnell Center for the Space Sciences, Washington University in St. Louis, St. Louis, Missouri, 63130, USA

Introduction: Bencubbin-type (CB) and high-metal (CH) chondrites belong to the same clan, due to their similar chemical compositions, e.g., similar oxygen isotopic compositions and high abundance of metal and sulfide. However, whether they derived from the same reservoir in the protoplanetary disk is poorly understood [1, 2]. CB chondrites have large chondrules (up to 20 mm), and these chondrules formed later than chondrules in other groups of chondrites [3, 4], i.e., ~5 Ma after solar system formation. The CB chondrules are also very depleted in moderately volatile elements [5], which may relate to their presumed formation during the collision of two planetesimals [3]. Nucleosynthetic ^{54}Cr isotope variations (expressed as ε^{54}Cr, per ten thousand deviation of mass-independent ^{54}Cr/^{52}Cr isotope ratios relative to terrestrial standards) are a powerful tool to test the genetic relationships among solar system materials [2, 6]. Chromium (Cr) has a 50% condensation temperature of 1291 K [7], and its volatility increases with the fO_2 [8]. Mass-dependent Cr isotope variations (expressed as δ^{53}Cr, per mil deviation of mass-dependent ^{53}Cr/^{52}Cr ratios relative to NIST SRM 979) can be used to study isotopic fractionation during evaporation processes [9, 10]. The siderophile nature of Cr also makes it a tracer for metal-silicate segregation.

Samples and Methods: We selected four CB chondrites and three CH chondrites (including the data in [2]) for mass-independent Cr isotope measurments by the total evaporation method on Trion TIMS (FUB), ion-exchange column chemistry and the mass spectrometric method is decribed in [11]. The CB chondrules were extracted from the Gujba (fall) meteorite. The δ^{53}Cr values were measured on Triton TIMS (FUB) using double spike techiques [12] with an external 2SD uncertainty of ~0.013 ‰.

Results: CB and CH chondrites show homogenous ε^{54}Cr values of 1.51 ± 0.09 (2SD, N = 4) and 1.54 ± 0.13 (2SD, N = 3), respectively. Bulk Gujba has a δ^{53}Cr value of −0.28 ± 0.01 (2SD, N = 2) that is isotopically lighter than its chondrules with δ^{53}Cr values ranging from −0.32 to 0.02. Gujba chondrules have variable Cr contents (2900 – 4000 ppm), Mn/Cr (0.09 – 0.54) and Al/Mg ratios (0.086 – 0.118) , and the Mn/Cr and Al/Mg ratios are broadly anti-correlated with the δ^{53}Cr values.

Discussion and Conclusion: The ε^{54}Cr similarities between CB and CH chondrites strongly suggests that they formed from similar or the same precursors. Their ε^{54}Cr values are also similar to ε^{54}Cr of CI chondrites (~1.5, [2, 6]) which show the highest ε^{54}Cr value of chondrites, rich in presolar grains. However, CB and CH chondrites do not share common Δ^{17}O compositions. Furthermore, CB and CH chondrites have higher ε^{54}Cr values than the metal-bearing CR chondrites, suggesting that the latter derive from another reservoir. Thus, although CB-CH-CR chondrites are all relatively metal-rich compared to other carbonaceous chondrites, the assigned clan designation [13] should be reconsidered.

The isotopically heavy Cr in Gujba chondrules compared to the measurement of bulk Gujba could have been caused by Cr loss during the impact processes. This is further suggested by the “heavy” Cr and decreasing Al/Mg and Mn/Cr ratios. Note that, only in oxidized conditions, Cr would be more volatile than Mn [8]. This may further suggest the Gujba CB chondrules formed at a relatively oxidized condition [5]. Alternatively, isotopically heavy Cr in CB chondrules (silicates) could be caused by equilibrium isotope fractionation during metal-silicate segregation, which results in the isotopically light Cr in the matal phase, consistent with the *ab initio* calculation [14].

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