IMPACT OR SOLAR NEBULA ORIGIN OF CB CHONDRITES? EVIDENCE FROM FE ISOTOPES.

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Introduction: CB chondrites are unusual objects among the carbonaceous chondrites. They are characterized by extremely high metal contents (60 to 80 wt. %), abundant BO chondrule fragments and CC chondrules, as well as, the occasional occurrence of refractory inclusions, Al-rich chondrules and hydrated matrix lumps. A common feature is the presence of impact melts along grain boundaries that formed at relatively low temperature [1]. Many characteristics of these meteorites are consistent with a condensation origin: bulk compositions with high and unfractionated refractory element contents and strong depletions in moderately volatile element abundances, and the presence of chemically zoned metal (e.g., [2], [3]). However, there is a dispute whether condensation occurred in the solar nebula at a range of pressures, T and G/D ratios or later in a vapor cloud of a giant impact. Recent work shows that Pb-Pb ages and Hf-W systematics of Gujba and Hammadah al Hamra 237 (HaH 237) are consistent with a formation age at ~ 4563 m.y., about 5 m.y. after CAI formation [4, 5]. Such, relatively, young ages were interpreted to be consistent with late condensation from a vapor cloud formed during a giant impact of large planetesimals [4]. Here we report on bulk Fe isotope compositions in order to explore the evidence for a nebula or impact origin of these meteorites.

Fe isotopes: We analyzed the Fe isotopic composition of 20 mg samples of a metal separate of Gujba, and metal-rich samples of HaH 237 and Isheyevo by MC-ICPMS (Neptune). Irrespective of the small sample size, our analyses can be considered as bulk data, given that metal is the dominant constituent of these meteorites and by far the major carrier of Fe. Samples were dissolved by rock digestion methods and Fe was chemically separated by ion exchange chromatography. Measurements were performed with high mass resolution to separate Fe isotopes from molecular mass interferences (e.g., ArO) and applying standard bracketing (IRMM-014) with external mass bias correction using a Cu standard. Typical external reproducibility is 0.04 ‰ (2 SD). Further analytical details are given in [6]. All samples show mass dependent fractionation of ^{56}Fe and ^{57}Fe (Fig. 1). Metal in Gujba has Fe isotope composition of (δ^{56}Fe = +0.025±0.056 and δ^{57}Fe = +0.055±0.056), whereas HaH 237 (δ^{56}Fe = -0.297± 0.014 and δ^{57}Fe = -0.415±0.032) and Isheyevo (δ^{56}Fe = -0.443± 0.019 and δ^{57}Fe = -0.645± 0.026) bulk samples have compositions dominated by light Fe. The shift towards light Fe compositions in the latter two CB chondrites is much larger than typical of bulk carbonaceous and ordinary chondrites (δ^{56}Fe = ± 0.07) (Weyer et al. 2005; unpublished data).

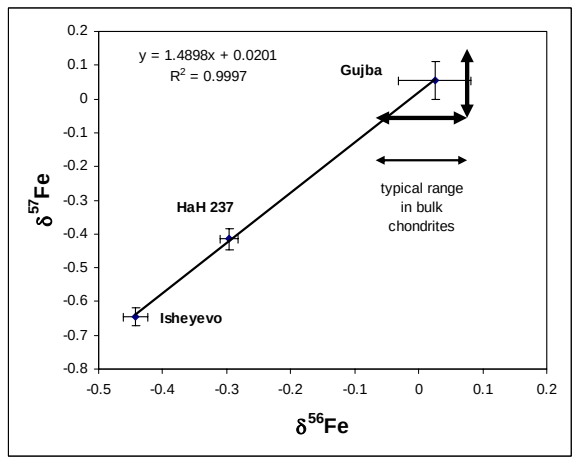

Figure 1: Mass dependent Fe isotope composition of metal in Gujba, and metal-rich bulk samples of Hammadah al Hamra 237 and Isheyevo. [Range of Fe isotopes in bulk samples of carbonaceous and ordinary chondrites are shown for comparison (Weyer et al., 2005 unpl. data)].

Discussion: CB chondrites are highly diverse objects and are chemically related to CR and CH chondrites [3]. Based on grain size of metal and chondrule fragments and presence/absence of refractory inclusions and of hydrated matrix lumps, two subgroups were introduced, coarse grained CB_a (Bencubbin/Weatherford/Gujba) and fine-grained CB_b (QUE 94411, HaH 237, and Isheyevo). The finding of a refractory inclusion in Gujba complicates its classification. Zoned metal grains are only observed in CB_b chondrites. The presence of type I and type II POP, PO and BO chondrules ties Isheyevo closer to CH chondrites than any of the other CBs [7].

In-situ measurements of Fe and Ni in zoned metal grains in HaH 237 show that on average rims have lighter Fe and Ni isotope compositions than Ni-rich cores [8]. The range in fractionation (8‰/amu) is consistent with rapid disequilibrium condensation. Our

data and previous findings of light ^{65}Cu in HaH 237 [9] confirm such a process even on the bulk level and imply that HaH 237 and Isheyevo metal formed in a reservoir more depleted in light Fe isotopes than metal in Gujba. We observe a sequence of Fe isotopes with increasingly lighter Fe from Gujba through HaH 237 to Isheyevo.

This finding has major implications for the formation of CB chondrites. A possible sequence includes: (a) formation of a gas phase enriched in light Fe isotopes, e.g., by condensation of early metal that was lost from this reservoir or by partial evaporation of Fe in a giant impact; (b) condensation of metal representing Gujba metal, and (c) further condensation of metal from an increasingly depleted reservoir under low pressures representing HaH 237 and Isheyevo metal.

The lack of zoned metal in Gujba could imply a prolonged period of extensive equilibration at higher temperatures. This is also consistent with the finding that the low temperature component, e.g., hydrated matrix lumps, are missing in these meteorites. On the other hand, CB_b chondrites must have experienced rapid removal from the high T zone to a low T regime which allowed (a) survival of some zoned metal and (b) incorporation of low T components, such as hydrated matrix lumps, as suggested by [1].

Since the observed range in Fe isotope fractionations among CB chondrites is much larger than that observed in bulk chondrites, and the chemical and mineralogical similarities among CB chondrites point to a rather localized source region, it is more likely that they formed in a vapor cloud produced by a giant impact rather than in the solar nebula. Such a formation environment is consistent with the younger formation ages recorded by Gujba and HaH 237 [4, 5].

However, the strong depletion of moderately volatile elements in HaH 237 cannot be the result of the giant impact. The ^{53}Cr/^{52}Cr and Mn/Cr ratios in HaH 237 are the lowest ratios measured in carbonaceous chondrites [10] and they fall on an isochrone with carbonaceous chondrites that defines an age close to the formation age of CAIs [10, 11]. Clearly the bulk of the Mn was lost at that time. Later loss of Mn from a chondritic reservoir during giant impact is incompatible with the observed Mn-Cr systematic.

References: [1] Meibom A. et al. (2005) *Meteoritics & Planet. Sci., 40,* 1377-1391. [2] Krot A. N. (2002) *Meteoritics & Planet. Sci., 37,* 1451-1490. [3] Weisberg M. K. et al. (2001) *Meteoritics & Planet. Sci., 36,* 401-418. [4] Krot A. N. (2005) *Nature, 436,* 989-992. [5] Kleine T. et al. (2005) *GCA, 69,* 5805-5818. [6] Weyer S. (2005) *EPSL, 240,* 251-264. [7] Ivanova M. A. et al. (2005) *Meteoritics & Planet. Sci., 40,* A74. [8] Alexander C. M. O'D. and Hewins R. H. (2004) *Meteoritics & Planet. Sci., 39,* A13. [9] Russell S. S. et al. (2003) *Meteoritics & Planet. Sci., 38,* A124. [10] Shukolykov A. and Lugmair G. W. (2001) *Meteoritics & Planet. Sci., 36,* A188-A189. [11] Palme xxxx