

IMPACT FORMATION OF CB CHONDRITES: THE METAL-RICH BODY HAD A SILICATE MANTLE. A. V. Fedkin¹, L. Grossman^{1,2}, M. Humayun³, S. B. Simon¹ and A. J. Campbell¹, ¹Dept. of Geophysical Sci., Univ. of Chicago, 5734 S. Ellis Ave., Chicago, IL 60637. avf@uchicago.edu, ²Also Enrico Fermi Institute, Univ. of Chicago, ³Dept. of Earth, Ocean & Atmospheric Sci., Florida State Univ., Tallahassee, FL 32310.

Introduction: Several lines of evidence suggest that CB chondrites condensed from the plume created in a large impact [1, 2, 3]. Pd/Ir ratios in unzoned metal grains in the CB_a chondrites require condensation from a gas with partial pressures of siderophiles many orders of magnitude higher than possible for the solar nebula [1], a fact confirmed by [4]. The plume in which condensation of both metal and chondrules in CB_as occurred was ascribed to a protoplanetary impact between a metallic and a low-FeO silicate body [1]. Chemically zoned metal grains in the CB_bs are also zoned in Fe isotopes, with light isotope-enriched cores grading outward to heavier compositions at their rims [5, 6], suggesting rapid, kinetically-controlled condensation as might be expected in an impact plume. Complementary Fe isotopic mass-fractionations between metal grains and chondrules in both CB_as and CB_bs [6, 7] indicate that the metal grains and chondrules are cogenetic, and that both CB chondrite types probably formed in the same process. The aim of the present work is to determine what the composition of the silicate impactor must have been in order that the compositions of the silicate droplets that condensed from its vapor plume under the same conditions as the metal grains match the compositions of chondrules observed in the CB chondrites.

Technique: At first, the impacting planetesimals were assumed to be a low-FeO, silicate-rich body and a metallic body containing solar proportions of Fe, Ni, Pd and Ir, as in [1]. A third component, residual nebular gas complementary to H chondrites, was also assumed to be present. The enrichments of the plume in matter from the metallic body and from the silicate-rich body relative to hydrogen were allowed to vary independently. The VAPORS program [8] was used to calculate the equilibrium compositions of silicates that co-condense with metal, and the bulk Fe, Ni, Co and Cr contents of that metal as a function of T at various combinations of dust enrichments and P^{tot} . Pd and Ir contents of the metal were then calculated using the same vapor pressure and activity coefficient data as in [9]. As work progressed, it was found necessary to add a fourth, more Ca- and Al-rich component to the plume.

Results: Fig. 1 compares computed trends of condensate metal grain compositions with observed bulk compositions of unzoned [1] and zoned [9] metal grains in CBs. Even at very high metal enrichments in

the plume, the high P^{tot} needed to fit the Pd/Fe vs Ni/Fe trends in the unzoned metal grains, as well as the contrastingly low value of P^{tot} needed to match the compositions of the zoned metal grains are typical. In Fig. 3, compositions of CC, SO and BO [10, 11] chondrules and chondrule-like objects from CBs are plotted (BO plotted as SO) in a portion of the CaO+Al₂O₃-MgO-SiO₂ triangle, and form an array with CaO+Al₂O₃ varying from 0 to 25 %. When any silicate rock is vaporized in this system, the variation with temperature of the composition of the subsequently recondensed silicate assemblage starts at the CaO+Al₂O₃ apex, increases its MgO content while passing well to the SiO₂-poor side of the chondrule array, and finally veers toward the SiO₂ apex, always crossing the array at only a single point if CaO+Al₂O₃ of the starting material is low enough. Thus, the chondrule composition array cannot be reproduced by condensation from a vapor plume formed by impact between a metallic body and either a chondrite, an aubrite, a diogenite, a howardite, a eucrite, a dunite or a harzburgite. The higher the CaO+Al₂O₃ of the vaporized rock, the higher the CaO+Al₂O₃ will be at the point where its recondensation product crosses the chondrule array. This suggests that the chondrule array can be explained by the impact model only if two silicate components were vaporized in the impact, one with high CaO+Al₂O₃, such as a howardite, and one with a much lower CaO+Al₂O₃ content. If the impact plume is spatially heterogeneous, containing variable proportions of the two vaporized silicate components, a family of recondensation trajectories will result that cross the chondrule array from end to end.

Noting the solar proportions of siderophiles in CR chondrite metal [12] and oxygen isotopic similarity of CR silicates to those in CBs, we assumed that one of the impacting bodies was a CR chondrite that had differentiated into a core and mantle. MELTS [13] was applied to the bulk composition of volatile-free Renazzo [14] to compute the equilibrium metal and silicate compositions at 1900K and $\log f\text{O}_2 = \text{IW}-2.5$, and Cr was distributed between them as in [15]. This metal composition was adopted as the CR core component of the plume. When MELTS was used at 1460K and the same $f\text{O}_2$, the complementary silicate was found to consist of 20% liquid, which was assumed to form a crust, and 80% solid with relatively low CaO+Al₂O₃, referred to as CR mantle. The crust

was assumed to have been stripped away by impacts prior to the CB-forming impact between the residual CR planetesimal and a body with the overall composition of the Kapoeta howardite [16]. When enough CR core and total silicate are present in the plume to yield atomic Ni/H and Si/H of 10^4 and $1500 \times$ their solar values, resp., and P^{tot} of the plume is 10^{-2} bar, the calculated trajectory of liquid condensate metal compositions is a good fit to the Pd/Fe (and Ir/Fe) vs Ni/Fe (Fig. 1) and Cr vs Ni (Fig. 2) trends seen in unzoned CB metal grains. Zoned grain compositions are fit at lower P^{tot} , where they condense as solids. Trajectories of silicate compositions computed for various CR mantle/Kapoeta ratios sweep through the entire range of CaO+Al₂O₃ contents of CB chondrules (Fig. 3) and capture the negative slope of their FeO vs SiO₂ trend (Fig. 4).

Conclusions: A set of physico-chemical conditions was found that allows co-condensation of metal and silicate compositions like those in CB chondrites from a plume of vaporized planetesimals, but only if the bodies that impacted to form the plume had contrasting silicate compositions whose relative proportions varied spatially within the plume.

References: [1] Campbell A. J. *et al.* (2002) *GCA*, 66, 647-660. [2] Rubin A. E. *et al.* (2003) *GCA*, 67, 3283-3298. [3] Krot A. N. *et al.* (2005) *Nature*, 436, 989-992. [4] Fedkin A. V. *et al.* (2013) *LPS XLIV*, Abstract #2309. [5] Alexander C. M. O'D. & Hewins R. H. (2004) *MAPS*, 39, A13. [6] Zipfel M. & Weyer St. (2007) *LPS XXXVIII*, Abstract #1927. [7] Tang H. & Dauphas N. (2012) *EPSL*, 359-360, 248-263. [8] Ebel D. S. & Grossman L. (2000) *GCA*, 64, 339-366. [9] Campbell A. J. *et al.* (2001) *GCA*, 65, 163-180. [10] Krot A. N. *et al.* (2001) *Science*, 291, 1776-1779. [11] Krot A. N. *et al.* (2001) *MAPS*, 36, 1189-1216. [12] Kong P. *et al.* (1999) *GCA*, 63, 2637-2652. [13] Ghiorso M. S. & Sack R. O. (1995) *Cont. Min. Pet.*, 119, 197-212. [14] Weisberg M. K. *et al.* (1993) *GCA*, 57, 1567-1586. [15] Chabot N. L. & Agee C. B. (2003) *GCA*, 67, 2077-2091. [16] Mittlefehldt D. W. *et al.* (1998) In *Revs. Min.* 36, pp. 4-1-4-195.

