

**A KINETIC MODEL FOR CHEMICAL AND FE ISOTOPIC ZONING OF METAL GRAINS IN CB<sub>6</sub> CHONDRITES BY CONDENSATION FROM A PLUME MADE BY IMPACT VAPORIZATION OF DIFFERENTIATED CR CHONDRITE BODIES.** A. V. Fedkin<sup>1</sup>, L. Grossman<sup>1,2</sup>, M. Humayun<sup>3</sup>, S. B. Simon<sup>1</sup> and A. J. Campbell<sup>1</sup>. <sup>1</sup>Dept. of Geophysical Sci., Univ. of Chicago, 5734 S. Ellis Ave., Chicago, IL 60637. avf@uchicago.edu, <sup>2</sup>Enrico Fermi Inst., Univ. of Chicago, <sup>3</sup>Dept. of Earth, Ocean & Atmospheric Sci., Florida State Univ., Tallahassee, FL 32310.

**Introduction:** In pursuing the idea that CB chondrites condensed from a vapor plume created in a large impact [1, 2, 3], one of the impacting bodies was assumed in [4] to have the overall composition of a CR chondrite and to have differentiated into a core, mantle and crust. Here, the second body is assumed to be identical to the latter. Simultaneous enrichment of Ir/Fe and Pd/Fe ratios in unzoned metal grains in CB chondrites requires high partial pressures of siderophiles [1,4], conducive to condensation at high temperature, where the alloy would have condensed as a liquid, and under near-equilibrium conditions. In contrast, chemical zoning of the zoned metal grains [5, 6] in general and light Fe isotope enrichment of their cores [7, 8, 9] in particular suggest kinetically controlled condensation, probably at relatively low partial pressures and correspondingly low temperatures, where the grains would have condensed as solids. In the present work, a kinetic model is used to find physico-chemical conditions for a region of the plume that account for both the chemical and Fe isotopic zoning of zoned metal grains in the CB<sub>6</sub> chondrites.

**Model:** Compositions of the metal core and silicate fraction of the differentiated CR body were computed by applying MELTS [10] to a water-free, Renazzo-like composition at  $\log f_{O_2} = IW - 2.5$  and 1900K. The silicate was then differentiated into 80% solid mantle and 20 % liquid crust by using MELTS at the same  $f_{O_2}$  and 1460K. Water was assumed to have been accreted afterward, amounting to 15-20 wt% of the total silicate. The plume formed in an impact between two such differentiated CR bodies was assumed to be spatially heterogeneous in  $P^{tot}$  and relative amounts of residual nebular gas, vaporized core, vaporized mantle and vaporized crust. Equilibrium condensation models give good matches to the compositions of unzoned metal grains and CB chondrules in plume regions with  $P^{tot} = 10^{-2} - 10^{-3}$  bar, and Ni/H and Si/H enrichments of  $3 \times 10^3 - 3 \times 10^4$  and 300-500, resp., relative to solar composition [11]. Similar Ni/H and Si/H of  $2.5 \times 10^3$  and 500, resp., were used for the zoned grains.

**Method:** The kinetic condensation model of [12], employing the Hertz-Knudsen equation to compute the flux of all elements or isotopes of interest across gas-condensed phase interfaces, was applied to a single silicate droplet, whose radius would reach ~0.35 mm

upon total condensation of lithophiles, and the number of coexisting metal grains that would each grow to a radius of ~200  $\mu m$  upon total condensation of the proportionate amount of siderophiles. The initial composition of the droplet was assumed to be that of the equilibrium silicate at the assumed nucleation temperature and  $P^{tot}$ . At lower temperature, equilibrium vapor pressures over the droplet were computed with MELTS when  $FeO > 0.3$  wt%; otherwise, the CMAS model [13] was used. For the metal phase, an initial nuclear radius of 0.01  $\mu m$  was assumed; activity coefficients were from [14] for Fe, Ni and Cr and from [6] for Co, Pd and Ir. In addition to using the same evaporation coefficients and isotopic fractionation factors as in [12], the evaporation coefficients of Ir, Pd, Co and Cr in the metal and that of Cr in the silicate liquid were assumed to be equal to that of Fe in the respective phase. Cooling rates of 50-150K/hr were assumed.  $P^{tot}$  was assumed to be  $1.6 \times 10^{-4} - 3 \times 10^{-4}$  bar at the metal nucleation temperature, but a linear dependence of  $\log P^{tot}$  vs  $1/T$  was also assumed such that  $P^{tot}$  fell by either 1 (the P/10 case) or 3 (P/1000) log units in the 500K interval below that temperature. The compositions of the silicate droplet and external metal grains were calculated as a function of falling temperature. Metal was assumed to condense as concentric spherical shells upon the preexisting metal grains. The latter were not allowed to equilibrate internally or with the silicate droplet, but the droplet was allowed to equilibrate its internal  $f_{O_2}$  gradually with that of the ambient gas, as in [12]. At each temperature step, the gas composition was corrected for material that had condensed in the previous step, so the changing composition of the metal reflects removal from the gas of material by both metal and silicate phases. As found in [6], supersaturation of the metal phase must be assumed to avoid huge Ir enrichments in grain centers. In the present work, the Fe abundance is so high that the silicate droplet becomes 10 times richer in total Fe than either BO or CC chondrules unless droplet nucleation occurs well below the onset of metal condensation. Accordingly, model results illustrated here are for metal nucleation at 1740K, i.e.  $\Delta T = 101K$  and 146K below the equilibrium condensation temperature of Ir, the most refractory of the siderophiles considered here, in the P/10 and

P/1000 cases, resp., and for delay of silicate condensation until 1665K. Results are relatively insensitive to the vaporized crust/mantle ratio or the water content of the silicates.

**Results:** Elemental zoning profiles computed at a cooling rate of 50K/hr are compared (Fig. 1) to those measured in [6] by LA-ICP-MS with a spot diameter of  $\sim 30 \mu\text{m}$ . In so doing, the centers of the measured profiles were assumed to be the points of highest Ir content, and average concentrations along successive  $30 \mu\text{m}$  segments of the continuous theoretical profiles were plotted as discrete points centered  $30 \mu\text{m}$  apart. Concentration profiles of Ir, Ni, Co and Cr in 3 grains are well fit by the models under the conditions noted, although predicted Co contents are slightly lower than observed. Smaller central peaks and shallower profiles would result from lower  $P^{\text{tot}}$  or Ni/H and from higher cooling rate or  $\Delta T$ . The P/1000 case gives better fits than P/10, capturing the Cr upturn at the grain edges especially well. Both cases end at 1238K, where both Fe and Cr are nearly fully condensed in the P/10 case, and have basically stopped condensing in P/1000. The more rapid decline of  $P^{\text{tot}}$  in P/1000 causes less condensation at each temperature. This becomes particularly acute at lower temperatures where Cr, due to its greater volatility, becomes more excluded from the grain than Fe, leading to lower Cr concentration at the edges. Calculated  $\delta^{56}\text{Fe}$  (Fig. 2) is -18‰ in the grain cores, due to more rapid condensation of the lighter isotope, and rises to rim values of +99 (P/10) and +4.5‰ (P/1000). The core-rim difference in  $\delta^{56}\text{Fe}$  in the latter case is in good agreement with that measured in a CB metal grain, 16‰ [7], but larger than those of others, 5‰ [8], and 8‰ and 0‰ [9]. An impact-generated vapor plume with spatial heterogeneity in physico-chemical conditions is a viable environment for forming both unzoned and zoned metal grains as well as the chondrules in CB chondrites.

**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.* (2014) *LPS XLV*, Abstract #2153. [5] Petaev M. I. *et al.* (2001) *MAPS*, 36, 93–106. [6] Campbell A. J. *et al.* (2001) *GCA*, 65, 163–180. [7] Alexander C. M. O'D. & Hewins R. H. (2004) *MAPS*, 39, A13. [8] Zipfel J. & Weyer St. (2007) *LPS XXXVIII*, Abstract #1927. [9] Richter F. M. *et al.* (2014) *LPS XLV*, Abstract #1346. [10] Ghiorso M. S. & Sack R. O. (1995) *CMP*, 119, 197–212. [11] Fedkin A. V. *et al.* (2015) *GCA*, subm. [12] Fedkin A. V. *et al.* (2012) *GCA*, 87, 81–116. [13] Berman R. G. (1983) PhD, UBC. [14] Ebel D. S. & Grossman L. (2000) *GCA*, 64, 339–366.

