CB Chondrites Could Have Formed in an Impact Plume

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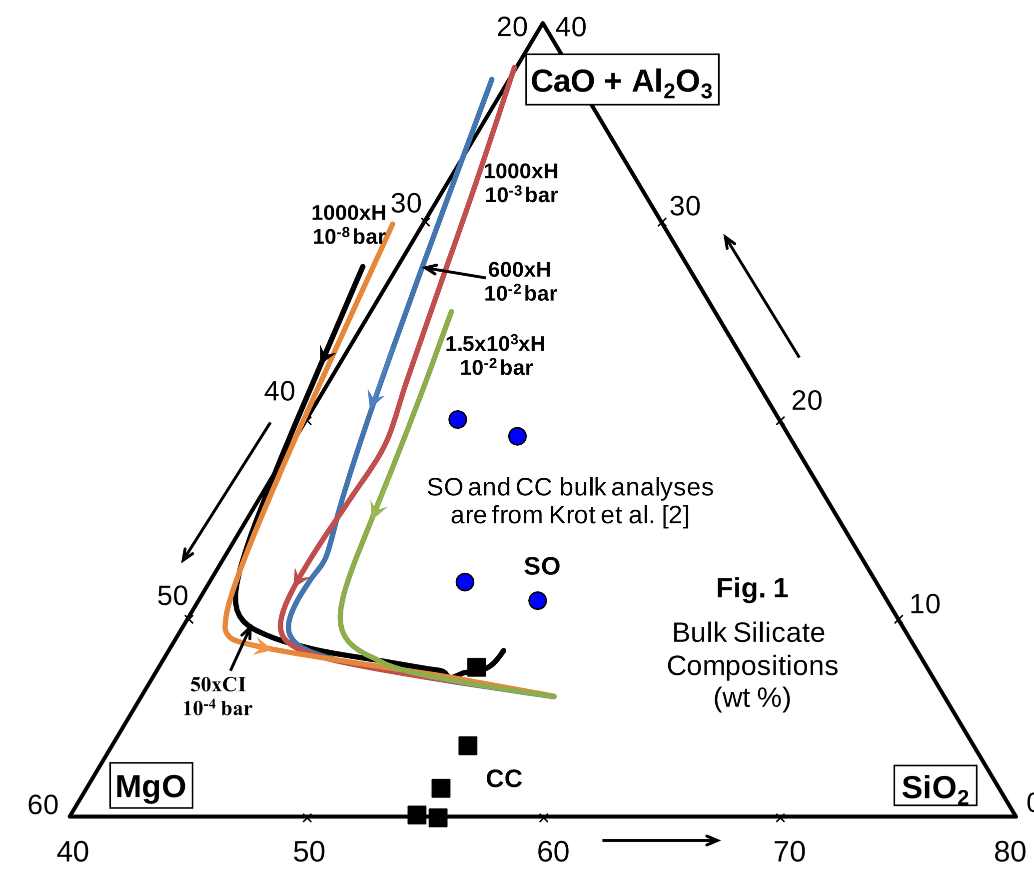
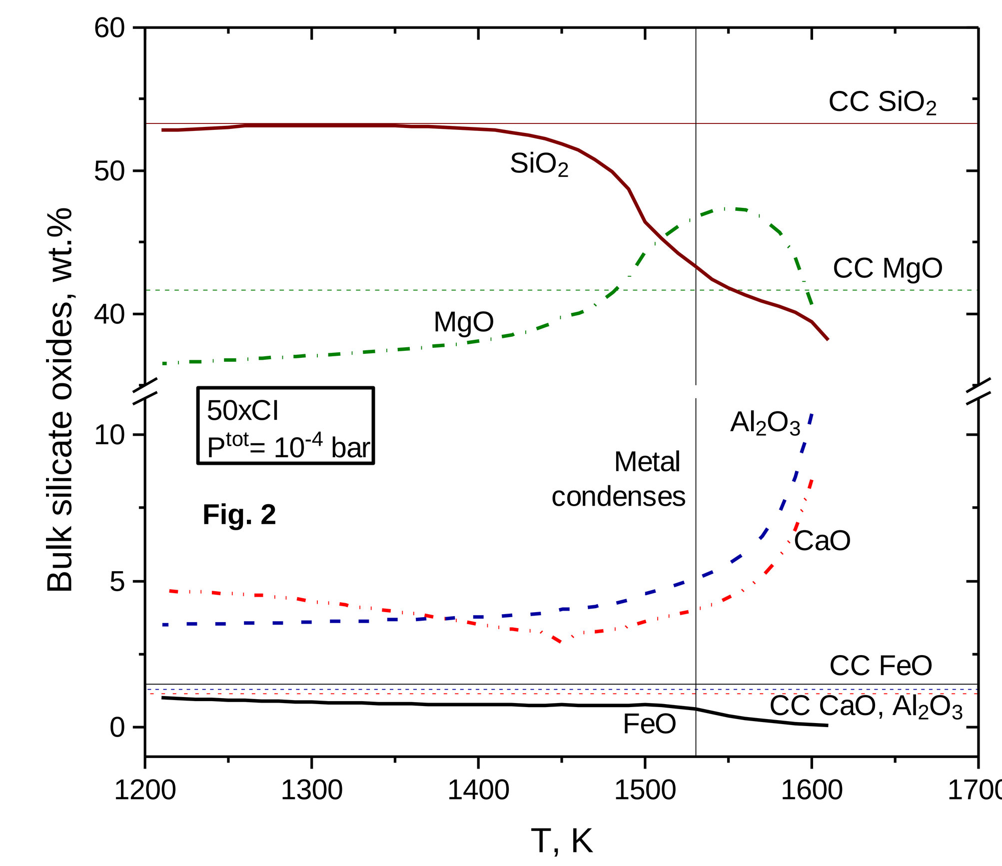
Introduction: Bencubbin-like meteorites (CB) are metal-rich chondritic breccias containing about 60 vol% metallic (Fe,Ni) [1]. Unlike the CB_a (Bencubbin, Weatherford, Gujba) subgroup, the CB_b (HH 237 and QUE 94411) chondrites contain abundant chemically zoned (Fe,Ni) metal grains [2]. Petaev *et al*. [3] proposed that the zoned metal from QUE 94411 (QUE) condensed at a total pressure (P^{tot}) of 10^{-4} bar from a solar nebular region enriched in dust of ~CI composition by a factor of 10-40 relative to solar abundances. Krot *et al.* [2] suggested that skeletal olivine (SO) chondrules in CB_b chondrites condensed at a higher T than cryptocrystalline (CC) chondrules, and that both types condensed at a higher T than the metal, all at conditions inferred in [3] and earlier than the formation of most chondrites. Campbell *et al*. [4] found that the Ir/Fe, Pd/Fe and Ni/Fe ratios in unzoned metal grains in the CB_a chondrites are consistent with condensation from a gas whose partial pressures of siderophiles were 10^7x higher than in a gas of solar composition at $P^{tot}=10^{-4}$ bar, and suggested that both the metal and the low-FeO, barred olivine (BO) and CC chondrules in the CB_as condensed from a plume generated by a protoplanetary impact involving a metal-rich body and one containing low-FeO silicates. Krot *et al*. [5] used ^{207}Pb-^{206}Pb dating to show that HH chondrules and SO chondrules from Gujba formed ~5 my after CAI condensation, and suggested that the components of CB_a and CB_b chondrites formed in a giant impact: SO chondrules and unzoned metal in Gujba by melting, CC chondrules in HH by gas-liquid condensation and zoned metal grains in HH by gas-solid condensation. This model does not explain the unique siderophile element contents of Gujba metal, however, and Fe isotopic fractionation between Gujba metal and chondrules [6] suggests that the unzoned metal condensed quickly before the Gujba chondrules. **The purpose of this work** is to test the impact plume model of [4] by looking for a set of conditions that would explain the origin of all the components of CB chondrites.

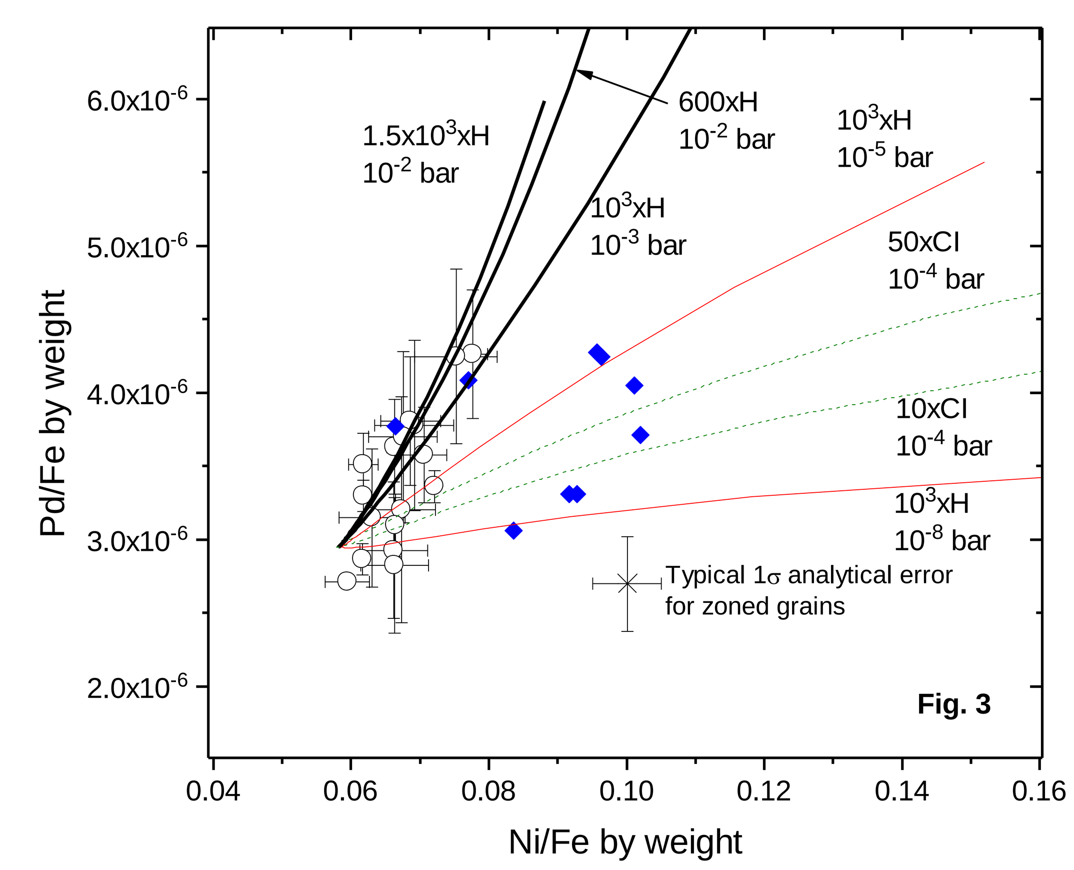
Technique: As in [4], a metallic and a silicate body were assumed to have impacted one another. The CR metal composition [7] and that of an H chondrite [8] were assumed for the metallic body and the silicate body, respectively. Dust is assumed to contain 2.8 parts of CR metal and 1 part of H chondrite by weight (see the Table), yielding a condensable fraction containing 60 vol% metal, corresponding to CB chondrites. The system composition is calculated by combining the composition of the dust and that of residual nebular gas complementary to the H chondrite component, so the dust enrichment is 9.6x larger for siderophiles than for lithophiles, relative to solar composition. Equilibrium compositions of silicates and metal (Fe,Ni,Cr,Co,Si) were computed with VAPORS [9] as a function of T at various combinations of dust enrichment and P^{tot}. Pd and Ir contents of the metal were then calculated using the vapor pressure and activity coefficient data of [10].

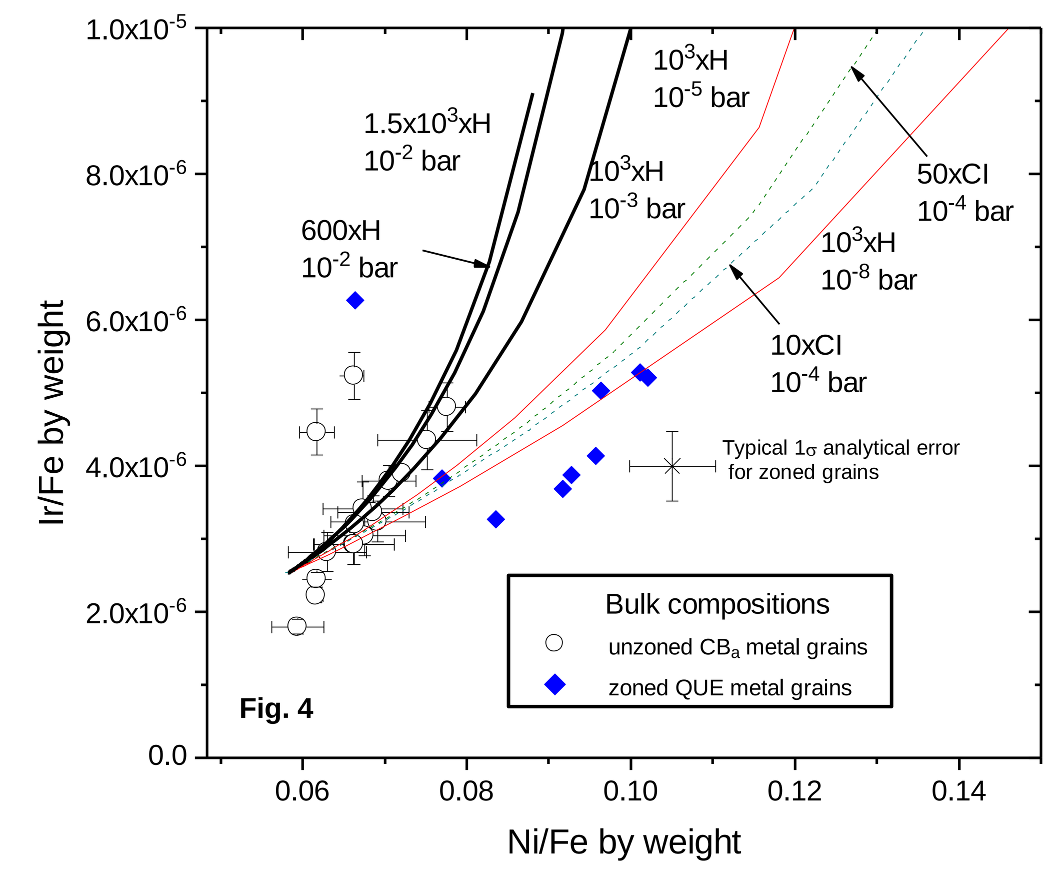
	Dust	Gas	System (H dust/gas=10^3)
	Atoms per 10^6 Si	Atoms per 10^6 Si	Atoms per 10^6 Si
Si	1.000E+06	0.000E+00	1.000E+06
Ti	2.466E+03	0.000E+00	2.466E+03
Al	6.891E+04	1.599E+04	6.893E+04
Cr	3.382E+04	0.000E+00	3.382E+04
Fe	8.545E+06	0.000E+00	8.545E+06
Mn	7.174E+03	2.376E+03	7.176E+03
Mg	9.474E+05	1.266E+05	9.475E+05
Ni	4.726E+05	0.000E+00	4.726E+05
Co	2.158E+04	0.000E+00	2.158E+04
Ca	5.094E+04	1.016E+04	5.095E+04
Na	4.556E+04	1.184E+04	4.557E+04
K	3.137E+03	6.332E+02	3.137E+03
O	3.435E+06	1.023E+07	3.445E+06
C	1.503E+04	6.834E+06	2.187E+04
S	1.014E+05	3.444E+05	1.017E+05
H	5.837E+04	2.790E+10	2.796E+07
He	0.000E+00	2.720E+09	2.720E+06

Results: At the low end of the range of CI dust enrichments, 10x, proposed by [3] for zoned metal grain formation, there is no field of silicate liquid stability. At the upper end, 50x, silicate condensate composition trends intersect the field of CC chondrules at the upper end of their range of $CaO+Al_2O_3$ (Fig. 1), but at an FeO content (0.77 wt%) at the low end of those for CCs (0.7-2.5 wt%), Fig. 2.



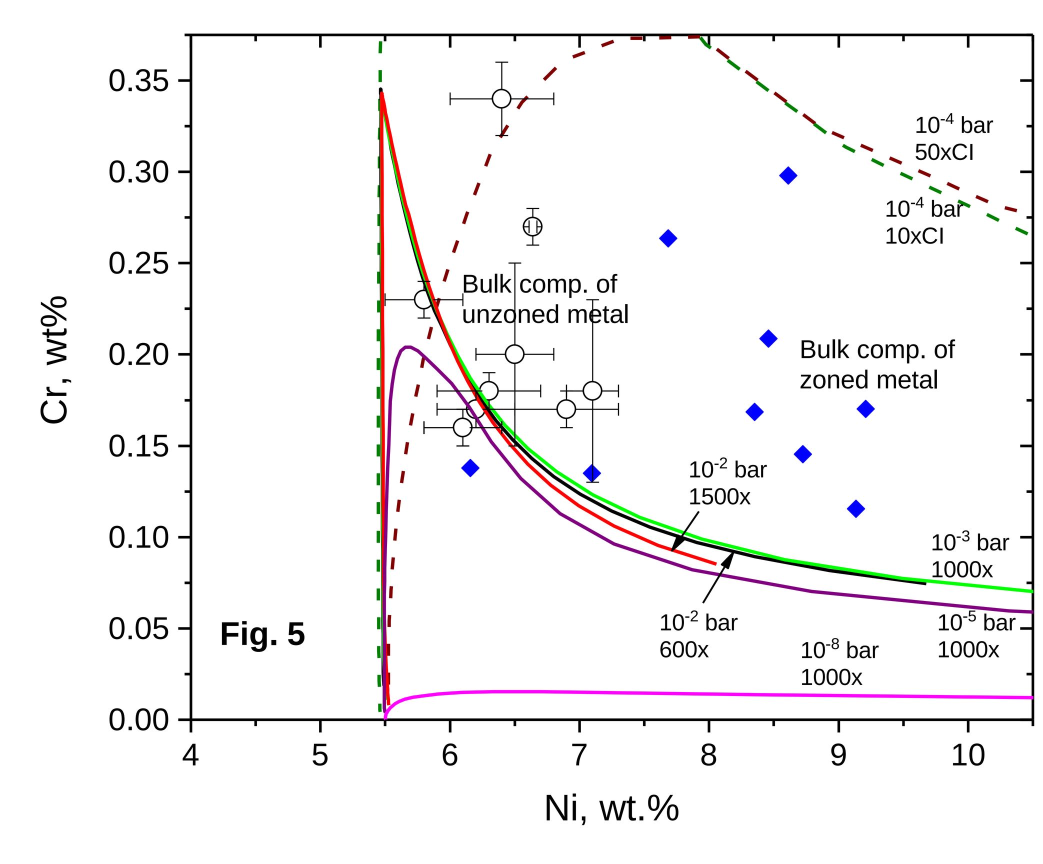






On Figs. 3 and 4, the family of curves for the 10-50x range of CI dust enrichments passes through a few of the bulk compositions of zoned metal grains. They intersect the composition trends of the unzoned grains at the lower ends of the ranges of Pd/Fe and Ir/Fe ratios; to reach the highest Pd/Fe ratios among the unzoned grains requires much higher siderophile partial pressures, as seen by [4]. It is noted that the modest P^{tot} and dust enrichment of [3] are possible solar nebular conditions not requiring an impact plume for their production. For the plume model involving an impact between a CR metal body and an H chondritic body, computed paths of silicate compositions do not match bulk compositions of SO chondrules but, for H dust enrichments of 600-1500x, FeO contents (0.8-2.2 wt%) are like those of CC chondrules where the paths intersect the CC chondrule trend (Fig. 1).

At these H dust enrichments, calculated composition paths of metal condensates at $P^{tot}=10^{-2}$-10^{-3} bar are very good matches to the bulk compositions of unzoned grains from CB_as in Figs. 3 and 4. Model curves at $P^{tot}=10^{-5}$-10^{-8} bar give good matches to Pd and Ir contents of many zoned metal grains from QUE and of those unzoned grains with relatively low Pd contents (Figs. 3, 4). A wide range of bulk Cr contents is observed at a given Ni content in both kinds of metal grains. The CR metal used in modeling is low in Cr (0.25 wt%) relative to solar proportions. Predicted Cr contents are in good agreement with those of many grains with low Ni contents but 30-50% below those of many high-Ni zoned grains (Fig. 5).



Conclusions: Condensation of metal in CB chondrites requires an H dust/gas ratio of 600-1500 relative to solar composition at P^{tot} of 10^{-2}-10^{-3} bar for unzoned grains (where they would be liquid) and 10^{-5}-10^{-8} bar for zoned ones (where they would be solid), Fig. 3. Both grain types could have formed in the same impact plume if it were heterogeneous in P^{tot}. Though the assumed dust enrichments would stabilize the FeO contents of CC chondrules, very few CB chondrules have bulk compositions lying along equilibrium condensation trends (Fig. 1), so they cannot form in the way suggested in [5]. Both SO and CC chondrules may have formed by melting of silicate mixtures. Higher silicate dust enrichments are needed to stabilize higher FeO contents of SO chondrules.

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