BENCUBBINITE FORMATION: THE TURBULENT LIFE OF METAL AS INFERRED FROM GERMANIUM ISOTOPES

G. Florin[1,2], B. Luais[1], T. Rushmer[2] and O. Alard[2], [1]CRPG-CNRS UMR7358, University of Lorraine, 54501 Vandoeuvre-les Nancy, France (gflorin@crpg.cnrs-nancy.fr, luais@crpg.cnrs-nancy.fr), [2]Macquarie University Sydney, Australia (tracy.rushmer@mq.edu.au, olivier.alard@mq.edu.au)

Introduction: Bencubbinites (CB) are carbonaceous chondrites that show an unusual enrichment in metal, up to 80% in the form of FeNi metal rounded grains. Their siderophile element composition is volatility-controlled, with a strong depletion in moderately siderophile and volatile elements (e.g. germanium) relative to CI abundances [1]. CB chondrites are subdivided in two subgroups, CBa and CBb, on the basis of their differences of texture and composition, including the presence of elemental and isotopic zonations in CBb (e.g. Fe, Ni, refractory and transitional elements), which are rare in CBa [2]. These zonations have been first described to result of condensation under canonical nebula conditions [3]. However, inconsistencies between PGEs zoning patterns in metal grains and equilibrium condensation from a solar gas at $P^{tot}=10^{-4}$bar [1] have led researchers to debate in favor of non-equilibrium condensation under metal-rich supersaturated gas [1]. Condensation modeling based on elemental, isotopic data in silicate and metal [4] and Fe, Ni isotope data in zoned metal grains [5] have described a zoned impact plume model through equilibrium/kinetic condensation for CBas and CBbs, respectively. As Fe and Ni variations record high temperature condensation ($T_{50\%}$≈1300 K at 10^{-4}atm), here we propose a complementary isotopic investigation of germanium (Ge) ($T_{50\%}$=883 K at 10^{-4} atm) in CB bulk metal and metal grains in order to identify lower temperature condensation.

Samples and Methods: Two CBa (Gujba, Benccubin) and one CBb (HaH 237) have been chosen to study equilibrium and kinetic condensation processes. As CBs metal have very low Ge contents (0.1-1.5 ppm [1]), 300mg of metal bulk of each meteorite, and two large metal grains separates from Gujba have been processed for Ge elemental and isotopic measurements. Bulk metal has been digested using HNO_3, while separate metal grains have been sequentially digested into three fractions of ≈33% each, from the edge, the middle and the core of the grains to assess isotopic zonation, called hereafter *"in situ"* fractions. Germanium purification from Fe-Ni matrix has been adapted from Luais protocols [6, 7] to allow the chemistry of large sample amount, by using 10ml of cationic (AG 50W-X8, H+ form) resin. Germanium isotopic measurements have been performed at the CRPG-Nancy (France) [6, 7] using the Neptune*Plus* MC-ICP-MS coupled to a hydride generator system. Ge isotopic compositions are reported as ‰ $\delta^{74/70}$Ge ratios relative to NIST 3120a Ge standard solution, and with a long-term reproducibility of 2SD ≈ 0.1‰.

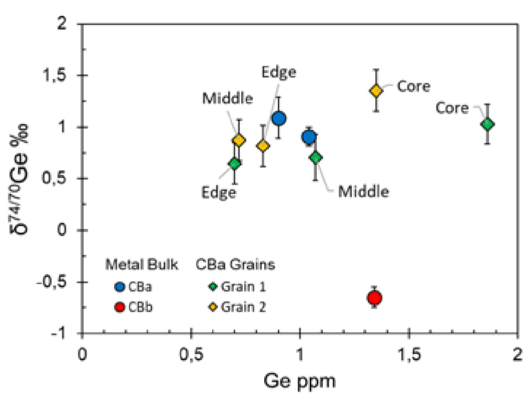

Figure 1: $\delta^{74/70}$Ge vs Ge in CB chondrites

Results and Discussion: We report the first Ge isotopic analyses on bulk metal of CB chondrites and *"in situ"* individual metal grain fractions. The two CB groups are easily resolvable for their bulk metal isotopic compositions, with $\delta^{74/70}$Ge= +0.97±0.16‰ and $\delta^{74/70}$Ge= -0.65±0.1‰ for CBa and CBb, respectively. The sequentially digested metal grains from Gujba (CBa) show a zonation in $\delta^{74/70}$Ge that decreases from the core to the edge (*Figure 1*).

During kinetic condensation, light isotopes are preferentially incorporated in the condensed phase. Our data indicate two cooling modes for CBa and CBb that reflect the thermal zoning of an impact plume [4]. Lower [Ge] and higher $\delta^{74/70}$Ge of CBa suggest condensation at equilibrium in an environment with low cooling and condensation rates such as the interior of the plume. CBb with higher [Ge] and lower $\delta^{74/70}$Ge would experience high cooling rates and kinetic condensation as expected for the external part of the plume. As most of Gujba (CBa) metal grains are known to be isotopically homogeneous in Fe and Ni [4], the $\delta^{74/70}$Ge zonations in the two analyzed grains are unexpected. We propose a two-step condensation at equilibrium. As the plume is cooling from the edge to the core, the centre of the plume would be to hot for metal to condense, thus CBa core had been firstly formed in a colder intermediate part. Then, due to turbulence, grains are carried in a warmer region (i.e. the centre) where Ge and its light isotopes evaporate, causing the metal of the core to be enriched in heavy isotopes. Finally, as temperature slowly drops, vapor re-condensation on the surface of previous metal grains leads to the light external Ge isotopic composition of new metal condensates.

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