IGNEOUS DIFFERENTIATION PRESERVED IN A LARGE METAL GRAIN FROM THE RENAZZO CR2 CHONDRITE

N. Chaumard[1], M. Humayun[2], B. Zanda[1], and R. H. Hewins[1,3]

[1] Institut de Minéralogie, de Physique des Matériaux, et de Cosmochimie, UPMC, MNHN – UMR CNRS 7590, 61 rue Buffon, 75005 Paris, France.
[2] Dept. of Earth, Ocean, and Atmosphere Science & National High Magnetic Field Laboratory, Florida State University, 1800 E. Paul Dirac Drive, Tallahassee, FL 32310, USA.
[3] Dept. Earth & Planetary Sciences, Rutgers University, Piscataway, NJ 08854, USA.

Introduction

Origin of metal, which is a ubiquitous phase in carbonaceous chondrites (CCs) [e.g. 1], is still subject to debate. Different models of formation have been proposed such as direct condensation from the nebular gas [e.g. 2], condensation of vaporized Fe-Ni alloy [e.g. 3], reduction of iron contained in silicates [e.g. 3, 4], and destabilization of sulfides [e.g. 5].

Large isolated metal grains in CR chondrites, one of the most metal-rich group of CCs [e.g. 6], appear to have originated as liquid droplet, but little evidence of igneous differentiation in these former droplets has been reported so far. To enhance our understanding of the origin of metal grains in CCs and the possible formation of metal from a liquid as argued by [7], we present here a detailed LA-ICP-MS analysis of a large metal grain found in the CR2 Renazzo chondrite with excellent igneous zoning preserved.

Methods

We imaged a fragment of Renazzo by CT scanning (v|tome|x 240L from GE Sensing & Inspection Technologies Phoenix X|Ray) to enable analytical measurements passing through the centers of metal grains. Then, we cut and polished the fragment until we obtained a surface corresponding to an equatorial section of a millimeter-sized metal grain isolated in the matrix (Fig. 1).

SEM-BSE-SE images and EDS maps (at *MNHN*): Tescan VEGA II LSU electron microscope equipped with a SD^3 detector (Bruker).

Laser ablation ICP-MS analyses (at *FSU*): New Wave UP193 FX excimer laser ablation system coupled to a Thermo Element XR ICP-MS.
- Laser tracks: 15 µm spot size, 5 µm.s^{-1} speed, 50 Hz repetition rate, 100% power output (1.49 GW.cm^{-2})
- Laser spots: 150 µm spot size, 10 s. dwell time, 50 Hz repetition rate, 100% power output
- Standards: North Chile (Filomena) IIA and Hoba IVB iron meteorites, and NIST SRM 1263a

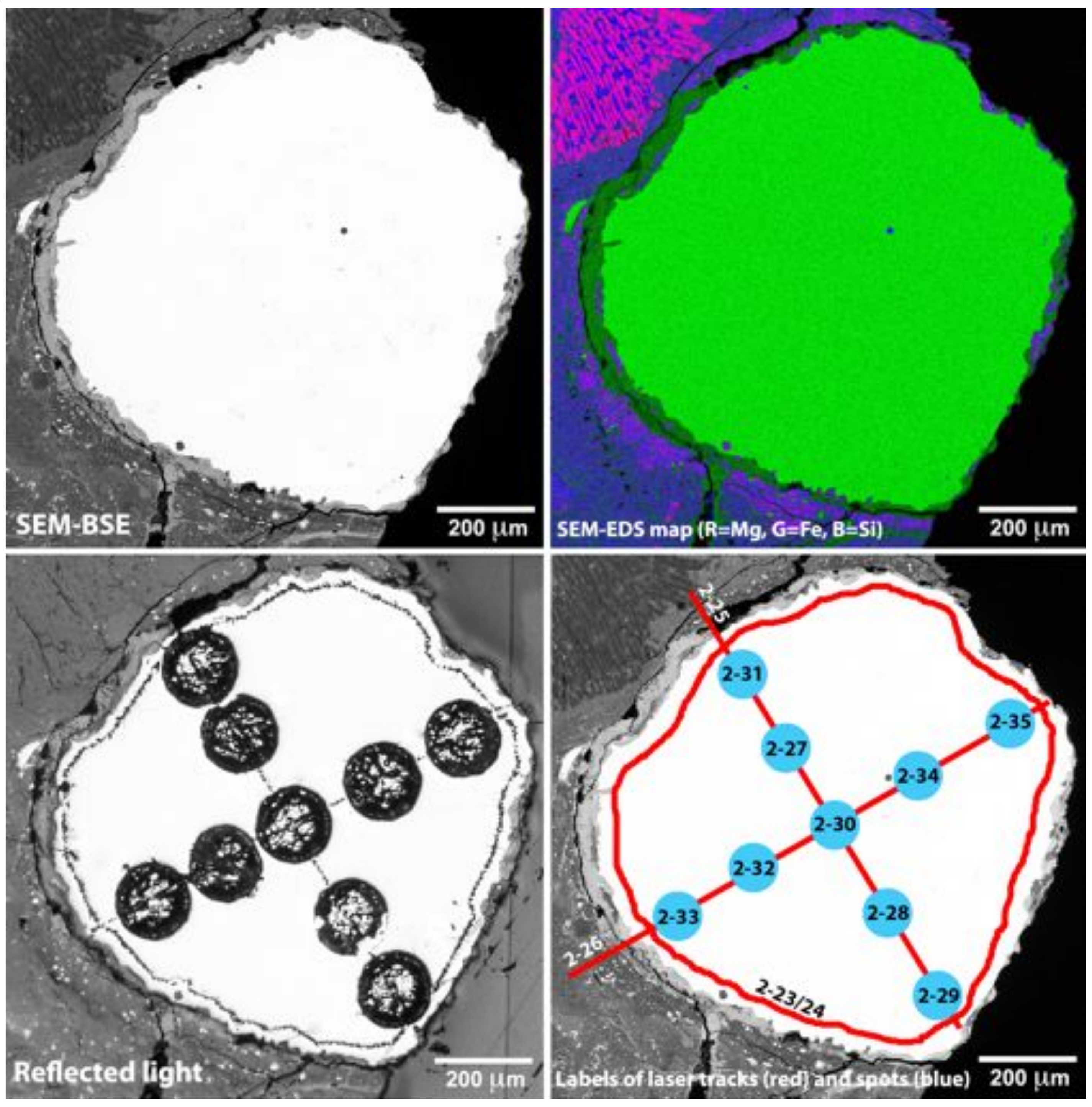
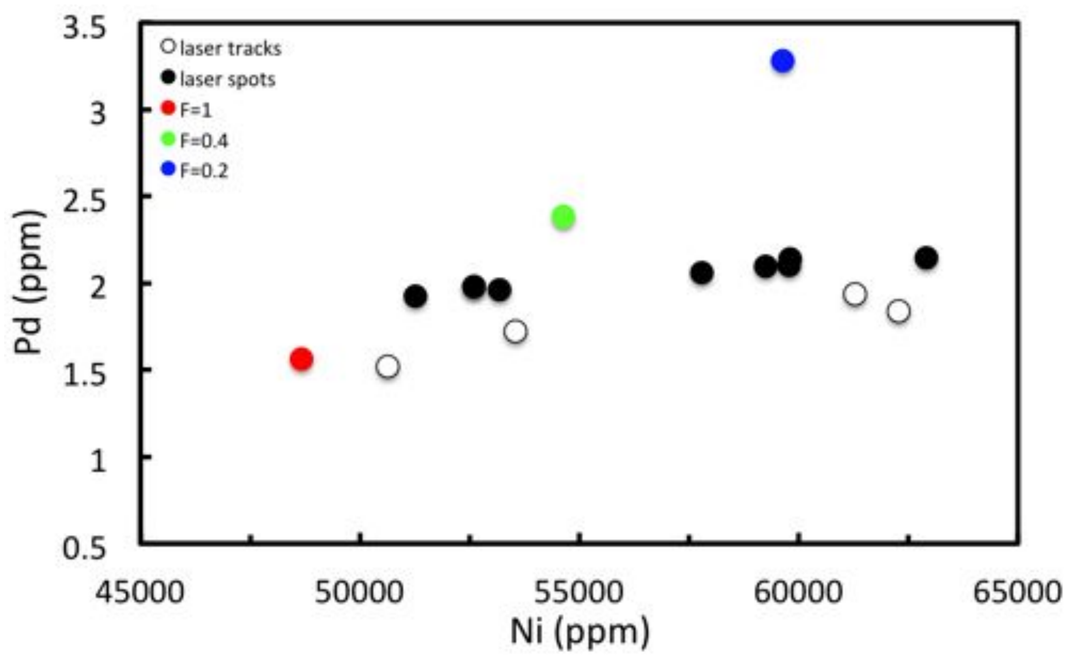


Figure 1: Various images of the metal grain investigated here, before and after LA-ICP-MS analysis.

Results

- Au is correlated with volatile siderophile elements (Cu, Ga, and Ge), and anticorrelated with refractory siderophile elements, as well as Ni, Co, and Pd. W and Ni are correlated with Pd (Fig. 2).
- Symmetric chemical zonation for Ir (Fig. 3a) and Os, which exhibit ~1 order of magnitude variation in their ratios relative to Ni (Fig. 4).
- The Os-, Ir-rich zone displays subchondritic W/Re ratios and high abundances of compatible elements (e.g. Re, Os, Ir, Ru) while the most external spots display a relatively flat pattern in refractory elements, with abundances close to the CI values (Fig. 4).
- U-shaped chemical profiles for Cu (Fig. 3b), Ga, and Ge measured for laser tracks passing through the center of the grain.
- Using the method developped by [8], cooling rates estimated here range from 0.1 to 1 K.h^{-1} for peak temperature of ~1473±100 K.

Figure 2. Pd vs. Ni for averaged track compositions and spot analyses measured by LA-ICP-MS. Theoretical abundances (colored points) were calculated for solid metal in equilibrium with a fractionated liquid, initially of CR metal bulk composition of [10], for residual melt fraction (F) = 1 (red), 0.4 (green), and 0.2 (blue).



We used the solid metal/liquid metal partition coefficients defined by [9] to calculate compositions of a liquid with the bulk composition of CR metal [10] that evolved during fractional crystallization (FC) and the solid in equilibrium with this liquid for different melt fractions (F) (Fig. 2, 4).

Negative anomalies for Pd, abundances of W, Re, Os, Ir, and Co, as well as, to a lesser extent, Ru, Pt, Rh, and Mo abundaces are well reproduced.

Measured Au, As, Cu, Ga, and Ge abundances display larger variations than those predicted by our model of FC (Fig. 4). The lowest abundances of these volatile elements were measured in the core of the grain.

Discussion

- Os and Ir chemical zoning, siderophile element patterns, anticorrelation Pd-Au, and correlation W-Pd all support a formation by FC. Our model of FC confirms this igneous origin, in particular for the negative anomalies in Pd which cannot be a result of condensation.
- Based on the chemical zoning patterns, the first metal to crystallize was the Os-, Ir-rich zone (Fig. 5). The latest metal in the crystallization sequence evident in this grain is at the borders.The residual liquid is not observed.
- Since the lowest Au, As, Cu, Ga, and Ge contents were measured in the core of the grain, abundances of these elements were most probably modified by diffusion after crystallization. Enrichments for these elements from the core to the borders of the grain relative to the prediction of our FC model support a re-condensation of Au, As, Cu, Ga, and Ge to the exterior of the grain that diffused inwards during cooling.
- Igneous zoning profiles, e.g. Ir and Os, were only preserved due to the lower diffusion coefficients of these elements relative to Au, As, Cu, Ga, and Ge [11]. However, former igneous zoning profiles were, depending on the diffusion coefficient of the element considered, more or less affected by diffusion after crystallization (Fig. 2; Pd diffuses faster than Ni at T<1300°C).

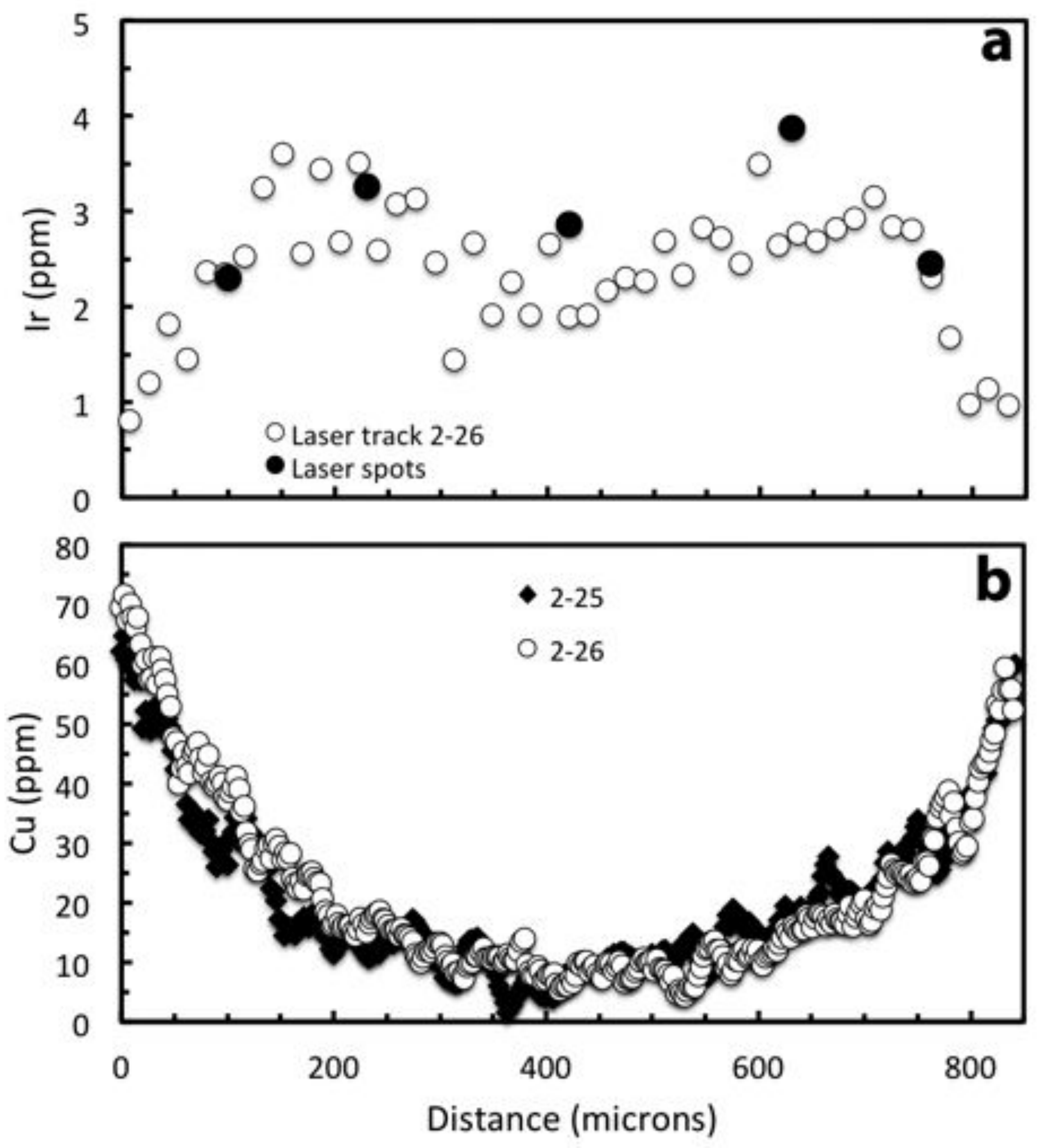


Figure 3. (a) Zoning profile of Ir for the 2-26 laser track passing through the center of the grain (empty circles) and for the 5 spot analyses measured along this track (black circles). (b) Zoning profile of Cu for the two laser tracks (2-25 and 2-26) passing through the center of the grain.

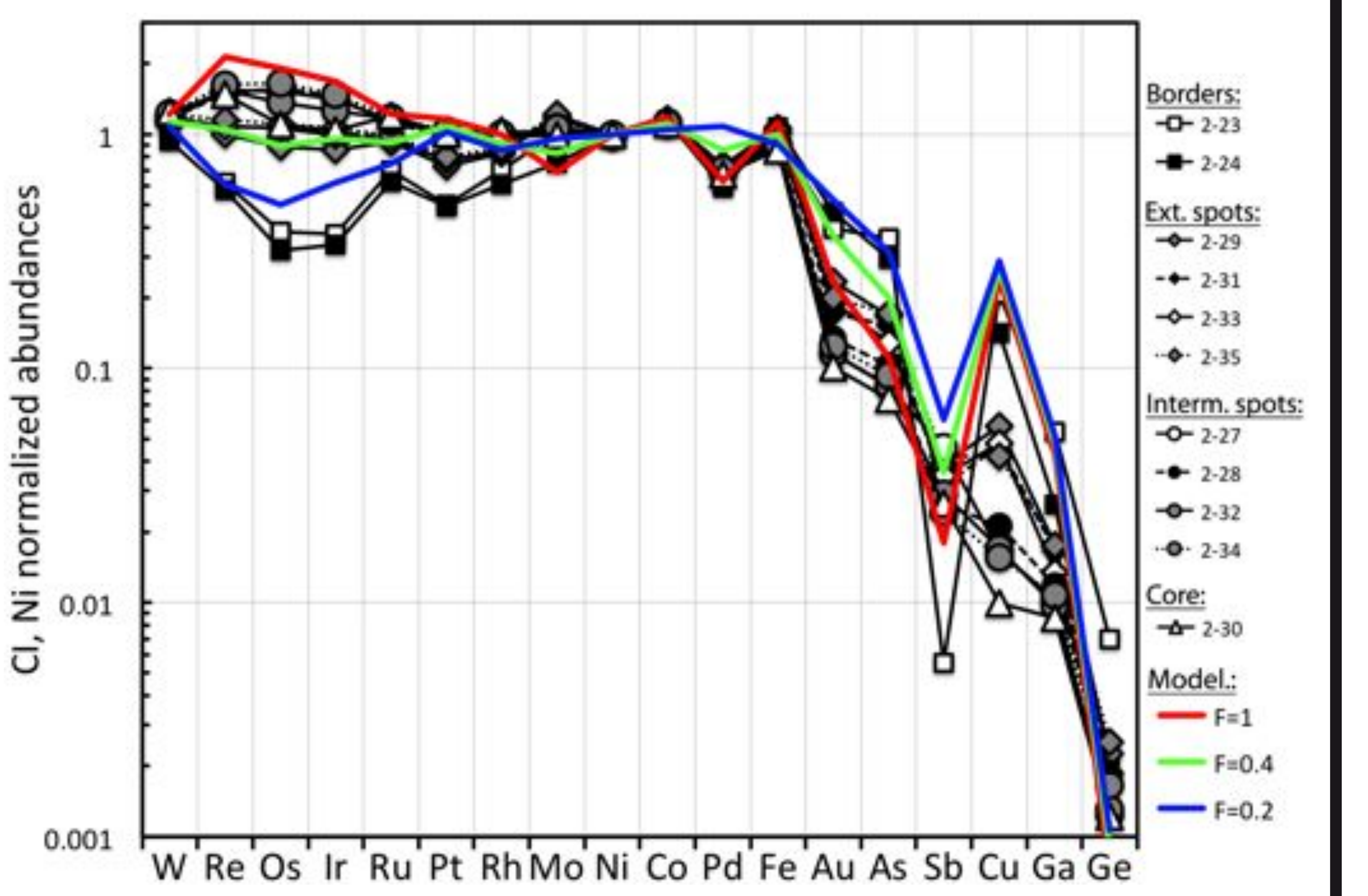
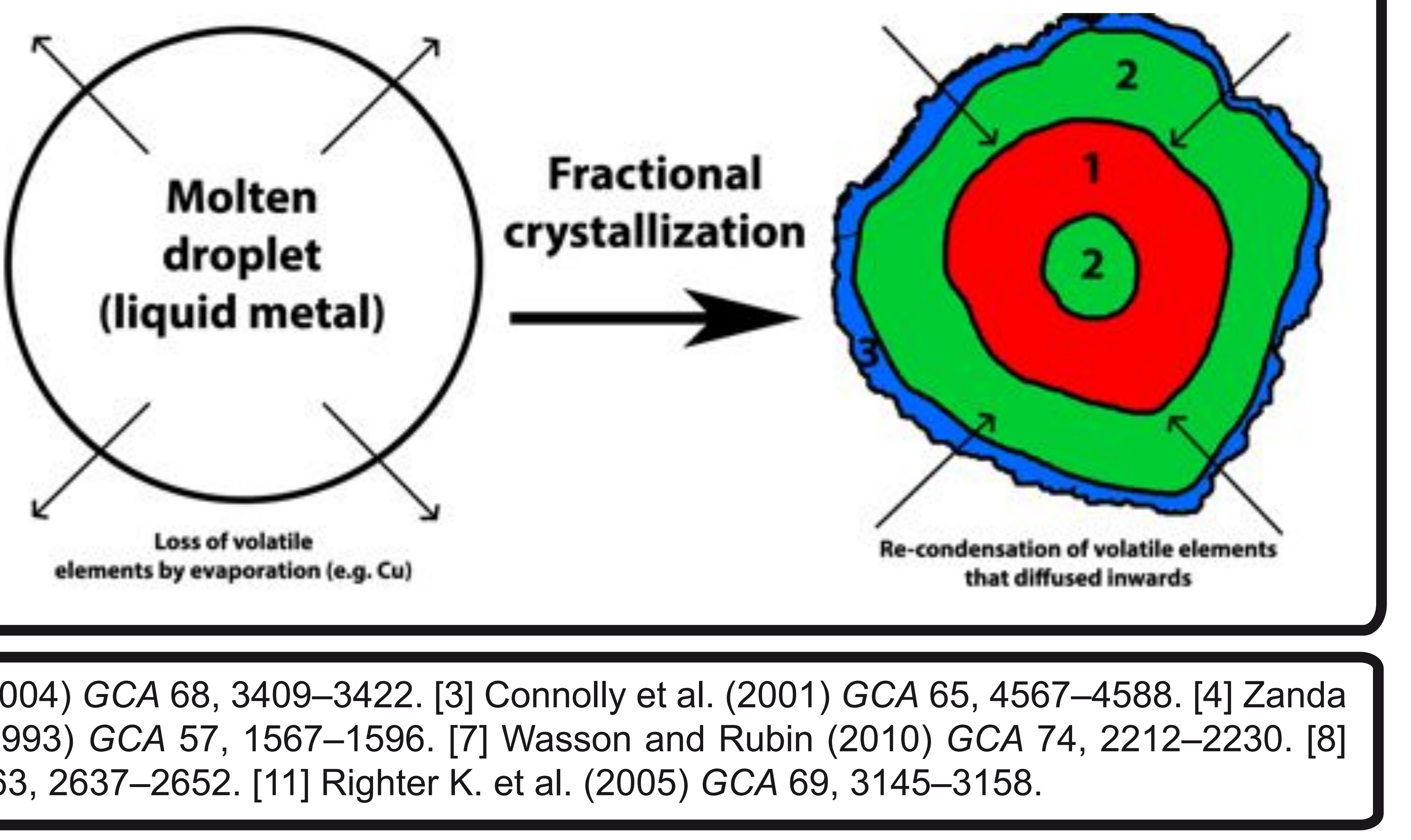


Figure 4. CI-, Ni-normalized siderophile element pattern for track and spot analyses measured by LA-ICP-MS. Pattern calculated for solid metal in equilibrium with a fractionated liquid, initially of CR metal bulk composition of [10], for residual melt fraction (F) = 1 (red), 0.4 (green), and 0.2 (blue).

Conclusion

The origin of this large metal grain can be explained by the fractional crystallization of a molten droplet with a bulk composition of CR metal, followed by the evaporation of volatile siderophile elements such as Au, As, Cu, Ga, and Ge which re-condensed to the exterior of the grain then diffused inwards during cooling.

Figure 5. Sketch of the proposed formation scenario for the large isolated metal grain study here. The 1, 2, and 3 labelled areas correspond to the first, second, and third solid metal which crystallized.



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