THE FREQUENCY OF FE-POOR RELICTS IN TYPE II CHONDRULES OF CARBONACEOUS AND ORDINARY CHONDrites

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Introduction: Relict grains are mineral fragments that are in chemical disequilibrium with surrounding minerals and mesostasis [1]. The most common relict grains are Mg-rich (olivine or pyroxene) in porphyritic Fe-rich (type II) chondrules [2,3]. Typically, they show sharp transitional boundaries between the core and normally-zoned rim [4]. The petrographic and geochemical constraints suggest that these relict grains are part of the precursor material of type II chondrules, which were not totally melted during the chondrule-forming event(s) [1,5,6]. Analysis of natural chondrules and experimental analogs indicate that ameboid olivine aggregates (AOA) or type I-like chondrules could be the source of these relict grains [5,7,8].

To constrain further the nature of the dust present in the formation region of type II chondrules, we determined the frequency and Petrographic characteristics of their relict grains, using polished sections of four unequilibrated chondrites found in El Médano (hereafter EM) and Los Vientos (hereafter LoV) dense collection areas. These correspond to three CO-type carbonaceous chondrites (EM 397, EM 465 and LoV 123) and one L-type ordinary chondrite (LoV 098).

Method: The petrography and mineralogy of type II chondrules and relicts were determined through optical microscope, backscattered electron (BSE) image, X-ray compositional maps and spot analysis. We used two Secondary Electron Microscopes (SEM): Zeiss Evo MA10 with an energy dispersive spectroscopy (EDS) and Oxford X-MAX N 20 SDD at Universidad de Atacama and Universidad Austral de Chile, respectively. The analysis condition of both was a 3 nA electron beam accelerated at 15 kV. Modal abundances of type II chondrules and percentage abundance of relicts were determined through manual point counting (2000 random points) using the JMicrovision software.

Results and discussion: Results and discussion: We examined all type II chondrules in the four sections (N=490). We selected ten representative type II chondrules with relict grains for detailed petrographic study, seven in the carbonaceous chondrites and three in the ordinary chondrite. All ten chondrules are composed of relatively large fayalite phenocrysts associated (sometimes) with smaller ones immersed in a feldspathic mesostasis (Fig. 1 and 2). The mean fayalite composition of host olivine is 24.4±8.4 (range of 14.86-40, N=13) and 33.3±11.9 (range of 10.39-49.02[1] [2], N=36) in ordinary and carbonaceous chondrites, respectively. The chondrules are semi-rounded but not, in general, perfectly circular in the cross section. Mean sizes are 400 and 250 µm in ordinary and carbonaceous chondrites, respectively. Our survey estimates low quantities of sulfides, metal beads, and chromites in almost all the studied chondrules.

![Figure 1. BSE images of type II chondrules and relicts in CO carbonaceous chondrites. a) Chondrule Ch_07 in EM 465 displays a Fe-poor relict with normal zoning (white arrow) as well as a pyroxene-rich chondrule[1] relict with apparent diameter of 170 µm (lower right). b) Chondrule Ch_18 in LoV 123 shows a Fe-poor chondrule-like relict.](image-url)
Abundant 20 to 30 µm metal beads (mainly kamacite) are immersed in Ca-poor pyroxene crystals. The position of Fe-poor relicts is random among type II chondrules and most of them were found as (i) isolated phenocrysts surrounded by Fe-rich rims or (ii) clusters of phenocrysts (3 or more), where each grain is surrounded by a Fe-rich mantle (Fig. 2). We described two relict grains that have metal beads (kamacite) of ~15 µm in diameter (Fig. 1b).

The modal abundance of type II chondrules is 9.2, 6.4, 6.9 and 37.2 vol% in LoV 123, EM 465, EM 397 and LoV 098, respectively. Previous modal abundance determination of type II chondrules in CO chondrites showed significantly lower range, 3.6 to 1.1 vol% [9], compared to our results. Regarding ordinary chondrites, a 55.1 vol% of type II chondrules in Hallingeberg (L3.5) and a 36.2 vol% in Sharp (H3.4) was estimated [9], similar to our survey in LoV 098 (L3).

The frequency rate of relict grains in type II chondrules of CO chondrites is chondrite-dependent with a range between 38.3 to 48.7 % and a mean value of 45.6% (115 with relicts and 137 without relicts). Our SEM survey of the LoV 098 ordinary chondrite shows that only 19.7% of type II chondrules present relict grains (47 with relicts and 191 without relicts). This is much lower than the estimate of 36.4% previously reported for Semarkona (LL 3.0 chondrite) [2]. Our results for CO chondrites also show significantly lower values than reported for ALHA77307, where three of the four type II chondrules studied contained forsterite relicts (75%) [3]. Subsequent analysis of Colony, Allan Hills A77307, and Yamato 81010 by [10] shows that 26 of 28 type II chondrules contain relicts (92%). The difference in the occurrence of relicts in type II chondrules could be related to (i) a bias from using a 2D section [11], or (ii) intrinsic heterogeneities between the different CO carbonaceous chondrites.

The high abundance of coarse-grained components in CO chondrites (~60 vol% [12]) could indicate that fine-grained particles were restricted in the CO nebular reservoir, and probably controlled by a high dust/gas ratio. In this sense, the high dust/gas ratio in the CO nebular reservoir agrees with the high number of relicts in type II chondrules [10], therefore a high abundance of dust should have been present at the time of type II chondrule melting event. However, the mean chondrule sizes of CO chondrites (90 µm [12]) are representative of a dust-poor environment, which tends to produce small chondrules, few igneous rims and few compound chondrules [13].

These findings suggest that relicts Fe-poor grains in type II chondrules are heterogeneously distributed in the CO parent body(ies). These results can improve the current analysis of dust/gas ratio and total gas pressure in the CO chondrite nebular reservoir.

**Figure 2.** Type II chondrules and relicts in LoV 098. a) BSE images and b) false color compositional maps of chondrule Ch_12. Fe-poor relicts are found as (i) isolated phenocrysts surrounded by a thin fayalite-rich rim (upper left) and (ii) clusters of phenocrysts (right), where one of them shows an oscillatory zoning pattern (white arrow).