

ACCRETION OF DUST TO MAKE FINE-GRAINED RIMS ON STILL COOLING CHONDRULES

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Introduction: Primitive chondrites are samples of the asteroids formed in the early solar system [1]. Understanding their accretion in term of temporality, mechanisms and physical conditions is fundamental. Located at the interface between the high temperature components and the fine-grained matrix (mostly formed at low temperature) fine-grained rims (FGRs) most likely hold valuable information about the dust accretion process. However, most primitive chondrites (and their FGRs) are affected by secondary hydrothermal modifications that have obscured their original nature to various degrees. In addition, FGRs are difficult to analyze since they consist of a heterogeneous nanometer-sized phase assemblage. To address these problems, we conducted a systematic survey of FGRs in three of the least altered chondrites from different chondrite groups (Semarkona, DOM 08006, QUE 99177, following previous work on Paris [2]) using the ACADEMY methodology [3] at the SEM and TEM scales. The objective is to study how chondrules could have interacted with the fine-grained dust of the nebula.

Method: For each sample, we selected a set of representative rimmed chondrules showing minimal traces of alteration. Using the ACADEMY methodology, we did high resolution SEM mapping coupled with EPMA analysis, to obtain phase abundances, a density map and the bulk composition of the analyzed area. Four FIB sections were then extracted from each meteorite (12 in total), in the rims and their adjacent matrix for quantitative TEM analysis.

Results: At the SEM scale, texture, modal abundances and compositions differ between FGRs and their adjacent matrix. The amorphous silicate is always more abundant in the rim (mean $\sim 93 \pm 7\%$) than the matrix (mean $\sim 80 \pm 6\%$), while anhydrous silicates and sulfides are less abundant ($4 \pm 0.05\%$ vs. $10 \pm 0.1\%$ and $0.5 \pm 0.004\%$ vs. $2 \pm 0.01\%$ respectively) and smaller ($< \text{few microns}$) in the rim, yielding distinctive compositions for rims and matrix.

At the TEM scale, the matrices of DOM 08006 and Semarkona show domains of amorphous silicate associated with randomly distributed crystalline nano-phases (sulfides, Fe-Ni metal, anhydrous silicates) and an abundant porosity ($\sim 8\%$ and 20% respectively). The associated rims in Semarkona and DOM 08006 (and Paris) exhibit more compact textures ($\sim 2.6\%$ and 5.8%) in which crystalline phases are not randomly dispersed anymore but are grouped in specific regions (clumps) and embedded in an amorphous/poorly crystallized silicate. In Semarkona, one rim shows a progressive, radial microstructure evolution. Starting from the same crystalline clumps + amorphous microstructure but getting closer to the chondrule, the abundance of the poorly crystallized silicates decreases while the abundance and grain size of the anhydrous silicates and Fe-sulfides increases. Inversely, in QUE 99177 no textural difference is observed and the porosity is low both in the matrix and the rims ($\sim 4\%$). Despite these textural differences, the compositions in major elements of the amorphous regions are similar for the rim and the matrix within a given chondrite (but differ between chondrite).

Discussion: Pristine chondrites reveal systematic differences between matrices and FGRs while the composition of the amorphous silicate is similar in both areas. It suggests that matrix and FGRs accreted similar type of dust but were subsequently affected afterwards by different physical processes [4]. (1) Matrix appears to have accreted a higher amount of crystalline phases in comparison to the rim, leading to a slightly different global composition. This could be explained either by the addition of chondrules fragments after rim formed [5], or represent an independent reservoir enriched in crystalline phases. (2) FGRs: in all groups, when they texturally differ from their adjacent matrix, appear to evolve toward the same micro-texture (compact amorphous + clumps of crystalline phases). Assuming that the matrix preserved the initial texture, FGRs in all groups must have been affected by a similar process to pass from the initial texture to the observed one. Aqueous alteration is unlikely to account for this feature, given the elevated abundance of amorphous silicate and the absence of secondary alteration phases in FGRs [6]. As an alternative, we propose that FGRs accreted on chondrule rapidly after their formation, while they were not entirely cooled, whereas matrix accreted later in a cooler environment. Accretion on a “hot” particles could induce a mild annealing and explain their more compacted nature. If, for each chondrite group, dusts accreted on chondrules at a different temperature, it might have led to different degrees of compaction/annealing of the sub-domains that could possibly explain the second order textural differences observed between the rims in different groups.

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