Evidence for Accretion of Fine-Grained Rims in a Turbulent Nebula for CM Murchison.

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Introduction: Fine-grained rims (FGRs) are dust-sized material that surrounds chondrules and refractory inclusions in chondritic meteorites. The origin of FGRs in CMs is still debated and formation in both nebular [1] and parent body [2-4] settings have been proposed. One observation taken as evidence for nebular formation of FGRs in CMs is a positive correlation between rim thickness and the size of the interior chondrules [1,5], which is not expected for formation in a parent body regolith [3]. However, previous measurements were made using 2D thin sections that yield only apparent chondrule size and rim thicknesses. In addition, many CMs show evidence of deformation that would have altered the shape of the chondrule and rim [6-7]. An alternative theory of FGR formation proposes that the rim forms through aqueous alteration of the chondrule on the parent body [2]. If true it is expected that as alteration proceeds and the volume of FGR increases, the shape of the chondrule core would increase in irregularity as embayments are formed along the chondrule exterior [4]. In this scenario it also may be expected that rim composition is influenced by the composition of the core particle. We are using X-ray CT to examine the 3D morphology and composition of FGRs in CM Murchison for which we have previously documented the deformational strain and resulting aqueous alteration [6]. Previously [8] we reported that the size relationship between the FGRs and interior chondrule cores in CM Murchison are consistent with nebular FGR formation as suggested by [9]. Here we explore whether the nebular environment was laminar or turbulent, which should result in slightly different FGR/chondrule size relationships [5,9]. We also define a new shape index to more unambiguously characterize the chondrule core to evaluate whether the irregular (non-spherical) shape of some Murchison chondrules is a primary or secondary (i.e., alteration) feature.

Methods: We scanned six small orientated chips (0.143 – 3.6 g; some embedded in epoxy) of CM Murchison USNM 5487 at the University of Texas High-Resolution X-ray Computed Tomography Facility (UTCT). The final reconstructed voxel (3D pixel) size ranged from 5.5 to 9.9 microns. Chondrules within the X-ray CT datasets were manually segmented twice in Avizo: both with and without the FGR. Segmentation data was exported into the Blob3D program [10-11] and chondrule size and orientation measured with and without the FGR. Chondrule FGR volume was determined by subtraction of the two measured volumes. To determine the relationship between the FGR volume and interior core radius while including the uncertainty in FGR volume (4.1%) we used the Levenberg-Marquardt method to determine a non-linear least squares fit to the data [12]. Chondrule shape irregularity is quantified via a Roughness index, which we define as the surface area of the chondrule divided by the surface area of a best-fit ellipsoid to the chondrule. This ensures that the chondrule shape irregularity measurement is independent of the degree of flattening the chondrules experienced during parent body deformation [6].

Results: A total of 61 chondrules were segmented. We find a very strong correlation ($R^2 = 0.98$) using a power law relationship between the rim volume and the equivalent spherical radius of the chondrule core as suggested by [9] for nebular FGR formation. The power law exponent of this relationship indicates that the nebula environment was weakly turbulent and that the rimmed chondrules were slightly larger than Kolmogorov-stopping-time nebular particles [9]. There is no correlation ($R^2 = 0.00$) between the degree of irregularity (Roughness) of the chondrule and the relative rim volume, suggesting that the FGR is not a result of alteration of the chondrule core and is instead a primary feature. FGR composition as inferred from effective X-ray attenuation coefficient appears essentially uniform across interior chondrule types and compositions, also making formation by chondrule alteration unlikely. Finally, we find a chondrule-roughness dependence of the rim volume to interior chondrule radius relationship when the data are split into two groups based on the Roughness index.

Conclusions: We find that the size relationship between the FGRs and interior chondrule cores in CM Murchison are consistent with FGR formation in a weakly turbulent nebula as suggested by [9]. We propose that the irregular shape of some chondrules in CM Murchison are a primary feature resulting from chondrule formation and that chondrules with a high degree of surface roughness accreted a relatively larger amount of nebular dust compared to smoother chondrules.

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