Morphological Evidence for Nebular Formation of Fine-Grained Rims in CM Murchison with Subsequent Deformation on the CM Parent Body.

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Introduction: The origin of fine-grained rims (FGRs) in CM chondrites is intensely debated and formation in both nebular [1] and parent body [2-4] settings has been proposed. In particular researchers have argued whether there is [1] or is not [3] a correlation between rim thickness and the size of the enclosed object, with the former scenario argued as evidence of a nebular origin [1,5]. However, these measurements were made using 2D thin sections and therefore yielded only apparent chondrule size and rim thicknesses. Further, many CMs show evidence of deformation which would have altered the shape of the chondrule and rim [6-7]. One 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]. Our goal is to examine the 3D morphology of FGRs in CM Murchison for which we have previously quantified the deformational strain [6]. Using the true 3D geometry of the FGRs we will determine if there is a positive correlation between the thickness [1,5] or volume [8] of the rim and the size of the interior chondrule and also look for evidence of FGR deformation which may have occurred during the impact(s) which foliated and lineated the chondrules in Murchison [6]. We will also examine the shape of the interior chondrule core to determine if there is a positive correlation between shape irregularity and relative FGR volume, as might be expected for FGR formation through chondrule alteration [2].

Methods: Six small orientated chips (0.143 – 3.6 g; some embedded in epoxy) of CM Murchison USNM 5487 were scanned at the University of Texas High-Resolution X-ray Computed Tomography Facility (UTCT) at 70 or 90 kV X-ray energy. 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 [9-10] 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 FGR thickness for each chondrule prior to deformation the FGR volume was distributed evenly around a spherical chondrule of equivalent volume to that measured with Blob3D (radius is reported as equivalent spherical radius). To determine the current (post-deformation) 3D thickness of the FGR around the chondrule a new algorithm was implemented in Blob3D. For each rimmed chondrule, the algorithm "looks outward" from the chondrule center along a set of 3D traverses evenly covering a unit sphere and measures the thickness of the rim in each direction. The average rim thickness among all chondrules in each orientation is then calculated and plotted on a stereonet to determine if there is any spatial coherence to the varying rim thickness around the chondrules. Chondrule shape irregularity (departure from sphericity) is quantified using the shape factor as defined by [11].

Results: A total of 61 chondrules were segmented. We find a moderate linear correlation between the average, pre-deformational thickness of the rim and equivalent spherical radius of enclosed chondrule core ($R^2 = 0.73$). However, 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 [8] for nebular FGR formation. In addition, the FGRs are consistently thicker (by ~2% of the chondrule core diameter) in the plane of foliation, indicating that the rims were deformed by the impact(s) which deformed the Murchison sample and therefore were in place at the time of deformation on the CM parent body. Finally, we find that although some chondrule cores show an extremely irregular shape, there is no correlation ($R^2 = 0.05$) between the degree of irregularity (shape factor) and the relative rim volume. This suggests that the FGR is not a result of alteration of the chondrule core.

Conclusions: We find that the size relationship between the FGRs and interior chondrule cores in CM Murchison are consistent with nebular FGR formation. After chondrule accretion to the CM parent body, the rims were deformed along with the interior chondrule cores to produce slightly thicker rims in the plane of foliation. Although some chondrule cores have highly irregular shapes there is no correlation between the degree of irregularity and proportional FGR volume suggesting that FGRs are not a result of chondrule alteration, and instead that the irregular shape of chondrule cores may be an original feature not related to subsequent FGR formation.

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