Introduction

The origin of fine-grained rims (FGRs) in CM chondrites is intensely debated with arguments and evidence for both nebular [1,2] and parent body [3,4] formation. 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 of FGRs [1,5]. These measurements were made using 2D thin sections and therefore yielded only apparent chondrule size and rim thickness as the orientation of the section to each chondrule is unknown. Further, many CMs show evidence of deformation which modified the shape of the chondrule and/or the rim and therefore complicate the interpretation of the rim thickness and geometry as related to its origin [6-8].

Approach and Methodology

X-ray computed tomography (XCT) of a 44.4 g sample of CM Murchison (USNM 5487) revealed an impact-derived foliation and weak lineation defined by partially altered POP chondrules [6]. We scanned a 0.143 g chip of the same sample at lower energy (70 kV) and higher resolution (5.5 µm pixel) to allow discrimination of the FGRs around the deformed chondrules (Figure 1). Using Astea’s microCT v.13, we manually segmented each chondrule (40 total) twice both with and without the FGR. The segmented data is then imported into the Blob3D program to measure the chondrule size and orientation in 3D [9-10].

Results

Chondrule Size Frequency

Figure 2 Segmented chondrule size frequency distribution (N=40). Chondrule size distribution differs with and without inclusion of rim.

Chondrule Orientations

Figure 4 Rim volume versus interior chondrule equivalent spherical radius. The data is well fit by a power law relationship as proposed by [12] for chondrules accreting dust rims in the protoplanetary nebula. The data less well fit by a simple linear function (R² = 0.91).

Chondrule Shape Factors

Figure 8 Chondrule shape factors of interior chondrule versus whole chondrule. There is a weak correlation (R² = 0.25) between the shape of the interior chondrule and the whole chondrule, however a similar correlation is present when using the long, intermediate, or short axis of the ellipse (R² = 0.42-0.46). The data is well fit by a power law (exponent 0.44, R² = 0.35).

Chondrule Aspect Ratios

Figure 9 Chondrule aspect ratio vs. rim thickness. There is no correlation, indicating that the thickness of the FGR is independent of the morphology of the enclosed chondrule.

Conclusions

- A moderate linear correlation of FGR thickness with the size (radius) of the interior chondrule (Fig. 3) and a very strong power law correlation of FGR volume (Fig. 4) with the interior chondrule radius supports a nebular origin for FGRs in CM Murchison [5,12].
- The chondrules are deformed and show evidence of a weak foliation as has been documented previously in this sample and attributed to impact [6].
- The interior chondrules show a wide range of morphologies with some highly irregular shapes, however the exterior chondrule shape factors of the CMs do not reflect the irregular morphology of the interior chondrules, with smoother shapes closer to an idealized sphere or ellipse (Fig. 6).
- In addition, the thickness of the rim is uncorrelated with the shape factor (degree of irregularity) of the enclosed chondrule suggesting that the formation of the FGR is not related to the origin of the surface morphology of the interior chondrule.
- The aspect ratio of the external chondrules including the FGR is strongly correlated to the aspect ratio of the enclosed chondrule suggesting that the FGR forms after the deformation event.
- Although correlated, the lower aspect ratio of the external rimmed chondrule compared to the internal chondrule for some chondrules is best explained by a different strain response of the FGR relative to the interior chondrule resulting in a more uniform FGR thickness (Figure 10).
- Finally, while the aspect ratio correlation and constant rim thickness could suggest that the FGR formed after the impact deformation event, other evidence suggests pre-deformation formation including: 1) rim/chondrule size relations supporting nebular formation [16, 61]; 2) the presence of deformed chondrules in the protoplanetary nebula [20]; 3) deformation of the interior chondrules indicating a nebular origin [21]; 4) the presence of deformed chondrules in the protoplanetary nebula [20]; 5) no correlation with the shape factor of the enclosed chondrule suggesting that the FGR is nearly uniform around the interior chondrule.

Future Work

We are currently segmenting more chondrules in two other XCT data sets of the same sample at higher and lower spatial resolutions (3.0 and 7.15 microns) to get a wider range of chondrule sizes and a more statistically significant sample size. We are also modifying the Blob3D program to allow measurement of the thickness of the FGRs in 3D to confirm their generally homogenous thickness. We would also like to further investigate the power law relationship of FGR volume to enclosed chondrule size (radius) to see if it can be used to constrain the formation environment of FGRs as suggested by [12].

References


Acknowledgements

R.D. is grateful to the Meteoritical Society for a student travel grant that offset the cost of attending this meeting. R.D. is supported by the NASA Earth and Space Science Fellowship Program - Grant No. 80NSSC17K0469.