

# New Insights into Chondrite Formation Histories from Fine Carbon Structure Revealed by Raman Imaging

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**Introduction:** Macromolecular carbon (MMC) is a common constituent in chondrites especially those of low petrologic grade.[1] Raman spectra can discern differences in MMC [2] sufficient to classify carbonaceous chondrites to the tenths place [3,4], serving as a sensitive measurement of thermal history. Raman imaging instruments can visualize changes in MMC structure over a sample's surface area with micron resolution[e.g.5,6] and many modern instruments are capable of this imaging over mm- or even cm-sized areas [7]. This opens a new window into chondrule formation and alteration histories, as MMC thermal processing can be visualized for small features such as chondrules and matrix. In general, chondrites show a progression of decreasing carbon content going from low to high petrologic grade.[1] Almost all of the carbon is found in the meteorite matrix and little carbon is observed in refractory materials.[1] Raman imaging can directly image MMC abundance and structure, and we demonstrate an example here wherein a chondrule in a CO3 chondrite exhibits MMC with *lesser* thermal metamorphism than MMC in the matrix.

**Results:** We collected a Raman image of a chondrule in DaG 749. The image was collected on a WITec  $\alpha 300$  Raman imaging microscope using 532 nm excitation. The results are shown in Figure 1. As observed in Figure 1 a-c, we obtain different MMC Raman spectra within a porphyritic olivine chondrule compared to the surrounding matrix. The matrix MMC spectrum contains narrow D and G bands with a full width half height (FWHH) of  $\sim 125$  and  $\sim 65$   $\text{cm}^{-1}$ , respectively, while the MMC in the chondrule has D and G bands with large FWHHs of  $\sim 120$  and  $\sim 200$   $\text{cm}^{-1}$ , respectively. In addition, the D band peak position is upshifted in the chondrule ( $\sim 1360$   $\text{cm}^{-1}$ ) compared to the matrix ( $\sim 1345$   $\text{cm}^{-1}$ ) and the G band position is downshifted in the chondrule ( $\sim 1580$   $\text{cm}^{-1}$ ) compared to the matrix ( $1610$   $\text{cm}^{-1}$ ). Also, the  $I_D/I_G$  band intensity ratio is larger for the matrix ( $\sim 1.1$ ) MMC compared to that in the chondrule ( $\sim 0.9$ ).

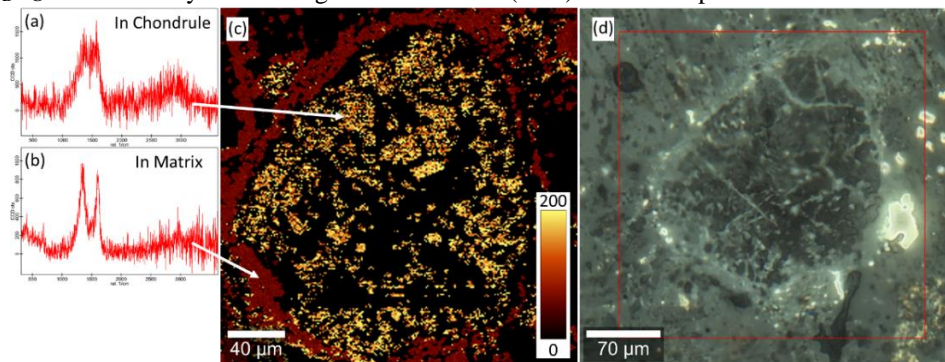


Figure 1: Significant differences are seen in structure of MMC in chondrules versus matrix of this CO3 chondrite (DaG 749). Inset (d) is a reflected light image of the chondrule that was Raman imaged where the red box indicates the area of the Raman image. Inset (c) is a Raman image of the MMC D band FWHH. Insets (a) and (b) show representative Raman spectra of MMC found in the chondrule and matrix, respectively.

**Discussion:** These results indicate that the MMC in the chondrule has a significantly different structure compared to that in the matrix.[2] The MMC structure in the chondrule appears to be consistent with less thermal alteration compared to that of the matrix.[3] This is a surprising result as it implies a history wherein the matrix was metamorphosed separately from the chondrule and to a greater degree, which would have to occur prior to parent body coalescence. The generic assumption is that chondrules experienced greater thermal excursions than either the matrix or coalesced parent body, leading to chondrule MMC with generally greater microstructural ordering than that seen in the matrix. This example indicates that much work can be done examining the structure of MMC on this scale, both in a greater number of examples and across the range of carbonaceous chondrite types. Statistical analysis will be performed on all MMC spectra within the images to examine the heterogeneity, distribution, and average MMC structures within the matrix and chondrules. This information can be used to explore the thermal history of chondrites on an individual-chondrule scale, enabling new insights into meteorite formation.

**References:** [1] Marty B., Alexander C., and Raymond S., (2013) *Reviews in Mineralogy and Geochemistry*, 75: 149-181 [2] Ferrari A. C. and Robertson J. *Physical review B*, 61(20): 14095. [3] Bonal, L., et al. (2006) *GCA*, 70(7), pp.1849-1863.[4] Bonal L. et al. (2016) *Geochimica et Cosmochimica Acta*, 189; 312-337. [5] El Amri, et al. (2005). *Spectrochimica Acta Part A*, 61(9), pp.2049-2056. [6] Frosch, T., et al. (2007) *Analytical Chemistry*, 79(3), pp.1101-1108. [7] Wang, A., e al. (2015) *PSS*, 112, pp.23-34.