THE AGUAS ZARCAS METEORITE: A REVIEW OF CHONDRULES AND FINE-GRAINED RIMS OBSERVED WITHIN A NEW CARBONACEOUS CHONDRITE (CM2) FALL. I. Kouvatsis[1] and J. A. Cartwright[1]; Department of Geological Sciences, University of Alabama, Tuscaloosa, AL 35487, USA. E-mail: ikouvatsis@crimson.ua.edu.

Introduction: A significant meteor event was reported in Aguas Zarcas, Costa Rica, on 23rd April 2019. The fireball was caught on cameras of the National Seismological Network (RSN), and hundreds of stones (totaling a mass of ~27 kg) were recovered subsequently from within the projected strewn-field. The meteorite was identified as a CM2 carbonaceous chondrite [1]. CM chondrites are rich in carbon (1.5 - 6 %) and are thought to come from C-type asteroids. Chondrules are less abundant compared to other groups (20% vol.), with an average diameter of 0.3 mm [2].

Here, we report preliminary findings of a detailed study of chondrules and fine-grained rims (FGRs) within a sample of Aguas Zarcas. We discuss the lithology of our sample and the implications for the Aguas Zarcas parent body.

Methods: Optical microscopy imaging was performed on the Zeiss Axio Imager within the Cartwright Cosmochemistry Lab (CCL), University of Alabama (UA). Using this instrument, we have produced high resolution images at 5, 10, and 20x magnification in reflected light (RFL) to document the chondrule types and the FGRs within the specimen .

Scanning electron microscopy was carried out using the JEOL 7000 Field Emission Scanning Electron Microscope (FE SEM; 20kV) at the Central Analytical Facility (CAF) of UA. We measured bulk compositions of chondrules and FGRs, and created elemental maps using Energy-Dispersive Spectroscopy (EDS).

Results: *Optical microscopy:* We have investigated 53 chondrules within our sample to characterize the chondrule types, shapes, size, and the thickness of FGRs surrounding them. Overall, we estimate that the sample is ~ 21% vol chondrules. Our investigations have shown that the specimen is dominated by two lithologies: 1) chondrule poor (CP) ~16% vol chondrules; 2) chondrule rich (CR) ~23% vol. chondrules, both with prominent fine-grained rims (FGRs). The CR area also exhibits larger chondrules (up to 1500 µm) compared to the chondrule poor area (typically 100-300 µm). The majority of chondrules display complex features, and are irregularly-shaped porphyritic/granular with a fine-grained matrix (Fig. 1). Many chondrules are altered and have cavities filled with fine-grained material. This influences their shape and eccentricity making radius measurements difficult. In some cases we have two or even three chondrules clumped into each other (Fig. 1a). Given the two lithologies observed and the prevalence of FGRs in the sample, we have determined the surface area of FGRs relative to the chondrules that they sur-

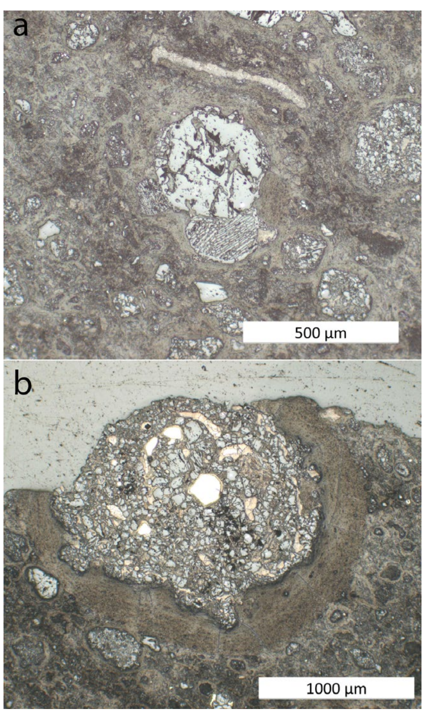

Fig. 1. RFL images of chondrules in Aguas Zarcas. (a) 'Clumped' chondrules, (b) The largest chondrule (~1500 µm) of our specimen with a FGR of ~400 µm (c).

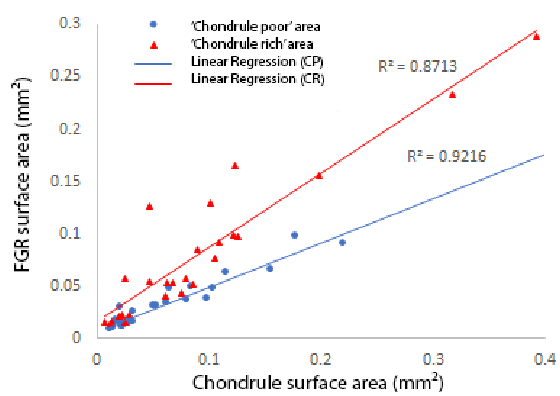

Fig. 2. Surface area of chondrules vs FGRs for "chondrule poor" (blue) and "chondrule rich" (red) areas.

round, as shown in Fig. 2. We have observed two positive linear correlations for each lithology. The CR trend is more correlated than the CP trend, which equates to a larger FGR surface area for equivalent sized chondrules. Both CP and CR trendlines are highly correlated with their underlying datasets (R^2 = ~0.9). This is significant as it may suggest that both chondrules and rims were formed under different conditions.

Scanning electron microscopy: The SEM/EDS mapping revealed a discrepancy in certain element distribution among chondrules and their FGRs (Fig. 3). For example, magnesium (Mg) and iron (Fe) (Fig. 3b,c), shows that Mg occurs in higher abundances in the chondrule, while Fe is found in higher abundance in the FGR and matrix. This suggests that the distribution of Fe is different compared to Mg and could relate to mobilization of Fe towards the FGR and the matrix and/or retainment of Mg in the chondrule. Similar distribution patterns were observed in other carbonaceous chondrites, where aqueous alteration may be a possible cause [3].

Discussion: For both CP and CR areas, the surface area of FGRs increases linearly with increasing chondrule surface area: the larger the chondrule the thicker the FGR that surrounds it. However, there is a difference between the two areas of the sample – the CP area shows a smaller FGR to chondrule:surface-area ratio compared to the CR area. This may reflect a compositional boundary or transition zone in the parent body, or it could suggest that chondrules and rims were formed in different locations or through different processes. Alternatively, it may relate to a sample-specific irregularity without further implications for the parent body.

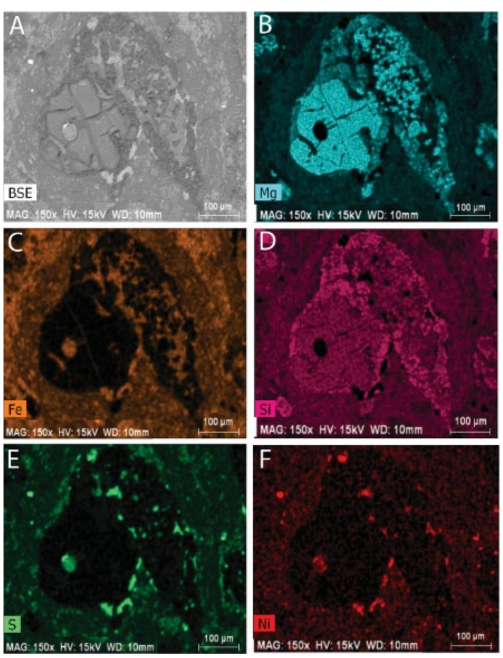

Fig. 3. BSE (A) and K alpha maps of: (B) Mg ; (C) Fe ; (D) Si ; (E) S ; (F) Ni of two 'clumped' chondrules. One of the chondrules appears deformed which may suggest active relative movement between the chondrules during early accretion stage.

The elemental discrepancy shown in Fig. 3 may result from complementarity – an apparent feature that results from elemental loss from a chondrule and subsequent reabsorption into the matrix during chondrule formation. The complementarity model suggests that chondrules and matrix within a chondrite group formed from a single CI-like reservoir [3]. CI chondrites are considered to be among the most primitive in the Solar System from a chemical point of view, as their bulk compositions are similar to that of the solar photosphere excluding volatiles. Therefore, elements lost during chondrule formation are reabsorbed by the matrix, generating sub-chondritic elemental ratios (lower compared to CI) in chondrules and super-chondritic (higher compared to CI) in the matrix [3].

Conclusions & Future work: The two lithologies found within our sample are unusual, as is the observed differences in chondrules and FGRs. It is also likely that our preliminary investigations have highlighted complementarity in the sample. We are continuing our work on Aguas Zarcas, with an aim to expand our FGR research to other carbonaceous chondrite clans (CV, CR, CK, etc.) and to different petrologic types, in order to record variances in FGR thicknesses and elemental distributions. We will study the influence of irregularities in chondrule shape, ellipticity and roughness in relation to changes in FGRs thickness. Furthermore, we will be running a series of electron probe microanalysis (EPMA) point analyses on chondrules in both CP and CR areas to determine chemical composition differences that may exist, and could relate to a possible compositional boundary.

Overall, the origin of FGRs, their formation time, and the possible relationship with chondrules and matrix material remains unclear. With further study, we may shed additional light on these features. Studies at the nanometer-scale may also be useful, as some rare FGRs have been shown to contain presolar grains [4], which predate the formation of our Solar System, and thus formed under nebular conditions.

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References: [1] Meteoritical Bulletin Database: Entry for Aguas Zarcas, 05/2019. [2] Scott E. R. D. & Krot A. N., (2007) *Treatise on Geochemistry* 1:1.07:1-72. [3] van Kooten E. et al. (2019) *Proc. Natl. Acad. Sci. U.S.A.* 116:18860-18866. [4] Haenecour P. et al. (2018) *Geochimica et Cosmochimica Acta,* 221:379-405.