CLAST POPULATIONS WITHIN THE CM2.2 BRECCIATED CARBONACEOUS CHONDRITE AGUAS ZARCAS: IMPLICATIONS FOR UNDERSTANDING AQUEOUS ALTERATION ON RYUGU. P. M. C. Martin[1] and M. R. Lee[1], [1]School of Geographical and Earth Sciences, University of Glasgow, G12 8QQ, U.K. (p.martin.2@research.gla.ac.uk).

Introduction: With the successful return of the JAXA Hayabusa2 sample collection from the *Ryugu* asteroid, the study of extra-terrestrial carbonaceous samples is now, more than ever, relevant in answering one of planetary science's most prominent question: the origin of Earth's water **[1, 2]**. Carbonaceous chondrites have a relatively high water content (~ 9 wt%; **[3]**) and show signs of having undergone various degrees of aqueous alteration. Such alteration is thought to have stemmed from a heating event that occurred the CM parent-body **[4]**. To this day, the intensity and duration of this heating process remain poorly constrained.

Aguas Zarcas was originally classified as CM2 (Mighei-like) following the petrographic description by L. Garvie (Arizona State University, USA) and oxygen isotope analysis by laser fluorination by K. Ziegler (University of New Mexico, USA) **[5]**. Since then, Aguas Zarcas was further categorized as a CM2.2 brecciated carbonaceous chondrite (according to the classification provided by **[3, 6]**), using Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS) and Raman Spectroscopy **[7]**.

In this study, we further investigate the brecciated nature of Aguas Zarcas by characterising the different grades of aqueous alteration of its larger clasts.

Materials and Methods: This investigation compiles the study of three polished thin sections and two polished blocks from *Aguas Zarcas*. Each sample was fully mapped by EDS using a Zeiss Sigma Variable Pressure Analytical Scanning Electron Microscope (SEM; accelerating voltage of 20 keV; carbon coated ~10 nm thickness). Clasts within the samples were identified using BSE (Backscattered Electron) images in conjunction with the geochemical maps. Size and shape measurements (i.e. surface area, major and minor axis length, circularity) of these objects were made using ImageJ. Several locations of interest were then further mineralogically analysed by Raman spectroscopy using a Renishaw InVia coupled with a 512 nm laser source (power up to 45W and 2400 grating).

Results: *Aguas Zarcas's* clastic matrix is fine grained, dominated by phyllosilicates, Ca-carbonates and iron sulphides (cf. **Fig. 1**). The extent of aqueous alteration throughout the samples is relatively homogeneous and due to the low clast density, the chondrite verifies its CM2.2 classification [**3, 6, 7**].

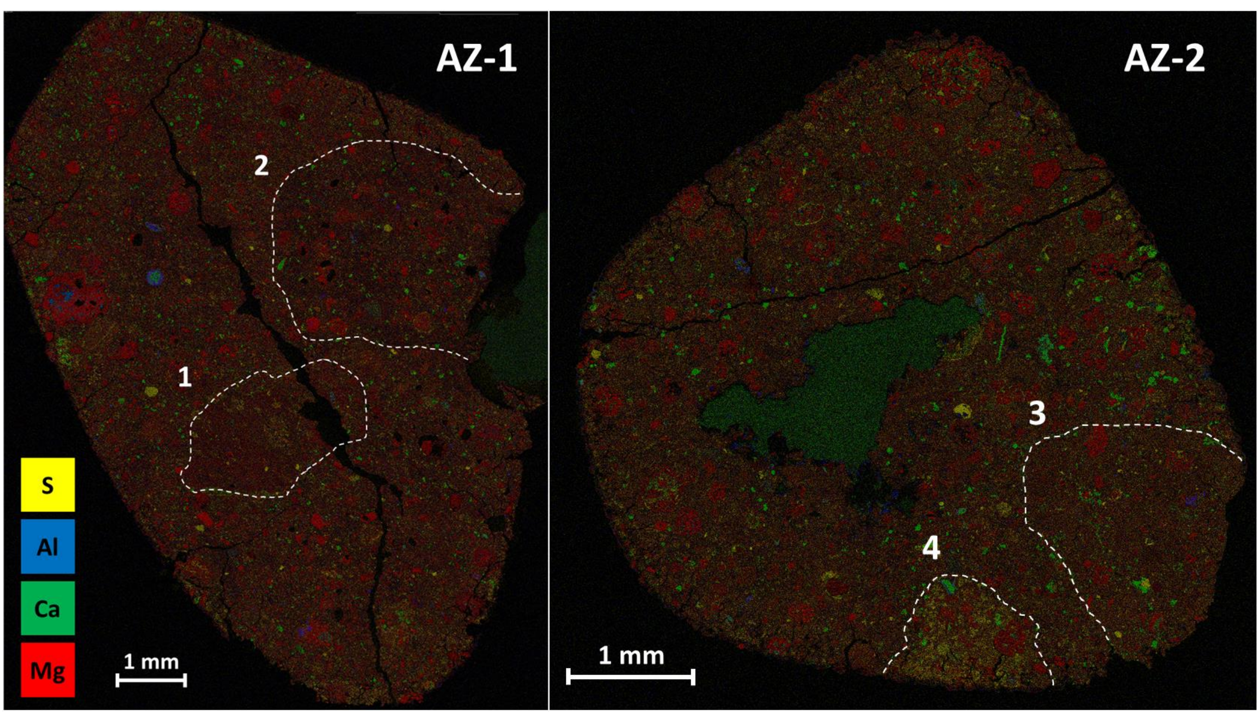

Fig. 1. *EDS layered images of two studied thin sections (AZ-1 and AZ-2) of Aguas Zarcas. The outlined areas correspond to identified clasts (note that the large darker green areas are holes within the thin sections).*

The chondrite is classified as a breccia due to the presence of nine clasts found among the five samples. These were identified by searching petrographically or geochemically distinct large areas (≥ 1 mm) surrounded by a Fine-Grained Rim (FGR) of sub-millimetric thickness. The clasts' sizes range from 0.96 to 3.57 mm in length (major axis), with an average of 1.71 mm (σ = 0.89). An average clast density of 11.05 areal% (σ = 7.80) across all studied samples has been determined, with the clasts covering approximately 12.86% of the total surface of the samples (1323.58 mm^2).

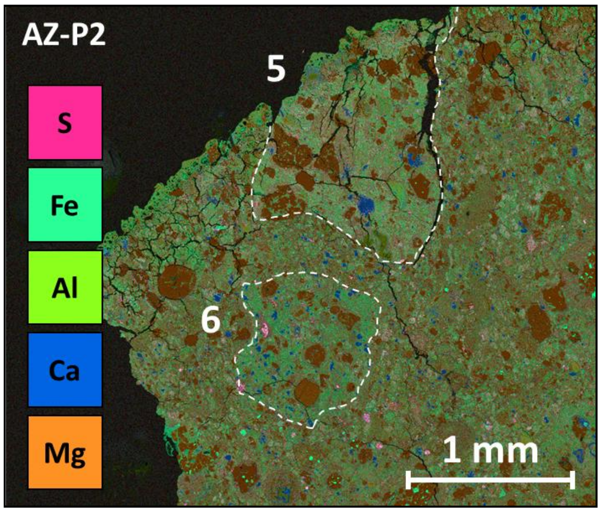

Fig. 2. *EDS layered image of two Mg-poor clasts from one of the studied polished blocks of Aguas Zarcas (AZ-P2).*

All of the clasts are of carbonaceous material and fit the CM classification but show various degrees of aqueous alteration. Raman spectroscopy has revealed the presence of dolomite and calcite within the fragmented chondrules and within larger phenocrysts within the clasts. The mesostasis within chondrules has been completely altered and replaced with phyllosilicates. This observation was confirmed with EDS analysis (cf. **Figures 1** and **2**) and is consistent with previous studies of highly altered CM chondrites **[3, 4, 6, 7]**.

There are three major populations of clasts in total across the studied samples:

Mg-rich clasts (n = 4): They appear as darker areas with a relatively low contrast compared to the surrounding fine-grained clastic matrix (cf. clasts 1, 2, and 3 in Fig. 1). They are very aqueously altered but with a significant textural difference (very fine material, no FGR's around objects within, and a "smoothed-out" texture). These clasts are readily identifiable in BSE images but show a chemical composition very similar to the matrix.

Mg-poor clasts (n = 2): Light gray in BSE images with relatively moderate contrast. This lithology hosts a higher number of larger Ca-carbonates (calcite) and larger sub-millimetric Mg-bearing phenocrysts than in the rest of the chondrite's matrix. Despite their matrix being very similar in composition to the rest of the sample's clastic matrix (cf. clasts 5 and 6 in Fig. 2), it seems to be depleted in fine-grained Mg-phyllosilicates.

TCI-rich clasts (n = 3): Light gray in BSE images with lower contrast than the previous lithology. They are easily distinguished in EDS maps as they appear as large Tochilinite-Cronstedtite Intergrowth (TCI) clumps (cf. clast 4 in Fig.1) due to the high content of Fe-S phases within their matrix.

Conclusions: According to the updated classification for CM based on the degree of aqueous alteration provided by [**8**], which expands on **[3, 6]**, the discovered Mg-rich clasts seem to be on the lower end of said scale defined by (CM2.0-2.2), since the composition of the matrix is quite similar to the rest of the meteorite.

The Mg-poor clasts seem to be less altered than the rest of the chondrite (CM2.2-2.3) as the clastic matrix is made of Mg-rich fragments and bears a higher volume of Ca-carbonate grains. Fe-Ni sulphides, such as pentlandite, occur in chondrules. Pyrrhotite has not been identified in our study, although its presence is possible and would indicate a lower degree of aqueous alteration **[3, 6]**.

The Mg-rich and the TCI-rich clasts both appear to be similar in composition to the matrix, with the TCI-rich clasts corresponding to a higher degree of aqueous alteration (CM2.2-2.3). This could likely be due to a geochemical homogenization caused by an alteration event that occurred after clast incorporation on the CM parent body. Therefore, it is of utmost importance to pursue the study the brecciation process within CM chondrites as it can provide invaluable information for understanding the evolution of asteroids such as *Ryugu*.

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