ORGANIC MATTER IN THE AGUAS ZARCAS (CM2) METEORITE: HIGH ABUNDANCE OF ALIPHATIC CARBON IN METAL-RICH LITHOLOGY.

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Introduction: The Aguas Zarcas meteorite is a new CM2 chondrite which fell on 23 April 2019 (local time) in Costa Rica. Aguas Zarcas is brecciated and contains several different lithologies, e.g., metal-rich lithology (see also Kerraouch et al. [1]) and CI-like lithology. This fresh CM2 chondrite gives us good opportunities for analyses of organic matter (OM) without terrestrial contamination and weathering, particularly some stones which were collected before rain fell over the fall site. We also aim to characterize local heterogeneities and associations of organic and mineral phases using state-of-the-art microscopic techniques to constrain the origin and evolutionally processes of OM during pre- and post-accretion.

Methods: Small particles (a few hundreds of micrometer) from normal (CM2) lithology and metal-rich lithology were pressed on KBr plates, and infrared (IR) absorption spectra were obtained using a Fourier transform infrared micro-spectrometer (microFTIR). Ultrathin sections (100 nm-thick) from each lithology were prepared using a focused ion beam (FIB) for scanning transmission X-ray microscopes (STXM) on BL4U at the UVSOR and on BL19 at the Photon Factory, KEK. Carbon X-ray absorption near-edge structure (C-XANES) spectra of the FIB sections were obtained using the STXMs. Sulfur embedded ultramicrotomed thin sections (~100 nm-thick) were prepared on a diamond window for an atomic force microscope (AFM) based IR nanospectroscopy using tapping mode which is suitable for loosely bound samples [2, 3].

Results and Discussion: *FTIR.* Fig. 1 shows FTIR spectra of the Aguas Zarcas meteorite. A broad band around 3400 cm^{-1} and a Si-O band at 1000 cm^{-1} are characteristic of phyllosilicates, although there would be significant contribution of terrestrial adsorbed water on the 3400 cm^{-1} band. These IR features are consistent with CM2 chondrites [4]. Organic features at around 2900 cm^{-1} (aliphatic C-H) are not clearly seen at the most of analyzed spots, but some spots in the metal-rich lithology show large aliphatic features at 2955 cm^{-1} (CH_3), 2925 cm^{-1} (CH_2), and 2855 cm^{-1} (CH_3+CH_2). The CH_2/CH_3 ratio is larger than typical CM/CI/CRs [4], indicating the presence of longer aliphatic chains.

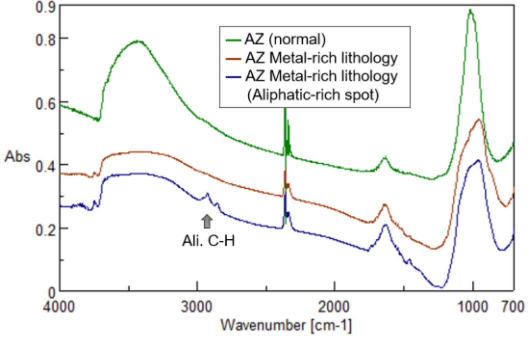

Fig. 1: FTIR spectra of the Aguas Zarcas (AZ) meteorite.

STXM-XANES. The STXM elemental maps of Aguas Zarcas show some organic-rich spots (Fig. 2, left panels). Less organic-rich spots are observed in the metal-rich lithology (Fig. 2b-d) comapred to the CM2 lithology (Fig. 2a). C-XANES spectra of the organic-rich spots show peaks at 285 eV (aromatic), 286.5 eV (C=O), 287.5 eV (aliphatic), 288.5 eV (C(=O)O), and 290.5 eV (carbonate). The C-XANES features of the CM2 lithology are similar to those of typical CM2 such as Murchison and its insoluble OM [5, 6]. However, the C-XANES features show that OM in the metal-rich lithology is rich in aliphatic carbon compared to the CM2 lithology and typical CM2. The aliphatic-rich nature of the metal-rich lithology is consistent with the IR spectra; some of these shows large aliphatic C-H peaks (Fig. 1). Local heterogeneities within each FIB section exist but lower extent compared to the heterogeneity among lithologies. Note that FIB sections from the metal-rich lithology are optically dense, and thus the quality of the C-XANES spectra are not as good as the CM2 lithology due to the high baseline absorption (absorbance ≈ 0.6-1.2).

AFM-IR. Preliminary results from AFM-IR of Aguas Zarcas (the CM2 lithology) are shown in Fig. 3. The point spectra indicate that OM (C=O at 1710 cm^{-1} and aromatic C=C at 1600 cm^{-1}) localy exists (Fig. 3b).

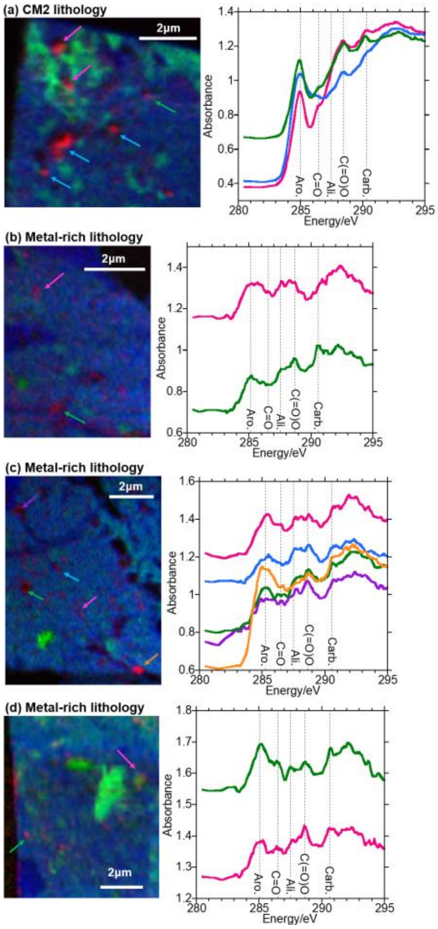

Fig. 2: (*Left*) STXM elemental maps (red: C, green: Fe, blue: O) of the Aguas Zarcas (AZ) FIB sectios. (*Right*) XANES spectra of AZ obtained from the spots indicated by arrows in the elemental maps (left panels). (a) AZ normal lithology, and (b-d) AZ metal-rich lithology.

These organic peaks are not clear in the bulk IR spectra, likely due to low contents of OM. The C=O peak is probably due to carboxyl/ester (-C(=O)O-) rather than ketone (-C(=O)C-), considering the C-XANES features (Fig. 2). Although there is a H_2O absorption in the bulk spectra at 1640 cm^{-1} that is mostly due to terrestrial adsorbed water (Fig. 1), this H_2O peak is not shown in the AFM-IR spectra by maintaining dry atmosphere. The silicate Si-O band has a peak center between 1020 cm^{-1} to 960 cm^{-1}, which is consistent with the bulk IR spectrum (20x20 μm aperture, Fig. 1) with a peak center at 1000 cm^{-1}. The 1020 cm^{-1} peak can be assigned to antigorite/saponite, and the 960 cm^{-1} peak can be assigned to olivine/pyroxene/chrysotile/lizardite [7].

We obtained AFM-IR maps with 1710 cm^{-1}, 1600 cm^{-1}, 1020 cm^{-1}, and 960 cm^{-1} (Fig. 3c-f). The analyzed area predominantly consist with phyllosilicates (1020 cm^{-1}, likely serpentine/saponite), and some 960 cm^{-1} dominated regions (likely olivine/pyroxene) exist (Fig. 3e,f). Aromatic C=C is distributed in micrometer to sub-micrometer regions over all the analyzed area, particulary the middle region is also dominated in C=O (indicated by arrows in Fig. 3c,d).

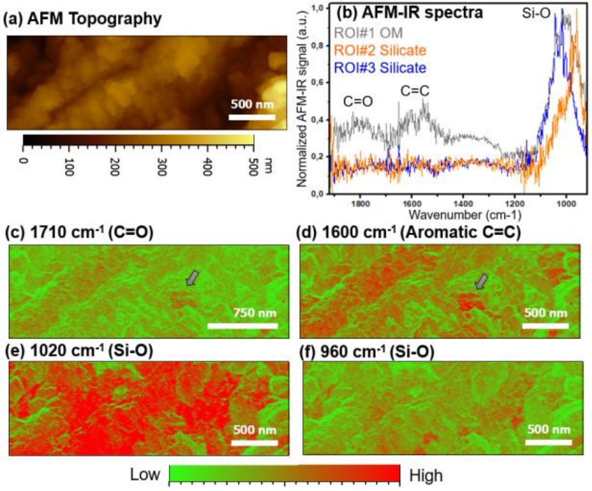

Fig. 3: AFM-IR results of the Aguas Zarcas meteorite. (a) AFM topography, (b) AFM-IR spectra, (c-f) AFM-IR maps.

Implications and Conclusive remarks: OM in the CM2 lithology in the Aguas Zarcas meteorite is consistent with CM2 chondrites such as Murchison. However, OM in the metal-rich lithology is unique with high aliphatic concentrations, indicating that more primitive nature of OM compared to typical CM. The OM in the metal-rich lithology would rather be similar to cometary OM [8]. Submicrometer distributions and heterogeneities of OM and minerals are observed by AFM-IR. Although there is a possibility of artifacts in this preliminary data, it is promising that this technique gave us new insights into origin and evolutionally scenarios of OM in primitive Solar System materials.

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