

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

Y. Kebukawa<sup>1\*</sup>, M. E. Zolensky<sup>2</sup>, J. Mathurin<sup>3</sup>, E. Dartois<sup>4</sup>, C. Engrand<sup>3</sup>, J. Duprat<sup>3</sup>, A. Deniset-Besseau<sup>5</sup>, A. Dazzi<sup>5</sup>, M. Fries<sup>2</sup>, T. Ohigashi<sup>6</sup>, D. Wakabayashi<sup>7</sup>, S. Yamashita<sup>7</sup>, Y. Takeichi<sup>7</sup>, Y. Takahashi<sup>8</sup>, M. Kondo<sup>9</sup>, M. Ito<sup>10</sup>, Y. Kodama<sup>11</sup>, Z. Rahman<sup>12</sup>, and K. Kobayashi<sup>1</sup>, <sup>1</sup>Faculty of Engineering, Yokohama National Univ., Japan, <sup>2</sup>ARES, NASA Johnson Space Center, USA, <sup>3</sup>Univ. Paris-Saclay, CNRS, IJCLab, France, <sup>4</sup>Univ. Paris-Saclay, CNRS, ISMO, France, <sup>5</sup>Univ. Paris-Saclay, CNRS, ICP, France, <sup>6</sup>UVSOR Synchrotron, Institute for Molecular Science, Japan, <sup>7</sup>Institute of Materials Structure Science, High-Energy Accelerator Research Organization (KEK), Japan, <sup>8</sup>Department of Earth and Planetary Science, The Univ. of Tokyo, Japan, <sup>9</sup>Instrumental Analysis Center, Yokohama National Univ., Japan, <sup>10</sup>Kochi Institute for Core Sample Research, JAMSTEC, Japan, <sup>11</sup>Marine Works Japan Ltd., Japan, <sup>12</sup>Jacobs, NASA Johnson Space Center, USA. \*Email: kebukawa@ynu.ac.jp

**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 including metal-rich lithology (see also Kerraouch et al. [1]) and CI-like lithology. This fresh CM2 chondrite provides an opportunity 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 aim to characterize local heterogeneities and associations of organic and mineral phases using state-of-the-art microscopic techniques to constrain the origin and evolutionary 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) apparatus 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 to perform atomic force microscope based IR nanospectroscopy (AFM-IR) 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<sup>-1</sup> and a Si-O band at 1000 cm<sup>-1</sup> are characteristic of phyllosilicates, although there would be significant contribution of terrestrial adsorbed water on the 3400 cm<sup>-1</sup> band and at 1640 cm<sup>-1</sup>. These IR features are consistent with CM2 chondrites [4]. Organic features at around 2900 cm<sup>-1</sup> (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<sup>-1</sup> (CH<sub>3</sub>), 2925 cm<sup>-1</sup> (CH<sub>2</sub>), and 2855 cm<sup>-1</sup> (CH<sub>3</sub>+CH<sub>2</sub>). The CH<sub>2</sub>/CH<sub>3</sub> ratio is larger than typical CM/CI/CRs [4], indicating the presence of longer aliphatic chains.

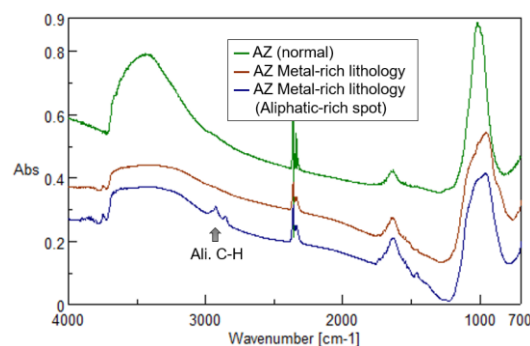


Fig. 1: FTIR spectra of the Aguas Zarcas (AZ) meteorite.

*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) compared 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 to a 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.

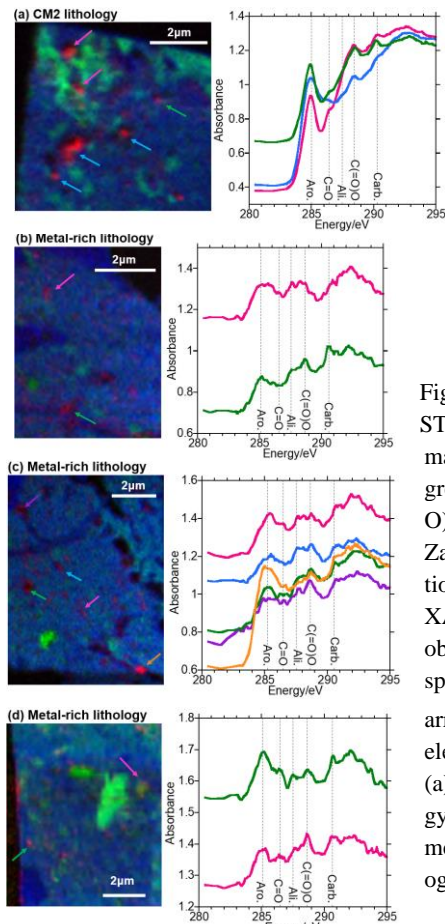


Fig. 2: (Left) STXM elemental maps (red: C, green: Fe, blue: O) of the Aguas Zarcas FIB sections. (Right) XANES spectra obtained from the spots indicated by arrows in the elemental maps. (a) CM2 lithology, and (b-d) metal-rich lithology.

The point spectra indicate that it is possible to localize OM with C=O (at  $1710\text{ cm}^{-1}$ ) and aromatic C=C (at  $1600\text{ cm}^{-1}$ ) at a small scale in Aguas Zarcas (Fig. 3b). These organic peaks are not clear in the bulk “far field” classical IR spectra, likely due to low content of OM and possible overlap with adsorbed water contribution at  $1640\text{ cm}^{-1}$ . The C=O peak is probably due to carboxyl/ester ( $-\text{C}(=\text{O})\text{O}-$ ) rather than ketone ( $-\text{C}(=\text{O})\text{C}-$ ), considering the C-XANES features (Fig. 2). Although there is a  $\text{H}_2\text{O}$  absorption in the bulk spectra at  $1640\text{ cm}^{-1}$  that is mostly due to terrestrial adsorbed water (Fig. 1), this  $\text{H}_2\text{O}$  peak is significantly reduced in the AFM-IR spectra by maintaining dry atmosphere. The silicate Si-O band has a peak center between  $1020\text{ cm}^{-1}$  to  $960\text{ cm}^{-1}$ , which is consistent with the bulk IR spectrum ( $20\times 20\text{ }\mu\text{m}$  aperture, Fig. 1) with a peak center at  $1000\text{ cm}^{-1}$ . The  $1020\text{ cm}^{-1}$  peak can be assigned to antigorite/saponite, and the  $960\text{ cm}^{-1}$  peak can be assigned to olivine/pyroxene/chrysotile/lizardite [7] (the mineral band attribution in AFM-IR is in progress).

We obtained AFM-IR maps at  $1710\text{ cm}^{-1}$ ,  $1600\text{ cm}^{-1}$ ,  $1020\text{ cm}^{-1}$ , and  $960\text{ cm}^{-1}$  (Fig. 3c-f). The analyzed area predominantly consist of phyllosilicates ( $1020\text{ cm}^{-1}$ , likely serpentine/saponite), and some  $960$

$\text{cm}^{-1}$  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. The middle region particularly exhibit C=O features (indicated by arrows in Fig. 3c,d).

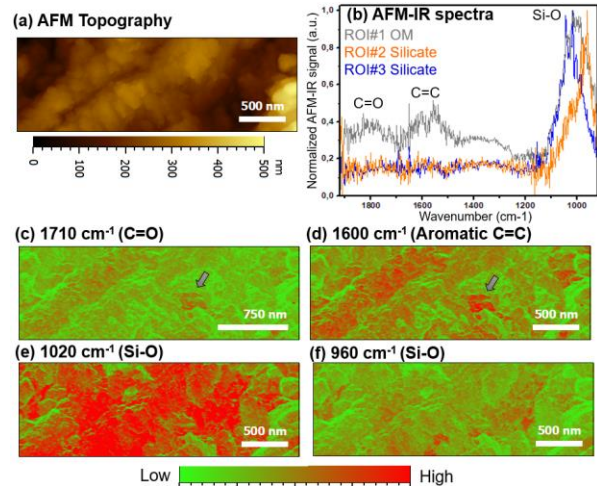


Fig. 3: AFM-IR results of the Aguas Zarcas meteorite. (a) AFM topography, (b) AFM-IR spectra (#1 and 2 are outside, and #3 is inside of the mapping area), (c-f) AFM-IR maps, arrows indicate the C=O features.

**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 a more primitive nature of OM compared to typical CM. Submicrometer distributions and heterogeneities of OM and minerals are observed by AFM-IR. Although there is a possibility of artifacts in these preliminary data, it is promising that this technique, giving access to the chemical heterogeneities at small spatial scales, will give us new insights into origin and evolution scenarios of OM in primitive Solar System materials.

**Acknowledgments:** We thank Robert Ward for donating the Aguas Zarcas meteorite for scientific use. This study was supported by JSPS KAKENHI, and JSPS Core-to-Core program “International Network of Planetary Sciences.”

**References:** [1] Kerraouch I. et al. (2020) *This conference*. [2] Mathurin J. et al. (2019), *Astron. Astrophys.*, 622, A160. [3] Mathurin J. et al. (2020) *This conference*. [4] Kebukawa Y. et al. (2019) *Meteoritics & Planet. Sci.*, 54, 1632–1641. [5] Le Guillou C. et al. (2014) *Geochim. Cosmochim. Acta*, 131, 368–392. [6] De Gregorio B. T. (2013) *Meteoritics & Planet. Sci.*, 48, 904–928. [7] Salisbury J. W. et al. (1991) In *Infrared (2.1–25  $\mu\text{m}$ ) spectra of minerals*, John Hopkins University Press, Baltimore.