

**VARIABILITY OF ORGANIC MATTER ACROSS CI CHONDRITES AND RYUGU.** B. T. De Gregorio<sup>1</sup>, G. D. Cody<sup>2</sup>, R. M. Stroud<sup>3</sup>, S. A. Sandford<sup>4</sup>, C. Le Guillou<sup>5</sup>, M. A. Marcus<sup>6</sup>, and H. Yabuta<sup>7</sup> <sup>1</sup>US Naval Research Laboratory (Code 6366, 4555 Overlook Ave SW, Washington, DC 20375; bradley.degregorio@nrl.navy.mil), <sup>2</sup>Carnegie Institution for Science, Washington, DC, <sup>3</sup>Arizona State University, Tempe, AZ, <sup>4</sup>NASA Ames Research Laboratory, Moffett Field, CA, <sup>5</sup>Université de Lille, Villeneuve d'Ascq, France, <sup>6</sup>Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, <sup>7</sup>Hiroshima University, Hiroshima, Japan.

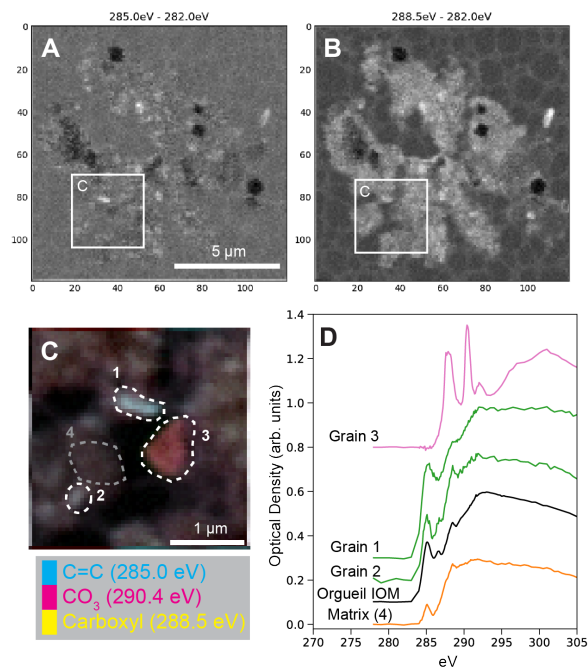
**Introduction:** Petrologic and isotopic analysis of the mineral components of regolith samples from asteroid 162173 Ryugu collected by the JAXA Hayabusa2 spacecraft indicate a strong affinity with CI chondrite meteorites [1-3]. Preliminary investigations of organic matter in Hayabusa2 samples also report similarities with insoluble organic matter in CI and CM chondrites [4]. However, the Ryugu samples also contain a wide diversity of organic functional chemistry not previously observed in those aqueously altered chondrites [e.g., 3-5]. Due to their rarity, organic matter in CI chondrites is understudied relative to other chondrite classes. Here we investigate several CI samples with the same analytical approaches used for samples collected by Hayabusa2 for a more accurate comparison between CI and Ryugu organic matter.

**Samples and Methods:** Crushed, fine-grained matrices of CI chondrites Orgueil, Alais, and Ivuna were prepared by sulfur embedding and ultramicrotome sectioning, using the clean protocols developed for Ryugu samples [4]. We performed scanning-transmission x-ray microscopy (STXM) and x-ray absorption near-edge spectroscopy (XANES) at beamline 5.3.2.2 at the Advanced Light Source, Berkeley National Laboratory [cf. 5]. Carbonaceous grains were located *in situ* in the fine-grained matrix and x-ray image stacks were acquired from those regions. Carbon XANES peak parameters were quantified using methods described in [6] to obtain the relative proportions of organic functional groups in each carbonaceous grain.

**Results:** Discrete, carbonaceous grains were present in all CI samples, dispersed throughout the fine-grained matrix. The organic functional group chemistry of these grains is generally consistent with XANES data of insoluble organic matter (IOM) residues from aqueously altered CI and CM chondrites (Figure 1). However, the relative proportion of polyaromatic functionality (C=C, represented by a  $1s \rightarrow \pi^*$  peak centered around 285 eV) varies, while the ratio of ketone (C=O, 286.7 eV) and carboxyl (COOH, 288.5 eV) is relatively static. This trend is revealed by plotting the relative proportion of aromatic, ketone, and aliphatic/carboxyl peaks (Figure 2).

*Orgueil.* Of the 20 carbonaceous grains analyzed so far, all of them fall within the IOM-like description, forming a continuous distribution between aromatic-rich and aromatic-poor functionality (Figure 2). We have not yet observed any highly aromatic grains, occasionally reported in other Orgueil [6], Murchison [8] and Ryugu [4, 5] samples. These highly aromatic spectra are characterized by a broader, more intense aromatic peak, a decreased proportion of ketone and carboxyl functionality, and a flat-topped  $\sigma^*$  peak above 290 eV.

*Alais.* Four carbonaceous grains in Alais were consistent with the range of IOM-like grains in Orgueil (Figure 2). Carbonaceous grains 1 and 2 in Figure 1C, D exemplify the variation of XANES spectra within the IOM-like grains. Some ultramicrotome slices of



**Figure 1.** STXM-XANES data of carbonaceous grains in an ultramicrotome section of Alais matrix. (A, B) X-ray absorption difference maps (285 eV – background and 288.5 eV – background, respectively) help locate carbonaceous grains. (C) Functional chemistry map, with three carbonaceous grains identified, along with a region of C-rich matrix. (D) XANES spectra of carbonaceous grains and matrix in (C).

Alais show a high abundance of diffuse organic matter throughout the fine-grained matrix (Figure 1B). C-XANES spectra of this diffuse carbon show low aromaticity and a high proportion of carboxyl functionality and some aliphatic bonding, indicated by a broad peak centered around 287 eV (Figure 1D), consistent with previous data from diffuse carbon found throughout the fine-grained matrix of carbonaceous chondrites [6]. One of the Alais discrete grain has a C-XANES spectrum similar to this diffuse carbon spectra (Figure 2).

Nanoscale carbonates were also observed within the Alais matrix, with a sharp  $\text{CO}_3$  peak at 290.4 eV (Figure 1). The extended fine-structure of these spectra are consistent with magnesite or breunnerite [9]. However, these spectra also include an intense peak at 288.1 eV, inconsistent with carbonate minerals and suggesting these grains may be partially altered organic matter.

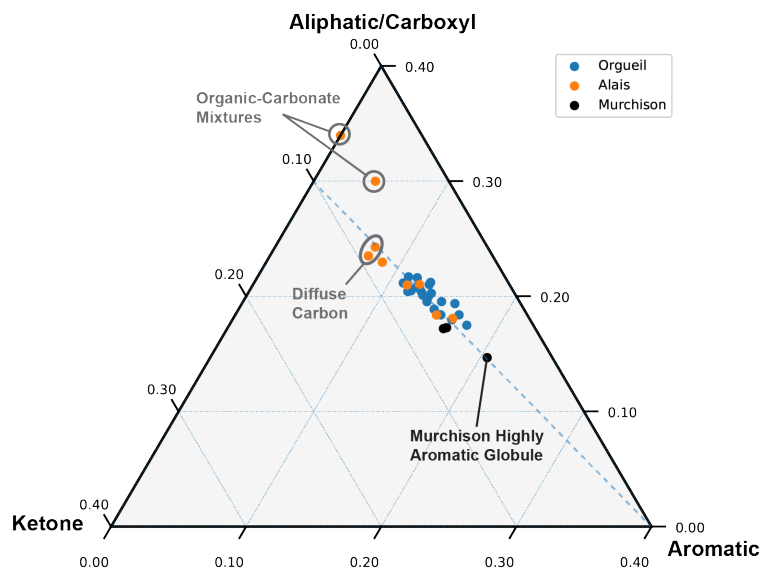
*Ivuna*. Analysis of *Ivuna* samples is ongoing at the time of this report.

**Discussion:** Perhaps the largest distinctions between XANES of Ryugu and CI carbonaceous matter are the lack of two major types of functional group chemistry missing from the latter samples—“highly aromatic” grains and the so-called “aromatic” grains [4], which together are reported to comprise

over half of the discrete carbonaceous grains in Hayabusa2 samples [5]. This difference could be due to sample source bias between collection of surface regolith by the Hayabusa2 spacecraft and deeper material excavated and ejected by asteroid impact events. If so, it implies that organic matter in the surface and interior experienced markedly different processing environments.

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**References:** [1] Yada T. et al. (2022) *Nat. Astron.*, 6, 214-220. [2] Yokoyama T. et al. (2022) *Science*, Early View. [3] Ito M. et al. (2022) *Nat. Astron.*, 6, 1163-1171. [4] Yabuta H. et al. (2022) *LPSC LIII*, Abstract #2241. [5] De Gregorio B. T. et al. (2022) *LPSC LIII*, Abstract #1634. [6] Le Guillou C. et al. (2014) *GCA*, 131, 368. [7] Stroud R. M. et al. (2022) *LPSC LIII*, Abstract #2052. [8] De Gregorio B. T. et al. (2013) *M&PS*, 48, 904. [9] Brandes J. A., Wirick S., and Jacobsen C. (2010) *J. Synchrotron Rad.*, 17, 676.



**Figure 2.** Distributions of organic functional group chemistry as determined by XANES peak quantification. Aliphatic and carboxyl peaks are not distinguished by the quantification method used here. Murchison data are taken from [8].