

ORGANIC ANALYSIS OF SUTTER'S MILL CHONDRITE USING C-XANES. Y. Kebukawa^{1*}, M. E. Zolensky², A. L. D. Kilcoyne³, Z. Rahman⁴, P. Jenniskens^{5,6}, T. Mikouchi⁷, K. Hagiya⁸, K. Ohsumi⁹, M. Komatsu¹⁰, and G. D. Cody¹. ¹Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC, ²NASA Johnson Space Center, Houston, TX, ³Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, ⁴Jacobs-Sverdrup, Houston, TX, ⁵SETI Institute, Mountain View, CA, ⁶NASA Ames Research Center, Moffett Field, CA, ⁷Department of Earth and Planetary Science, University of Tokyo, ⁸Graduate School of Life Science, Hyogo University, Hyogo, Japan, ⁹Japan Synchrotron Research Institute, Japan, ¹⁰Department of Earth and Planetary Science, Waseda University, Tokyo, Japan. *E-mail: ykebukawa@ciw.edu.

Introduction: The Sutter's Mill meteorite fell in El Dorado County, California on April 22, 2012. This meteorite is a regolith breccia composed of CM chondrite and highly-reduced xenolithic materials.

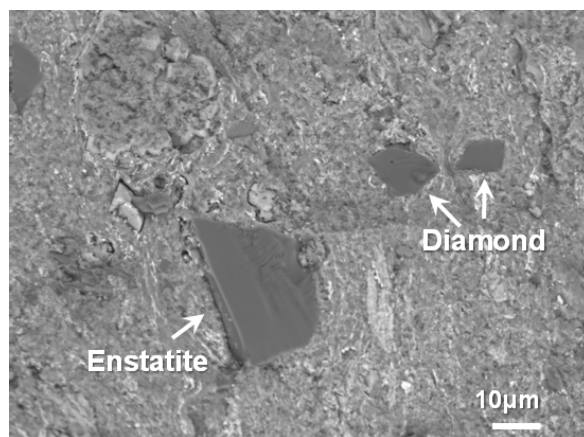


Fig. 1: BSE image of some matrix phases of SM2-5.

The basic mineralogy and petrography of the Sutter's Mill chondrite has been described [1], but since this is a regolith breccia it is critical to describe the exact lithology of each sample analyzed. Sutter's Mill meteorite SM2 was one of the few meteorites collected before it rained, and so best preserves the original asteroid regolith mineralogy. The fragment analyzed here, SM2-5, identified in [1], is a breccia of olivine and low-Ca pyroxene aggregates, some with fine-grained dust mantles, CAI, unusual lithic fragments, fragments of olivine and low-Ca pyroxene (up to 1 mm), very abundant oldhamite grains (verified by synchrotron X-ray diffraction at Beamline 37XU, SPring-8: SXR), diamond crystals (SXR) and fine-grained organics (Fig. 1). No chondrules are present. Fe-Ni sulfides are fine-grained, usually associated with Fe-Ni phosphides, and less common than oldhamite. SXR of the fine-grained silicate matrix revealed that it consists mainly of submicron olivine. There are no carbonates or sulfates, and metal grains are rare. The olivine rich matrix could be primitive, fine-grained material, or a product of thermal metamorphism, however, the homogeneous distribution of Na and K in the

matrix suggests that it has not experienced aqueous alteration. We interpret this lithology as a highly comminuted regolith breccia [1]. The striking abundance of oldhamite, phosphides, enstatite and diamonds suggests a physical mixing of C and E chondrites, and possibly ureilite material. The scarcity of metal in a rock which includes E chondrites materials could be due to gravitational settling.

In this work, we analyzed a fine grained matrix area surrounding a diamond grain using C-, N-, and O-X-ray absorption near-edge structure (XANES), in order to characterize organic matter.

Experimental: A ~100 nm-thick section was extracted with a focused ion beam (FIB) at JSC from the SM2-5. The section was analyzed using the scanning transmission X-ray microscope (STXM) on beamline 5.3.2.2 at the Advanced Light Source (ALS), Lawrence Berkeley National Laboratory for XANES spectroscopy [2]. The beamline is particularly designed for light elements, such as C, N, and O *K*-edge energy regions, but we are also able to obtain *L*-edge absorptions of some heavier elements such as Ca and Fe.

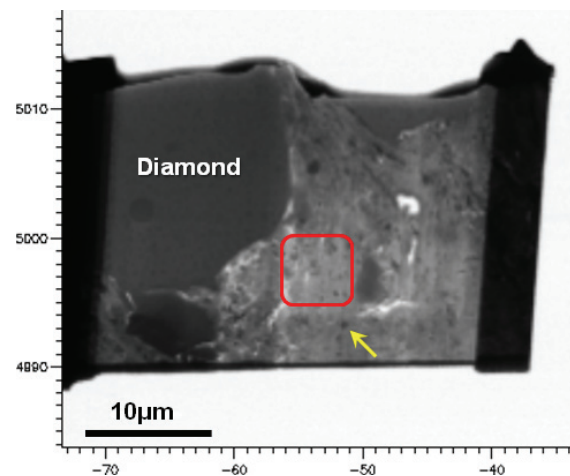


Fig. 2: STXM image of the FIB section of SM2-5. The red square is the area analyzed with C-, N-, O-XANES. The yellow arrow indicates the C- and Ca-rich grain, probably carbonate. The darker area (upper left) is a diamond grain. The red area is mostly matrix material.

Results and discussion: Fig. 2 shows a STXM image obtained at 390 eV. The darker area (upper left in Fig. 2) is a diamond grain (verified by SXRD after STXM-XANES analysis), and the lighter area is the fine grained matrix region (lower right). Fig. 3a is a C-XANES spectrum obtained from the fine grained matrix area close to the diamond (red square in Fig. 2). The C-XANES spectrum reveals absorption features at 284.7 eV that is assigned to the $1s-\pi^*$ of aromatic and olefinic carbon ($C=C^*-H,C$). Absorption at 286.5 eV is assigned to $1s-\pi^*$ of aryl, vinyl-ketone ($C=C^*-C=O$, $C=C-C^*=O$), while absorption at 288.4 eV is assigned to $1s-\pi^*$ of carboxyl ($OR(C^*=O)C$). Absorption at 290.2 eV is assigned to carbonate. Small peaks at 292.0 eV and 297.1 eV are due to absorption of potassium L -edges. There is no $1s-\sigma^*$ exciton feature at 291.6 eV, indicating that this matrix area has never experienced significant thermal metamorphism [3]. The abundant $C=O$ groups and no exciton features indicate that the organic matter has primitive molecular structures similar to insoluble organic matter (IOM) from CM/CI/CR chondrites. However, no significant N-bearing functional groups are observed with N-XANES. There is a C- and Ca-rich grain ($<1 \mu m$) where C-XANES revealed absorption features at 290.1 eV that was assigned to carbonate (Fig. 3b).

Fig. 4 shows Ca-Fe-C elemental map of the FIB section obtained by STXM. There is a transparent, round Ca-rich inclusion ($\sim 2 \mu m$ in diameter) in the diamond, the exact nature of which is still unknown.

Organic analysis of the FIB section of SM2-5 using C-XANES reveals that CM/CI/CR chondrite-like primitive organic matter is present in the fine-grained matrix material. It should be noted that this lithology has not experienced aqueous alteration like other CM or CI/CR chondrites. If this type of organic matter is synthesized in an aqueous environment, as proposed by Cody et al. [4], the organic matter would be mixed with the fine-grained matrix components after its synthesis. Any aqueous activity was too small to leave such physical evidence.

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References: [1] Jenniskens P. et al. (2012) *Science*, 338, 1583–1587. [2] Kilcoyne, A. L. D. et al. (2003) *J. Synchrotron Rad.*, 10, 125–136. [3] Cody, G. D. et al. (2008) *Earth Planet. Sci. Lett.*, 272, 446–455. [4] Cody, G. D. et al. (2011) *PNAS*, 108, 19171–19176.

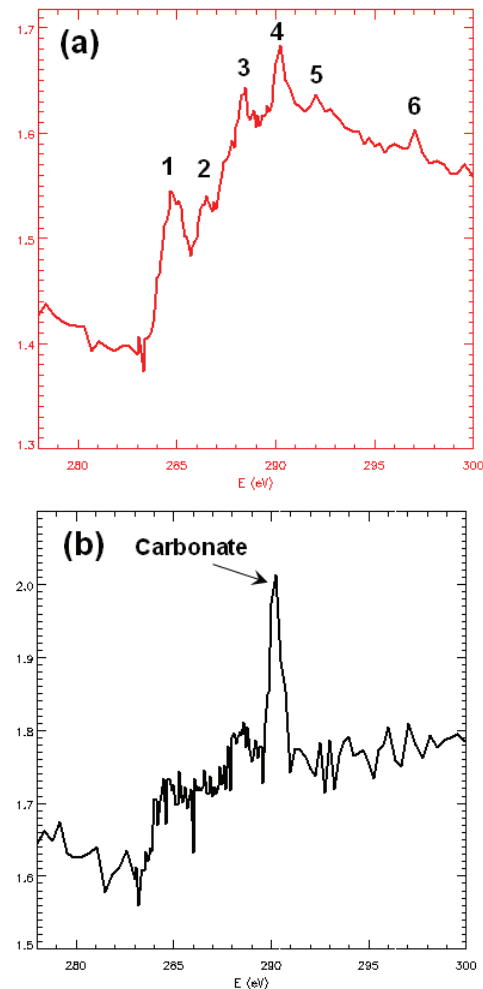


Fig. 3: (a) C-XANES spectrum obtained from the fine grained matrix area. 1) 284.7 eV: $C=C^*-H,C$; 2) 286.5 eV: $C=C^*-C=O$, $C=C-C^*=O$; 3) 288.4 eV: $OR(C^*=O)C$; 4) 290.2 eV: carbonate; 5 & 6) 292.0 and 297.1 eV: L_3 - and L_2 -edges of potassium, respectively. (b) C-XANES spectrum obtained from the C- and Ca-rich grain.

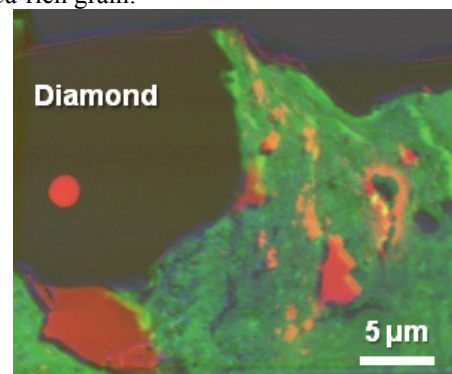


Fig. 4: STXM elemental map of the FIB section of SM2-5. Ca in red, Fe in green, and C in blue. The diamond grain (upper left) looks dark due to its high optical density.