

# Investigation of Organic Matter in the Allende Meteorite using Scanning Transmission X-ray Microscope at Photon Factory.

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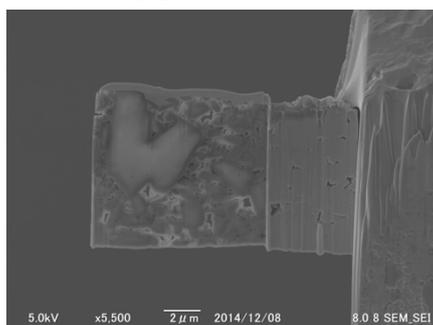
## Introduction:

Allende meteorite (Allende), which is classed as carbonaceous meteorite (CV3), fell in Pueblito de Allende, Chihuahua State, Mexico, on February 8, 1969. Allende is composed of chondrule, calcium-aluminium-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), Fe/Ni metal, and matrix. Organic matter (OM) is contained in matrix phase. OM in the Allende was investigated using acid extraction method [1]. Acid treating, however, has not only damage for OM (e.g. loss of insoluble compound like a carbonate) but also poor regioselectivity. In addition, distribution of OM in the matrix of Allende at the submicron-scale has not investigated yet.

We improved these problems using focused ion beam (FIB) method, which has better regioselectivity and lesser damage to the sample than the acid treating method. FIB method was used to the CM and other type meteorites (e.g. Le Guillou *et al.* (2014) [2]). After sample preparation using FIB, distribution and characterization of OM in the matrix of Allende at the submicron-scale was investigated by scanning transmission X-ray microscopy (STXM).

## Experiment and Method:

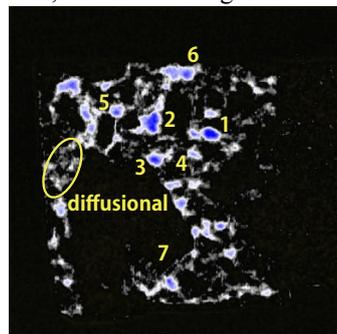
In the present study, we prepared focused ion beam (FIB) milled thin section (approximately 100-150 nm thickness) of Allende which was transected from a region of fine-grained matrix. The specimen is shown in Figure 1. Then, carbon X-ray absorption near-edge structure (C-XANES) and carbon elemental map was obtained by compact scanning transmission X-ray microscope (compact STXM) which is installed to BL-13A at Photon Factory, high energy acceleration research organization (KEK) [3].



**Fig. 1:** SEM secondary electron image of the thin foil specimen for compact STXM.

## Results and Discussion:

The compact STXM analysis revealed that the thin section of matrix in Allende contained C-rich particulate and diffusional OM (Figure 2). The C-XANES spectra were obtained from C-rich particulate, diffusional OM, and total carbon region of thin section, as shown in Figure 3.



**Fig. 2:** Carbon elemental map of the specimen. Particulate and diffusional OM is indicated blue and white respectively.

As to particulate OM, seven of C-rich grains, which are similar to Allende's insoluble organic matter (IOM) reported by Cody *et al.* (2008) [1]. Some of seven C-rich grains has exciton peak of the diamond (288.6-288.9 eV). Existence of this peak indicates the possibility that nano-diamonds are contained in these grains. In addition, one of the C-rich grains has possibility of contain of C-N bond (nitrile or heterocyclic imine).

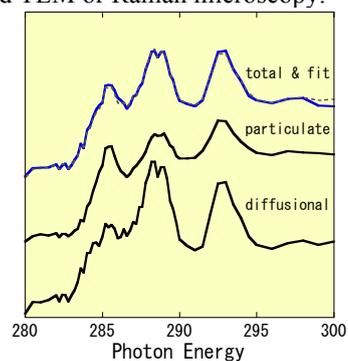
As to diffusional OM, distributing like vein, whose C-XANES were carboxylic rich OM compared to grains. Diffuse OM was investigated in CM and CI chondrites by C-XANES, whose compositions were mainly labile- and low-molecules OM and which was carboxylic rich OM was reported by Le Guillou *et al.* (2014) [2]. However, C-XANES of diffuse OM, was investigated in this study, is different from that reported previously. This difference caused from the difference of empirical temperature between CV, CI, and CM.

C-XANES obtained from total carbon region of thin section was fitted by C-XANES extracted from particulate and diffusional OM. Fitting results shows particulate: 48.6% and diffusional 51.4 %. This result suggested that OM in the Allende matrix phase was mainly composed by these two types.

From these investigations, OM present as particulate and diffusional in the matrix phase of Allende meteorite was revealed. And compact

STXM measurement indicated that particulate have IOM-like feature, and possibility of containing nano-diamonds and C-N compounds. On the other hand, diffusional OM is carboxylic-rich OM.

As to the future work, existence of nano-diamonds and C-N compounds should be confirmed by transmission electron microscope (TEM) and N-XANES respectively. In addition, vestige of thermal metamorphosis between OM and inorganic minerals should investigate by compact STXM and TEM or Raman microscopy.



**Fig. 3:** C-XANES of diffusional OM, C-rich particulate, and total carbon region of thin section, from bottom to upper. Fitting line indicated as dotted line.

#### References:

- [1] Cody G. D. et al. (2008) *EPSL*, 272, 446-455.
- [2] Le Guillou C. et al. (2014) *GCA*, 131, 368-392.
- [3] Takeichi Y. et al. (2014) *Chem. Lett.*, 43, 373-375.