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Evidence of minimum aqueous alteration in rock-ice body recorded in ultracarbonaceous micrometeorite

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Introduction:

Ultracarbonaceous micrometeorites (UCMMs) are unique extraterrestrial materials that represent large sizes of high carbon contents [1]. In our recent study of an UCMM D05IB80 collected from near the Dome Fuji Station, Antarctica [2], it has been revealed that: (i) ten-micron-sized large organic material accounted for most part of the sample, (ii) the organic material was extremely rich in nitrogen functional groups such as nitrile, imine, and amide, (iii) sulfur is identified within the organic material surrounded by pyrrhotite rim, and (iv) there was no anomalies in hydrogen, carbon and nitrogen isotopic compositions. These features have not been observed from typical chondritic organic material, while they are partially similar to those from CR3 chondrite [3] and some particles from Comet Wild 2 [4]. In order to enhance our understanding of the origin and formation of UCMMs, we have carried out TEM observation of the focused ion beam (FIB) section of D05IB80.

Experimental:

Bulk mineralogy of an UCMM D05IB80 was investigated by using synchrotron radiation X-ray diffraction (SR-XRD) at the Photon Factory. D05IB80 was embedded in epoxy and ultramicrotomed into 70-nm-thick sections. After ultramicrotomy, the potted butt of the micrometeorite was analyzed by a Hokudai isotope microscope system at Hokkaido University. A thin section was prepared by the dual beam FIB-SEM JEOL JIB-4501 at Ibaraki University. Carbon-, Nitrogen-, and Oxygen-X-ray absorption near edge structure (XANES) spectra of the FIB sec-tion were acquired using a scanning transmission x-ray microscope (STXM) at the beamline 5.3.2.2., Advanced Light Source, Lawrence Berkeley National Laboratory. After STXM, the FIB section was observed by JEOL JEM-2100F field emission TEM at JEOL Corporation and by JEOL JEM-2100 at Ibaraki University.

Results and discussion:

Elemental mapping analysis and high resolution observation of the boundaries between the UCMM and the epoxy were performed. There are two types of boundaries between them, one is smooth and another is globular. Although morphologies are considerably different between these boundaries, high-resolution images revealed that there are very thin ($<$ 5 nm) layers composed of less electron transparent material than carbonaceous material at the surfaces of both boundaries. Both of the surface areas containing less electron transparent material are enriched in C, O, Si, S, and Fe.

Minor crystalline phases identified are olivine and Ni-bearing pyrrhotite. Olivine occurs as a polycrystalline ag-gregate. On the other hand, Ni-bearing pyrrhotite occurs as fine-grained subhedral to rounded crystals embedded in amorphous silicate. The size and morphology of the amorphous silicate object containing Ni-bearing pyrrhotite are similar to GEMS (glass with embedded metal and sulfide) that are commonly observed in chondritic porous inter-planetary dust particles (CP IDPs) (e.g., [5]). However, no Fe-Ni alloy was identified from these GEMS-like objects. Observation of Ni-bearing pyrrhotite and GEMS-like objects without metals implies that the UCMM are very slight-ly aqueously altered. This condition could have been locally occurred at the early formation stage of the rock-ice bodies including comets and icy asteroids. The repetitive warming process of ice might have promoted the formation of ten micron-sized large, nitrogen-rich organic material observed from D05IB80. Association of organic material and sulfur supports the presence of fluid chemistry on the parent body. These features appear to be a very pristine signature of interaction of mineral, ice, and organics in the primitive small body.

References:

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