Three-dimensional structure of matrix of the Ivuna meteorite using micro X-ray CT and FIB serial sectioning

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CI chondrites are chemically the most primitive material in the solar system because of their bulk composition similar to the solar photosphere except for volatiles [1]. They have undergone extremely strong aqueous alteration. Their matrices mainly consist of phyllosilicates and include mineral grains such as magnetite, sulfides, carbonates and sulfates. Two types of phyllosilicates are known; coarse aggregates of serpentine and saponite and fine aggregates of serpentine, saponite and ferryhydrite [2]. CI chondrites are composed of rock fragments with different lithologies. Four lithologies were identified for the Ivuna meteorite based on the mineral composition using SEM [3]. Fragments of four CI chondrites were classified into eight lithologies based on the textures and the chemical compositions of the matrices using SEM and TOF-SIMS, and a model for aqueous alteration and accumulation was proposed [4]. Each lithology has fine and complex texture. Detailed 3D structures enable us to obtain information such as cavity, which is not available in 2D. From the information, we may understand original state before aqueous alteration, detail process of aqueous alteration such as movement of a fluid. For this purpose, we observed 3D structure of a fragment of the Ivuna meteorite with high resolution using X-ray tomography and FIB serial sectioning.

We made detailed observation of fragments in a thin section of the Ivuna meteorite and obtained elemental maps with FE-SEM/EDX (JEOL JSM7001F/Oxford Instruments X-Max^N 150mm^2). Based on the result, a cube ~25 μm in size was sampled from one of the fragments using SEM/FIB (FEI Helios NanoLab G3). Then, the 3D structure of the cube sample was imaged by SIXM (Scanning Imaging X-ray Microscopy) [5] at BL47XU of SPring-8, Japan with the pixel size ~100 nm. After the CT imaging, we obtained serial BSE images of some portion of the sample with higher resolution by serial sectioning using FIB and observation with FE-SEM (FEI Helios NanoLab G3). From these 3D images, structures in the matrix and mineral grains were extracted using image analysis.

The SEM/EDX study of the thin section showed that the fragment examined in 3D has Mg-rich matrix mainly consisting of coarse and elongated phyllosilicate aggregates (~50 nm in width and ~500 nm in length). Mineral grains of magnetite, pyrrhotite and Ni bearing sulfates were also observed, but any carbonates were not. These features correspond to lithology II (carbonates are absent but sulfates are dominant) of [3] and lithology CGA (Coarse-grained phyllosilicate aggregate) of [4]. We found that the matrix consists of objects a few mm in size, which are aggregates of Mg-rich phyllosilicates covered with Fe-rich phyllosilicate and seem to be spherical in 2D. Hereafter, we call this object PC (phyllosilicate composite).

In the CT images, rod-shaped crystals of magnetite (~1×5 μm) and cavities in irregular and hexagonal-plate shapes were observed as well as PC. Cavities in hexagonal shape (~5×1 μm) should be empty crystals formed by leaching of original pyrrhotite or carbonate. In the serial SEM images, PCs and magnetite crystals was clearly recognized, but cavities not because spattered substances by FIB were redeposited in the cavities. We found that PCs are irregular ellipsoids in 3D, and the directions of elongations of PCs and magnetite crystals are random, suggesting that no remarkable movement of a fluid was occurred during aqueous alteration. Matrix texture consisting of PCs might be a result of strong aqueous alteration of fine aggregates of sub-micron grains of minerals and/or amorphous silicate.

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Keywords: CI meteorite, aqueous alteration

