Aqueous fluid inclusion candidates in Sutter's Mill meteorite (CM) and their 3D micro-textures using X-ray micro-tomography combined with FIB sampling. A. Tsuchiyama[1], A. Miyake[1], M. E. Zolensky[2], K. Uesugi[3], T. Nakano[4], A. Takeuchi[3], Y. Suzuki[3] and K. Yoshida[1]. [1]Graduate School of Sience, Kyoto University. E-mail: atsuchi@kueps.kyoto-u.ac,jp. [2]NASA, JSC. [3]JASRI, SPring-8. [4]AIST, GSJ.

Introduction: Aqueous fluids in the early solar system are preserved in some H chondrites as inclusions in halite (e.g., [1]). Although potential aqueous fluid inclusions are expected in carbonaceous chondrites with aqueous alteration [2], they have not been surely confirmed. In order to search for these fluid inclusions, we have developed a new X-ray micro-tomography technique combined with FIB sampling and applied this technique to a carbonaceous chondrite.

Experimental: Sutter's Mill meteorite (CM) was used as a sample. Polished thin sections of this meteorite were observed with an optical microscope and FE-SEM (JEOL 7001F) to choose mineral grains 20-50 μm in typical size, which may contain aqueous fluid inclusions. We selected fourteen grains of calcite, two grains of FeS (FeS and a mixture of FeS-(Fe,Ni)S), one grain of (Zn,Fe)S, and one grain of enstatite. Then, a cube-shaped sample with a roof 20-30 μm in size (hereafter we call this "house") is extracted from the mineral grain by using FIB (FEI Quanta 200 3DS). The house was attached to a thin W-needle by FIB.

Each house was imaged by a SR-based absorption imaging micro-tomography system with a Fresnel zone plate at beamline BL47XU, SPring-8, Japan. The absorption imaging experiments were made at two different X-ray energies, 7 and 8 keV, to identify mineral phases (dual-energy micro-tomography [3]). The size of voxel (pixel in 3D) was 50-80 nm, which gave the effective spatial resolution of ~200 nm. A terrestrial quartz sample [4] with an aqueous fluid inclusion with a bubble was also examined as a test sample for the present method.

One aqueous fluid inclusion candidate and the test sample were further examined using scanning-imaging X-ray microscopy (SIXM) [5], which makes possible to obtain 3D phase-contrast and absorption-contrast images simultaneously.

Results and discussion: A fluid inclusion of 5-8 μm in quartz (test sample) was clearly recognized in CT images taken by the absorption imaging micro-tomography. A bubble of ~4 μm was also identified as X-ray refraction contrast although the absorption difference between fluid and bubble is too small to be recognized. Volumes of the fluid and bubble can be obtained from the 3D CT images [4].

Ten calcite, one FeS-(Fe,Ni)S and one (Zn,Fe)S grains have inclusions >1 μm in size (the maximum: ~5 μm). Calcite grains are usually surrounded by serpentine, which are also surrounded by cronstedtite-tochillinite coherent intergrowth. Larger voids with an irregular shape (<10 μm) are present between calcite and serpentine. Tiny inclusions (<1 μm) were also observed in all the grains examined. These results show that mineral grains have more inclusions than expected from 2D observations. These inclusions are candidates for aqueous fluid inclusions, which were formed during hydrothermal alteration.

Relatively larger inclusions (>1 μm) in mineral grains have a variety of shapes, from spherical to irregular. The shape of one inclusion in a calcite grain is a hexagonal plate (2.5x2.5x1 μm), showing that this is a negative crystal. Relatively larger and tiny inclusions were distributed randomly in mineral grains. This indicates that the inclusions are not ones formed along healed cracks but may be formed during the growth of mineral grains probably in hydrothermal alteration process.

The X-ray absorption contrasts of the inclusions show that they are not solid inclusions. One calcite grain has a spherical inclusion ~2 μm in size, which seems to have a bubble and a tiny solid daughter material inside as three-phase inclusion. However, no clear bubbles were observed in the other inclusions, indicating that we cannot determine whether they really have aqueous fluids inside or merely vacant voids. Even if any materials are not present in the inclusions at present, there is a possibility that aqueous fluids were incorporated into mineral grains during aqueous alteration, and the fluids escaped from the inclusions. Sub-micron solid materials were also observed in some inclusions.

The test sample (aqueous fluid inclusion in quartz) and the three-phase inclusion candidate in calcite were examined by SIXM. The aqueous fluid can be recognized in quartz by phase-contrast ($\delta \sim 4 \times 10^{-6}$, where $1\text{-}\delta$ is the refractive index by X-ray), which is nearly proportional to the density. However, we cannot recognize any aqueous fluid in the three-phase inclusion candidate probably because the volume is too small.

As we know the exact 3D position of the inclusion, we will analyze the inclusion by SIMS after freezing the sample as has been done for a halite sample [6]. The present technique is useful for examining small inclusions not only in carbonaceous chondrites but also in other meteorites and terrestrial materials as well.

References: [1] Zolensky et al. (1999) *Science*, 285, 1377-1379. [2] Zolensky et al. (2004) *MAPS*, 39, A118. [3] Tsuchiyama et al. (2013) *GCA*, 116, 5-16. [4] Yoshida et al. (2014) Annual Meeting of Japan Assoc. Mineralogical Sciences. [5] Takeuchi et al. (2014) 12th Internat. Conf. on X-Ray Microscopy. [6] Yurimoto et al. (2010) *MAPS*, 45, A5178.