COMBINING FOCUSED ION BEAM AND SYNCHROTRON TOMOGRAPHY TO IDENTIFY FLUID PATHWAYS IN HEATED CM CHONDRITES WITH IMPLICATIONS FOR RYUGU AND BENNU

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Introduction: CM chondrites are among the most chemically primitive meteorites in our collections and also the most aqueously altered [1, 2]. Analysis of CM chondrite porosity and permeability using transmission electron microscopy (TEM) indicates that the permeability of these meteorites is very low and would only permit fluid flow across length scales of <100 µm over the duration of aqueous alteration [3]. However, a subset of CM chondrites have been thermally metamorphosed [e.g. 4] and they are currently some of the best analogues for material on the surfaces of the asteroids Bennu and Ryugu, which are currently being sampled by OSIRIS-Rex and Hayabusa2 respectively [5, 6]. The driver of this metamorphism is unknown, but solar radiation, impact and radiogenic heating have all been suggested [7]. During heating CMs have lost a proportion of their volatiles, including water, and this process requires transport over the order of meters to kilometers, at odds with the low permeability calculated by TEM [4]. However, TEM samples are generally limited to 20×10×0.1 µm volumes and as such larger scale features may be missed. The development of plasma focused ion beam (P-FIB) technology now enables extraction of much larger sample volumes (e.g. 100×100×100 µm) in reasonable time frames (2-3 hours). These large samples can then be characterized in 3D, either using FIB tomography combined with 3D energy dispersive X-ray spectroscopy (EDS) and/or synchrotron tomography, to identify features that may not be present in a typical TEM sample.

Method: We extracted two quadrilateral shaped 60×60×40 µm samples of the heated CM Elephant Moraine (EET) 96029 across the boundary between a fine-grained rim (FGR) and the matrix using the P-FIB at the University of Glasgow. The internal structures of these samples were studied by X-ray tomography at the Spring8 synchrotron in Japan, and by FIB tomography. EDS maps were collected at the middle and end of the FIB-tomography analysis. The 3D porosity was calculated from both datasets using Avizo®.

Results: Both P-FIB and synchrotron tomography results show that the matrix and FGR porosity is similar to previous published values [3]. However, the FGR-matrix interface is characterized by 5-33 µm wide fractures (Fig. 1). The high permeability of these fractures would permit fluid flow over the order of meters [8]. The synchrotron data reveal that some of these fractures have been infilled (Fig. 1A; yellow), while EDS data collected during the P-FIB tomography indicate that the fractures are decorated with soluble elements such as S, and Ca (Fig. 1C). These observations suggest that fluids once flowed along these fracture surfaces and as such could facilitate volatile loss.

Implications for Bennu and Ryugu: Our data indicate that volatile loss from CM chondrites is possible through a network of fractures at the matrix-FGR interface. In addition, complete 3D characterization of large sample volumes can be undertaken through a work flow of P-FIB extraction followed by synchrotron and FIB tomography.

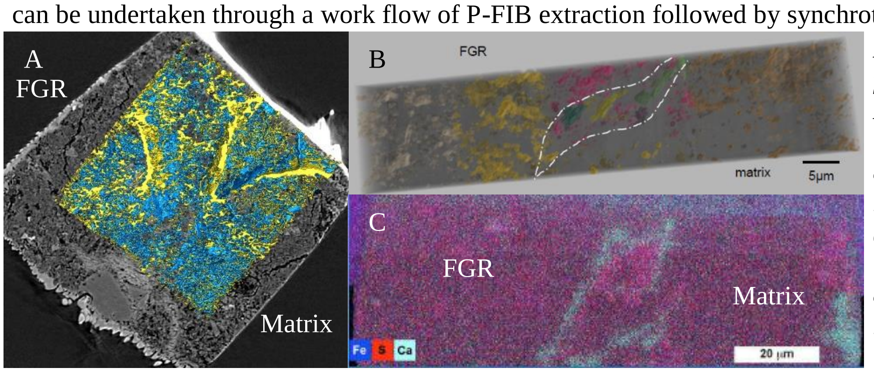

Figure 1. Porosity analysis data from the Sprin8 beamline (A) and FIB tomography (B) revealing large interconnected fractures across the interface between the matrix and FGR of EET 96029. (C) EDS imaging half way through the FIB tomography analysis revealing that the FGR-matrix interface is decorated with Ca and S.

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