Characterization of fluid flow path regarding iddingsite formation in the Martian meteorite Yamato 000593 based on the 3D Fe chemical species imaging

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Motivation and Goal:

Aqueous-altered olivine known as an iddingsite texture in nakhlites is considered as alteration track of Martian aqueous origin, since (i) the iddingsite crosses over the fusion crust and (ii) the high temperature-released hydrogen isotope value (δD) of iddingsite was high up to 900‰ (related to Martian surface water) [1,2]. The formation age of the iddingsite, however, was 633 ± 23 Ma, when the surficial water had been completely lost (nakhlites formed at 1327 ± 39 Ma) [3]. Therefore, it is reasonably understood that the iddingsite formation is related to thermal fluid alteration originated from a subsurface icy reservoir such as permafrost (heating source is uncertain; e.g., meteorite impact) [4]. The origin and detail formation process of iddingsite including the number/scale of alteration events are still unclear, although the limited research groups are enthusiastically investigating iddingsite. For instance, Noguchi et al. (2009) wrote that "we cannot conclude unambiguously that the aqueous alteration recorded in the Y 000593 nakhlites occurred in a single event" [5].

Here we focus on the alteration assemblages of iron minerals in iddingsite. In our recent unpublished study [6], Y 000593 preserves a number of SO_4-rich grains/veins, and this goethite/jarosite-bearing vein coexists with smectite group clay minerals. In addition, we found that the iddingsite itself has a structure gradually changing from olivine to goethite/jarosite. These sulfate-rich iddingsites were also reported by previous researchers [e.g., 5]. In contrast, Tomkinson et al. (2013) reported the siderite iddingsite vein usually altered in the reductive and high-pH environment [1]. Suzuki et al. (2018) reported the heterogeneous distribution of Ca-rich siderite ($FeCO_3$) and Mg-related rhodochrosite ($MnCO_3$) in micron meter scale in iddingsite [7]. These results suggested that Y 000593 experienced several stages of alteration events (at least twice). Therefore, we investigated the 3D Fe chemical species imaging of these secondary minerals in iddingsite by 3D-XAFS-CT (synchrotron-based X-ray computed tomography with elemental speciation). We also tried to estimate fluid flow path related to the iddingsite formation event(s).

Samples and Experiment:

The powder samples of Y 000593 (approximately 1 x 1 x 1 mm^3) were used to 3D-XAFS-CT at SPring-8 BL-37XU. The theoretical voxel size of the reconstructed 3D image was 0.65 x 0.65 x 0.65 μm^3 (below 1 μm^3), which allows us to visualize the 3D structure of olivine-goethite/jarosite (or carbonates) segmentation layer. Tomkinson et al. (2017) showed the 3D imaging of each component of nakhlite (e.g., visualized the 3D distribution of titanomagnetite grains in mesostasis) [8]. The CT analysis and data acquisition were conducted by ImageJ software. The methodology of reconstruction was referred from Hanna and Ketcham (2017) [9].

Results and Discussion:

We reconstructed the 3D image of olivine in Y 000593. The slicing image shows a vein structure (indicated by orange arrows in Fig. 1). The reconstructed 3D volume image of olivine morphology is shown in Fig. 2, showing iddingsite distribution. Iddingsite 3D network reconstructed image was also obtained. After that, we tried to obtain by iron distribution 3D imaging. However, the visualization of the iron image could not be done, because of the absorption of transmittance X-ray by the sample at the Fe absorption edge energy (especially at the post-edge energy region). Therefore, we are trying to XAFS-CT analysis (the Fe(II)/Fe(III) imaging using pre-edge energy region, and speciation by standard fitting for Fe-XANES spectra). Detail results of the XAFS-CT will be presented. The final goal of this study is the restoration of the formation environment (e.g., pH and temperature) of iddingsite with its fluid path from the discussion about sequence and degree of the alteration process by 3D-XAFS-CT results.

References

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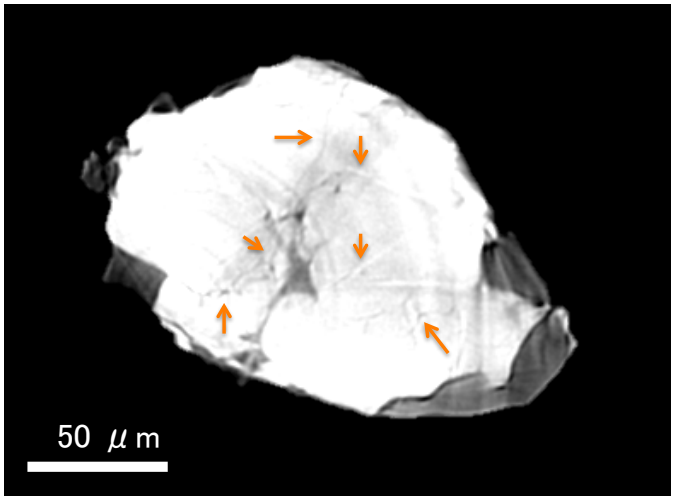

Fig. 1: The slicing image of olivine of Y 000593. Orange arrows indicate iddingsite structure.

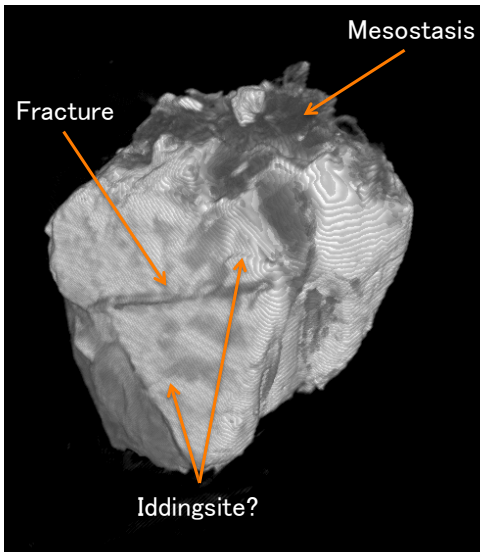

Fig. 2: The reconstructed 3D volume image of olivine morphology. Gray-black colored region is mesostasis.