Aqueous alteration of Yamato 000749 based on multi-probe microscopic observation

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Motivation

Based on the results of Mars explorations and researches of Martian meteorites for many years, there is a high possibility that liquid water had existed extensively on Mars for a long time (Sekine, 2012). Martian meteorite is one of the important clues for restoring the past Martian surface environment that cannot be unveiled by Mars surface survey alone. It is expected that a member of Martian meteorites, nakhlites have evidences for a rock-fluid reaction occurred on Mars. One of the representative evidence for the rock-fluid reaction is "iddingsite", which is an alteration texture formed in and around olivine grains in nakhlites. Many kinds of secondary minerals occur in the iddingsite through the rock-fluid reaction. The mineral assemblages, chemical compositions and chemical species of the secondary minerals depend on the varied parameters such as temperature and pH of the fluid. Suga et al. (2017) described the secondary minerals in the iddingsite of nakhlites Yamato (Y) 000593. Another Martian meteorites, Yamato (Y) 000749 is also a member of Yamato 00 nakhlites like Y 000593, containing abundant iddingsite. Based on Cohen et al. (2017), Y 000749 was located at the lower portion of the same nakhlites source compared to Y 000593. It is likely that these nakhlites have different mode of alteration even in the same source. Such heterogeneity on the mode of aqueous alteration would be related to the past hydrothermal environment on Mars.

Methods

We clarified the mineral species, chemical compositions and chemical species of the iddingsite in Y 000749 using a combined SEM-Raman-FIB-TEM-STXM technique. Pervasive iddingsite textures were observed along the fractures and grain-boundaries of the olivine grains in Y 000749 through FE-SEM observations and Raman spectroscopy analysis. Several portions including iddingsite were extracted and processed to be thin foils by FIB for TEM/STEM and STXM analyses.

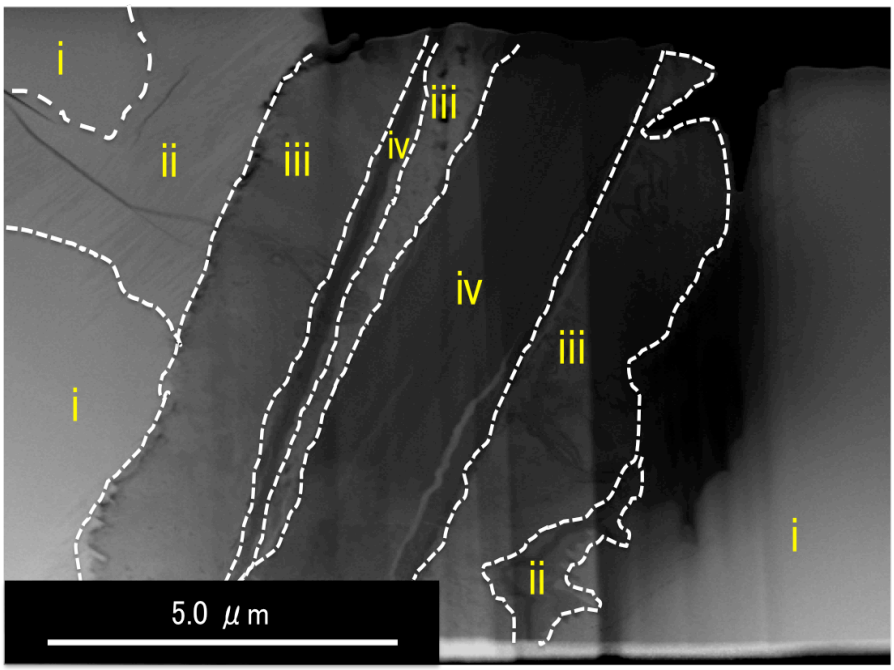
Results and Discussion

As a result, laihunite, ferrihydrite, goethite, poorly-crystallized silica mineral (it looks like smectite but details are uncertain) and minor iron sulfates were identified in the iddingsite. Laihunite was identified by Raman spectrum and selected area electron diffraction (SAED) pattern. Ferrihydrite and goethite were identified by Raman spectra, O- and Fe-XANES spectra and SAED patterns. Poorly-crystallized silica mineral was identified by Raman spectrum and TEM-EDS analysis. Minor iron sulfate was identified by S-XANES spectrum. Iddingsite in Y 000749 has a layered structure along the fractures of the olivine grains i.e., laihunite, ferrihydrite (and goethite) containing a trace amount of iron sulfate, poorly-crystallized silica minerals from the outside of the iddingsite vein towards the center of the vein (Fig. 1). Considering the occurrences of the secondary minerals, the formation sequence is as follows; i) laihunite, ii) ferrihydrite and lesser amounts of goethite and iron sulfates, iii) poorly-crystallized silica minerals.

Based on the occurrences and formation conditions of the secondary minerals, it is expected that Y 000749 experienced at least three different alteration events. We propose the following aqueous alteration history in Y 000749. At the first alteration event, Mg and Fe coordinated in olivine were dissolved in the fluid and a part of Fe in the relict olivine was oxidized to form laihunite. In the second alteration event, iron dissolved in the fluid was precipitated as ferrihydrite (and/or goesite). Then, at the third alteration event, Si dissolved in the fluid was precipitated as poorly-crystallized silica minerals. Suga et al. (2017) reported that the iddingsite of Y 000593 includes laihunite, opal-A, jarosite, natrojarosite, goethite and ferrihydrite. Comparing this result with our result of Y 000749, the species and quantity ratio of secondary minerals are different each other. The alteration is initiated by the formation of ferrihydrite subsequent to the formation of laihunite both in Y 000593 and Y 000749, which would occur under high-temperature and high-pH conditions (Treiman, 2005). The mode of subsequent alteration changes in between Y 000593 and Y 000749, because there is difference in the species of secondary minerals formed in the iddingsites. Sulfates were formed in Y 000593, but in Y 000749, few sulfates were observed, and alternatively, poorly-crystallized silica minerals were formed. As described above, based on Cohen et al. (2017), burial depths of Y 000749 and Y 000593 are different in the same nakhlites complex. It is likely that the alteration condition depends on the burial depth even in the same source.

Conclusions

From mineral species and layered structure of secondary minerals in the iddingsite, the fluids involved in the alteration of Y 000749 were hot and oxidative and Y 000749 have experienced at least three aqueous alteration events. In addition, by comparing each secondary minerals in the iddingsite of Y 000749 and Y 000593, we found both meteorites, which were considered paired meteorites in previous studies had experienced alteration at different depths. This is consistent with Cohen et al. (2017). In other words each histories of experienced alteration were different even though the same Nakhlite complex. Through this study, it can be said we approach the elucidation of Mars alteration environment by investigating altered texture in Martian meteorites using multi-probe microscopic observation.



i : Olivine ii : Laihunite iii : Ferrihydrite iv : Poorly-crystallized silica minerals

: Olivine : Laihunite : Ferrihydrite : Poorly-crystallized silica minerals

(i) (ii) (iii) (iv)

Figure 1. STEM-HAADF image and schema of representative iddingsite in Yamato 000749

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