The Difference Acidic Condition of Aqueous Alteration Event of Nakhla and Yamato 000593 Based on Chemical Speciation

*Hiroki Suga¹, Natsumi Sago¹, Masaaki Miyahara¹, Takuji Ohigashi², Yuichi Inagaki², Akira Yamaguchi³, Eiji Ohtani⁴

1. Graduate School of Science, Hiroshima University, 2. UVSOR Synchrotron, Institute for Molecular Science, 3. National Institute of Polar Research, 4. Graduate School of Science, Tohoku University

Nakhlites (e.g., Nakhla, Lafayette, Governador Valadares, Millar Range (MIL) 03346, and Yamato (Y) 000593) originating from the near-surface of the Mars are expected to record a water-rock reaction (alteration) occurred on the Mars. One of the representative alteration textures is “iddingsite texture”, which is observed in and around the olivine grain of nakhlites [e.g., 1]. A nonstoichiometric distorted olivine-type mineral laifunite [(Fe²⁺Fe³⁺)₂(SiO₄)₂], which is one of the alteration products of original olivine, was formed in the iddingsite texture [2]. The iddingsite was crosscut by fusion crust, indicating that the iddingsite including laifunite was formed on the Mars before it was delivered to the Earth [3]. A member of Nakhlites, Y 000593 and MIL 03346, which are expected to originate from the subsurface (~10 m in depth) of the Mars, has a remarkable amount of jarosite [KFe₃(SO₄)₂(OH)₆]-bearing iddingsite [2, 4]. Iron sulfates including jarosite were detected on several provinces of Mars’ s surface such as Meridiani plume, strongly suggesting the existence of surface (or sub-surface) liquid water (probably high acidic brine) at least one period in the Martian history [5, 6]. These jarosite-bearing nakhlites would become a keystone for a direct linkage between Martian meteorites and Martian surface materials. Therefore, we have tried to describe secondary minerals in the Yamoato 000593 for elucidating environment on the Mars during a wet-period by using a microscopic speciation technique; a FIB-assisted STXM combined with a TEM/STEM observation.

A polished chip sample of Y 000593 (subsample, 120) was prepared for this study. Iddingsite textures were observed using a FE-SEM/EDS first. A laser micro-Raman spectroscope was employed for phase identification. Ultra-thin sections of iddingsite textures were prepared by a FIB system for STXM and FE-TEM/STEM analyses.

Laihunite, Opal-A [SiO₂ • nH₂O], jarosite, natrojarosite [NaFe₂(SO₄)₂(OH)₆], goethite [FeO(OH)], and ferrihydrite [5Fe₂O₃ 9H₂O] were identified from the iddingsite of Y 000593 based FIB-assisted STXM-TEM/STEM analyses subsequent to FE-SEM/EDS and Raman analyses. The presence of natrojarosite, one of the quad phase of jarosite [7], suggests that Y 000593 experienced low pH (= 1-4), low temperature (80-240 °C), and SO₄-rich aqueous alteration process. Iddingsite can form below 500 , and most of them were formed between 100 and 50 [8], which is consistent with the alteration temperature of Y 000593 deduced from the existence of natrojarosite. The alteration condition of Nakhala with siderite (FeCO₃)-bearing iddingsite texture was estimated to be about mid pH (= 6-8), low temperature (150-200 ), and CO₂-rich fluid [9]. Because Mars rover Opportunity detected sulfate minerals such as jarosite and natrojarosite, Y 000593 is a better sample than the other near-surface nakhlites to understand the late-stage acid-sulfate alteration event. Laihunite (was formed at temperatures between 400-800 in [10]) was only reported from Y 000593 and MIL 03346 in the near-surface nakhlites, implying that these two nakhlite might have experience different alteration process compared to other near-surface nakhlites [4]. Our STXM-TEM/STEM analyses reveal the alteration process from original olivine to laihunite; Fe²⁺/Fe³⁺ ratio gradually decreases from olivine to laihunite, which probably corresponds to the difference of superlattices of laihunite (2M and 3M phase) [11]. Short time oxidation related to formation of the 2M phase [11], suggests that Y 000593 experienced a temporary heating event. We found mismatch on the formation temperatures between natrojarosite and laihunite. The
discrepancy may indicate that these minerals were formed different alteration events; i.e., laihunite was formed before the late-stage acid-sulfate alteration event.


Keywords: Nakhlite, Yamato 000593, Iron sulfate mineral, Laihunite, Acidic aqueous alteration on the Mars, FIB-assisted STXM/TEM