SECONDARY MINERALS IN MARTIAN METEORITE MIL 03346 AS DETECTED BY RAMAN IMAGING SPECTROSCOPY. Z.C Ling¹, Alian Wang², ¹School of Space Science and Physics & Shandong Provincial Key Laboratory of Optical Astronomy & Solar-Terrestrial Environment, Shandong University, Weihai 264209, China; ²Department of Earth & Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, United States (zcling@sdu.edu.cn).

Introduction: Shergottites, Nakhlites and chassignites are meteorites (also named SNC meteorites) from Mars which recorded the diagenetic processes on the red planet. The nakhlites are clinopyroxenites thought to have crystallized as cumulates within a thick basic-ultrabasic lava flow or shallow(~100m) on Mars 1.3 Ga [1]. Miller Range (MIL) 03346 is a nakhlite meteorite collected from Antarctic region, which is reported to experience a fast cooling process [2]. It was suggested that MIL 03346 may be the most oxidized SNC meteorite recognized to date [3]. The discovery of the jarosite, a hydrous sulfate, in MIL 03346 is firstly put forward by Herd et al.[4] indicating original aqueous alteration happened during its stay on Mars. Since then, MIL 03346 is intensively studied for understanding of Martian geology and surface environment [5-6]. It was found to have a large amount of veins containing low-temperature alteration phases.

There is debate on the origin of the alteration minerals in MIL 03346. The detection of sulfates (jarosite, gypsum, etc) on Mars have been validated by orbital spacecraft and surface rover missions in recent years[7-8]. Based on D/H isotopic ratios and textural evidence, Vicenzi et al. [9] concluded that the jarosite in veins is likely martian in origin and associated with aqueous alteration on the martian surface. McCubbin et al. [5] support the possibility that the jarosite found in melt inclusion of MIL 03346 is preterrestrial. However, the petrologic and isotopic data of MIL 03346 suggest that these sulfates, along with other evaporate minerals, have a terrestrial origin[1,6]. Hallis et al. [10] measured the D/H ratio of the iddingsite-like alteration veins in MIL 03346 and found the δD values were within the terrestrial range. While considering the MIL 03346 is a heavily terrestrial weathered meteorite, the hydrogen exchange with the Earth’s atmosphere should play an important role for this observation.

Here we report a preliminary study of MIL 03346,168 thin section by using the Raman imaging spectroscopy. Our goal is to get the spatial relationship of secondary hydrated minerals in this meteorite, to seek evidences that may hint their origins, and to understand their potential significance in Mars’ paleo-climate. We concentrate on the alteration mineral phases in this meteorite in our study that suggest the aqueous history of the meteorite. The veins and mesostasis contain volatile elements and hydrated minerals which is of great importance for understanding the martian aqueous history.

Experiments: The major minerals and secondary mineral phases in MIL 03346,168 thin section were investigated using a new Raman imaging facility, an inVia® Raman System (Renishaw Company), at Washington University in St. Louis. The green laser (532 nm line by Nd:YAG laser) is focused on the sample using a 50x objective, leading to an approximately 1 μm diameter spot. The typical Raman spectra for individual minerals grains were generally collected between 75 to 1350 cm⁻¹ with a exposure time of 30 s for 2 co-add. The Raman imaging measurements was conducted in the “Streamline™” mode using the same objective, and an automatic microscopic stage with ~100 nm movement accuracy and precision.

Figure 1. The global image of MIL03346,168

For the ease of Raman imaging measurements, we subdivided the meteorite into A to F regions (as shown in Figure 1). The image origin position (0,0) of this meteorite is repeatable by the control of encoded prior high precision motorised XYZ stage. We firstly point check the Raman spectra of specific grains in each region to acquire the endmember spectra, and then perform the Raman imaging measurements for the Regions of Interest (ROIs) with the intent to get the information on the spatial distributions of secondary minerals in this thin section.

Results and discussions:

The typical Raman spectra, which was taken directly on individual mineral grains in the meteorite, are shown in Figure 2. Some olivine grains are found to be...
zoned, with Fe-enriched rim, indicating by their Raman peak positions. Most of the pyroxene grains are clinopyroxene-rich which confirm the classification of this meteorite to nakhlite. MIL 03346 is reported to have the smallest abundance of olivine and largest abundance of mesostasis among all known nakhlite[11]. The skeletal titanomagneteites are distributed randomly in the mesostasis. We found very few feldspar grains in measurements. Some small grains are found in the mesostasis, which is K-rich feldspar determined by the Raman peak positions. The absence of albite feldspar suggest that rapid cooling occurred toward the end of crystallization [2]. The amorphous ferrihydrite grains are commonly find in the mesostasis, appears having generative relation with neighbor hydrated minerals. In addition, minor amount of apatite grains are also found in the mesostasis of MIL 03346.

Figure 2. The typical Raman spectra of minerals in MIL 03346

We find a series of secondary minerals, e.g., K-jarosite, bassanite, gypsum, γ-CaSO₄ etc., as vein filling materials in MIL 03346. The mesotasis is rich with a lot of tiny grains with non-crystalline amorphous nature, which suggest a fast cooling history of this meteorite. There are magnetite along with some Fe rich pyroxene grain. In the veins, we find bassanite is the major mineral with some appearances of gypsum or even γ-CaSO₄(1026 cm⁻¹). The mineral K-jarosite is found both in the veins and the mesostasis (as shown in Figure 3) by its diagnostic spectral features. The jarosite veins become more common towards the center, while bassanite veins have even stronger associations with the edges of MIL 03346. Some jarosite veins have small vugs related to later on alterations. For the studied regions, we found fewer secondary phases (e.g., bassanite, jarosite) in A and F region than those of the others (B/C/D/E). This may suggest a tendency of water erosion for the studied thin section.

The findings of sulfate minerals in MIL 03346 indicate a period of interaction between rock and water in the past martian enviroment. The bassanite is widely distributed in the veins of MIL 03346, with a few occurrence of gypsum and γ-CaSO₄ minerals. The gypsum veins were also found by the opportunity rover near the rim of Endavour Crater, which are the evidence of a dilute water or even habitable conditions in this region [12].

Figure 3. Selected images for alteration phase like bassanite, gypsum, and jarosite (with Raman image). The red indicate the vein of jarosite and large jarosite grains in the mesostasis.

Conclusion and future work

We conducted a Raman imaging study of MIL 03346, 168. Our study suggest a wide spreading of the secondary minerals (e.g., jarosite and bassanite), which are most noticeably found within the mesostasis or the veins cutting through cumulate minerals. More laboratory work is required to provide indications and constraints for the understanding of the alteration phases in the meteorite as well as their existence on Mars.

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