ALTERATION MINERALOGY IN MARTIAN REGOLITH BRECCIA NORTHWEST AFRICA 7034 USING RAMAN SPECTROSCOPY

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Introduction: Martian meteorites are only available samples from Mars, which provide valuable information about past environmental conditions on Mars. Northwest Africa 7034 is the first Martian regolith breccia identified based on oxygen isotope [1] and Noble gas isotopic compositions [2]. The bulk composition of NWA 7034 closely matches the estimates of the average Martian surface as measured by the gamma ray spectrometer on the Mars Odyssey Orbiter and to the crustal rocks and soils in Gusev Crater as measured by the Alpha Proton X-ray Spectrometer on the Mars Exploration Rover Spirit [1,3-4]. NWA 7034 has elevated abundances of Martian H_2O in the bulk rock (6000 ppm) [1], which appears to be entirely Mars origin based on its O-isotopic composition. These features suggest that NWA 7034 and its pairings are the best sample to directly investigate the secondary processes that occur on Martian surface and how these processes may have changed through time.

In this study, we identified the alteration phases in this meteorite using laser Raman spectroscopy and Scanning Electron Microscopy (SEM). Various alteration assemblages have been found in the lithic clast and matrix of the meteorite. According to their distribution in this section, we suggest the meteorite experienced both Martian in-situ and terrestrial aqueous alteration.

Analytical methods: The polished section of NWA 7034 (F3-1) in this study was prepared at UC Davis. Raman spectra of NWA 7034 were measured by Renishaw inVia® Raman Microscope in Shandong University, Weihai, China. We employed green laser (532 nm) for excitation and measured Raman shift range of 100-4000 cm^{-1} with a spectral resolution better than 1 cm^{-1}. Before each measurement, a Si wafer was used as the wavelength calibration standard. 100× objectives were used for the fine-grained alteration phase analysis and the spatial resolution of laser spot is better than 1 μm.

Back-scattered Electron (BSE) mosaic of NWA 7034 section was obtained using electron probe microanalysis in the Insittute of Geology and Geophysics, Chinese Academy of Sciences in Beijing. The high Magnification BSE images of individual mineral particle were collected by FEI SEM in Shandong University. Composition analyses were made using an Oxford INCA EDS (IE250X-Max50) with an ultrathin windowed Si (Li) detector.

Petrography: The NWA 7034 thick section was about 2 mm × 4 mm in size [5]. This meteorite consists of a rounded lithic breccia clast with igneous crystallization texture, a basalt clast, several crystal clasts and fine-grained bulk matrix (Figure 1). The breccia clast shows the subophitic texture. The aspect ratio of the euhedral plagioclase laths (mainly 1-2 μm wide) is about 10. The recrystallized subhedral pyroxene grains envelop the well-developed plagioclase laths. The accessory minerals in the breccia clast include Fe-Ti-Cr oxides (magnetite, chromite, hematite) and Fe sulfides (pyrite, pyrrhotite). The bulk matrix with the granoblastic texture contains pyroxene, plagioclase, and many other crystal clasts (magnetite, apatite, Fe sulfides). Both plagioclase and pyroxene crystal clast show irregular fractures. But plagioclase is not transformed into maskelynite, indicating the very weakly shock effects. The fusion crust was noted in the top of the matrix part, which could be possibly altered by terrestrial chemical alteration.

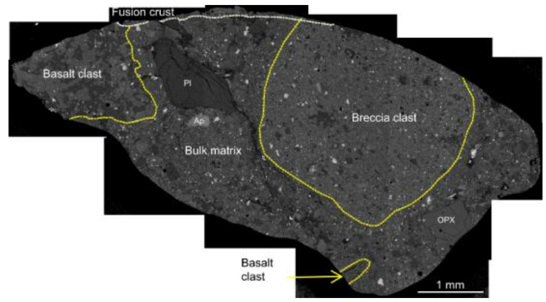

Figure 1 BSE image of Martian meteorite NWA 7034

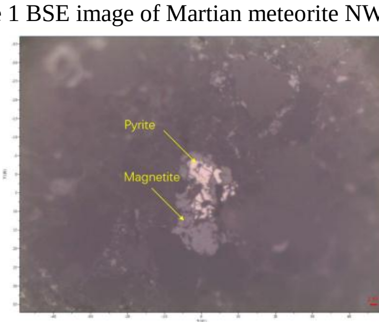

Figure 2 Optical image showing the altered pyrite associated with magnetite in the bulk matrix.

Alterations assemblages: over 30 pyrite grains have been identified in the bulk matrix,. All the pyrite crystals are altered to magnetite or hematite (Figure 2). This is consistent with previous observation [6]. This type of alteration assemblage locates in the bottom of the section. The most abundant oxides in the bulk matrix is magnetite (>50 grains). Many of them show hematite exsolution, which suggests the meteorite experienced oxidation (Figure 3).

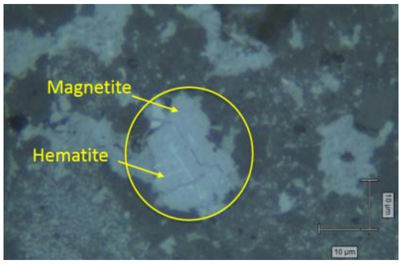

Figure 3 Optical image showing the magnetite fragments with exsolution textures of thin lamellae of hematite in the bulk matrix.

In the breccia clast, we observed lots of alteration phases (>20 grains) with honeycomb structure. They usually show as the assemblage of white and gray phases (WG) in the optical reflectance image (Figure 4). Raman spectra of these phase exhibits strong fluorescence background and no sharp peaks, which makes it difficult for phase identification. Based chemical composition acquired by EDS analysis, we speculate the gray phase are magnetite or maghemite while the white is pyrrhotite. This assemblage all concentrates in the top part of the clast close to the fusion crust, which suggest this alteration occurred on Earth. The altered pyrite and isolated magnetite have also been found in the breccia clast. Being different with WG phases, they all distributed in the bottom of the clast.

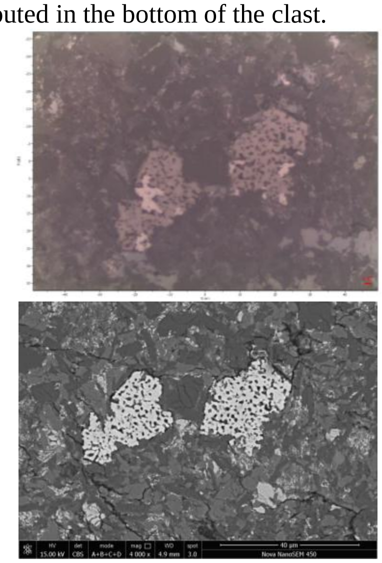

Figure 4 Optical (top) and SEM (bottom) image showing the pyrrhotite and magnetite/maghemite assemblage in the breccia matrix.

Comparison with Nakhlites: All Martian nakhlites contain small quantities of aqueous alteration minerals. There are at least two populations of martian weathering products: (1) clay minerals formed in situ within olivines, by the alteration and hydration of silicates and (2) precipitation of carbonates and sulfates within cracks and veins [7-8]. In the thin section of NWA 7034, no olivine is found. We did not find any clay minerals in the cracks of pyroxene and plagioclase. The most abundant secondary mineral assemblages are partially oxidized Fe sulfides and magnetite/hematite. Evaporite mineral assemblages, such as Ca/Mg/Fe sulfate and carbonates in the Nakhlites, are not found in this meteorite. This may suggest piror to the ejection of Mars surface, this rock experienced fast water rinsing or other geological processes that could totally remove all the water-soluble sulfates formed during the oxidation of Fe sulfides.

Conclusions: The alteration assemblages in NWA 7034 provides strong evidence that it was hydrothermally altered. Fe sulfides in both breccia clast and the matrix are partly transformed into magnetite and hematite. The similar alteration assemblages in the breccia clast and the matrix suggest hydrothermal activity must have occurred after the lithification of the regolith breccia. More detailed work is need to identify more fine grained secondary mineral and confirm if the aqueous alteration for this meteorite occured on Mars

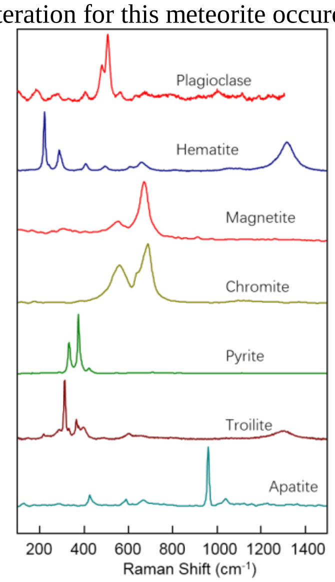

Figure 5 Typical Raman spectra of silicates, oxides, sulfides minerals in NWA 7034

Acknowledgement: We thank Prof. Q.-Z Yin (UC Davis) for sharing the meteorite. This study is supported by the National Natural Science Foundation of China (41303051, 41490633, 41590851, 41473065 and 41573056).

References: [1] Agee et al. (2013) *Science*, 339, 780-785. [2] Cartwright et al. (2014) *EPSL*, 400, 77-87. [3] Humayun et al. (2013) *Nature*, 503, 513-516. [4] McCubbin et al. (2016) *JGR*, 121. [5] Yin Q.-Z. et al. (2014) *45th LPSC*, Abstract #1320.[6] Lorand et al. (2015) *MPS*, 50, 2099-2120. [7] Grady et al. (2007) *38th LPSC*, Abstract #1826. [8] Changela and Bridges (2011) *MPS*, 45, 1847-1867.