MARTIAN VS. TERRESTRIAL ALTERATION ASSEMBLAGES IN MIL 03346 AND NAKHLA: HYDROGEN ISOTOPE AND COMPOSITIONAL COMPARISONS. L. J. Hallis[1], G. J. Taylor[1], J. D. Stopar[2], M. A. Velbel[3] and E.P. Vicenzi[4], [1]HIGP/SOEST, NASA Astrobiology Inst., Univ. of Hawaii, Honolulu, HI 96822 USA. [2]SESE, Arizona State University, Tempe, AZ, 85287. Email: lydh@higp.hawaii.edu. [3]Department of Geological Sciences, 206 Natural Science Building, Michigan State University, East Lansing, MI 48824-1115. [4]Smithsonian Institution, Museum Conservation Institute, Suitland, MD 20746.

Introduction: Pre-terrestrial (Martian) secondary alteration phases, including smectite clays, sulphates, carbonates and halide salts, have been reported within the nakhlite group of Martian meteorites by numerous authors [1-5]. For Martian meteorite falls (e.g., Nakhla) all secondary phases are commonly assumed to be pre-terrestrial, but some of Nakhla's inventory of highly soluble minerals (e.g., halite) occurs in fractures and vugs in the fusion crust, and therefore post-dates Earth arrival of Nakhla [6]. In Martian meteorite finds, effects of terrestrial aqueous weathering and contamination are superimposed upon and often modify pre-terrestrial aqueous-alteration mineral assemblages.

Miller Range (MIL) 03346 is a heavily terrestrially weathered nakhlite found in the Antarctic in 2003. Iddingsite-like clay veins determined to be pre-terrestrial are well documented in this meteorite [7-9]. Jarosite ($KFe^{3+}_3(OH)_6(SO_4)_2$), known to occur on Mars where it indicates acidic solutions [10], is also a common alteration phase within MIL 03346 [11,12] - in addition to, and in association with, Ca-sulphate. Some jarosite in MIL 03346 is demonstrably pre-terrestrial [13]. Jarosite has been reported within other Martian meteorites (QUE94201 and RBT04262), and its origin has been widely debated [14,15]. The aim of our research is to determine which occurrences of secondary alteration phases within MIL 03346 are terrestrial and which (besides [13]) are pre-terrestrial. We also aim to establish how the extensive terrestrial weathering on the meteorite surface affected pre-existing Martian weathering phases.

The pre-terrestrial origin of secondary phases can be established via measurement of their deuterium/hydrogen (D/H) ratios. Because of the preferential loss of the lighter hydrogen isotope to space after the cessation of Mars' dynamo, the Martian atmosphere is currently ~5 times enriched in deuterium compared to terrestrial seawater [16]. The difference between D/H in terrestrial and pre-terrestrial hydrated secondary phases can therefore be detected using ion microprobe techniques [17-19].

Methods: We utilised the JEOL JSM-5900LV scanning electron microscope at the University of Hawaii (UH) to produce high-resolution backscatter electron images of four MIL 03346 polished thin sections (126, 128, 173 and 174) prepared at the NASA Johnson Space Center, and one UH polished thin section of Nakhla (110). Secondary-phase major-element chemistry was determined with a JEOL JXA-8500F electron microprobe, also at UH. The amount of hydration within each phase was established with a WiTec confocal Raman microscope with 532 nm (green) laser at UH. Deuterium and hydrogen isotopic compositions were analysed in situ with the UH Cameca ims 1280 ion microprobe, with a Cs+ primary beam.

Results: *SEM Imaging.* Iddingsite-like clay veins were observed only within olivine phenocrysts, and are sometimes cross-cut by < 5µm Fe-oxide (probably goethite) veins. In contrast, Ca-sulphate and jarosite veins are associated with clinopyroxene grains and the mesostasis (Fig. 1). These sulphates are much more abundant within regions <100 µm from a terrestrially weathered surface (established by the presence of Antarctic varnish layers). Areas further than 100 µm from an exposed edge contain less Ca-sulphate, and even lower abundances of jarosite. This is very similar to the distribution of aqueous corrosion features in olivine previously attributed to terrestrial weathering of MIL 03346 [20].

Phase composition and Raman Spectra. Our EMP and Raman analyses of iddingsite concur with those of Stopar [21], indicating these veins are likely composed of smectite clay and fine-grained goethite. Ca-sulphate within thin-section MIL 03346,173 shows Raman fluorescence features associated with the presence of water, indicating these veins are composed of gypsum. Both Raman spectra and electron microprobe analyses suggest jarosite is K-rich in thin section 173.

D/H ratios. D/H analyses were performed on secondary alteration phases within thin sections of both MIL 03346 and Nakhla, the latter of which was intended to constrain the Martian alteration D/H end-member. Our initial results were produced without any prior heating; the thin-sections had simply been placed in a high-vacuum environment at room temperature for 2 weeks prior to analysis. The samples were still heavily contaminated with terrestrial water, as revealed by measureable terrestrial D/H in anhydrous phases (e.g., augite). Therefore, we dehydrated the samples in a vacuum oven at 50°C for 1 week prior to collection of the next set of analyses. These subsequent analyses indicate that all surface water was removed during heating, but the D/H ratios of all phases still remain within error of the terrestrial region for both Nakhla and MIL 03346.

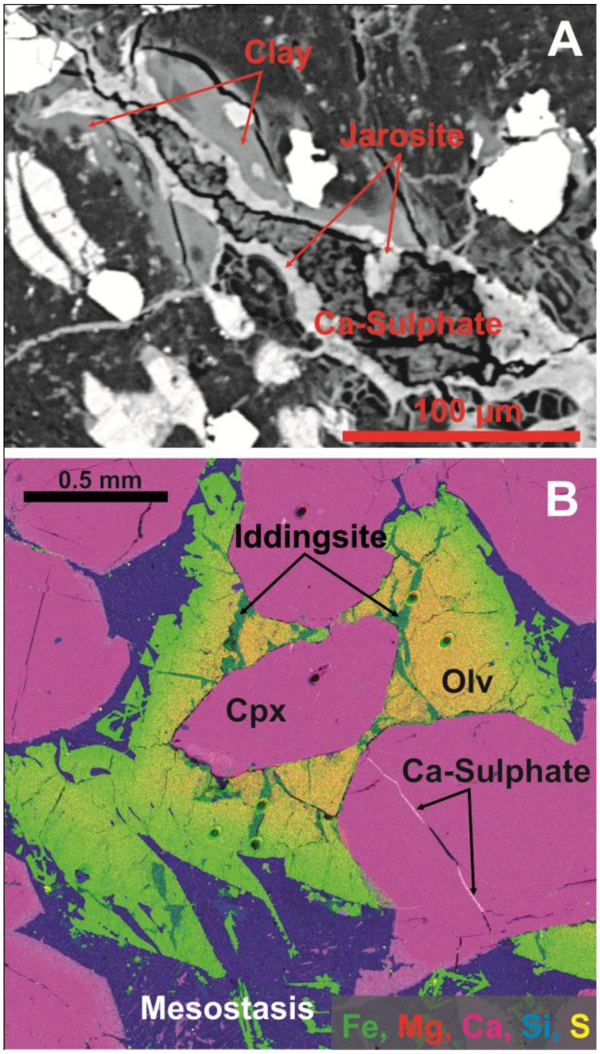

Fig. 1: (a) Backscattered electron image of an area of thin section MIL 03346,174 showing Ca-sulphate enclosed by jarosite within the mesostasis. Fe-rich clay (terrestrial?) also appears to have formed around the jarosite. Towards the centre of the section (b) sulphates are less abundant (Ca-sulphates in white), and an olivine phenocryst contains iddingsite veins (dark green). Jarosite is not present in the centre of this or any of the other three MIL 03346 thin sections.

Discussion and Conclusions: BSE and x-ray imaging, along with EMP analyses and Raman spectra, indicate that K-rich jarosite and Ca-sulphate within MIL03346 are associated with areas that have been exposed to terrestrial weathering processes. This association indicates these sulphates formed during the residence of MIL 03346 in the Antarctic. In contrast, iddingsite veins are distributed uniformly throughout MIL 03346 regardless of distance from fusion crust or exposed fracture surfaces. Measurements of jarosite D/H appear to support a terrestrial origin, but analyses of iddingsite veins within Nakhla indicate interstitial terrestrial water is present within the hydrated alteration phases of our samples. Despite being a fall, Nakhla has been exposed to a certain amount of terrestrial weathering [6], which may have affected the D/H systematics of its iddingsite veins. Further heating at higher temperatures may remove this contamination, but may also begin to remove a proportion of the Martian hydrogen we wish to analyse. To minimize the affects of terrestrial atmospheric D/H disturbance on future analyses we are in the process of cutting new thin sections of Nakhla and MIL 03346, which are being prepared without the use of water.

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