PRELIMINARY ANALYSIS OF NAKHLITE MIL 03346, WITH A FOCUS ON SECONDARY ALTERATION.

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Introduction: MIL 03346 is a new Antarctic Martian meteorite that has been classified as a clinopyroxenite and nakhlite based on its abundant calcic pyroxene [1]. We have completed a preliminary petrologic analysis of MIL 03346 thin section 94 and present our findings here. Several brownish patches are visible under optical microscopy and are likely associated with alteration. Similar discoloration is observed on all of the olivine grains present. Characterizing alteration processes in this meteorite is important for understanding aqueous alteration on Mars. Models of dissolution rates have been explored by [2-3] to constrain the duration of aqueous processes over Martian history. However, aqueous alteration is a complex process, and here, we explore the alteration of olivine and deposition of secondary minerals in order to better understand Martian aqueous processes.

Methods: Thin section MIL 03346-94 was studied using optical microscopy, X-ray elemental mapping, electron probe microanalysis (EMPA), and backscattered electron (BSE) imaging. X-ray elemental maps were acquired using the wavelength dispersive spectrometers (WDS) on the University of Hawaii's electron microprobe. These elemental maps were used to create a mineral map applying the technique of [4], which involves classification of mineral phases with ENVI image processing software. Using this map, the modal mineralogy of MIL 03346 was determined and weathering products were identified for further analysis (Fig. 1). EMPA was performed using WDS X-ray spectroscopy. BSE images of this thin section (Fig. 2) were obtained with the Hawaii Institute of Geophysics and Planetology's JEOL JSM-5900LV Scanning Electron Microscope (SEM). We performed analyses of alteration products not easily resolved elsewhere (such as those residing in small veins) using the EDS spectrometer attached to this instrument.

Preliminary Results: In our preliminary analysis of MIL03346, we calculated mineral modes for our thin section. We observed 78 vol% augite (including Fe-rich rims); 19% mesostasis (composed of sodic plagioclase, feldspar, phosphates, titanomagnetite-magnetite-spinel, and glass), 2% olivine, 0.9% "alteration" (in veins and voids and along grain boundaries and cracks), 0.09% Ca-sulfate (presumably gypsum).

The most abundant mineral, pyroxene, has an average core composition of $En_{37}Fs_{23}Wo_{40}$. The pyroxene rims are more iron-rich and have an average composition of $En_{21}Fs_{38}Wo_{41}$. Using the technique described by [5-6], we measured the crystal size distribution of the pyroxene population (998 grains), defining size by the width of the grains [5]. The meteorite has the largest average grain size (0.27mm) of any nakhlite and the largest maximum size (1.1mm). On the standard CSD plot (Fig. 3), MIL 03346 has the shallowest slope of any of the nakhlites. It also has the most pronounced turnover at small sizes. This depletion of fine grains could be caused by annealing or by cessation of nucleation accompanied by continued growth. For the linear portion of the plot, slope is equal to –1/(growth rate * residence time) [7]. Assuming growth rates for all the nakhlites were approximately the same, the smaller slope for MIL 03346 indicates a longer residence time. This suggests that annealing caused the depletion of small sizes, consistent with slow cooling. However, the slower cooling is inconsistent with the much finer grain sizes of the plagioclase crystals in the mesostasis.

The mesostasis in MIL 03346 is finer-grained than most nakhlites. SEM observations indicate that the fine-grained groundmass includes sodic plagioclase and feldspars, FeTi-oxides (dendritic), phosphates, spinels (including magnetite-titanomagnetite), orthopyroxene (rare), and glassy patches. The average composition of the mesostasis is ~17.3 wt% Al_2O_3, ~60.6% SiO_2, ~6.6 FeO, ~4.8% CaO, ~3.3% Na_2O, ~2.2% K_2O, ~1.3% P_2O_5, with lesser amounts of MgO, SO_3, TiO_2, and MnO.

A preliminary survey of secondary products in MIL 03346 reveals incipient alteration of olivines. Patches of olivine appear to be at various stages of decomposition showing a compositional progression from olivine to increasing states of alteration: Mg, Fe, SiO_2 $\rightarrow$ Fe, SiO_2 +/- Mg (with a low sum, possibly due to H_2O) $\rightarrow$ Fe, SiO_2 + Cl, S (most weathered). Olivine vein materials are consistent with gypsum, Fe,K-sulfates (?), and mobilized olivine components. The average composition of vein material in olivines is poorer in Mg and Fe than the "altered" olivine composition and richer in Si. Compared to other nakhlites [8-9], the average vein material is depleted in Al, Mg, Ca, and Na.

Gypsum is found in cracks, voids, and veins throughout the thin section. Gypsum is a typical evaporate and has filled in cracks and voids left between minerals. It may have been deposited as fluids in the rock evaporated. There is some association with "brown" weathered areas, probably rich in iddingsite [e.g., 10] (although we have not identified iddingsite at this time).

Discussion: Bridges et al. [11-12] propose that secondary minerals in Martian meteorites may result from an evaporation sequence where carbonates, anhydrite, gypsum, halite, and clays form. While this is possible for MIL 03346, our preliminary survey has not been able to positively identify any of these secondary minerals besides gypsum, which was readily identified in EMPA and SEM

EDS. However, from our study, it is obvious that numerous phases are present in "altered" areas, and a more in-depth search may reveal additional evaporate minerals.

Alteration occurs mostly along mineral boundaries and cracks. Alteration of olivine is patchy and present especially near mineral boundaries. A noticeable progression in olivine dissolution is observed as Fe, Mg, and Si are lost and other components are emplaced (esp. S and Cl). The alteration fluid probably contained S, Cl, and K, which were later deposited as water evaporated. Alteration of pyroxene is not as prevalent, as suggested by the presence of unaltered igneous rims (sums near 100). Mobilization of Ca and S in fluids allows the growth of gypsum laths. Surface materials highly enriched in S at Meridiani Planum are suggestive of S-rich brines on Mars [13]. MIL 03346 may also have been exposed to S-rich brines causing dissolution of olivine (and other phases to a lesser extent).

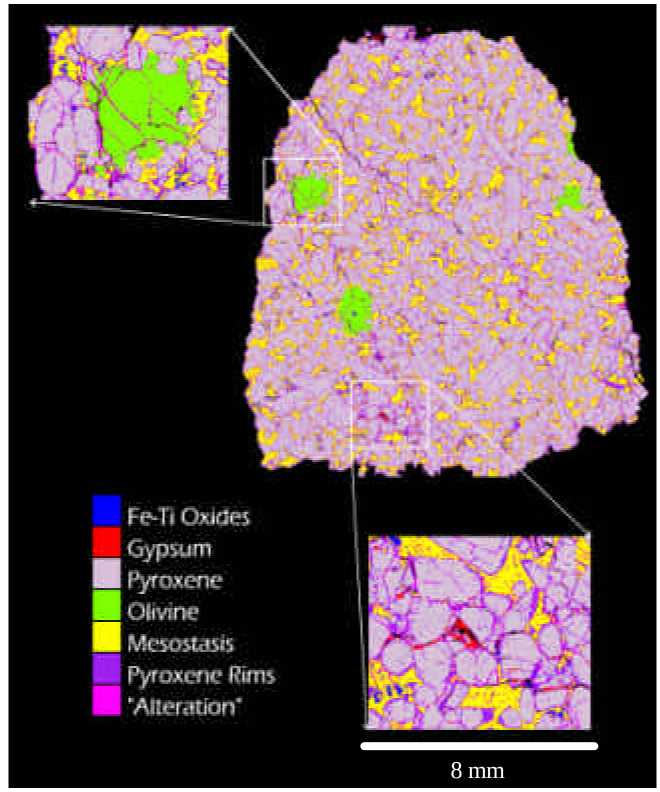
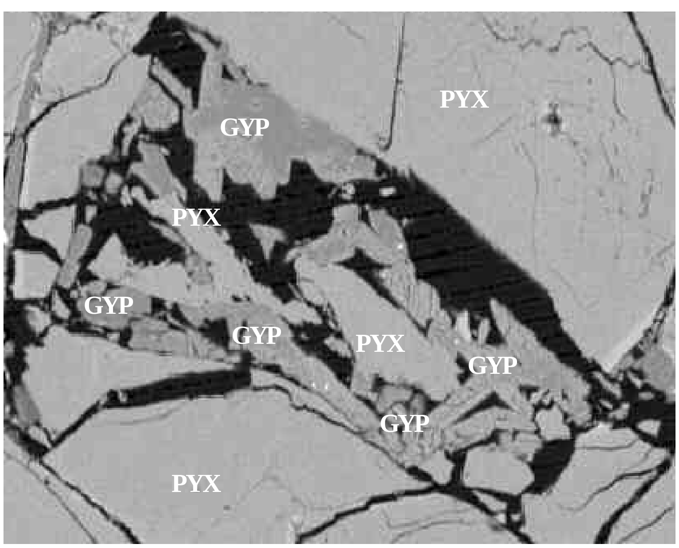
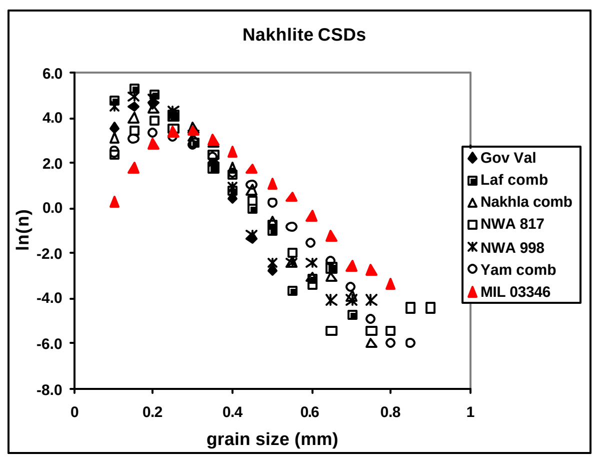


Figure 1 (top right): Microprobe mineral map. Callouts illuminate alteration veins in olivine grain (top, left) and gypsum deposited in veins and voids (bottom right, also in Fig. 2).

Figure 2 (below): SEM backscatter image of gypsum laths (GYP) between pyroxene grains (PYX). Image is ~300 x 600 microns. This area is characterized by brownish alteration in optical microscope view.

Figure 3 (right): Crystal-size distribution of pyroxenes in nakhlites.





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