MULTIPHASE AQUEOUS ALTERATION OF THE NAKHLITE NORTHWEST AFRICA 817.

M. R. Lee[1], B. E. Cohen[1,2], D. F. Mark[2], A. Boyce[2] [1]School of Geographical & Earth Sciences, University of Glasgow, UK (Martin.Lee@Glasgow.ac.uk), [2]Scottish Universities Environmental Research Centre, East Kilbride, UK.

Introduction: The nakhlites are igneous rocks that were impact-ejected from the mid-Amazonian crust of Mars. These meteorites are composed principally of augite, olivine, and a polymineralic/glass mesostasis. Most olivine grains contain veins of iddingsite, which is a very fine grained and hydrous product of aqueous alteration [1-3]. The original work on Northwest Africa (NWA) 817 concluded that its iddingsite formed on Mars, and in multiple phases [4, 5]. However, as NWA 817 is a find and will have experienced hot desert weathering, products of Martian aqueous alteration could have been terrestrially overprinted. Establishing the mineralogical, chemical and isotopic signatures of aqueous alteration on Mars, and how they may be modified by terrestrial weathering, is crucial for using nakhlites to explore the provenance of Martian fluids and their interaction with the planet's crust.

Materials and methods: The NWA 817 samples studied were obtained commercially, and none have a fusion crust. The olivine grains and their iddingsite veins were characterised by SEM imaging and electron backscatter diffraction, and by transmission electron microscopy (TEM) of foils prepared using the FIB technique. A JEOL ARM aberration-corrected TEM was used to acquire images, chemical analyses, and to measure the valence state of Fe by electron energy loss spectroscopy. The deuterium/hydrogen ratio of a 77.5 mg bulk sample was determined by pyrolysis stepped heating using a VG Optima dual-inlet mass spectrometer.

Results: Iddingsite is most abundant within grains of olivine, which comprise 13.4 vol. % of the samples studied, and have a core-to-rim compositional zoning of Fa_{57} to Fa_{85}. The olivine contains 6-20 vol. % iddingsite that occus in serrated veins that are most abundant in the Fa-rich grain rims. Three components of the iddingsite were recognised by differences in their mean atomic number (Z) and location within the veins: (i) low-Z axial bands; (ii) intermediate-Z body of the vein; (iii) high-Z rims. The majority of each vein is intermediate-Z iddingsite, with low-Z iddingsite forming a ~1 micrometre wide band on vein axes. The main constituents of these two components are SiO_2 (~42 wt%), FeO (~34 wt%) and MgO (~6 wt. %), with totals of ~85 wt. %. High-resolution TEM shows that the axial bands contain crystals 3-4 nm thick whose ~1 nm lattice fringe spacing is consistent with smectite. The intermediate-Z iddingsite contains smaller (2-3 nm thick) crystals of smectite. High-Z iddingsite lines vein walls, and may also cross-cut the other two components. Its main constituents are FeO (~43 wt. %), SiO_2 (~25 wt. %) and MnO (~5 wt. %), with totals of ~81 wt. %. The high-Z iddingsite contains coarse crystals of smectite, but must also have one or more Fe-rich minerals that have yet to be identified. Stepped pyrolysis shows that NWA 817 contains 0.45 wt. % H_2O, and δD values range from -31 to -24 ‰ (V-SMOW). Narrow veins of calcite occur throughout both of the studied samples, and cross-cut all constituents including olivine grains and the three iddingsite components. Barite crystals, some of which are Sr-rich, are scattered throughout the sample and are particularly common within the high-Z iddingsite. Both the calcite and barite are typical products of hot desert weathering [7].

Discussion: The δD value of NWA 817 iddingsite can reveal the provenance of fluids responsible for aqueous alteration. High values would indicate that these fluids had equilibrated with Mars' D-rich atmosphere, whereas a low or negative δD would suggest their derivation from the Martian mantle. However, low values could also indicate that the fluids were terrestrial, or that Martian iddingsite had exchanged its H whilst on Earth. Previous work by [4] found that NWA 817 iddingsite has a mean δD of -170 ±14 ‰, and we also recorded low values. These results contrast with analyses of iddingsite in other nakhlites, which have yielded a Martian atmospheric signature (δD up to ~1000 ‰; [7, 8]). NWA 817 may therefore have been altered by fluids sourced from the Martian mantle [4], or by fluids that had equilibrated with Mars' atmosphere but with the high δD signature of the iddingsite being later erased during hot desert weathering. In support of the second possibility is that the petrographic context, chemical composition and mineralogy of NWA 817 iddingsite is closely comparable to that of most other nakhlites (i.e., olivine-hosted veins of nanocrystalline smectite; [2, 3]). Such a similarity implies that the nakhlites were altered under comparable physico-chemical conditions and by fluids of the same provenance (i.e., that had equilibrated with the Martian atmosphere). The loss of a Martian atmospheric signature from NWA 817 iddingsite is consistent with the abundance of hot desert weathering products in the samples studied, and it is also possible that the high-Z iddingsite formed terrestrially. The history of NWA 817 iddingsite remains a question with important implications for understanding the sources of fluids in the Martian crust, and the integrity of Martian alteration products in meteorite finds.

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