MARTIAN ALTERATION IN UNIQUE METEORITE NWA 8159?

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Introduction: The augitic basalt Northwest Africa (NWA) 8159 is reportedly derived from a highly depleted mantle source not represented elsewhere in the Martian meteorite collection [1-3]. An early Amazonian crystallisation age of 2.3 ± 0.5 Ga also indicates that NWA 8159 is unrelated to other Martian meteorite groups [2]. Previous studies have shown that this basalt consists of augite (~50 %) and plagioclase (~40 %), olivine (~5 %), magnetite (3%) and orthopyroxene (2 %), with minor ilmenite, merrilite, Cl-apatite and Cr-spinel [4]. P-rich olivine cores are preferentially altered, and it has been suggested that this alteration occurred on Mars [3]. However, NWA 8159 is not a fresh find - its fusion crust is replaced by a weathered yellow-brown patina [4], and the interior of the meteorite contains veins of terrestrial carbonate [3]. We analysed the olivine alteration in NWA 8159 with the aim of determining whether it has a Martian origin, and if so how it formed.

Results: One thin-section (3.5 × 3.5 mm) was prepared from a chip of NWA 8159 purchased by the Scottish Universities Environmental Research Centre (SUERC). A garnet-bearing shock vein of variable width (maximum 400 µm) runs through the thin-section, and is cross-cut in numerous places by calcite veins, the largest of which is ~100 µm wide and 2 mm long. Calcite veins are associated with magnetite that has been weathered to a mixture of calcite and goethite. Thus, textural relationships suggest that both calcite and goethite are terrestrial.

Olivine (Fo_{41-17}) is P-enriched towards the grain cores, with up to 2 wt % P_2O_5. These cores are preferentially altered, while the olivine rims remain unaltered. As olivine grains in other Martian basalts have unaltered cores with high P contents [5], it has been suggested that NWA 8159 olivine cores were originally P-rich as opposed to becoming P-rich upon alteration [3]. As well as being P-rich, the altered olivine is rich in Al and Ca compared to unaltered olivine (up to 4 wt % Al_2O_3 and 3 wt % CaO), but depleted with respect to Fe, Mn and Mg.

The nakhlites contain olivine-hosted smectite known to originate on Mars [e.g., 6], and similar alteration products have been analysed *in situ* on the Martian surface [7]. In contrast, terrestrially-formed smectite has been reported in the shergottite Dhofar 019 [8-9]. Comparing NWA 8159 olivine alteration with these Martian and terrestrial smectites reveals it is chemically similar to the smectite in the Miller Range nakhlites (Fig. 1). This similarity could suggest that the NWA 8159 olivine was altered on Mars. However, as the Miller Range nakhlites and NWA 8159 are similar in their igneous mineralogy and chemical composition [10], alteration similarity may equally reflect a similar original composition for the meteorite. Calcium abundances are similar for nakhlite and Dhofar 019 smectite, and NWA 8159 olivine alteration (up to ~3 wt % CaO [9,11]). Transmission electron microscope (TEM) analyses of Dhofar 019 alteration revealed calcite intergrown with smectite, whereas the main smectite calcium source is gypsum in the Miller Range nakhlites [9,11]. NWA 8159 olivine alteration products lack detectable sulfur, thus gypsum is unlikely to be the calcium host. However, calcium could be present in smectite, brought into olivine by a Martian magmatic or hydrothermal fluid.

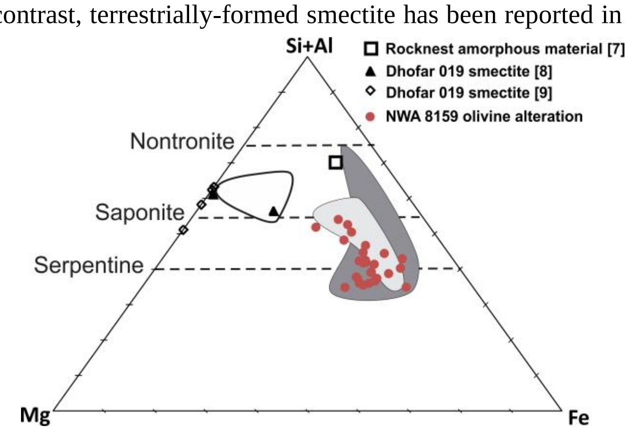

Fig. 1: Triplot comparing the chemical composition of Martian and terrestrial alteration in Martian meteorites. Martian smectite data are from Nakhla, Governador Valadares and Lafayette (light grey envelope [6]), and the four Miller Range nakhlites (dark grey envelope,[11]). Amorphous material from the Martian soil [8], and typical terrestrial saponite compositions (white envelope [6]) are plotted for comparison.

Future work: We are currently preparing focused ion-beam sections of for TEM analysis. The presence of calcite in olivine alteration will suggest a relationship with the terrestrial calcite veins in NWA 8159, whereas other calcium-rich phases (e.g., Ca-smectite) are more likely to have been produced on Mars.

References: [1] Agee et al. (2014) *77th Meteoritical Society meeting*, Abstract #5397. [2] Simon et al. (2014) *77th Meteoritical Society meeting*, Abstract #5363. [3] Shearer et al. (2015) *46th Lunar & Planetary Science Conference* Abstract #1483. [4] Agee et al. (2014) *45th Lunar & Planetary Science Conference* Abstract #2036. [5] Shearer et al. (2013) *Geochimica et Cosmochimca Acta* 120, 17-38. [6] Changela and Bridges (2011) *Meteoritics and Planetary Science* 45, 1847-1867. [7] Blake et al. (2013) *Science* 341, 1239505. [8] Taylor et al. (2002) *Meteoritics & Planetary Science* 37, 1107–1128. [9] Hallis et al. (2016) *Meteoritics & Planetary Science (in review)*. [10] Herd et al. (2014) *45th Lunar & Planetary Science Conference* Abstract #2423. [11] Hallis et al. (2014) *Geochimica et Cosmochimica Acta* 134, 275–288.