MARTIAN VS. TERRESTRIAL ALTERATION OF APATITE IN THE UNIQUE NORTHWEST AFRICA 8159 METEORITE. E.V. Christou[1], L.J. Hallis[1], L. Daly[1,2], I. McCarroll[2], M. Garbrecht[2], L. Jang[2], C.L. Hayward[3], Y. Liu[2], J. Cairney[2] and M.R. Lee[1]. [1]School of Geographical & Earth Sciences, University of Glasgow, Glasgow, UK; [2]Centre for Microscopy & Microanalysis, University of Sydney, Sydney, Australia; [3]School of Geosciences, Grant Institute, University of Edinburgh, Edinburgh, UK. E-mail: e.christou.1@research.gla.ac.uk

Introduction: The Martian meteorite Northwest Africa (NWA) 8159 is a uniquely old (2.37 ± 0.25 Ga) shergottite [1], consisting of augite (~50 %), plagioclase (~40 %), olivine (~5 %), magnetite (3%) and orthopyroxene (2 %), with minor ilmenite, merrilite, apatite and spinel [1-6]. NWA 8159 olivine grains are mantled by subsolidus reaction rims of magnetite and orthopyroxene. Both the olivine cores [1-5] and apatites [6] have been altered. It remains unclear whether this alteration is related to ancient aqueous activity on Mars or terrestrial alteration after the meteorite fell to Earth [6]. NWA 8159 shows some undoubtedly terrestrial weathering with calcite veins cross-cutting the rock in numerous places [1-3,6]. We are investigating NWA 8159 apatite to define the parental melt and aqueous source volatile composition; hence, we should firstly determine which alteration phases within NWA 8159 apatite are terrestrial and which are Martian.

Methodology: One thin-section (sample A) and one indium-mounted polished sample (B) were prepared from chips of NWA 8159, and both were coated with 20µm carbon. Energy Dispersive X-ray spectroscopy (EDS) maps were collected using a Carl Zeiss Sigma - Variable Pressure - Field Emission Gun - Scanning Electron Microscope (VP-FEG-SEM) at the University of Glasgow to distinguish the aqueously formed minerals in NWA 8159 and determine their stoichiometric composition. Electron Probe Microanalysis (EPMA) at the University of Edinburgh was conducted on apatite grains to obtain higher precision volatile compositions (F, Cl, H_2O) of the apatite. We extracted electron transparent Transmission Electron Microscopy (TEM) sections and Atom Probe Tomography (APT) needles of apatite using a Ga focused ion beam microscope at the Universities of Glasgow and Sydney. Scanning Transmission Electron Microscopy (STEM) and EDS analyses were performed at the University of Sydney [FEI Themis - Z double-corrected 60-300 kV S/TEM] to determine the nanoscale texture of NWA 8159 apatite, its chemistry and the nature of the aqueous alteration / host mineral boundary. APT of the apatite (via the LEAP 4000X) at the University of Sydney evaluated the 3D elemental composition of the apatite and intergrown phases.

Results: SEM-EDS maps of sample A (7.5 × 1.3 mm) detected 48 apatite grains (>10 µm) [Fig. 1; 1/3 of the entire sample map] that are commonly associated with magnetite phenocrysts. Both samples have similar apatite abundances and textures. SEM and EPMA revealed apatite grains with a sub-grain granular texture, where anhedral apatite sub-grains (< 10 µm) are intergrown with magnetite and a Si-rich phase [Fig. 2].

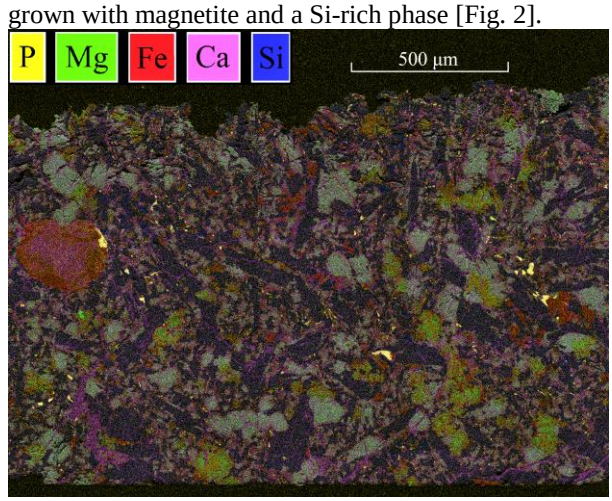

***Figure 1**: SEM-EDS false-colored map of a NWA 8159 domain, where Apatite (Ap) = yellow, Magnetite (Mag) = red, Feldspar (Fsp) = Blue, Olivine (Ol) = Green, Pyroxene (Px) = Grey, Calcite (Cal) = Pink.*

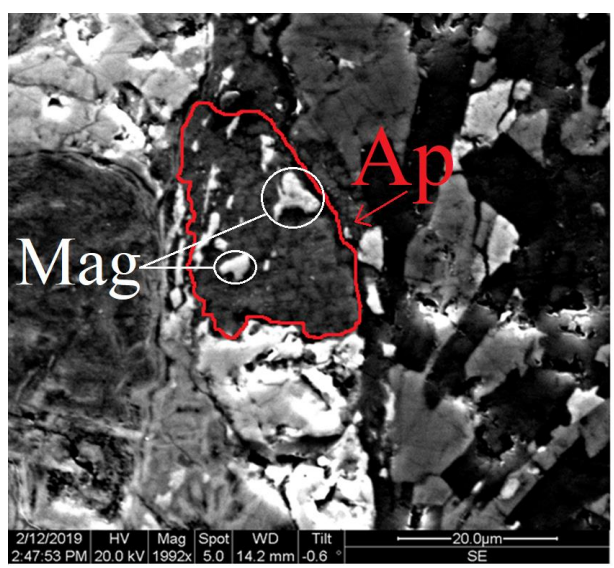

***Figure 2**: Secondary electron (SE) image of a NWA 8159 apatite grain with an intergrown crystallization texture between apatite (Ap) and magnetite (Mag). EPMA and TEM datasets were also obtained from this apatite grain (sample A, Fig.1: west, largest Ap grain).*

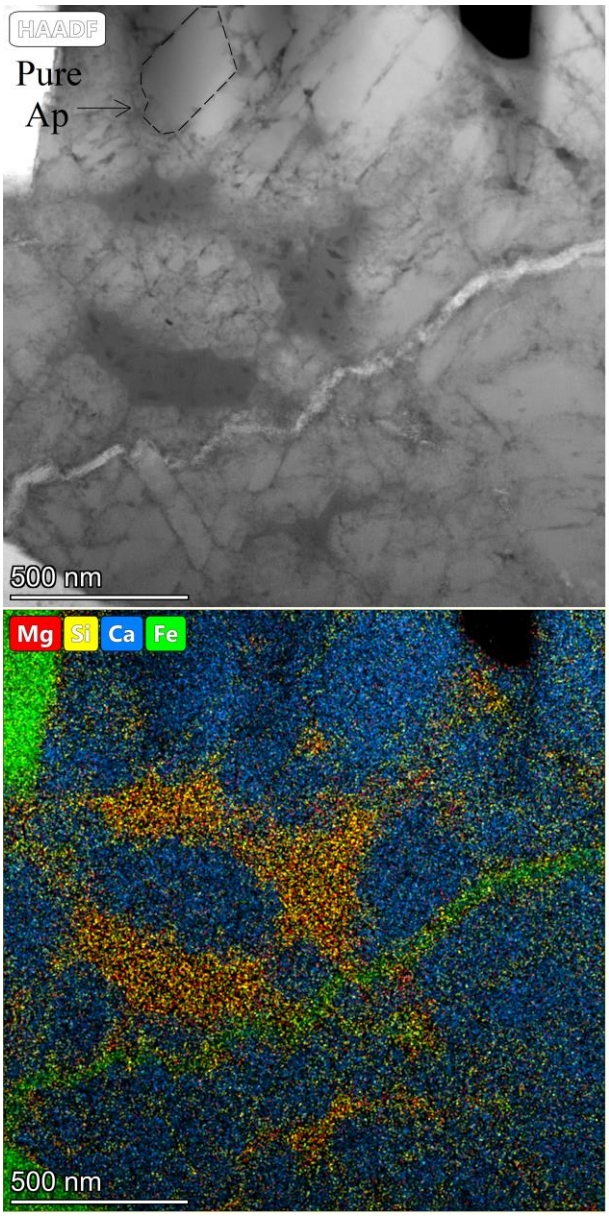

***Figure 3**: High-Angle Annular Dark Field (HAADF) STEM and EDS false-color map of an apatite 'ROI' with pristine (pure) and altered grains. Apatite = blue, Magnetite = green, Phyllosilicate = yellow.*

EPMA of pristine apatite reveals a F-rich composition [6]. TEM and APT results from selected areas of apatite [Fig. 3-5] show the extensive nature of its alteration. Magnetite grains 100 nm in size are intergrown within apatite. Fe-, Mg- and Al-rich phyllosilicate veins are commonly at the boundary between apatite and magnetite, preferentially altering the apatite. APT analysis of an apatite needle [Fig. 5] shows areas of C-enrichment (brown spheres) within the boundary between apatite (pink) and phyllosilicate (red/grey areas), which may indicate the presence of carbonate. Determining the nature of this carbonate, e.g. calcite or siderite, would enable us to infer whether this alteration is of terrestrial or Martian origin, respectively.

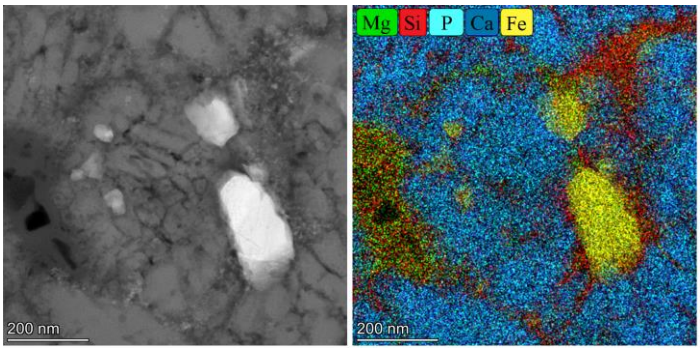

***Figure 4**: HAADF STEM and EDS false-color map of intergrown magnetite (yellow) and Fe-, Mg-rich phyllosilicate (red), alongside apatite (blue) and olivine (green).*

Future Work: Aqueous alteration and carbonate precipitation could have occurred on either Mars or Earth. Future work will involve detailed analyses of three more NWA 8159 apatite needles via correlative APT and TEM to define the composition of the altering fluids and establish the carbonate species. Eventually, we aim to determine the meteorite's terrestrial exposure age by measuring the stable, radiogenic and cosmogenic Cl- isotope ratios [7].

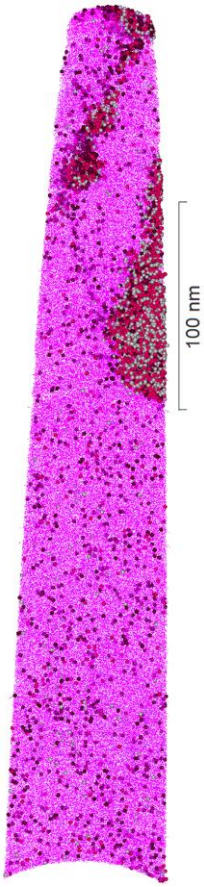

***Figure 5** (right): Atom probe data 3D model of the elemental composition of NWA 8159 apatite needle 1. 45M atoms were detected after a 48-hour experiment.*

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References: [1] Herd C.D. et al. (2017) GCA 218, 1-26. [2] Hallis L.J. et al. (2016) 79th MetSoc, Abstract #6442. [3] Agee C.B. et al. (2014) 77th MetSoc, Abstract #5397. [4] Shearer C.K. et al. (2019) GCA 258, 242-257. [5] Sharp T.G. et al. (2019) GCA 246, 197-212. [6] Christou E.V. et al. (2019) 82nd MetSoc, Abstract #6283. [7] Patterson L.J. et al. (2005) Geoch. Geoph. Geosys., 6, Q01005.