Olivine Alteration of Shergottite Northwest Africa 10416. J. D. Piercy, J. C. Bridges, L. J. Hicks, J. L. MacArthur and J. Michalowska, Space Research Centre, Leicester Institute of Space and Earth Observation, University of Leicester, UK, LE1 7RH, j.bridges@leicester.ac.uk.

Introduction: Studying secondary alteration phases in martian meteorites, allow us to form hypotheses regarding martian water-rock reaction processes [1]. The initial step in these studies and the aim of this work is to identify whether the secondary alteration phases are terrestrial or martian.

Northwest Africa (NWA) 10416 is an olivine-phyric martian Shergottite with olivine grains that show orange-brown altered cores and clear unaltered rims (Fig. 1). Based on the olivine alteration, previous studies have suggested a formation model for this meteorite which incorporates magma mixing and assimilation [2,3,4]. We have performed microanalysis of these olivine grains by various techniques in order to help test whether the olivine core alteration is terrestrial or not; the results of which we present here.

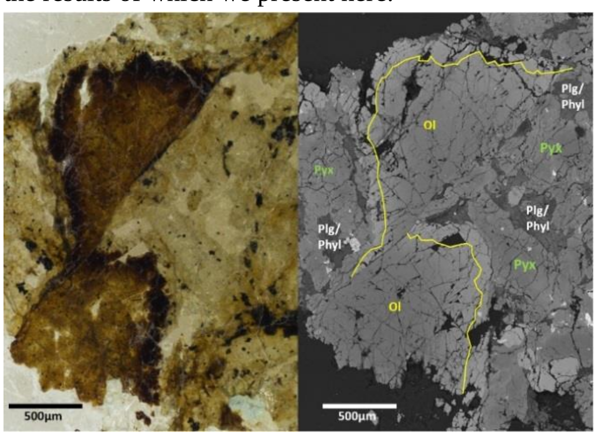

Figure 1 - Optical and Back Scatter Electron (BSE) image comparison of a fractured olivine grain in NWA 10416. Altered core - clear rim boundary shown as yellow line on BSE image. Minerals labelled: olivine (yellow), pyroxene (green) and plagioclase with phyllosilicate alteration (white).

Methods: A thin section of a 2.1 g sample was cut and initially characterised through Back Scattered Electron (BSE) imagery and Energy Dispersive X-ray fluorescence (EDX) spectroscopy, using a Phillips Environmental Scanning Electron Microscope (ESEM) XL-30 at the University of Leicester's Advanced Microscopy Centre. Fe-K X-ray Absorption Spectroscopy (XAS) was carried out using the 2.5µm resolution I-18 microfocus spectroscopy beamline at the *Diamond* synchrotron, UK. Measurements were taken from 6900 eV to 7500 eV, with a higher resolution of 0.1 eV increments measured over the X-ray Absorption Near Edge Structure (XANES) region; 7100 eV to 7125 eV.

Mineralogy: Our sample is without a fusion crust and shows a groundmass of green pyroxene and white plagioclase containing ~1 mm diameter orange-brown olivine phenocrysts. Shock-melt veins and brown alteration are present.

Olivine. Comprises ~15% of the analysed thin section. These grains are ~1 mm size and consist of orange central zones, dark brown outer bands and clear, unaltered olivine in the outer margins of the larger grains. There are also smaller groundmass olivine grains (Fig. 1). The olivine grain shown in Figure 1 clearly displays a large fracture cutting and displacing half of it. It is notable that the orange-brown colouration is also displaced by fracturing; the significance of this is discussed below.

The large phenocrysts show chemical variation consistent with igneous zonation, this can be seen as a contrast gradient under BSE imagery (Fig. 1). The grains have Mg-rich olivine cores, $Fo_{78}Fa_{22}$, and rims of almost equal Mg and Fe content olivine, $Fo_{52}Fa_{48}$ (Fig. 2).

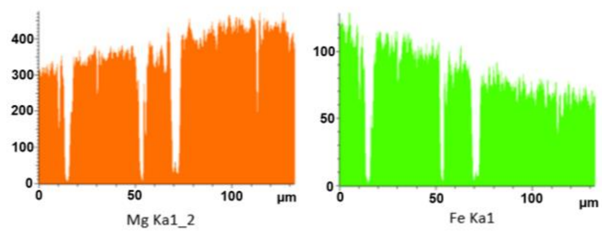

Figure 2 - Element maps of Mg (orange) and Fe (green) taken from a line cutting an olivine grain from rim to core. The graph shows distance vs counts, and a clear gradient in both elements that represents an igneous fractional crystallisation zonation.

Pyroxene. Comprises ~50% of the analysed thin section, of which ~50% show typical igneous zonation through the grains' compositional variation; they have Mg-rich pigeonite cores, $En_{75}Fs_{20}Wo_5$ and Ca-rich augite rims, $En_{49}Fs_{19}Wo_{32}$. The Fe content experiences oscillatory zoning. Fractures and melt-veins cut through the compositional variation.

Plagioclase. Comprise ~30% of the analysed thin section and is mostly crystalline labradorite, $Ab_{37}An_{63}Or_0$. However ~10% of grains observed had been converted to the glassy maskelynite phase due to shock, which is consistent with their positions adjacent to or near shock-melt veins and fractures (Fig. 1).

A large amount, ~50-60%, of all plagioclase grains have been affected by secondary alteration. The alteration appears to have depleted the Na and Ca contents, and enriched the Al content relative to unaltered grains. Preliminary data and texture patterns suggest a phyllosilicate composition. X-ray diffraction analysis is ongoing.

Inclusions. Accessory minerals include: Ti-bearing magnetite, ilmenite, Ti-bearing chromite, chromite and Fe-sulfides. These were observed throughout the samples groundmass and clear groundmass olivines, however were rarely seen within the altered olivine grains.

X-ray Absorption Analysis: XAS measurements were taken on the sample in order to gather information about the oxidation state across the altered olivine grain and the nature of fluid alteration (Fig. 3). Higher resolution measurements of 0.1 eV increments were taken across the XANES region (7100 eV to 7125 eV), because the best indication of oxidation is present from the pre-edge features and the absorption edge position.

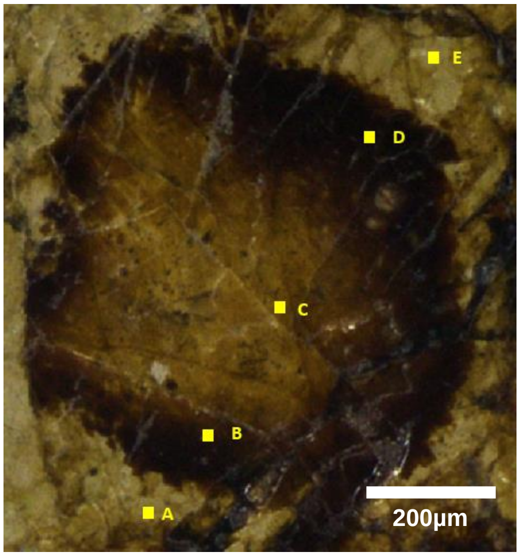

Figure 3 – Optical image showing locations corresponding to XAS data shown in Figure 4. Points A and E are within the olivine grains clear rim, whereas points B and D lie within the cores brown boundary and C in its orange core.

Figure 4 shows a definite oxidation variation across the sites indicated in Figure 3. The pre-edge features of B and D (brown boundary of olivine core) differ from A, C and E which suggests some compositional variation. The initial section of the absorption edge (and the entire edge) shows the following order from highest absorption energy to lowest, and therefore highest oxidation state to lowest; D, B, C, A, E. In terms of the olivine grain, the brown core boundary is of the highest oxidation state, followed by the orange core and lastly the clear rims.

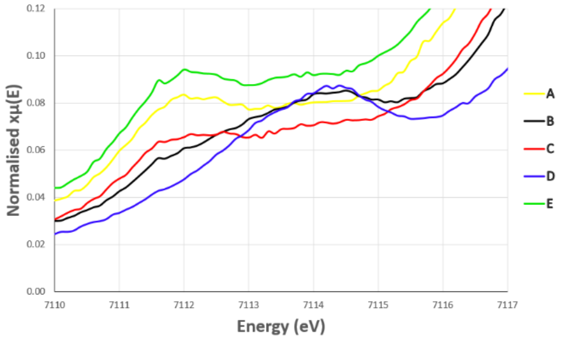

Figure 4 – XAS data of pre-edge region and initial part of the absorption edge. Lines A, B, C, D and E correspond to XAS sites shown in Figure 3.

Discussion: Previous studies [2,3] suggested that the olivine alteration is pre-terrestrial due to serrated boundaries between the olivine grains and groundmass, as well as an overlap in composition of the clear rims and clear groundmass olivine when compared to the altered olivine cores. Oxygen isotope analysis [4] suggests an 'overprinting by terrestrial alteration' in the cores of the olivine grains, meaning the secondary alteration, that caused the orange-brown colouration, might have been caused on Earth.

Our XAS data indicates an oxidation trend across the olivine grain, which in turn could indicate a reaction front at the core-rim boundary. It has been observed that Fo-olivine is more susceptible to alteration over its Fa counterpart under oxidizing conditions when subject to low-temperature surface fluids [5]. This can explain why we only see the alteration within the Mg-rich olivine cores.

One possible model to explain the alteration pattern that the parent rock underwent igneous zonation as it cooled quickly, creating the olivines' Mg-rich cores and rims of almost equal Mg, Fe. Martian shock effects caused veins and fracturing of the compositionally zoned olivines (Fig. 1). During it's time in Northwest Africa, groundwater exploited the fractures and altered the olivine in a way that was controlled by the pre-existing, igneous compositional zonation.

References: [1] Changela H. G. and Bridges J. C. (2011) *Meteoritics & Planet. Sci., 45*, Nr 12, 1847–1867. [2] Herd C. D. K. et al. (2016) *LPS XLVII, Abstract #2527*. [3] Vaci Z. (2016) *LPS XLVII*, Abstract #2538. [4] Ziegler K. (2016) GSA, Paper #49-5. [5] Hausrath E. M. and Brantley S. L. (2010) *JGR, 115*, 2156–2202.