THE THERMAL AND ALTERATION HISTORY OF NWA 8114 MARTIAN REGOLITH.

J. L. MacArthur[1], J. C. Bridges[1], L. J. Hicks[1] and S. J. Gurman[2]. [1]Space Research Centre, Dept. of Physics & Astronomy, Univerity of Leicester, LE1 7RH, UK, jm650@le.ac.uk [2]Dept. of Physics & Astronomy, Univerity of Leicester, LE1 7RH, UK.

Introduction: NWA 8114 (a pair of NWA 7034) is a polymict [1] martian basaltic breccia [2] with a bulk-rock age of ~2.1 Ga [2] containing zircons dated at ~4.4 Ga [3]. It is the first sample of the martian regolith [3], with varied clasts bound in a fine grained matrix [4].

As the most hydrated martian meteorite identified to date [2], the majority of the water is thought to be hosted by hydrous Fe oxides, with a minor contribution from apatite [5]. The ferric phrases maghemite and goethite have been detected [6], making this potentially the most oxidized known martian meteorite [1,6]. The oxygen isotope ratio of water shows $\Delta^{17}O$ values above the terrestrial fractionation line and the D/H isotope ratio analyses also support the martian origin of water in NWA 7034 [2].

The meteorite was likely formed as a result of an impact event [7] which may have led to hydrothermal systems causing further alteration to it [6,8]. Our work characterises the partial breakdown, and mantling by fine-grained material, of pyroxene clasts, in terms of their oxidation state and related textures. We combine this with mineral thermometry to reveal the thermal history of the impact regolith within which the parent rock of this meteorite formed.

Methods: Three polished sections from the main mass of NWA 8114, held at the University of Leicester (UL), were examined. A Hitachi S-3600N SEM was used with an INCA 350 EDX system for initial elemental analyses. This was followed by analyses with a JEOL 8600S EPMA with an accelerating voltage of 15 kV and a beam current of 30 nA.

The I-18 beamline at the *Diamond Light Source* synchrotron, Oxfordshire, UK, was used for X-ray absorption near edge structure (XANES) analyses. A 5µm resolution map was taken over two zoned areas (Fig. 2) at 140 stepped energy levels to examine around the Fe-K edge. XANES analyses were also carried out at sample points on a representative variety of pyroxene and oxide clasts. The data was normalized and deglitched using Athena before fitting the Fe-K edge energy and the 1s → 3d pre-edge features with a spline method for baseline subtraction [9].

Results: Over 1000 SEM and over 400 EPMA analyses points were taken, leading to a clast classification system of pyroxenes (pigeonite and augite, homogenous and exsolution), feldspars (plagioclase and alkaline), iron oxides (FeO, magnetite and Ti-rich magnetite) and phosphates (Cl-apatite), with some mixed clasts showing combinations of these.

Applying px thermometry techniques [10] to the exsolution clasts yielded temperatures of 900-1050 °C, similar to 840-1000°C identified by [4]. The composition of cryptoperthite alkaline feldspar clasts, $Ab_{8-20}Or_{80-92}$, suggest that they experienced very slow cooling, as they separated nearly to the pure end members, albite and orthoclase.

The largest clast identified (Fig. 1a), pyroxene with bulk composition $Wo_{13}En_{30}Fe_{57}$, has a rim of material accreted to it (highlighted in Fig 1a), which formed after the veins on the left of the image as it crosscuts them. The rim is enriched in feldspar An_{24-39} towards the edge. A basaltic clast (Fig. 1b) shows zonation with primarily pyroxene end member composition of $Wo_{31-38}En_{41-45}Fe_{19-24}$, with varying proportions of feldspar An_{34-43} and pyroxene end members as shown in Fig. 2.

These areas of accretion and zonation have been investigated using Fe-K XANES (Fig. 1c and d) to determine their oxidation state.
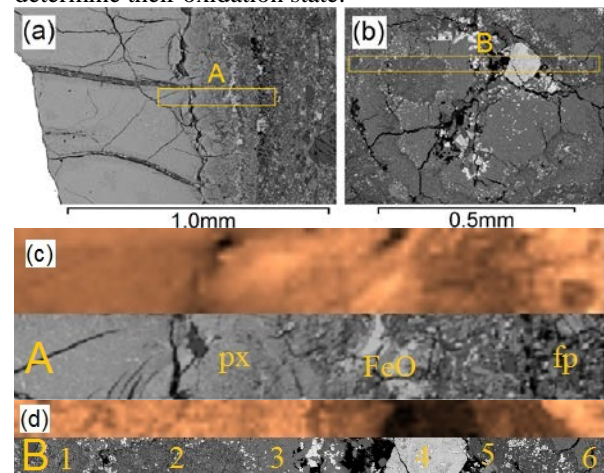

Fig. 1: (a) and (b) BSE images of pyroxene clasts showing sample regions A and B. **(c) (top)** Fe-K XANES map of A, 65 x 450 µm, showing normalized intensity measured at 7120.0 eV, light = Fe^{2+}, dark = Fe^{3+} **(bottom)** BSE image of A, showing varied pyroxenes (px) with the accreted rim between the iron oxide (FeO) and feldspar (fp). **(d) (top)** Fe-K XANES map of B, 40 x 640 µm, showing normalized intensity measured at 7120.0 eV, light = Fe^{2+}, dark = Fe^{3+} **(bottom)** BSE image of B, showing basaltic compositions *1, 2, 3*(main bulk of clast)*, 5, 6* plotted in Fig. 2 (*4* is Ti-magnetite).
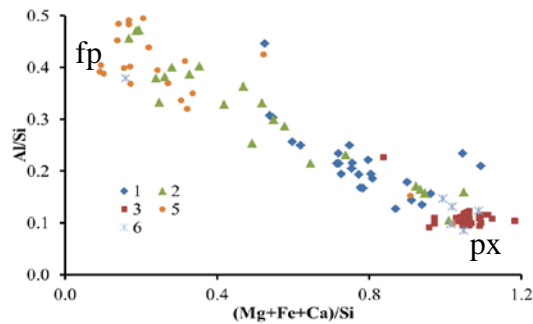
Fig. 2: (Mg+Fe+Ca)/Si ratio plotted against Al/Si (all atomic wt.%) to show the compositions in the zoned px clast (B, Fig. 1d) from An_{34-43} feldspar (fp) to px.
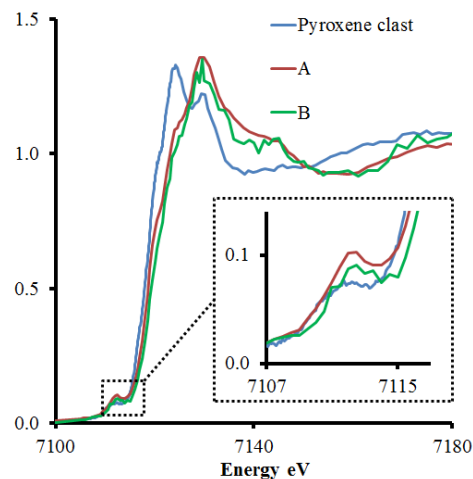

Fig. 3: Typical normalized Fe-K edges for a pyroxene clast (blue) and areas A (accretion rim, red) and B (zoned px clast, green) (see Fig. 1). Inset shows the pre-edge 1s → 3d centroid.
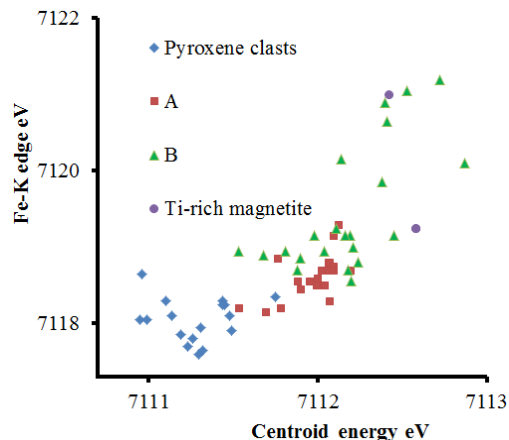

Fig. 4: Centroid vs Fe-K edge energies for different clasts and for different point samples from areas A and B (Fig. 1).

The two areas show higher Fe-edge and centroid energy positions than the more pristine pyroxene clasts (Fig. 3, 4) and are thus more oxidized [9]. Area B is slightly more oxidized than area A (Fig. 4), though this is partly accounted for by the magnetite in area B seen in Fig. 1d-*d*.

This oxidation can be quantified using the $Fe^{3+}/\Sigma Fe$ silicate calibration scale developed in [9] which indicates that the pyroxene clasts have 0% $Fe^{3+}/\Sigma Fe$; while areas A and B have 18% - 40% $Fe^{3+}/\Sigma Fe$, with a few iron oxide areas reaching 60% $Fe^{3+}/\Sigma Fe$.
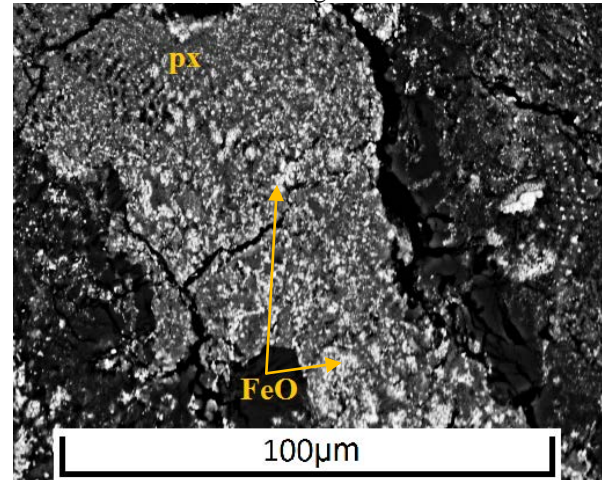

Fig. 5: Area within A (Fig.1c) showing iron oxide (FeO, white) crystallization within the accretion rim of pyroxene (px, grey) breaking down.

Discussion and Conclusions: The fine grained matrix associated with the accreted rim material (A) and the breakdown (B) of the basaltic pyroxene clast ($Wo_{31-38}En_{41-45}Fe_{19-24}$) were associated with oxidation from the ferromagnesian minerals. SEM and EPMA examination of the pyroxene oxidation suggests the growth of iron oxide rich domains (Fig. 5). This is consistent with the presence of a fluid within the regolith blanket for considerable time at high temperature, likely over 1000 °C, for pyroxenes to react. The zoned clasts are typically enriched in feldspar An_{34-43} towards their edges. For the first time, this meteorite makes it possible to recreate the thermal history of a large regolith blanket on Mars and offers the potential to prepare a full thermal model.

References: [1] Stephen N.R and Ross A.J. (2014) *LPSC XLIV,* Abstract #2924. [2] Agee C. B. et al. (2013) *Science 339,* 780-785. [3] Humayun, M. et al. (2013) *Nature 503*, 513-516. [4] Santos A.R. et al. (2014) *LPSC XLIV,* Abstract #2513. [5] Muttik N. et al. (2014) *GRL 41*, p. 2014GL062533. [6] Gattacceca J. et al. (2014) *GRL 41*, 4859-4864. [7] Hewins R.H. et al. (2014) *LPSC XLIV,* Abstract #1416. [8] Humayun M. (2014) *Meteorit. Planet. Sci.* 49 Abstract #5413. [9] Hicks L. et al. (2014) *GCA 136,* 194-210. [10] Lindsley D.H. and Andersen D.J. (1983) *JGR:Solid Earth 88 S02*, A887-A906.