ANALYSIS OF SPACE WEATHERED ITOKAWA GRAINS USING FE-K XANES AND TEM

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Introduction: Space weathering is largely the result of the bombardment by electrons and protons from the solar wind upon the exposed surface. Asteroids like S-type 25143 Itokawa show these effects as an apparent darkening and reddening of the affected surfaces [1].

Samples returned by the JAXA Hayabusa mission from the Itokawa asteroid have featured space weathered rims to depths of >100 nm, consisting of a partially amorphised composite rim of the substrate grain mineralogy with nanophase Fe^0 (npFe) particles, and an outer rim of amorphous redeposited vapor material from dust impacts of neighboring minerals [2].

Samples and Methods: Five Itokawa grains from the first touchdown site have been allocated to this study: RB-QD04-0063; RB-QD04-0080; RB-CV-0089; RB-CV-0011; and RB-CV-0148. Each were embedded in epoxy resin and ~100 nm thick FIB-SEM sections were obtained for TEM analyses and X-ray synchrotron nanoprobe analyses. Four of the five Itokawa grains are olivines, one of which (#0063) also features plagioclase inclusions, and the fifth grain is pyroxene (#0089). All of the FIB sections have amorphous space weathering rims measuring up to 100 nm thick, and feature npFe particles (e.g. Figure 1 shows space weathering in #0063).

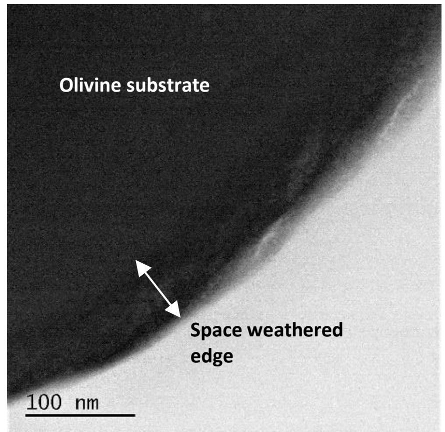

Figure 1: Bright-Field image of amorphised space weathered rim on RB-QD04-0063, imaged using a JEOL JEM-ARM200F at ePSIC.

Three of the Itokawa grains (#0063, #0080, and #0089) have been analysed using the I-14 X-ray Nanoprobe Beamline at the Diamond Light Source synchrotron. In order to analyse any Fe-redox changes in the space weathered rim from substrate mineralogy, Fe-K XAS spectra are obtained from a series of XRF maps typically measuring between 7000 and 7300 eV, with a higher resolution range of energy increments over the XANES features (~7100-7150 eV).

Results: The Fe-K absorption spectra between the space weathered rim and the substrate mineralogy are compared in Figure 2. The olivine grains #0063 and #0080 typically show a trend of positive shifts of up to ~0.5 eV (±0.25 eV) in the Fe-K absorption edge positions, whereas the pyroxene grain #0089 shows very little to no variation in the weathered rim. The shift is minor, but such positive shifts in the Fe-K absorption edge can be deduced semi-quantitatively as an increase in the oxidation state from ferrous (Fe^{2+}) to ferric (Fe^{3+}), as previously observed in other Itokawa grains, Comet Wild 2 samples, and martian meteorites [2-5]. A positive shift of ~0.5 eV (±0.25 eV) in our results suggests an increased oxidation state ($Fe^{3+}/\Sigma Fe > 0.11 \pm 0.05$) on the surface rims of the Itokawa olivine grains.

Discussion: Studies of Apollo lunar soils have observed metallic npFe particles [8,9], possibly related to radiation induced segregation of the Fe from the silicates by solar wind and ion implantation. This is also seen in other Itokawa samples [10]. The lunar npFe particles were shown to contain oxidised Fe as Fe^{2+} and even components of Fe^{3+}, with increasing ferrous and ferric contents correlating with increased soil maturity [8].

The increased oxidation state shown by our results is small, but reveals the possible breakdown of the olivine into its amorphous state and the oxidation of the material, including npFe particles. The oxidation may be due to interaction with trace amounts of H_2O molecules by solar wind irradiation. However, the olivine-composed amorphised rim remains the dominant phase shown in our Fe-K XAS measurements.

Further similar studies are being considered for more Itokawa grains and lunar samples to be analysed using the I-14 nanoprobe to directly compare and reveal insights into the redox changes associated with space weathering.

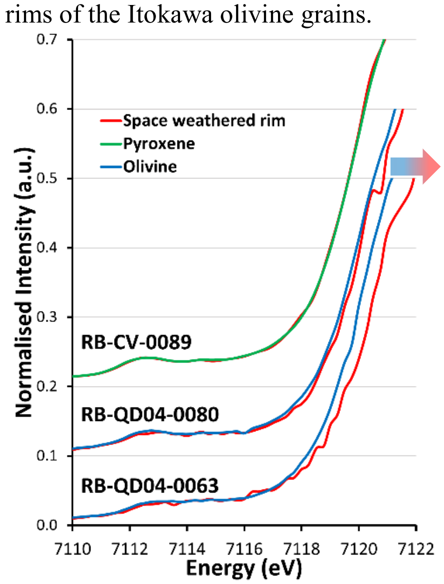

Figure 2: Fe-K XAS spectra of three Itokawa grains, including the substrate minerals olivine and pyroxene and their space weathered rims. RB-QD04-0063 shows a positive shift of ~0.5 eV in the Fe-K absorption edge.

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