Analysis of space weathered Itokawa grains using Fe-K XANES and TEM

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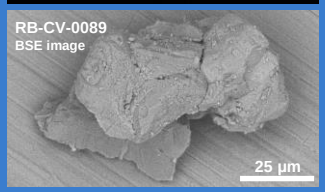
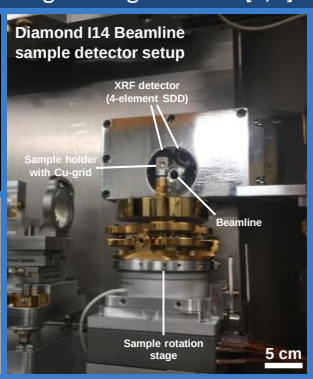
Introduction: Space weathering is largely the result of the bombardment by electrons and protons from the solar wind upon the exposed surface [1]. Samples returned by the JAXA Hayabusa mission from asteroid 25143 Itokawa have featured space weathered rims to depths of >100 nm, consisting of a radiation damaged partially amorphised composite rim of the substrate grain mineralogy with nanophase Fe-metal (npFe^0) particles, and an outer rim of amorphous redeposited vapor material from dust impacts of neighboring minerals [2,3].

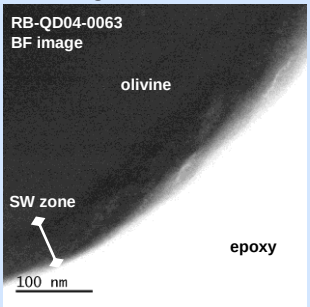


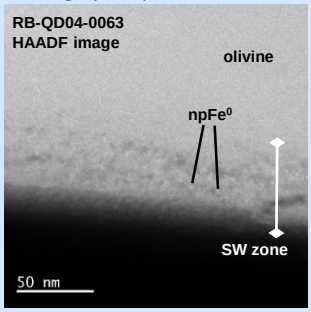


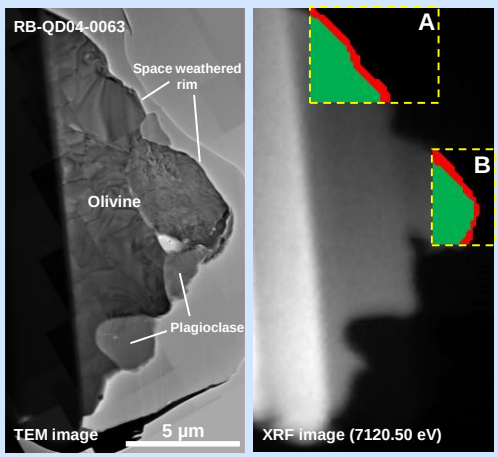
Experiment: Itokawa grains have been embedded in epoxy resin and ~100 nm thick FIB-TEM sections were obtained for STEM and X-ray synchrotron nanoprobe analyses.
Three of the Itokawa sections have been analysed using the I14 X-ray Nanoprobe Beamline at the Diamond Light Source synchrotron. In order to 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 7000-7300 eV, with a higher resolution of energy increments over the XANES region (~7100-7150 eV).

► Investigating Fe-redox changes in the space weathered rims from the substrate mineralogy of the Itokawa grains requires comparing the Fe-K XAS spectra. A positive shift in the Fe-K absorption edge (at 0.5 of normalised intensity) 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 [3-6].

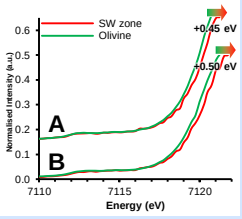
▼ **BF and HAADF-STEM** imaging of the space weathered rims obtained using a JEOL ARM200CF instrument at the electron Physical Science Imaging Centre (ePSIC) facility. All of the Itokawa FIB-TEM sections have space weathered rims measuring <100 nm thick and featuring npFe^0 particles.

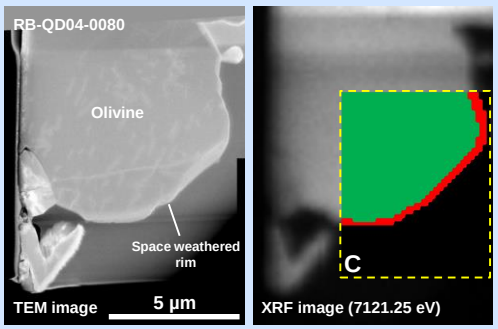




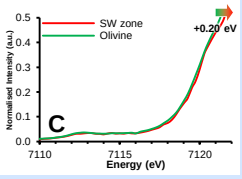


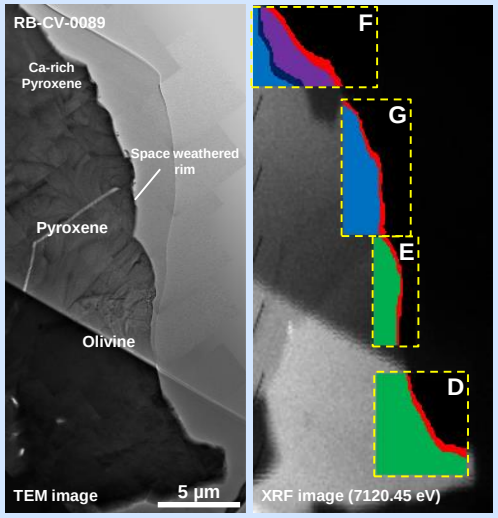
RB-QD04-0063
An olivine grain with small plagioclase inclusions. The Fe-K absorption edges shifted by up to **+0.50 eV** in the space weathered zones (SW zone) from the grain's substrate olivine. This shift suggests a ferric increase - **Fe^{3+}/ΣFe =0.10**.



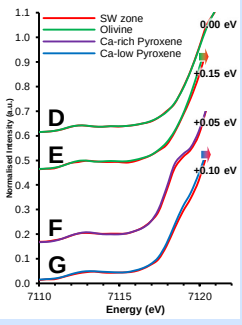


RB-QD04-0080
An olivine grain. An Fe-K absorption edge shift of up to **+0.20 eV** suggests a ferric increase in the SW zone (**Fe^{3+}/ΣFe =0.04**).





RB-CV-0089
The grain includes olivine and pyroxene, with Ca-rich pyroxene inclusions. Little to no significant shifting in the absorption edges of the SW zones (**<0.15 eV ~ Fe^{3+}/ΣFe <0.03**).



Discussion: The increased oxidation state shown by our results is small, but reveals the possible breakdown of the olivine, partial amorphisation, and the oxidation of the material. The oxidation may be due to interaction with trace amounts of H_2O molecules introduced by solar wind irradiation [7].
Space weathered rims in Apollo lunar soils contain npFe particles that have been oxidised to Fe^{2+} and even components of Fe^{3+}, with increasing Fe^{3+}/ΣFe correlating with increased soil maturity [8]. The npFe particles observed in our Itokawa samples may also have been oxidised, however the ferromagnesian-silicate phase of the rim remains dominant in our Fe-K XAS measurements. Future similar I14 experiments will include further Itokawa grains analysed along with Apollo lunar dust samples to directly compare and reveal insights into the redox changes associated with space weathering.

References: [1] Hiroi T. et al. (2006) *Nature*, 443:56-58. [2] Noguchi T. et al. (2011) *Science*, 333:1121-1125. [3] Noguchi T. et al. (2014) *Earth, Planets and Space*, 66:124. [4] Hicks L.J. et al. (2017) *Meteorit. Planet. Sci.*, 52:2075-2096. [5] Changela H.G. (2012) *GCA*, 98:282-294. [6] Hicks L.J. et al. (2014) *GCA*, 136:194-210. [7] Liu Y. et al. (2012) *Nat. Geosci.*, 5:779-782. [8] Thompson M.S. et al. (2016) *Meteorit. Planet. Sci.*, 51:1082-1095.