Nanoprobe XANES analysis of Space Weathered Itokawa Grains

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Introduction

Space weathering on Asteroid 25143 Itokawa is largely the result of the bombardment by electrons and protons from the solar wind. Its effects are manifested by the apparent darkening and reddening of the affected surfaces [1].

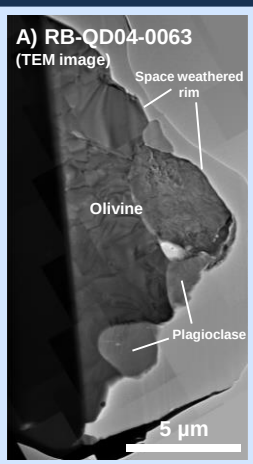
Previous studies of Itokawa samples returned by the JAXA Hayabusa mission have identified space weathering effects observed to depths of >100 nm [2]. Such effects include partially amorphised composite rims of the substrate mineralogy, featuring nanophase Fe^0 (npFe) particles, as well as outer rims redeposited vapour material from neighbouring grains.

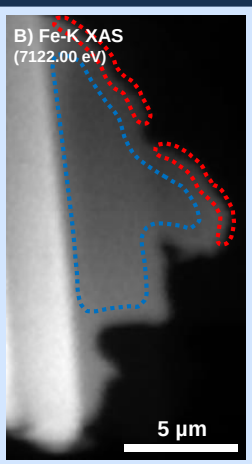
Investigation

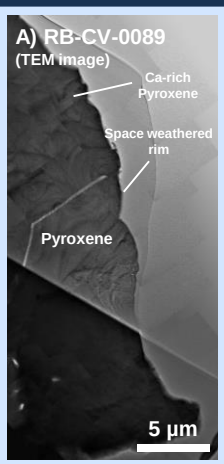
The space weathered rims of Itokawa grains have been analysed using the X-ray synchrotron nanoprobe I-14 Beamline at *Diamond Light Source*, to investigate Fe-redox changes.

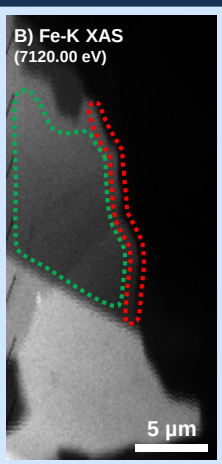
FIB-SEM sections of the grains were obtained for measuring Fe-K XAS maps from which to analyse energy shifts in the Fe-K XANES spectra.

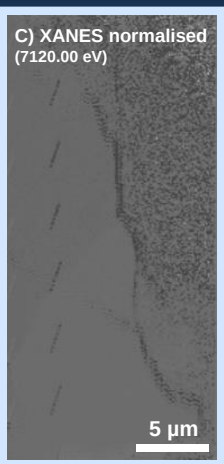
Imaging and chemical composition were obtaining using a JEOL 2100+ TEM.









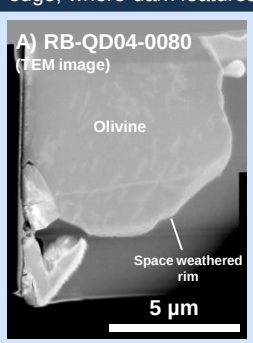


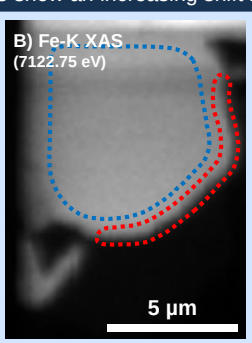
Results

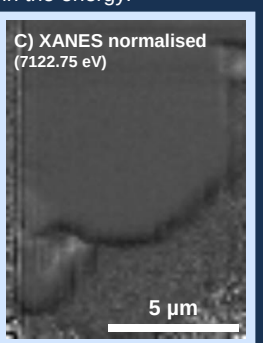
A) Using TEM imaging, space weathering effects have been identified on the rims of Itokawa grains: RB-QD04-0063; RB-QD04-0080; and RB-CV-0089.

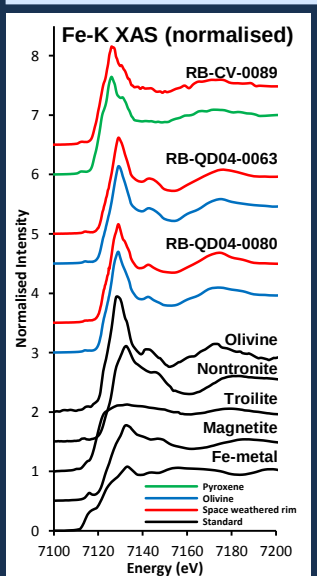
B) Fe-K XAS maps of each sample show the XRF at selected energies corresponding to the Fe-K XANES absorption edge position identified in the spectra of the space weathered rims.

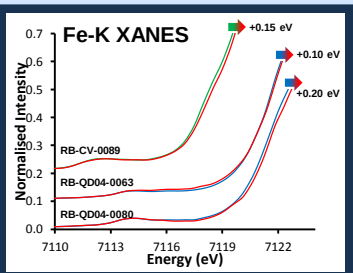
C) The Fe-K XANES map data is normalised. Analysing in *Mantis 2.3.02* [3], the maps reveal variations in the energy position at the Fe-K absorption edge, where dark features show an increasing shift in the energy.











Fe-K XANES

A positive shift in the Fe-K XAS absorption edge position can be deduced semi-quantitatively as an increase in the oxidation state from ferrous (Fe^{2+}) to ferric (Fe^{3+}), based on comparisons between reference materials of known ferrous-ferric content, similarly to previous studies of Itokawa, Comet Wild 2, and martian meteorite samples [2,4,5,6].

Therefore, a positive shift of up to ~0.20 eV suggests there may be an increased oxidation state **($Fe^{3+}/\Sigma Fe$ >0.05)** on the surface rims of the Itokawa olivine grains.

Discussion and Conclusion

Investigating space weathering effects in Apollo lunar soil using EELS, Thompson et al. [7] observed an increased Fe-oxidation state. The npFe particles had oxidised from metallic Fe^0 to Fe^{2+} and sometimes even Fe^{3+} with increased maturity. The presence of npFe particles in our samples has not been determined using the I-14 nanoprobe, but earlier studies of Itokawa grains found that space weathering can amorphise and reduce the Fe^{2+} in the silicates to form the metallic npFe particles [8].

An increased oxidation state of $Fe^{3+}/\Sigma Fe$ >0.05, for Itokawa grains, is small but reveals the possible breakdown and oxidation of the olivine into its amorphous state. The development of npFe particles may also have occurred, and any consequential oxidation of those particles, but they are clearly not the dominant phase detected in our Fe-K XAS measurements, remaining primarily olivine or pyroxene in composition. Due to our X-ray nanoprobe analyses of Itokawa samples, revealing insights into potential redox changes associated with space weathering, further similar studies are being considered for more Itokawa grains and lunar samples. These experiments will also inform studies of other airless Solar System bodies such as the returned samples of asteroids Ryugu and Bennu from the JAXA Hayabusa 2 and NASA OSIRIS-REx missions.

References: [1] Hiroi T. et al. (2006) *Nature*, 443, 56-58. [2] Noguchi T. et al. (2014) *Earth, Planets and Space*, 66:124. [3] Basham M. et al. (2015) *J. Synchrotron Radiat.*, 22, 853–858. [4] Hicks L.J. et al. (2017) *MAPS*, 52, 2075-2096. [5] Changela H.G. (2012) *GCA*, 98, 282-294. [6] Hicks L.J. et al. (2014) *GCA*, 136, 194-210. [7] Thompson M.S. et al. (2016) *MAPS*, 51, 1082-1095. [8] Noguchi T. et al. (2011) *Science*, 333, 1121-1125.