

Comparing Itokawa Grains and Chondrites Using X-Ray Absorption Spectroscopy.

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1. Introduction

The grains of S-class asteroid Itokawa returned by the JAXA *Hayabusa* mission in 2010 have mineralogical and isotopic affinities to LL5-6 chondrites [1,2,3]. To explore this relationship in more detail, we have measured with XANES and EXAFS the relative abundance of Fe³⁺ and Fe²⁺ ions in ferromagnesian silicates, in Itokawa grains and an LL5 chondrite.

1.1 Itokawa Samples

Four samples collected during the first *Hayabusa* touch-down were allocated to our group. RB-QD04-0008 is a ~40 µm wide composite grain composed of olivine and high-Ca pyroxene crystals. It contains a small amount of opaque grains (<2 µm diameter). RB-QD04-0011 and RB-QD04-0015 are composed of olivine with trace amounts of opaque minerals (<2 µm in diameter). They are 35 µm and 46 µm wide, respectively. RBQD04-0024 is a flat and thin ~50 µm wide grain composed of low-Ca pyroxene and plagioclase containing abundant small (<2 µm) opaque minerals.

2. Methods

All the samples were embedded in epoxy resin by using a N₂ purge glove box at the JAXA/ISAS curation facility. The grains were ultramicrotomed into 90 nm thick sections with a Reichert Ultracut-N for scanning transmission electron microscopy. Then the samples were carbon coated and observed by scanning electron microscopy (JEOL JIB-4501). For comparison, we also prepared a polished thin section of the Tuxtuac LL5 fall.

X-ray Absorption Near Edge Structure (XANES) and Extended X-ray Absorption Fine Structure (EXAFS) are an X-ray Absorption Spectroscopy (XAS) spectroscopic technique which we use to compare

Itokawa to chondrite meteorite samples. These analyses were made at the I18 X-ray microfocus spectroscopy beamline at the *Diamond Light Source*, Oxfordshire, UK. Energy selection is achieved with a Si (1 1 1) and (3 1 1) double crystal monochromator with fractional energy resolutions of 10⁻⁴-10⁻⁵. A Si drift Vortex detector was used to measure the X-ray fluorescence and absorbance of elements with Z > 40. Fe K edge X-ray XAS was performed on ~2.5 µm spots and also with a mapping routine over ~20 x 20 µm areas. Typical experimental conditions used for XAS were 1 s integration at each 0.2–0.4 eV energy step up to ~7100 eV, followed by a higher resolution of 0.1 eV energy steps over the XANES features up to 7150 eV, and continuing over the EXAFS region with steps of 2–4 eV up to 7660 eV.

After the XAS, the compositions of silicates in the Itokawa grains were measured by field-emission electron microprobe (FE-EPMA) at JEOL.

3. Results

The Fe-K XANES plots of olivine in three Itokawa grains show a clear absorption pre-edge feature, which is common to olivine in the Tuxtuac LL5 and terrestrial olivine (San Carlos) (Fig. 1). Their edge positions and the pre-edge centroid positions of olivine in the three Itokawa particles are 7119.5–7119.8 eV and 7112.5–7112.6 eV, respectively. These values are indistinguishable from those in terrestrial olivine and olivine in Tuxtuac.

The edge position and the pre-edge centroid position of low-Ca pyroxene in the Itokawa grain 0024 are 7119.7 eV and 7112.6 eV, respectively. These values are indistinguishable from those of low-Ca pyroxene in Tuxtuac LL 5 chondrite: 7119.8–8 eV and 7112.6–8 eV, respectively. In the case of high-Ca pyroxene in Itokawa, the Fe-K absorption spectrum of a mixture of high-Ca pyroxene and an Fe- and Ni-bearing phase was obtained because the latter exists

just below the high-Ca pyroxene in the Itokawa particle 0008. Nevertheless, the edge position and the pre-edge centroid position of the mixture of high-Ca pyroxene and Fe- and Ni-bearing phase are 7119.4 eV and 7112.6 eV, which are indistinguishable from the pre-edge peak derived from Fe^{2+} of terrestrial augite, 7119.3 eV and 7112.0 eV, respectively. The EXAFS suggested that the high-Ca pyroxene in 0008 is disordered and the low-Ca pyroxene in 0024 is ordered.

To estimate the Fe- and Ni-bearing phase beneath high-Ca pyroxene crystal in the Itokawa grain 0008, Fe-K and Ni-K X-ray absorption spectra were obtained. Ni-K absorption spectrum of the Ni-bearing area in 0008 is more similar to taenite in Tuxtuac and metallic Ni than those of pentlandite in Tuxtuac. This result is consistent with the Ni-K EXAFS data of these phases.

3.1. Chemical compositions of olivine and pyroxenes

Average and standard deviation of Fo mol% of olivine in RB-QD04-0008, 0011, and 0015 are 69.5 ± 0.6 (n=3), 70.3 ± 0.3 (n=3), and 69.0 ± 0.7 (n=2), respectively. Average and standard deviation of En and Wo mol% of low-Ca pyroxene in 0024 are 74.3 ± 0.3 and 2.2 ± 0.02 (n=3), respectively. En and Wo mol% of high-Ca pyroxene in 0008 are 46.1 and 41.9, respectively.

6. Discussion and Conclusions

The Fe-K edge positions and the Fe-K pre-edge centroid positions of olivine, low-Ca pyroxene, and high-Ca pyroxene in the four Itokawa grains are indistinguishable from those in Tuxtuac LL5 chondrite. These data indicate a negligible abundance of Fe^{3+} ions in ferromagnesian silicates in both the Itokawa grains and Tuxtuac, which is consistent with the mineralogical, petrological, and oxygen isotopic data of the Itokawa grains investigated in the initial analyses [1,2,3]. The four Itokawa grains do not contain small pentlandite inclusions, which is consistent with the low abundance of pentlandite in LL chondrites ($<<1\%$) [4,5].

Olivine and low-Ca pyroxene in the four Itokawa grains are homogeneous and their Mg# ratios are within the range of those in the equilibrated grains investigated during the initial analysis [1]. However,

the Wo content of low-Ca pyroxene is higher than those in the equilibrated grains (Wo1.4 [1]) and within the range of LL6 chondrites [6].

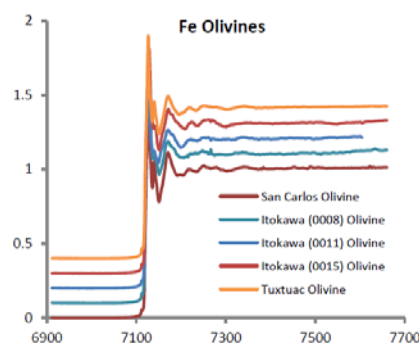


Figure 1. X-ray absorption spectra (normalized intensity vs. eV) around the Fe-K absorption edge for olivine and pyroxenes. Olivine in three Itokawa particles and Tuxtuac LL5 chondrite, and a terrestrial olivine (San Carlos).

En and Wo mol% of high-Ca pyroxene in RB-QD04-0008 are within the range of poorly equilibrated grains in the initial analysis [1]. The disordered structure of high-Ca pyroxene indicated by the Fe-K EXAFS data might be related to partial equilibration or shock. However, it does not show mechanical twinning. Similarly, olivine attaching to the high-Ca pyroxene does not show undulatory extinction. Therefore, partial equilibration is more plausible than shock as a cause of its disordered structure.

The Fe-K XANES and EXAFS data together with EPMA data of the four Itokawa grains suggest that the redox state experienced by the Itokawa grains are similar to those of LL chondrites. However, the four Itokawa grains represent a wide range of thermal metamorphism corresponding to petrologic types 4 to 6. Further analyses by TEM will help establish the petrologic type.

References

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