Transmission Electron Microscopy of Plagioclase-Rich Itokawa Grains: Space Weathering Effects and Solar Flare Track Exposure Ages.

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Introduction

Limited samples are available for the study of space weathering effects on airless bodies. The grains returned by the Hayabusa mission to asteroid 25143 Itokawa provide the only samples currently available to study space weathering of ordinary chondrite regolith. We have previously studied olivine-rich Itokawa grains and documented their surface alteration and exposure ages based on the observed density of solar flare particle tracks. Here we focus on the rarer Itokawa plagioclase grains, in order to allow comparisons between Itokawa and lunar soil plagioclase grains for which an extensive data set exists [1].

Samples and Methods

Four plagioclase-bearing grains from the JAXA collection were allocated for this study: RB-QD04-0058, RB-QD04-0074, RB-QD04-0090, and RA-QD02-0157. We embedded the particles in low viscosity epoxy and used an ultramicrotome to partly section three of the particles, placing the sections on TEM grids with continuous amorphous carbon support films. Sectioning of the fourth particle is underway. For two of the particles, the epoxy surrounding the particle was trimmed away on three sides to enable further sectioning utilizing a focused ion beam (FIB) instrument [2] (FEI Quanta 3D). The microtome and FIB sections were analyzed in a JEOL 2500SE scanning and transmission electron microscope (STEM) equipped with an energy-dispersive x-ray (EDX) spectrometer optimized for nanometer-scale quantitative x-ray mapping. Brightfield and darkfield images were acquired using both conventional TEM and STEM imaging. Solar flare particle tracks were imaged in STEM mode, and observed track densities were converted to apparent surface exposure ages using our recent calibration [3].

Results and Discussion

RB-QD04-0090 is an angular ~40 µm grain of twinned albitic plagioclase. No shock features are observed. EDX analyses give a composition of Ab85Or5An12. Solar flare particle tracks occur with a density of ~$5x10^9$ cm^{-2} which indicates a surface exposure of ~110,000 y (Figure 2). The particle is surrounded by a thin continuous amorphous rim ~50 nm wide. Quantitative EDX mapping shows that the rim consists of two layers, an inner amorphous layer ~20 nm thick with the same composition as the underlying crystal-line host, and an outer amorphous layer ~30 nm thick that is Fe-rich and compositionally distinct from the underlying layer and host grain (Figure 1). We interpret the inner layer as a solar wind amorphized layer, and the outer layer as a vapor deposit. Vapor deposits of this thickness are unusual for Itokawa grains, because most grains are typically dominated by solar wind damage [1, 3, 4]. Nanophase Fe grains are present as a thin outermost layer. A few adhering grains (also plagioclase) are attached to the grain surface. In addition, there are numerous ~0.1-0.3 µm crystals of NaCl on the grain surface. We also observed a thin continuous rim of NaCl surrounding the grain.

RB-QD04-0074 is an ~32 µm irregularly-shaped polymineralic grain. The grain contains major olivine (Fo65), twinned albite (Ab85Or2An12), and minor orthopyroxene (En65Fs33Wo2). The olivine and orthopyroxene are more Fe-rich than typical Itokawa grains [5] but consistent with literature data for LL chondrites [6]. The orthopyroxene contains a high density of stacking faults and the olivine contains numerous planar dislocations along (100). The planar dislocations in the olivine grain are consistent with those that develop due to moderate shock. The observed track density $6x10^7$ cm^{-2} (corresponding to counting 6 tracks in 10 μm^2) is very low and is approaching the limit that can be reliably counted in a grain this large by TEM methods. The track density implies a short surface exposure of ~2000 y. The plagioclase shows a solar wind amorphized outer layer ~10 nm wide. The olivine grain appears undamaged and does not show a nanocrystalline solar wind damaged rim like those on olivine-rich Itokawa grains [7]. RB-QD04-0074 is over an order of magnitude younger than the other olivine and plagioclase grains we have analyzed and was either freshly excavated from greater depth in the Itokawa regolith, or possibly had an origin as a relatively fresh fragment of a larger grain due to regolith gardening. This grain also shows surface adhering NaCl particles. We had not previously detected NaCl particles on previous Hayabusa samples analyzed in our lab. Noguchi et al. [8] detected NaCl and KCl particles on Itokawa grains but were unable to determine whether they were indigenous or possible contaminants.

RA-QD02-0157 is an angular ~38 μm grain dominated by albitic plagioclase and minor FeS and olivine. FIB sectioning is underway and here we report preliminary observations from ultramicrotome thin sections. The plagioclase shows twinning and is compositionally similar to the other albite grains in this study. We have not observed solar flare tracks in this particle to date, although there appears to be a thin amorphous layer (<10 nm) that likely represents solar wind damage. Analysis of a FIB section will provide a better constraint on exposure age of this grain. A small FeS grain adhering to the surface shows a damaged, outer layer consistent with our previous work on solar wind damaged sulfide grains in Itokawa samples.

Comparison to Lunar Plagioclase

We have previously established a relationship between the width of solar wind damaged rims on lunar plagioclase and olivine, and their surface exposure age based on solar flare particle track densities [1]. Although large compositional differences exist between the albitic Itokawa plagioclase grains and the dominantly Ca-rich plagioclase in lunar soils, the solar wind damaged rim widths in Itokawa grains follows the trend for lunar plagioclase. The Itokawa grains show space weathering features typical of immature lunar soil grains.

Conclusions

We analyzed the space weathering features on three Itokawa plagioclase-bearing grains. Particles RA-QD04-0074 and RA-QD02-0157 are relatively fresh with little surface modification from solar wind damage. The low track density for -0074 suggests a surface exposure age of ~2000y. Particle RA-QD04-0090 has a much longer surface exposure (~110,000 y) and corresponding surface alteration including a 30 nm thick vapor deposit overlying a solar wind damaged layer.

References

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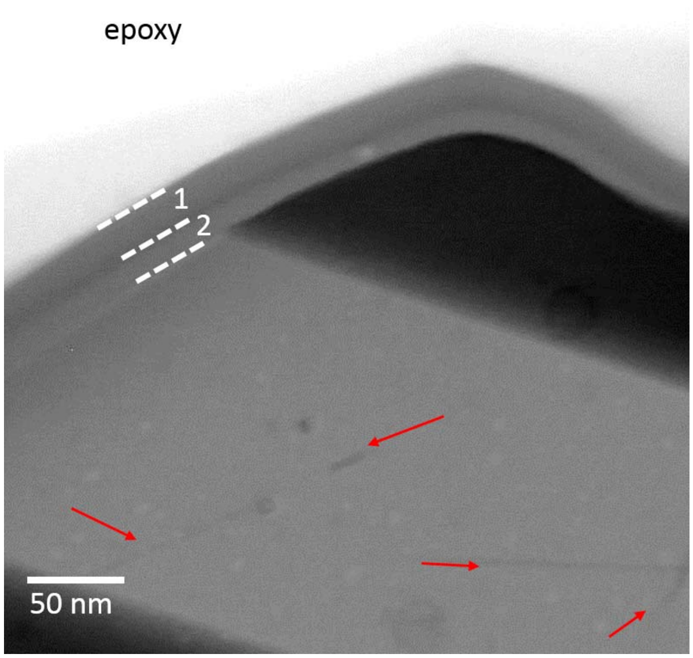

Figure 1. A brightfield STEM image from a FIB section of particle RA-QD04-0090 showing twinning in the host grain, solar flare particle tracks (red arrows), and a space-weathered rim consisting of two distinct layers, a vapor-deposited layer (1) and a solar wind damaged layer (2).