Relationships among morphology, solar wind irradiation, solar flare tracks, and noble gas isotopic signatures of 12 Itokawa grains

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Introduction: Surface material on airless bodies has been exposed to solar wind, solar and galactic cosmic rays, and micrometeoroid impacts. Various modification were reported on the outermost (<~50 nm) surface of Itokawa grains [1-6]. TEM observation of the microtextures of the cross sections of these grains suggests that solar wind irradiation plays an important role to form the surface modification [2-5]. Although it was expected that such textures were formed less than $\sim 10^3$ years [2, 5], the duration is estimated by the solar-wind noble gas concentrations of the different grains [7]. Therefore, the collaborative study of mineralogical and noble gas analyses for individual Itokawa grains are important to infer the evolution history of airless bodies. We developed analytical procedures to perform SEM, TEM, and noble gas mass spectrometry for individual extraterrestrial grains [8]. Here we report the results of the collaborative study of 12 Itokawa grains.

Materials and methods: Total 12 Itokawa grains were allocated for us in the AO2, 3, and 4 opportunities. Each grain was fixed on a baked Ta plate with acetone soluble glue. Thin (~100 nm) sections were prepared for the AO2 grains and thick (~1 μm) sections were prepared for the AO3 and 4 grains by FIB-SEM. The AO4 grains were observed in detail by FE-SEM before FIB. To avoid destruction of the original sample surfaces, SEM observations were performed at <3 keV accelerating voltages. Total exposure time to the atmosphere during FIB processes was less than 1 hour for every samples. The AO3 and AO4 sections were observed by high voltage TEM and they were thinned again by FIB-SEM and were observed by 200 kV (S)TEMs. The remaining samples were inserted into aluminum envelopes and were rinsed in whole with acetone to remove glue and the envelopes were transferred to a sample chamber for noble gas mass spectrometry in the N_2 grove box. The stepwise heating method was used to determine isotopic ratios and amounts of He and Ne in each grain using the modified MM5400 mass spectrometer.

Results and discussion: The twelve grains show variations in solar wind radiation damage and in solar flare track number densities. Two grains do not have space weathering rims and ^{4}He released only below 200 °C, but do not contain solar flare tracks. This indicates that these grains have been exposed to solar wind for a short duration ($<10^5$ years) at the surface layer (about 0-10 mm depth). A grain does not have space weathering rim and its solar flare track density is as low as $\sim 1\times10^8$ cm^{-2}. Isotopic ratios of He and Ne in this grain show excesses in ^{3}He and ^{21}Ne that are produced by galactic cosmic ray. It is plausible that this grain has existed deep interior (> ~10 mm) of Itokawa for long duration, and came to the surface of Itokawa very recently. Most Itokawa grains with $>6\times10^8$ tracks/cm^2 are not saturated in He and Ne and there is no simple positive correlation between the track densities and the noble gas concentrations. These unsaturated grains would have resulted from destructions after irradiation to solar activity. In contrast, many lunar regolith grains have $>5\times10^{10}$ tracks/cm^2. These grains have completely amorphized rims, which shows a stark contrast with those on Itokawa grains. These regolith grains are saturated in solar He although it is expected that such grains experienced multiple destruction. A large difference in exposure periods to solar activities between Itokawa and lunar samples probably resulted in these differences.

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