Collisional fragmentation of an olivine-enstatite-rich Itokawa particle

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Introduction: The regolith grains sampled and returned to Earth by the spacecraft Hayabusa from asteroid 25143 Itokawa allowed for the second time – after the Apollo missions – the direct study of space weathering effects [1] and confirmed the link between ordinary chondrites and the S-type asteroid [2]. The reported space weathering effects are due to both solar wind irradiation and impacts of micrometeoroids. They include nanocrystalline and amorphous layers [2-6], melt- and vapor-deposited layers [3, 5], and shock metamorphic features (e.g., lattice defects) [7]. In this work, we present the results of a study on grain RB-QD04-0092. This particle documents the complex dynamic evolution of the asteroid surface by impact gardening.

Sample and methods: In the context of the 4th International Announcement of Opportunity for Hayabusa sample investigation, we have received five Itokawa particles. Currently, we have focused on the investigation of particle RB-QD04-0092, which was sliced into five subsamples by focused ion beam (FIB) on a scanning electron microscope (SEM) and then studied by analytical transmission electron microscopy (TEM), following the procedure described by [6].

Observations and discussion: RB-QD04-0092 is a flat grain (29 x 25 x 8 µm) consisting of enstatite (En75-80) and olivine (Fo71-78). Numerous mineral fragments are attached to its surface (Fig. 1). They are mainly made of Mg-rich olivine, troilite, and plagioclase.

TEM reveals that the entire particle possesses a polycrystalline rim (maximum thickness 70 nm) and incipient vesicle/blister formation, indicating a moderate solar wind exposure [8]. Contrary to other observations [2], no (sulfur)-iron nanoparticles and amorphized rims were found. Solar flare tracks were observed in both enstatite and olivine with a density comparable to previously reported data ($10^8 – 10^9$ cm^{-2}; [4, 6]).

In addition to these features, olivine and enstatite show typical shock effects known for shocked meteorites, that is: (1) screw dislocations with Burgers vector [001] in olivine and (2) (100) clinoenstatite lamellae in orthoenstatite. This is the first report of clinoenstatite lamellae in Hayabusa-returned samples. Dislocations in olivine occur localized in at least three separate sites, suggesting more than just one impact event. We found a maximum length of the [001] dislocations of 2.5-3 µm. Taking the estimated dislocation velocity in experimentally shocked olivine [9], their time of propagation and, hence, shock duration can be approximated to be of the order of 1.5 ns. This short time indicates that the multiple collisions that RB-QD04-0092 underwent must have occurred with other tiny particles or fragments in the regolith of Itokawa. Clinoenstatite lamellae are relatively short, which is also in agreement with such small-scale grain-grain collisions. However, impact microcraters are absent on the surfaces of sites with the aforementioned shock effects.

Conclusions: The absence of a well-developed amorphous rim containing nanoparticles and the occurrence of at least four sites with shock effects and no microcraters indicate that RB-QD04-0092 was involved in active regolith gardening. This collisional gardening has the effect of reducing the effective exposure time of regolith grains.

Acknowledgements
We are grateful to JAXA for providing Itokawa particles. FIB-TEM facilities at FSU Jena were funded by the Gottfried-Wilhelm-Leibniz award to FL (LA 830/14-1). AF thanks the Alexander von Humboldt Foundation for a postdoctoral grant.

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