# Defect and exsolution microstructures in four pyroxene-rich grains from Itokawa

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**Introduction:** In 2010, the Hayabusa spacecraft returned precious regolith grains from the rubble pile asteroid 25143 Itokawa. Subsequent investigations confirmed the link between LL4-6 ordinary chondrites and the S-type asteroid Itokawa and revealed its eventful past [1, 2]. The processes reported in regolith grains comprise thermal annealing in the original parent body and the full range of space weathering effects from surface amorphization by ion bombardment to collisional fragmentation [2-6]. Pyroxenes, the second most abundant phase in ordinary chondrites, are an important source of information on these processes, as they develop various process-indicative defects. Thus, we pursued here a systematic study of the microstructures in ortho- and clinopyroxene grains from Itokawa and discuss the results in terms of thermal metamorphism and space weathering.

**Samples and methods:** In the context of the 4th International Announcement of Opportunity for Hayabusa sample investigation, we have obtained four pyroxene-containing Itokawa particles: RB-QD04-0092, RA-QD02-0205, RB-CV-0192, and RB-CV-0144 [7]. These grains were cut by focused ion beam (FIB) preparation on a scanning electron microscope (SEM) and then studied by analytical transmission electron microscopy (TEM), following the procedure described by [6].

**Results:** *RB-QD04-0092* is a flat grain (29 x 26 x 12 µm) consisting of orthopyroxene ($En_{78}Fs_{21}Wo_{1}$) and olivine ($Fo_{71-78}$). Both olivine and orthopyroxene show defects that are compatible with local shock metamorphism, i.e. olivine contains [001] dislocations, while orthopyroxene is pervaded by multiple (100) clinoenstatite lamellae. The regolith grain shows a 40-70 nm wide continuous damaged rim due to solar wind irradiation.

*RA-QD02-0205* is a prismatic grain (55 x 43 x 15 µm) that only consists of a single crystal orthopyroxene ($En_{74}Fs_{24}Wo_{2}$). The dominant defects are also pervasive (100) clinoenstatite lamellae, which are decorated by partial dislocations. The grain is surrounded by a 50 nm thin polynanocrystalline rim.

*RB-CV-0192* is also prismatic in shape (19 x 10 x 8 µm), and contains both orthopyroxene ($En_{76}Fs_{23}Wo_{1}$) and clinopyroxene ($En_{50}Fs_{7}Wo_{43}$). Adjacent olivine, plagioclase, and whitlockite were detected, too. Besides (100) clinoenstatite lamellae in orthopyroxene there are no other defects. The solar wind damaged polynanocrystalline rim is up to 50 nm thick.

*RB-CV-0144* is 17 x 12 x 5 µm in size and contains both orthopyroxene ($En_{79}Fs_{20}Wo_{1}$) and clinopyroxene ($En_{50}Fs_{6}Wo_{44}$). The pyroxenes possess subgrain boundaries and are traversed by thin (up to 10 nm) (100) exsolution lamellae. One side of the entire regolith grain displays a polynanocrystalline and layered rim of up to 60 nm thickness.

**Discussion:** The presence of amorphous to nanocrystalline rims documents the solar wind damage of Itokawa grains. Moreover, the occurrence of shock defects in localized areas of olivine and pyroxenes (clinoenstatite lamellae and dislocations) as well as the absence of microcraters on their surfaces indicate that cascades of collisions took place in the regolith. As consequence of active space gardening the effective exposure time of regolith grains must have been reduced. Of particular interest is the observation of thin exsolution lamellae in pyroxene, whose width of up to 10 nm points to slow cooling rates of < 1 °C per 1000 years at peak temperatures of 800°C [2, 8].

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