Morphological and Spectroscopic effect of space weathering on a C-type asteroid, documented by the microcraters on a Ryugu Grain A0112

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Introduction:

Understanding the effect of space weathering on various types of planetary surfaces is critical for interpretation of remote-sensing data obtained from such surfaces and for matching various meteorite types to potential parent bodies. While the effects of space weathering on anhydrous regolith materials is well understood on the basis of samples returned from the Moon [1,2] and S-type asteroid Itokawa [3–5], space weathering of hydrous, carbonaceous-chondrite (C-type) like asteroidal surfaces is still poorly understood. To acquire a better understanding of the role of micrometeoroid impacts in space weathering of C-type like asteroids, we studied the impact-craters found on Ryugu sample A0112, which is a large (3.0 × 1.8 mm) regolith grain collected at the first touchdown site from the asteroid's top surface [6,7]. The morphological and spectral analysis of the fragment were carried out at the Planetary Spectroscopy Lab (PSL) of the German Aerospace Center (DLR) and the Geochemical and Microanalytical Laboratories of the Museum für Naturkunde (MfN) in Berlin. Investigations on the physical, chemical, optical and spectral changes within the microcraters, could be explained by the influence of space weathering on Ryugu, altering the outer layer of this airless planetary body [8,9].

Methods:

For the morphological analysis of A0112, a Bruker X-ray micro-computed tomography (μCT) and a JEOL JSM-6610LV Scanning electron microscopy (SEM) with a Bruker Quantax 800 EDX system were used at the MfN. Micro-CT scans, as well as BSE images were collected with these instruments revealing the presence of several crater-like depressions (Fig. 1). The spectral analysis of A0112 was carried out at DLR and consisted of point-localized micro-infrared spectroscopy measurements acquired with the Hyperspectral Bruker Hyperion 2000 Micro-FTIR connected to a Bruker Vertex 80V FTIR in the VNIR (0.7 – 2 µm) and MIR (1 – 20 µm) spectral range. More than 50 point-localized reflectance measurements (NA = 0.4, FoV = 50 µm) consisting of 1000 scans at an optical magnification of 15x and a resolution of 4cm-1 were collected inside and away of the largest microcraters present in the A0112 grain. A Bruker Vertex 80V FTIR spectrometer and an ad hoc sample holder was used to measure bulk bi-directional reflectance spectroscopy of the fragment completely under vacuum, in the whole spectral range from UV to FIR (0.25 µm to at least 25 µm spectral range) with a 0.25 mm aperture.

Results and Discussion:

The μCT scans and BSE imaging revealed the presence of three large microcraters of 150–270 μm diameter, characterized by their crater depression, crater rim, irregular spallation zone and associated fractures, structurally consistent with lunar microcraters [10]. The fracture patterns resembling radial, concentric, and spallation fractures known from impact experiments in the strength regime [10]. Several smaller circular pits between 5 and 20 μm diameter were also identified. Further microscopical investigation with the high-magnification SEM imaging system revealed the presence of quenched impact melts characterized by its frothy, highly vesicular structure [11] within the bottoms and walls of most of these depressions and pits. EDS chemical maps and elemental analysis maps showed that the frothy materials are quenched silicate–sulfide emulsions, which reconfirms that the crater-like depressions and pits can be identified as impact craters. Quenched melt splashes up to 300 μm across exist not only on the crater-bearing side of A0112, but also on an additional side of the sample. These are similar in chemical composition to the frothy layers described recently from other Ryugu samples [11] and invariably comprise silicate–sulfide emulsions. High-resolution EDS element distribution maps furthermore suggest that the quenched melts contain immiscible FeNi metal droplets [12].

Most of the in-situ IR reflectance spectra from the non-crater-bearing sides of A0112 are consistent with infrared spectra of other Ryugu fragments [13] and showed pronounced spectral features at 2.71 µm, corresponding to OH-bearing phyllosilicates and carbonate doublets at 3.33, 3.47 µm and 3.81, 3.95 µm. However, the spectra acquired from the frothy material within the largest crater-like depression revealed to be different from its bulk composition and showed an almost flat and featureless spectra between 2 and 4 µm (Fig. 2). These spectra are comparable to those obtained from the CI chondrite Ivuna heated at 700 °C [14].

Assuming that the asteroid could be covered with these micrometeorite impacts due to continuous space weathering; these results could possibly explain why the NIRS3 remote sensing measurements of the asteroid observed reduced spectral features [15,16].

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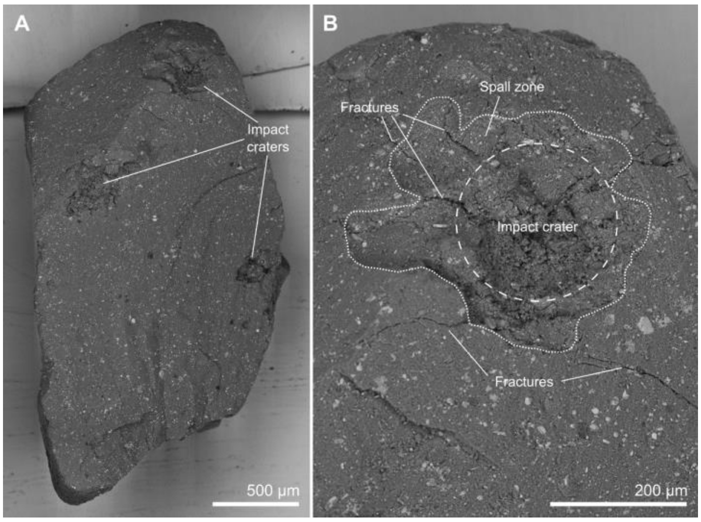

Figure 1. SEM-BSE images of the crater-covered side of A0112 (A) and the largest impact crater surrounded by a spall zone and surface-related, impact-produced fractures (B).

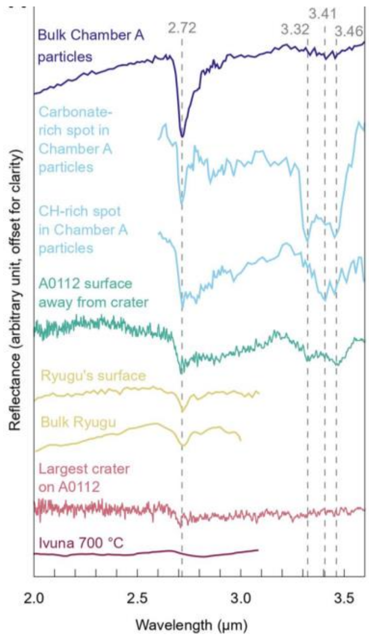

Figure 2. Reflectance spectra obtained from inside the largest impact crater on A0112 (red) compared against a spot far away from the craters (green). Also shown are spectra of bulk A particles (dark blue [13]), carbonate- and CH-rich spots on Chamber A particles (light blue [13]), Ryugu's bulk surface (yellow [15,16]) and heated Ivuna CI chondrite (pink and red [14]) for comparison.

References

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