CRISPY ON THE OUTSIDE, RAW ON THE INSIDE: IMPACT-INDUCED MELTING AND FRAGMENTATION OF C-TYPE ASTEROID REGOLITH DOCUMENTED IN A RYUGU SAMPLE

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Introduction: The surfaces of airless planetary bodies are continually exposed to hypervelocity impacts of micrometeoroids and influx of solar-wind ions. Collectively known as space weathering, these processes gradually alter the morphologies, microstructures, and chemical compositions of regolith grains exposed to space [1]. Because these changes also affect the optical properties of space-weathered grains [1], understanding space weathering is critical for interpretation of remote-sensing data obtained from airless planetary surfaces and for matching meteorites to parent bodies. While the effects of space weathering on anhydrous regolith materials is well understood and documented in samples returned from the Moon [1, 2] or S-type asteroid Itokawa [3, 4], space weathering of hydrous, carbonaceous chondrite-like (C-type) planetary surfaces is poorly understood. To better understand the role of micrometeoroid impacts in space weathering on C-type asteroids (cf. [5, 6]), we investigated a population of micrometeoroid impact craters on a large regolith particle resembling CI (Ivuna-type) carbonaceous chondrites that was recently returned from C-type asteroid Ryugu by JAXA's Hayabusa2 mission (e.g., [7]).

Materials & methods: We studied Ryugu particle A0112, a relatively large (3.0 × 1.8 mm) sample collected from the first touchdown site [7], using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), and X-ray micro-computed tomography (µCT) at Museum für Naturkunde Berlin and Bruker Nano Analytics, Berlin. Infrared reflectance spectra were obtained using a Bruker Hyperion 2000 at German Aerospace Centre in Berlin.

Results: SEM imaging revealed the presence of three large, crater-like depressions of 150–270 µm across as well as of several smaller, circular pits between 5 and 20 µm across on one of the surfaces of A0112 and the presence of frothy, highly vesicular materials that are interpreted as quenched impact melts (cf. [5]) lining the bottoms/walls of the large and small crater-like depressions. Reflectance spectra obtained from this material are almost featureless between 2 and 4 µm and resemble those obtained from the CI chondrite Ivuna heated to 700 °C [8]. EDS analyses and element distribution maps showed that the frothy materials are quenched silicate–sulfide emulsions, which suggests that the crater-like depressions and pits are impact craters. In addition, quenched melt splashes of up to 40 µm across exist on the crater-bearing surface of A0112. These are similar in chemical composition to the frothy layers described recently from other Ryugu grains [5] and invariably comprise silicate–sulfide emulsions. The melt splashes on A0112 match fusion crusts around the CI chondrites Orgueil and Alais [9] in chemical composition and resemble a quenched melt particle likely of impact-origin in Orgueil [10]. Furthermore, µCT scans revealed that the subsurfaces adjacent/below the large craters are intensely fractured; in particular, we observed fracture patterns resembling radial, concentric, and spallation fractures known from impact experiments [11]. Consistent with lunar microcraters [11], the large craters are surrounded by irregular spallation zones whereas the small craters are almost perfectly bowl-shaped.

Discussion & conclusions: The microcraters and quenched impact melts on Ryugu sample A0112 provide information on the nature and magnitude of impact-induced processing of C-type asteroid surfaces in relation to solar wind-induced space weathering. Sample A0112 appears to be the most intensely shocked Ryugu particle investigated so far—the vast majority of smaller Ryugu samples were reported to be either essentially unshocked [12] or only marginally affected by micrometeoroid impacts [5, 6]. Fracturing and spallation associated with the large craters also informs on the efficiency of impact-induced fragmentation of grains in C-type asteroidal regoliths [13]. Specifically, our observations suggest that spallation zones of micrometeoroid impact craters are likely sources of carbonaceous micrometeoroids arriving on Earth, contradictory to recent proposals based on unshocked Ryugu grains [12]. If the microcrater population on A0112 is representative of Ryugu's surface, our results have relevance for evaluation of the relative roles of thermal [14] vs. impact-triggered [11] comminution of, and dust production from, asteroidal regoliths.

Acknowledgments: We thank JAXA for allocation of Ryugu sample A0112.

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