Slickenside as a record of shock metamorphism on asteroid Ryugu

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Introduction: An asteroid is formed and evolved by repeated collisions. The Hayabusa2 spacecraft shows that boulders with layered structures occur on the asteroid Ryugu (*1*). The layered structure can be regarded as parallel cracks, which is one of the representative features related to shock metamorphism. Evidence of shock metamorphism is found in some polished Ryugu grains (C0055) (*2*). However, evidence of shock metamorphism has not been found on the surface of Ryugu grains. In the present study, we scrutinize the surface morphology of several Ryugu grains to find features of shock metamorphism.

Samples and experimental methods: Numerous small Ryugu grains, ~100 µm across on average, were allocated to the M-P F sub-team. Several grains from the chamber A (surface particles collected by the first touchdown) were attached on a gold (Au) plate (sample plate number: AP 042) with small amounts of epoxy glue in an N_2 filled glove box for surface morphology observation. The surface morphology of grains without any coating was observed by JEOL JSM-7100F and Hitachi S-5200 field emission gun scanning electron microscopes (FEG-SEM) at Tohoku Univ. and Hiroshima Univ., respectively. Some portions in the grains were excavated and processed to be ultrathin foils by a Hitachi SMI4050 focused ion beam (FIB) system at Kochi Institute for Core Sample Research, JAMSTEC after coating with osmium and carbon. The ultrathin foils were examined by a JEOL JEM-2100F transmission electron microscope (TEM) equipped with an energy dispersive spectrometer (EDS) at Tohoku Univ. Chemical compositions were measured by EDS under scanning TEM (STEM) mode.

Results and discussion: More than 24 grains adhered on the sample plate AP 042 were observed by secondary electron (SE) imaging (at a low accelerating voltage of 3.0–5.0 kV) to scrutinize the surface morphology. Some grains were broken into finer grains when grains were put on an Au plate, follows that fresh surface appeared newly. Most grains had a bumped or rough surface, and some grains had evidence of space weathering (*3*). On the other hand, two grains had a smooth surface on one side of the grain (Fig. 1). The smooth surface is not a single crystal surface. An obscure liner texture was observed on the smooth surface of one grain. An ultrathin foil was prepared from the smooth surface with a liner structure to observe its cross-section. The smooth surface looks like a weathering vein consisting of carbonate or iron-hydro/oxide minerals which are found in some carbonaceous chondrites. However, X-ray elemental maps indicated that there is no distinct difference in chemical compositions near the smooth surface. Bright-field (BF)-TEM images showed that the ultrathin foil consists mainly of fibrous phyllosilicates (saponite and serpentine) assemblage embedding small amounts of iron-sulfide and iron-oxide grains. The fibrous phyllosilicate assemblage is porous, and pores are filled with organic matter. These mineralogical features are like the Ryugu grains investigated in other works (*3, 4*). However, there is a distinct difference: the fibrous phyllosilicates assemblage near the smooth surface is compacted and the compaction degree increases toward the smooth surface. Lattice fringes corresponding to phyllosilicates become obscure with approaching the smooth surface, indicative of vitrification or dehydration. A ~200 nm layer from the smooth surface is heavily compacted, where the (001) basal planes of fibrous phyllosilicates are sub-parallel to the smooth surface. The smooth surface with a liner texture is a characteristic feature of a slickenside, which is found in terrestrial fault rocks and shatter cones around impact craters (*5*). The slickenside is formed by friction

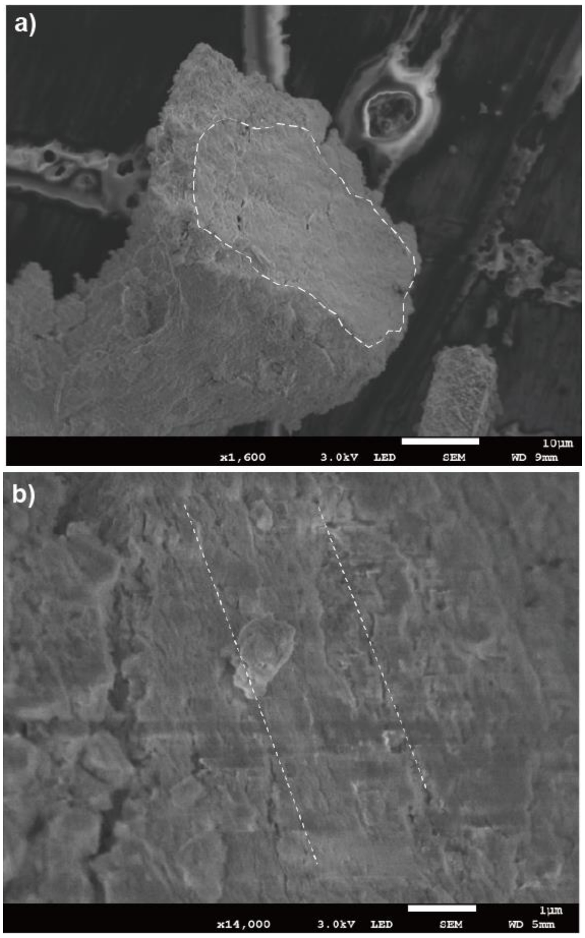

Figure 1. SE images. a) A grain with a smooth surface (dashed line) and b) a high-magnification image of the smooth surface with a liner structure (dotted line). Horizontal parallel stripes are artifact because of electron charge-up.

between rocks along the two sides of a fault. Hence, we propose that the smooth surfaces appearing on some Ryugu grains are the record of shock-induced shear deformation that occurred on the asteroid Ryugu. No evidence of decomposition is found in fibrous phyllosilicates near the smooth surface of Ryugu grains. This suggests that friction heating temperature is below the decomposition temperature of phyllosilicates (< ~700 °C) (*6*). A shock-melt vein is also formed by friction heating along a faulting zone in shocked meteorites (*7*). Such a melting texture is not observed in Ryugu grains. Ryugu's grains with slickensides do not adhere well to each other because shock-induced melting and subsequent quenching did not occur. Therefore, grains with slickensides can be easily detached from each other during fall into the earth. In addition, a slickenside is too thin to survive from atmospheric entry heating or terrestrial weathering. So, a slickenside could not be found in a meteorite.

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