SHOCK-INDUCED DEFORMATION RECORDED IN THE REGOLITH PARTICLES FROM C-TYPE ASTEROID RYUGU.

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Introduction: The Hayabusa 2 mission successfully returned with samples of C-type near-Earth asteroid (162173) Ryugu on December of 2020. Ryugu samples contain large quantities of volatiles such as water and noble gases [1, 2]. Studying Ryugu samples is a great opportunity to understand the shock metamorphism on water-bearing rubble-pile asteroids. In this study, we have examined shock metamorphism on sixteen coarse mm-sized particles recovered by the Hayabusa 2 mission.

Results: FE-SEM observation of polished surfaces of Ryugu samples shows they consist mainly of fine-grained phyllosilicates, carbonates, Fe sulfides, and magnetite. Chondrules and CAIs are absent from most of the samples. Heavy shock features such as shock melting or high-pressure mineral formation were not observed in all samples. However, some samples show weak to moderate shock effects. Among them, C0055 exhibits distinct shock deformation features. It shows strong uniaxial compression and high-density subparallel fractures. Synchrotron CT analysis revealed that the subparallel fractures extend across the entire particle in the direction perpendicular to the shock compression. C0055 is broken along subparallel fractures, showing a plate-like morphology. The average width between the fractures is 4.8 µm. Synchrotron X-ray diffraction (XRD) analysis indicated that phyllosilicates in this sample consist of serpentine and saponite, similar to other Ryugu samples. Anhydrous silicates such as olivine and pyroxene are absent in this sample. Many dolomites (5 ~10 µm in size) show planar fractures with an average width of 0.6 ± 0.3 µm (n=13). TEM observation reveals the presence of straight dislocations in the vicinity of the fractures of C0055 dolomite, while dislocation lines in other Ryugu dolomites are generally curly-like.

Discussion: Shock stages of meteorites are defined based on shock features in anhydrous silicates such as olivine, pyroxene, and plagioclase [3, 4]. However, such minerals are very rare and small (< ~10 µm) in Ryugu samples [5]. Hence in this study, we used hydrous silicates and carbonates which are abundant in Ryugu. Unlike anhydrous silicates, the shock stage classification of hydrous silicates has not yet been established, but the subparallel fractures in phyllosilicate-rich areas of C0055 can be used for shock intensity characterization. Phyllosilicate-rich matrix in the Murchison CM chondrite that was shocked to 4 and 10 GPa did not show such subparallel fractures, while that of a 21 GPs sample shows fractures [6]. Spacings between fractures are ~5 µm for both C0055 and the Murchison 21GPa sample. Subparallel fractures were produced upon pressure release when shock-heated phyllosilicates were partially dehydrated and expanded by heating. Therefore, production of the subparallel fractures is more dependent on heat than on pressure. The experimental shock compression requires higher pressure to produce subparallel fractures due to lower shock-induced heat than the natural impact, because shock pressure in experiment is attained by multiple reflection shock wave while it in natural events is attained by single shock. The heat generated during high pressure regime of experimental 21GPa-impact (145 J/g) is equivalent to that of 3.8 GPa-impact (170J/g) [6]. Therefore, in the natural impact events, the subparallel fractures start to form at pressures as low as 3.8 GPa. This suggests that C0055 might have experienced an impact exceeding 3.8 GPa. The presence of straight dislocations in dolomite in C0055 accompanied with planar fractures is compatible with mild shock.

Ryugu is a rubble pile asteroid that experienced a catastrophic impact [7]. Therefore, we expected the Ryugu sample to exhibit evidence of catastrophic impact, but our research showed most of the Ryugu samples do not. Even the most highly shocked C0055 does not show heavy shock features. The survival of phyllosilicates in C0055 indicates that the phyllosilicates are only partially dehydrated and decomposed. If they were completely dehydrated upon impact, then explosive expansion must have occurred and such materials could not be left behind in the regolith. Therefore, it is likely that there is not much material remaining from the catastrophic shock in present-day Ryugu.

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