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The effect of substrate structure of rubble-pile bodies on cratering process

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Introduction: Hayabusa obtained many high-resolution images and revealed that this asteroid has many unique morphological features which are not seen on other small planetary bodies. One of the most symbolic configurations are quasi-circular depressions (QCD) on boulder-rich surfaces, which are inferred as impact craters (Hirata et al,. 2009). If the QCDs are impact craters, then the surface crater retention age of Itokawa can be estimated based on crater chronology approach. However, age estimates has great uncertainty: 75Myr-1Gyr (Michel et al., 2009). The uncertainty in age results mostly from the uncertainty in crater scaling formed on the boulder-rich surface observed on rubble-pile bodies. The impact energy required for forming a crater on a small body is much smaller than that on a large body because of the limitation of catastrophic disruption energy (Benz and Asphaug, 1999). Impact cratering with such small energy on rubble-pile bodies are expected to follow a scaling low between the strength-regime rates and the gravity-regime cratering. The impactor destroys a surface boulder and dissipates its energy, then leading to a smaller crater: an armoring effect.

Moreover, impact induced mass loss is a critical value for estimating the life time of small bodies. The escape velocity of small bodies is very small. For example, Itokawa has an escape velocity of 10-20cm/sec. Thus, small bodies can easily lose their mass upon impact cratering.

As mentioned above, crater size and ejecta mass are important parameters for calculating the life-time of small bodies. However, these values for the rubble-pile bodies are not constrained well. Cratering process may be influenced greatly by the substrate structure of small bodies. In this study, the effect of the substrate structure of the rubble-pile bodies on the impact process is examined experimentally.

Experiment: Sintered glass beads blocks crashed into 8-15 mm chips and 200 micro meter glass beads are used as boulder simulants and regolith simulant in our experiments, respectively. We employ two types of targets: one consists of all boulders simulants (target 1) and the other consists of a surface layer of boulders simulants and regolith substrate (target 2). Polycarbonate projectiles 10mm diameter were launched at 160-180 m/sec of velocities. The impact cratering process was observed by a high-speed camera. We also measured the size of final crater and the ejecta mass.

Result: Crater size of target 1 is smaller by $\sim$20% than target 2, and ejecta mass of target 1 is smaller than by a factor of five than target 2. High-speed camera observations revealed that the surface boulders are destroyed by the impactor more heavily in the target 1. This difference occurs because the shock impedance of boulder simulants are larger than that of regolith simulant by a factor of ten and much stronger reflected stress waves comes back to the surface boulders for target 1, but the stress wave transmits efficiently from surface boulders to legolith layer in target 2.

These results suggest that the substrate structure of small bodies changes the impact process greatly. Crater size varies by $\sim$20% depending on substrate layers: boulders or regolith. Crater forming on bodies consisting of only boulder is smaller than bodies with regolith substrate but still much larger than crater on monolith (i.e., the scaling in strength-regime scaling). Consequently, the surface age of Itokawa could be on the younger side of the previous estimates as 75Myr-1Gyr with the strength-regime crater scaling. Furthermore, the substrate structures of the rubble pile bodies change the ejecta mass by 5 times. Rubble-pile bodies consisted of boulders possibly live longer.

Keywords: rubble-pile bodies, impact cratering, mass loss, fragmentation