Subsurface structure inferred from the relation between craters and their surrounding boulders on asteroid Ryugu

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The Hayabusa2 spacecraft reveals the surface geography of C-type asteroid Ryugu [1, 2, 3, 4]. Ryugu is a 1-km across rubble-pile body formed by the reaccumulation of impact fragments from the parent asteroid. It has ~100 impact craters [2, 3] and many boulders across the surface [2, 4]. Focusing on the relation between craters and their surrounding boulders, we found that the number densities of boulders inside and outside larger craters are almost the same, whereas the number density of boulders inside a smaller crater is lower than that outside the crater. The tendency may reflect the subsurface structure of Ryugu. In order to reconstruct the subsurface structure, we quantitatively investigate the number densities of boulders inside and outside craters having different sizes and depths.

Using the high-resolution images taken by an optical camera ONC-T onboard the Hayabusa2 spacecraft, we measured boulders with mean diameters $s > 0.8$ m aroud selected craters and obtained the cumulative size frequency destributions (CSFDs) of these boulders inside and outside each crater. We used ONC-T images of craters taken from an altitude of 2.7, 1.7, or 0.9 km from the surface of Ryugu. We analized total 21 craters; 2 craters newly found in this work and 19 craters from a list compiled in [3]. From the crater list we included all circular depressions (with and without rims) having depths shallower than 5-6 m based on the data in [5] and located within +/-20 deg from the equator. From regression analyses of boulder CSFDs around each crater, we calculated number densities of boulders ($s > 1$ m) inside $N_{b,in}$ and outside $N_{b,out}$ the crater and the ratio $N_{b,in}/N_{b,out}$. To check the result, we analized the boulder CSFD around the region where an artificial crater was excavated by an impactor SCI onboard the Hayabusa2 spacecraft [6] before and after the SCI impact using the same method.

Owing to the regional variation of boulder density, we found no clear dependence of $N_{b,in}$ on the crater depth d. However, we obtained a remarkable dependence of $N_{b,in}/N_{b,out}$ on d (Fig. 1): (A) $N_{b,in}/N_{b,out}$ ~ 0.5 for craters having d =< 2.2 m, which is consistent with boulders around the SCI crater (d = 2 m), (B) $N_{b,in}/N_{b,out}$ ~ 1 or larger for craters having d >= 4 m, (C) in the intermidiate range of crater depth (2.2 m < d < 4 m) $N_{b,in}/N_{b,out}$ are scattered and $N_{b,in}/N_{b,out}$ ~ 0.5 in the eastern hemisphere (40-230 degE) vs. $N_{b,in}/N_{b,out}$ ~ 1 in the western hemisphere (230-40 degE), though the number of such craters in each hemisphere is only three or four.

From these results, we reconstructed a three-layered subsurface structure of Ryugu, surface and subsurface boulder-rich layers and a boulder-poor layer sandwiched by the two. The depth of the boundary between the boulder-poor layer (the second layer) and the lower boulder-rich layer (the third layer) is estimated to be ~2.2 m in the western side and ~4 m in other regions. Such a layered structure may have been formed by the so-called Brazil-nut effect [7]. The western side having the thinner boulder-poor layer may be relatively young, which is consistent with a stablity analysis under a past rapid rotation of Ryugu [8].

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