RESURFACING PROCESS ON RYUGU CONSTRAINED BY CRATER DISTRIBUTION

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Introduction: Hayabusa2 observations have revealed various geomorphological features, such as impact craters and flow features on Ryugu [1]. One important finding on impact craters on Ryugu is depletion of small craters [1]. This suggests that resurfacing is very active in surface layers. Similar depletion in small craters has been observed on Eros, Itokawa, and Bennu [2,3,4]. Seismic shaking induced by impacts, regolith flow induced by the YORP effect, and granular convection have been proposed as resurfacing processes on these asteroids. In particular, seismic shaking has been modeled and shown to reproduce crater size frequency distributions on Eros and Itokawa [5,6].

However, unknown parameters, such as quality factor and diffusion constant, were assumed in the seismic shaking model. For example, strong cohesive force was assumed in the model, but Small Carry-on Impactor (SCI) experiment revealed that cohesive strength of subsurface layer on Ryugu is very small [7]. In this study, we estimate the crater retention age of Ryugu, Itokawa, Eros, and Bennu based on crater counting and crater production function. Then, we compare resurfacing processes among four asteroids.

Method: Crater retention ages can be estimated by using the crater size frequency distribution (CSFD) and the crater production function (CPF). The CPF consists of impactor distribution model and crater scaling relation. We used the main-belt impactor distribution calculated by [8] (BAL model) and a scaling law incorporating the armoring effect [9] for Ryugu, Itokawa, and Bennu. We assumed that cohesion strength on small asteroids is zero. For analysis, we produced crater production functions of a variety of ages. Reading an intersection of the CPFs with CSFDs constructed from actual observations yields the age required to form the number of observed craters. The age corresponds to lifetime (retention age) of craters. Thus, we derived the crater retention age t as a power-law function of crater diameter d, $t \sim d^a$. Then, we calculated the power-law indices a by using the least squares method.

Dataset: The CSFD of Eros is given by [2]. Crater candidates on Itokawa are counted and classified based on confidence levels (CL) by [3]. We counted crater candidates on Ryugu and classified in a similar fashion as Itokawa. We used CL1-2 crater candidates of Itokawa and Ryugu for our analysis. Crater candidates on Bennu are classified as distinct or less distinct [4], and we used distinct crater candidates.

Results: The power-law indices a were 2.8 ± 0.1 on Ryugu, 2.9 ± 0.3 on Itokawa, 2.5 ± 0.2 on Eros, and 2.9 ± 0.3 on Bennu, respectively (Fig. 1). Since different physical processes should yield different power-law index a, the similar a values suggest that a similar resurfacing process is dominant on these asteroids. Vertical intersects are controlled by resurfacing efficiency. The vertical intersect for Eros is larger than that for Ryugu, Itokawa, and Bennu, suggesting that resurfacing rate on Eros is smaller than other three asteroids.

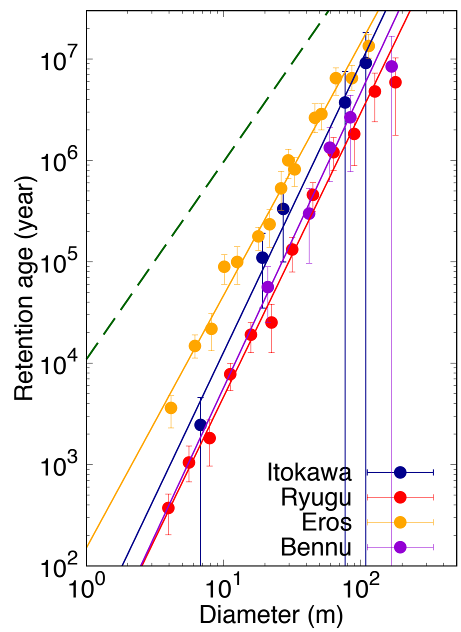

Fig. 1. Relation between crater retention age and crater diameter. Circles are data calculated from R-plot. Solid lines are linear fitting for the data points. Green dash line shows power-law with index $a=2$ (i.e., diffusion process).

Discussion: If crater degradation is controlled by diffusion processes (e.g., seismic shaking), the crater retention age is proportional to the square of crater diameter, i.e., $t \sim d^2$. However, the power-law indices of the four asteroids are significantly larger than 2.

Here we note that the power-law indices can vary depending on the models, such as the impactor size distribution and cohesion condition. Nevertheless, we found that the power-law indices of crater retention age are consistently larger than 2 despite the uncertainty in impactor size distribution. If we use a different impactor distribution model, such as [10] (OBG model), the power-law indices become even larger than the BAL model.

If we use a stronger cohesion condition, on the other hand, the power-law indices of the four asteroids become approximately 2 and are consistent with that of diffusion process. However, the small cohesion on Ryugu revealed by the SCI experiment [7] is inconsistent with this interpretation. Because the morphologies (e.g., raised rim and bowl shaped cavity) of craters on Bennu are similar to those on Ryugu [4], the cohesion on Bennu could be as small as that of Ryugu. The small cohesion may be true for Itokawa as well because Itokawa's crater retention age calculated under gravity-dominant condition is consistent with cosmic ray exposure ages and boulder distribution age [9]. Thus, small cohesion condition may be valid for Itokawa. On Eros, loose regolith layer thickness is estimated to be the order of tens of meters from the NEAR observations [11]. Cohesion on Eros is supposed to be small.

Here we focus on Ryugu's crater retention age plot. The Ryugu's plot (Fig.2) shows a transition at diameter $d \sim 30$ m. The retention age of craters 30 m in diameter at the near-Earth orbits is estimated to be about 3.5 Myr by using the method described in the method section. Craters on Ryugu can be classified as "red" or "blue" based on spectral slope of the inside craters [12] and the retention age of blue (fresh) craters on Ryugu is estimated to be about 8 Myr, suggesting that Ryugu has been in the near-Earth orbit at least for 8 Myr. This result implies that most of the raters smaller than about 30 m were produced at the near-Earth orbit and may be erased by resurfacing process at the near-Earth orbit.

The power-law index for the Ryugu data is significantly larger than 2. One interpretation for this is that the crater distribution on Ryugu reflects diffusion processes at different orbits. The size distribution of large craters ($\geq$ 53 m) on Ryugu may reflect diffusion processes in the main asteroid belt, and that for small craters ($\leq$ 13 m) may reflect those at the near-Earth orbit. That for mid-size craters may reflect transition from the main belt to the near-Earth orbit (Fig.2).

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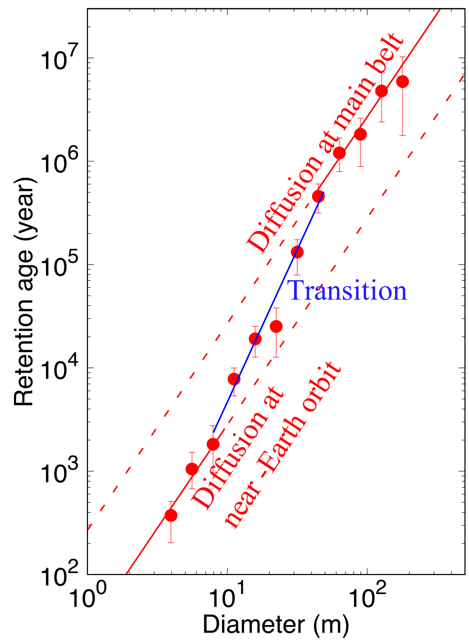

Fig. 2. Relation between crater retention age and crater diameter for Ryugu. The power-law indices of red lines are 2 (i.e., diffusion process). The upper red line is diffusion process in the main asteroid belt, and the lower red line is theoretical prediction for diffusion process at the near-Earth orbit. Blue line might record the transition from the main asteroid belt to the near-Earth orbit.