The shape and origin of the rubble-pile asteroid Ryugu

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In June 2018 Hayabusa2 arrived at near-Earth asteroid (NEA) Ryugu and has been successfully conducting remote-sensing observations from ~20-km or less altitudes and deploying rovers and a lander. Based on images taken by ONC-T, we constructed global shape models of Ryugu [1, 2]. In order to obtain a reliable shape model in a short period, we used two independent methods; the stereophotoclinometry (SPC) technique [3] and the Structure-from-Motion (SfM) technique [4]. Except for boulders and high latitudes, the two models are in good agreement with each other.
The total volume of Ryugu derived from an SPC-based shape model is 0.377±0.005 km^3. Gravity measurement revealed that the asteroid’s mass is (4.50±0.06) ×10^{11} kg. The bulk density is thus obtained as 1.19±0.03 g cm^{-3}. The density is significantly smaller than bulk densities (1.6-2.4 g cm^{-3}) measured for Ch- and Cgh-type having the 0.7-μm absorption [5]. However, it remains within the 0.8–1.5 g cm^{-3} range measured for BCG-types (B-, C-, Cb-, and Cg-type), which might be related to unheated icy asteroids [5]. The low bulk density of Ryugu is consistent with the spectral type (Cb-type) measured by ONC-T and NIRS3 [2, 6].
NIRS3 observations indicate that hydrated minerals are widely spread on the surface of Ryugu [6]. The presence of water ice, however, is unlikely for NEA Ryugu because the radiative equilibrium temperature (~250 K) is higher than the ice sublimation temperature (~230 K) at its central pressure of ~8 Pa and the thermal diffusion time of Ryugu is estimated to be much shorter than the typical dynamical lifetime of NEAs [1]. Note that the parent body of Ryugu located in the Main Belt might have water ice and low density of Ryugu could be ascribed to loss of volatile components without subsequent compaction. If we adopt the grain densities of CM carbonaceous chondrites (CCs), the derived total porosity is 57-63%. Adopting those of Orgueil CI CC, we predict the total porosity to be 50-52%. The estimated total porosity is even higher than that of rubble-pile asteroid Itokawa (44±4%) [8, 9], indicating that Ryugu is also a rubble pile.
Hayabusa2 reveals that Ryugu is a top-shape asteroid; a prominent elevated ridge around the equator. Although dozens of top-shaped asteroid have been found by ground-based radar, Ryugu is the first top-shape asteroid to be directly observed up close by a spacecraft. Bennu is the second one.
Derived surface slopes to the equipotential surface assuming the present shape and uniform interior

demonstrate least variation with latitude if, at some epoch, Ryugu had a spin period of 3.5 hours (about half of the current value) [1]. This suggests that the top shape was formed by centrifugally induced structural failure during a rapid rotation era. The deformation occurred either in the initial re-accumulation stage [10] or in the later quasi-statically spin-up stage (due to the YORP thermal effect) [11]. In the later stage, a deformation process might be induced either on the surface or in the interior, depending on the internal structure. The high porosity nature of Ryugu as well as no significant offset between the centers of figure and gravity suggest that the internal tensile strength of the asteroid is uniform and low.
NIR absorption feature of Ryugu obtained by NIRS3 is similar to those of heated/hocked CI/CM chondrites [6]. However, these meteorites are relatively rare whereas BCG types are abundant, so that another meteoritic counterpart of BCG types are expected. High porosity nature of Ryugu suggests that meteorites originated from BCG-type asteroids would be very fragile and should be destroyed at the atmospheric entry. This is consistent with the scanty of BCG-originated meteorites and a hypothesis that pyroxene-rich interplanetary dust particles (IDPs) are originate from BCG-types based on the mid-IR spectroscopy [5]. Thus, comparative studies of Ryugu and Bennu, not only in material science but also in physical properties and internal structure, are the key to understand the delivery system of water and organic materials from the snow line to Earth.

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Keywords: Planetary exploration, C-type asteroids, Rubble-pile objects, Hayabusa2

