GEOLOGICAL CHARACTERISTICS AND HISTORY OF ASTEROID RYUGU. H. Miyamoto[1], R. Hemmi[1], H. Kikuchi[2], G. Komatsu[3], C. Honda[4], T. Michikami[5], T. Morota[1], Y. Cho[1], P. Mitchel[6], O. S. Barnouin[7], S.Sasak[8], N. Hirata[9], N. Hirata[3], M. Hirabayashi[10], R. Honda[11], S. Kameda[12], E. Tatsumi[1], Y. Yokota[2], T. Kouyama[13], H. Suzuki[14], M. Yamada[15], N. Sakatani[2], M. Hayakawa[2], K. Yoshioka[1], M. Matsuoka[2], H. Sawada[2], S. Sugita[1] [1.]Dept Systems Innovation, University of Tokyo, Tokyo, Bunkyo, Japan (hm@sys.t.u-tokyo.ac.jp). [12]ISAS/JAXA, Sagamihara, Japan. [3] 3 Università d'Annunzio, Pescara, Italy. [4]Aizu University, Aizu, Japan. [5]Kinki University, Hiroshima, Japan. [6]Université Côte d'AzurObservatoire de la Côte d'Azur, CNRS, [7]Johns Hopkins Univ, Laurel, MD, United States. [8]Osaka Univ, Osaka, Japan. [9]Kobe Univ, Kobe, Japan. [10]Auburn University, Auburn, AL, United States. [11]Kouchi Univ, Kochi, Japan. [12]Rikkyo Univ, Tokyo, Japan., [13]AIST, Tsukuba, Japan. [14]Meiji Univ, Tokyo, Japan. [15]Chiba Tech, Narashino, Japan.

Introduction: Recent high-resolution radar observations reveal an increasing number of near-Earth asteroids (NEAs) have spinning-top shapes, which is intriguing because of its potential implication to the existence of common deformational processes of rubble-pile asteroids. The formation of a rubble pile is believed to be a result of reaccumulation of disrupted fragments from a parent body, which are held together by their self-gravity [1]. However, the nature of the reaccumulation and potential subsequent reshaping processes are matters of debate due both to the lack of close observation and to the difficulty in modeling a huge number of fragments. Even so, theoretical studies have advanced by adopting simplifications to keep simulations reasonably sized, and have succeeded in producing top-shaped bodies formed by centrifugally driven movements of internal [2,3] and/or surface materials [4,5] resulting from a fast spin or via reaccumulation after catastrophic disruption [6]. Although numerical studies are visually compelling, further observational support, especially close-up observations of top-shape asteroids, are needed to address the evolutional and shape-organizing processes of rubble-pile asteroids.

Hayabusa-2 spacecraft, developed by the Japan Aerospace Exploration Agency (JAXA), arrived at near-Earth asteroid (NEA) (162173) Ryugu in June 2018 [7-9]. This C-type asteroid has a spinning top shape, and thus, finally, we have an opportunity to investigate the geology and geomorphology of a top-shaped asteroid to obtain clues regarding the processes shaping such an asteroid.

Geological characteristics of Ryugu: The purpose of this study is to carefully investigate geomorphologic characteristics of Ryugu to aid our understanding of the processes shaping the body. Morphological implications and cross-cutting relationships are also studied to establish a formational sequence of geologic features. Important findings and their interpretations are as follows:

Ryugu has a continuous ridge (Ryujin Dorsum) at the equatorial region, which shows almost perfect circular silhouette when viewed from the poles, contrasting to the diamond-like silhouette viewed from the equatorial plane. The circularity of the Ryujin Dorsum is slightly defected by the existence of several large, crater-like, circular depressions including Urashima, the largest on Ryugu. This implies that Ryujin Dorsum is among the oldest features on this asteroid.

Two slight depressions on the Ryujin Dorsum appear to be associated with Tokoyo and Horai Fossae, the two wide troughs in the southern hemisphere. The southern extents of these troughs intersect at and are superposed by Otohime, the largest boulder on Ryugu located near the south pole, which gives an impression that they are a continuous, single structure. Although we cannot clearly trace these troughs up to the northern hemisphere, the combined length of these structures appears to form a boundary around a large portion of the body. In fact, the structure surrounds a bulge-like region, hereafter referred to as "the western bulge." Boulder and crater statistics indicate that the western bulge is deficient in large boulders and large crater-like circular depressions relative to the eastern side of the body [10, 11].

While such large-scale difference in topographic characteristics exists, evidence for the surface migration of gravel is limited to local scales. In addition, most large circular depressions still exhibit morphology of fresh craters, and some crater-like depressions overlap other crater-like depressions without destroying the morphologies of overlapping ones, which suggest resurfacing processes caused by impacts are limited. Furthermore, no clue exists for later modifications of large depressions on Ryujin Dorsum by the ridge-forming process, which indicates that the ridge formation process should be active only at an early stage of the Ryugu evolution and completely absent now.

Surface processes on Ryugu: These observations are intriguing because the formations of the equatorial ridge and the western bulge require the whole body-scale migrations of rubbles, while the local-scale features and cross-cutting relationship indicate particles are reluctant to migrate now. Possible interpretations may include 1) the surface or some portion of Ryugu is currently competent due to strong cohesive force even though unconsolidated at the time of ridge formation and 2) the particles may migrate only when additional energy is supplied.

We developed a simulated Ryugu materials (simplified Ryugu simulant, SRS) to simulate possible behaviors of regolith particles on Ryugu. The simulant is based on the idea that the composition of Ryugu is similar to those of carbonaceous meteorites, especially to CM or CI chondrite [8, 9, 12]. Because the main constituent mineral comprising carbonaceous chondrites is phyllosilicate, we used serpentine (mostly lizardite) as the base material for the simulant. The densities of the simulant are adjusted to range from 1.07 to 1.35 g/cm^2 with a bulk porosity of 54-65%. We distributed the simulant particles over styrofoam to simulate surface features of Ryugu.

A series of experiments are performed to study possible behaviors of particles under the Earth gravity. Such experiments are not intended to exactly simulate the conditions on Ryugu but to provide useful analogue ideas. Most importantly, we could simulate the active particle motions on Ryugu found through a sequence of images obtained at proximity phase of the mission. In these images, we observe some boulders migrate due to the effect of thruster of the Hayabusa 2 spacecraft. The particle migration itself is not a big surprise due to the low gravitational acceleration on Ryugu (a boulder of 1.19g/cm3 gives only 0.1 Pa to the surface), however, the real question is why only a few boulders migrate tens of meters while most others do not. Through our laboratory experiments, we find that due to the complex topographic conditions created by the boulders, the air flows concentrate at some part of the surface, which can initiate migrations of some particles. Even though all particles are not competent with almost no cohesion, only some migrate as observed on Ryugu. This implies that, even though only a few particles migrated on Ryugu, every gravel composing Ryugu surface is also not competent at all.

By using the locally developed high-resolution DTMs and images of very high emittance angles, we study the local orientations of boulders on Ryugu. We confirm that almost all boulders are resting on the surface of Ryugu with their longest axes almost perpendicular to local gravity. A very limited number of boulders exist on top of other boulders. Careful examinations of a few boulders on top of boulders found in high-resolution images indicate that this happens when the surface of a boulder is irregular and provides a local gravitational minimum in which another boulder appears to be trapped. Thus, we conclude that the locations of almost all gravel are perfectly arranged under local gravity, which implies that most gravels on the surface are at least locally reallocated.

Both the morphologies and textures of boulders suggest that they are generally fresh. Also, the margins of boulders are typically not buried by fines, even though clustered boulders with similar appearances and boulders appear to be split into pieces exist. Thus, processes of mechanical/thermal erosions of boulders by such as micrometeoroid impacts and thermal fatigue are either limited or a process removing the broken fines is more dominant.

These indicate that the surface of Ryugu has been covered by (or most likely the entire body of Ryugu was formed by) unconsolidated gravels, which have been subsequently and dynamically reallocated even after the formation of the body. As a result, the overall texture of the terrain surface becomes similar to the desert pavement, where fine sand occupies the gaps between larger gravel particles. Such configurations of particles are commonly observed on the surface of Itokawa and is interpreted as evidence for a heavily shaken rubble-pile [13].

The reallocations are not necessary result of impact-induced vibrations or spin-related internal deformations. They should have occurred during the original depositions of gravel at the time the formation of the asteroid. Global geological characteristics indicate both that the formations of the equatorial ridge predate the formations of large craters in the equatorial regions and that the clues indicating global-scale, landslide-like migrations of regolith at depths are limited. These collectively indicate that Ryugu is a weakly gravitationally bounded pile of unconsolidated rubble, whose large-scale topographic characteristics were mostly inherited at an early stage of its formational history.

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