INVESTIGATION OF DISTRIBUTION AND ORIENTATIONS OF BOULDERS ON ASTEROID RYUGU: IMPLICATIONS FOR SURFACE EVOLUTION. T. Ebihara[1], K. Yumoto[1], S. Sugita[1], R. Honda[2], S. Kameda[3], E. Tatsumi[1,4], Y. Cho[1], K. Yoshioka[1], H. Sawada[5], Y. Yokota[2,5], N. Sakatani[3], M. Hayakawa[5], M. Matsuoka[5], M. Yamada[6], T. Kouyama[7], H. Suzuki[8], C. Honda[9], K. Ogawa[10,11], T. Michikami[12], H. Miyamoto[1], T. Morota[1], [1]Univ. of Tokyo (ebihara-tatsuki@eps.s.u-tokyo.ac.jp), [2]Kochi Univ., [3]Rikkyo Univ., [4]Instituto de Astrofisica de Canarias, [5]Japan Aerospace Exploration Agency, [6]Planetary Exploration Research Center Chiba Institute of Technology, [7]National Institute of Advanced Industrial Science and Technology, [8]Meiji Univ., [9]Univ. of Aizu, [10]Japan Aerospace Exploration Agency, JAXA Space Exploration Center, [11]Kobe Univ, [12]Kindai Univ.

Introduction: Hayabusa2 spacecraft conducted close investigation at asteroid 162173 Ryugu from June 2018 to November 2019. Detailed observations by Hayabusa2 revealed numerous boulders on Ryugu's surface [1, 2] and its low bulk density (1190 kg/m^3), suggesting that Ryugu has a rubble pile structure [3, 4]. The observations of reflectance spectra on Ryugu's surface and stratigraphic relationship suggest that surface mass movement might have occurred from the equator and polar regions to the mid-latitude regions [1, 5]. In addition, morphological evidences for mass movement, such as imbricated boulders and run-ups deposits, have been reported [1]. However, the surface flows toward the mid-latitude region on Ryugu has not been quantitatively characterized.

The spatial arrangement and orientation of clasts has been used for analyses of past flow directions [e.g., 6]. On the surface of rubble-pile asteroid Itokawa, the arrangements of boulders were found in the boundary regions between the smooth and rough terrains, indicating gravel migration in the direction of local gravitational slopes [7]. To understand the direction and spatial scale of the mass movement, we investigated the shape of boulders and the relationship between their orientations (azimuth of major axis) and direction of gravitational slope on Ryugu. Based on these results, we discuss the mode of surface mass movement and the thickness of surface flow layer.

Method: Optical Navigation Camera Telescope (ONC-T) onboard Hayabusa2 [1, 8-11] has taken high-resolution images (~0.3 m/pixel) during the MASCOT deployment operation. Using these images, we created the catalog of boulders larger than 1 m in mean diameter near the equator (from 20°N to 30°S). This catalog includes size, axial ratio, azimuth angle of major axis of boulders. Considering the accuracy of shape measurement and identification of major axis of boulders, we used 496 boulders larger than 4 m in the mean diameter and the minor axis/major axis ratio less than 0.7 and observed in emission angle less than 30° (Fig. 1). We calculated the angle between their major axes and local gravitational slopes. To calculate local gravitational slopes, we used the SPC shape model of Ryugu [3] and took centrifugal force at the current rotation period (7.63 hours; [3]) into account.

Results: Boulders orientations are preferentially arranged such that its major axis is perpendicular to the local slope direction. Boulders in the northern hemisphere show stronger transverse orientation than those in the southern hemisphere (Fig. 2a). Furthermore, such transverse orientation of boulders is found frequently on the slopes > 15 deg on the equatorial ridge of Ryugu (Fig. 2b).

Discussion: The observed transverse orientation of boulders and relationship with degree of slope suggest that global mass movement has occurred on Ryugu in the direction of gravitational slope. The direction of mass movement is consistent with the flow direction indicated by spectral slope distribution because Ryugu has so-called "spinning-top" shape and its slope direction is almost from the equator to the mid-latitude regions [1, 5].

Such transverse orientation might be explained by rolling of larger clasts during landslides. Yamamoto [12] reported that clasts larger than the scale of surface roughness exhibit strong transverse orientation due to rolling on terrestrial talus slopes. Some boulders investigated in this study are larger than typical surface roughness of Ryugu, which is created by constituent grains, whose typical size is 3 m [1], consistent with the transverse orientation induced by rolling.

Another interpretation for the arrangement of boulders is the regolith run-ups which can occur on large boulder fixed to the surface [1]. During mass movement, regolith preferentially covers the upstream sides of large boulders. This would result in the boulder orientation in which apparent major axes of boulders are preferentially arranged transverse to the local slope direction. Higher resolution images obtained in the descending operations of Hayabusa2 shows that the topographically upper sides of some boulders are covered by regolith (Fig. 3). The regolith run-ups suggest that the thickness of surface flow layer on Ryugu is less than the height (~ a few meters) of large boulders.

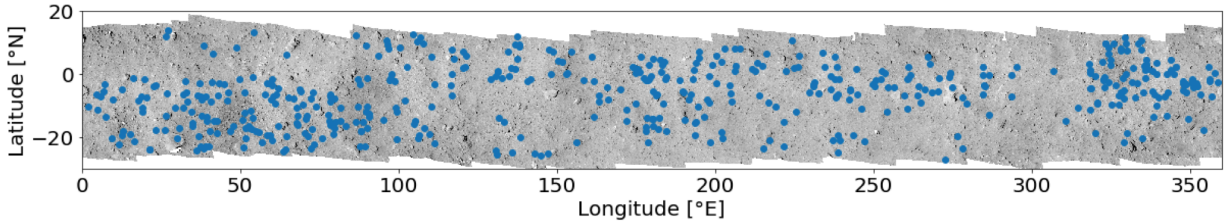

Fig. 1. Distribution of boulders used in this study indicated by blue circle, superposed on mosaic v-band images used to create the catalog of boulders.

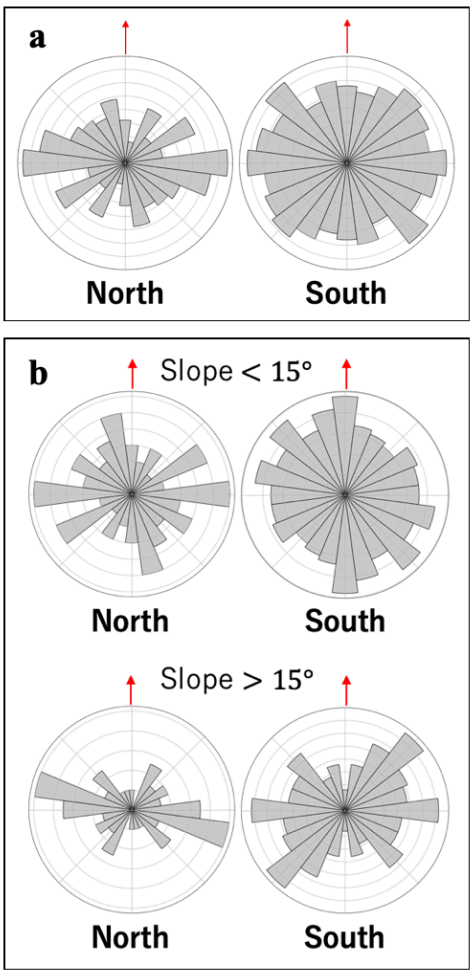

Fig. 2. Rose diagrams showing deviations of the major axes of boulders from the local topographic slope direction. The deviation angle is measured counter-clockwise from the down slope direction indicated by the top of the circles. (**a**) Rose diagrams include all boulders used in this analysis. (**b**) Upper panels include boulders in regions with slope less than 15°. Lower panels include boulders in regions with slope higher than 15°.

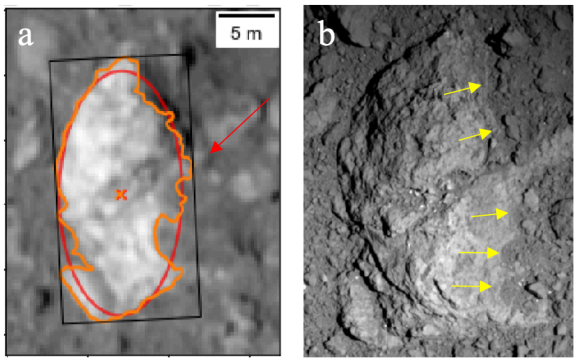

Fig. 3. Example of a boulder partially covered by regolith. (**a**) Image obtained during the MASCOT deployment operation (~0.3 m/pixel). Red allow indicates the local slope direction. (**b**) Higher resolution image of the boulder showed in (a). Yellow allows indicate regolith run-ups.

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