THE EVOLUTION OF RYUGU'S PARENT BODY CONSTRAINED BY HAYABUSA2 IMAGING OBSERVATIONS. S. Sugita[1,7], R. Honda[2], T. Morota[3], S. Kameda[4], E. Tatsumi[1], C. Honda[5], Y. Yokota[6], M. Yamada[7], T. Kouyama[8], N. Sakatani[6], H. Suzuki[9], K. Yoshioka[1], Y. Cho[1], M. Matsuoka[6], K. Ogawa[10], D. Domingue[11], H. Miyamoto[1], O. S. Barnouin[12], P. Michel[13], C. M. Ernst[12], T. Hiroi[14], T. Nakamura[15], H. Sawada[6], M. Hayakawa[6], N. Hirata[5], N. Hirata[10], H. Kikuchi[1], R. Hemmi[1], T. Michikami[16], Eric Palmer[11], R. Gaskell[11], M. Hirabayashi[17], R. Jaumann[18], K. Otto[18], N. Schmitz[18], S. E. Schröder[18], G. Komatsu[19], S. Tanaka[6], K. Shirai[6], M. Yoshikawa[6], S. Watanabe[3], Y. Tsuda[6], [1]Univ. of Tokyo (Tokyo, Japan, sugita@eps.s.u-tokyo.ac.jp), [2]Kochi Univ., [3]Nagoya Univ., [4]Rikkyo Univ., [5]Univ. of Aizu, [6]JAXA/ISAS, [7]PERC CIT, [8]AIST, [9]Meiji Univ., [10]Kobe Univ., [11]Planetetary Science Institute, [12]APL, Johns Hopkins University, [13]Observatoire de la Cote d'Azur, [14]Brown Univ., [15]Tohoku Univ. [16]Kindai Univ. [17]Auburn Univ., [18]DLR, [19]Univ. d'Annunzio

Introduction: JAXA's Hayabusa2 spacecraft arrived at asteroid 162173 Ryugu on June 27, 2018 and conducted global observations from 20 km of altitude first and subsequently conducted a number of high-resolution regional and local observations during low-altitude descents including a gravity-measurement free fall and touch-down rehearsals (Fig. 1). These observations have revealed many unexpected nature of Ryugu [e.g., 1 - 3]. In this study, we summarize optical imaging observation results focusing on the constraints they provide on Ryugu's parent body.

Spectroscopic Properties: The global observations have revealed many important properties of Ryugu [2]. Ryugu's average spectrum is Cb type and does not exhibit a strong 0.7-µm absorption band (Fig. 2). It has a very low 0.55-µm geometric albedo 0.045 ± 0.002, among the lowest in the solar system. Its crater retention age for small craters (≥ 10m) is very young (< a few Myr), strongly suggesting a high surface rejuvenation rate (Fig. 3).

Ryugu's Parent Body: The observed spectral characteristics of Ryugu is consistent with the dynamically most probable source asteroid families for Ryugu: Eulalia and Polana families in the inner main belt [4]. This agreement between the prediction from dynamic calculations and spectral observations suggests that one of the two asteroids is likely Ryugu's parent body. These families are among the most widely dispersed C-complex families in the inner main belt, allowing to deliver family members at very high flux rate to the ν_6 and 3:1 resonance zones at both inner and outer boundaries of the inner main belt, which are the dominant source of near-Earth objects (NEOs).

Boulders on Unconsolidated Surface: Other aspects of Ryugu surface can be learned from its geomorphologic observations. Very high abundance (about twice Itokawa) of boulders are seen on Ryugu. Many lines of evidence for mass wasting are found on Ryugu surface, such as wall slumping on impact craters and imbricated boulders on slopes on the equatorial ridge (Fig. 4). This observation indicate that the Ryugu surface is mechanically unconsolidated, allowing surface boulders to move easily. There are many impact craters on Ryugu surface. Most of them have classic bowl-shaped cavities with high circularities, and many of them possess well-defined rims (Fig. 1). These morphologic characteristics are consistent with gravity-regime formation, leading to a large mass of ejecta. These suggest that large mass of boulders and pebbles can be ejected from Ryugu to space over time.

Meteoritic Counterparts: These lines of evidence suggests that a large number of macroscopic objects of Ryugu-like materials may enter Earth's atmosphere, implying that there should be counterparts in our meteorite collection. One candidates is moderately dehydrated carbonaceous chondrites, which exhibit very low albedo and flat spectra. They are also found with high abundance in Antarctica, which has sampled the long-term average flux of infalling meteorites on Earth [5]. Another is interplanetary dust particles (IDPs), which also exhibit low albedos and account for large influx of extraterrestrial material to Earth. Although a decisive conclusion may not be obtained before analyzing Ryugu samples returned to Earth, currently available observational evidence, such as high boulder abundance on Ryugu, favors that its composition may be similar to moderately dehydrated carbonaceous chondrites. This would further suggest that Ryugu's relatively low abundance of hydrated minerals [3] may be due to partial dehydration on Ryugu's parent body.

Scenarios for Ryugu evolution: Ryugu's regolith and boulders are concentrated in a relatively small area in the dehydration track of the principal-component (PC) space (Fig. 5), suggesting that a large volume of Ryugu's parent body could have received similar degrees of partial dehydration. Such uniformity would be consistent with internal heating on the parent body. Nevertheless, global moderate dehydration due to impacts might also be possible if many impacts occurred on the parent body to heat up the entire body. The third possibility is that Ryugu is covered with materials that experienced only low-level aqueous alteration, possibly similar to some IDPs.

Conclusions: We cannot determine which scenario is the case until we analyze samples returned from Ryugu, but Hayabusa2 remote-sensing data support parent-body dehydration due to internal heating. This scenario suggests that asteroids that accreted materials condensed at low temperatures would have been formed either early enough to contain abundant radiogenic species, such as ^{26}Al, or formed in proximity to the Sun to experience other heating mechanisms. These would give an upper estimate for the snow line location at the timing of main belt accretion.

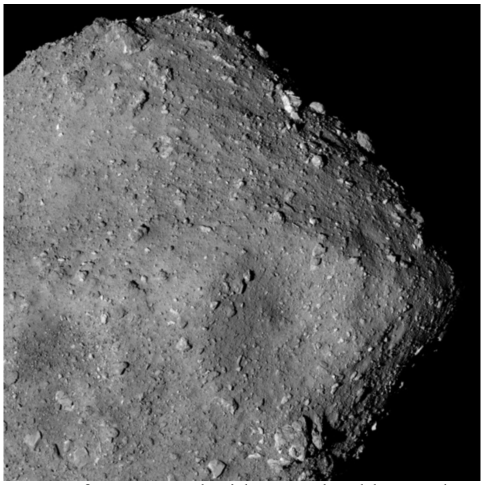

Fig. 1. Ryugu surface covered with many boulders and impact craters (hyb2_onc_20180720_145814_tvf_l2b).

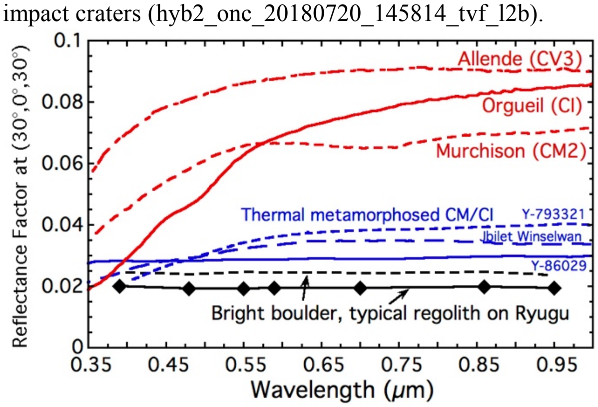

Fig. 2. Comparison between typical Ryugu surface colors and those of moderately dehydrated carbonaceous chondrites, and typical carbonaceous chondrites.

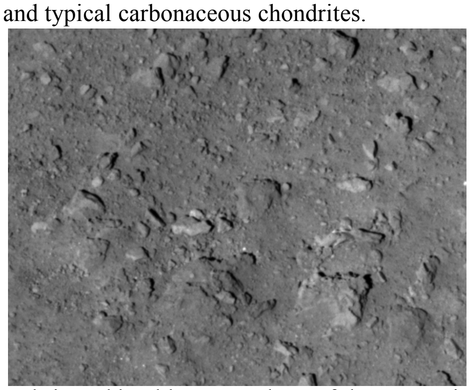

Fig. 3. Imbricated boulders on a slope of the equatorial ridge (hyb2_onc_20181003_151510_tvf_l2a).

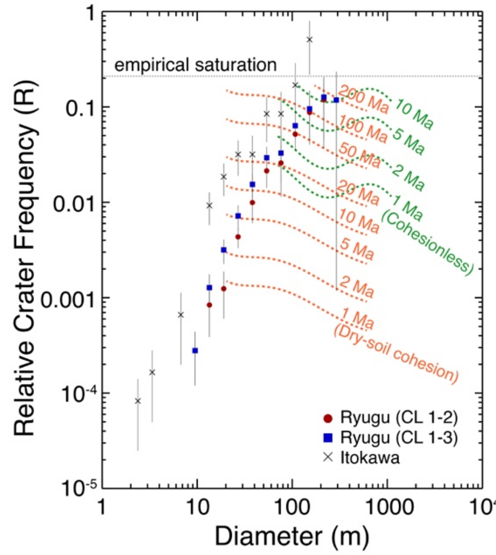

Fig. 3. Comparison of R-Plot between Ryugu and Itokawa along with crater production curves based on [6]. Crater statistics based on different tolerances for confidence levels (CL) are compared for Ryugu.

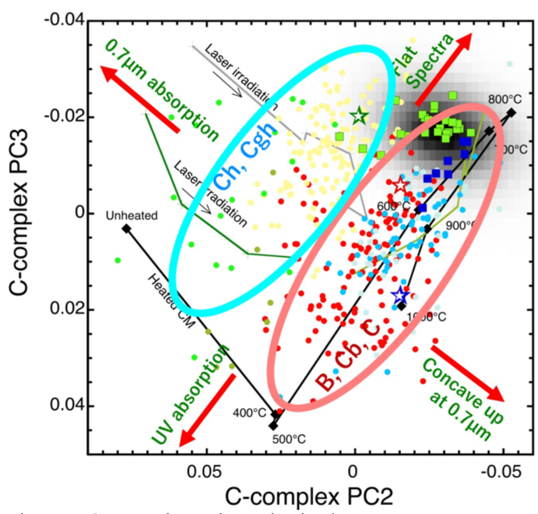

Fig. 5. Comparison in principal-component scores (PC2-PC3) between Ryugu regolith (black) and boulders (yellow) with main-belt C-complex asteroids [7], Murchison samples with heating (black line [8] and laser-irradiation (light green [9] and grey lines [8]) experiments are shown with Parent bodies, Polana (blue star), Eulalia (red star), and Erigone (green star).

References: [1] Watanabe et al. (2019) submitted to *Science*. [2] Sugita et al. (2019) submitted to *Science*. [3] Kitazato et al. (2019) submitted to *Science*. [4] Bottke et al. (2015) *Icarus 247*, 191. [5] Tonui et al. (2014) *GCA*, 126, 284. [6] Bottke et al. (1994) *Icarus*, *107*, 255. [7] Bus and Binzel (2002) *Icarus 158,* 106. [8] RELAB, Brown University, [9] Matsuoka et al. (2015) *Icarus 254*, 135. **Acknowledgements:** This study was supported by JSPS Core-to-Core program “International Network of Planetary Sciences”, CNES, and Univ. Côte d’Azur.