Impact histories inferred from exogenic boulders on asteroids Ryugu and Bennu

*ERI TATSUMI[1,2], Chiho Sugimoto[2], Seiji Sugita[2], Marcel Popescu[4], Humberto Campins[11], Julia de León[3], Amy A. Simon[5], Hannah H. Kaplan[6], Yuichiro Cho[2], Tomokatsu Morota[2], Rie Honda[7], Shingo Kameda[8], Yasuhiro Yokota[3], Koki Yumoto[2], Minami Aoki[2], Daniella N. DellaGiustina[10], Dathon R. Golish[10], Javier Licandro[1], Juan Luis Rizos[1], Takahiro Hiroi[12], Deborah Domingue[13], Michel Patrick[14], Dante S. Lauretta[10], Manabu Yamada[15], Naoya Sakatani[8], Toru Kouyama[9], Chikatoshi Honda[16], Masahiko Hayakawa[3], Moe Matsuoka[3], Hidehiko Suzuki[17], Kazunori Ogawa[3], Hirotaka Sawada[3]

1. Instituto de Astrofisica de Canarias, 2. Univ. of Tokyo, 3. ISAS/JAXA, 4. Astronomical Institute of the Romanian Academy, 5. NASA Goddard Space Flight Center, 6. Southwest Research Institute, 7. Kochi Univ., 8. Rikkyo Univ., 9. AIST, 10. Univ. of Arizona, 11. Univ. of Central Florida, 12. Brown Univ., 13. Planetary Science Institute, 14. Observatoire de la Côte d'Azur, 15. Chiba Institute of Tech., 16. Univ. of Aizu, 17. Meiji Uni.

Rubble-pile asteroids, such as (162173) Ryugu and (101955) Bennu, are formed as a result of catastrophic disruption of a parent body and re-accumulation of the fragments by self-gravity Michel and Ballouz et al. 2020). Therefore, reaccumulated rubble piles could include mixtures of materials from both the parent body and its catastrophic impactor, as they did in the case of 2008 TC_3 and the Almahata Sitta meteorites (Jenniskens et al. 2009). Indeed, six unusually bright, basaltic, meter-scale boulders were recently identified on Bennu's dark surface (DellaGiustina et al. 2021), and their close spectral matches to the Howardite-Eucrite-Diogenite (HED) meteorites and Vesta family members indicate that they originated from asteroid (4) Vesta. In parallel, bright exogenic anhydrous-silicate–rich materials were found on Ryugu (Tatsumi et al. 2021). The bright boulders on Ryugu are consistent with ordinary chondrite meteorites, based on their albedo and the weak or even absent absorption band at 2 μm. These exogenous materials on the surfaces of rubble-pile asteroids could be a key to constraining their specific impact conditions and collisional evolution.

In this study, we report further study of the visible spectrophotometry and morphology of exogenic boulders on Ryugu and Bennu using two multi-band cameras: the telescopic Optical Navigation Camera (ONC-T) onboard the Hayabusa2 spacecraft, and MapCam onboard the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) spacecraft, respectively.

For Ryugu, we first detected objects with peak reflectance brighter by a factor of >1.5 than the surrounding area. Tatsumi et al. (2021) found two spectral groups among the bright boulders: S-type with an absorption near 1 μm and C/X-type with a flat spectrum. That study found 6 S-types and 15 C/X-types, and here we report the additional finding of two S-types and ~70 C/X-types. We found that S-type bright boulders follow two parallel trends consistent with space weathering of ordinary chondrites. Fragments from projectiles suggest that Ryugu may not have formed directly from the original parent body, i.e., it is from a second or higher generation of collisional descendants (Sugimoto et al. in revision).

For Bennu, we directly surveyed the absorption near 1 μm, which is indicative of anhydrous silicates. We propose 77 objects of exogenic origin including 6 boulders previously reported by DellaGiustina et al. (2021). We find that proposed exogenic objects follow two mixing trends with respect to the average spectrum of Bennu (Tatsumi and Popescu et al. submitted). One trend can be explained by mixing with HEDs, as discussed in DellaGiustina et al. (2021), and the other trend can be explained by mixing with

another, of olivine-rich composition. Near-infrared spectra also support the possibility of multiple compositions among exogenic objects on Bennu. Le Corre et al. (submitted) also reached to the similar conclusion with a different methodology. Thus, similar to Ryugu, Bennu could represent a second or higher generation collisional fragment.

Using high-resolution images, we found that more than half of the exogenic objects that we identified on Bennu have breccia-like or inclusion-like morphologies. We do not observe a correlation between morphology and spectral shape.

Direct comparison of reflectance spectra of exogenic ,materials between Ryugu and Bennu suggests a compositional difference. Furthermore, the number density of exogenic objects > 0.5 m on Bennu is ˜40 times that on Ryugu (Tatsumi and Popescu et al. submitted). Bennu exhibits much more contamination from exogenic materials than Ryugu, which likely reflects differences in impact conditions, such as impact velocity and impactor size.

Michel and Ballouz et al. (2020) Nat. Commun. 11, 2655
Jenniskins et al. (2009) Nature 458, 485-488.
DellaGiustina et al. (2021) Nat. Astron. 5, 31-38.
Tatsumi et al. (2021) Nat. Astron. 5, 39-45.
Sugimoto et al. (in revision) Icarus.
Tatsumi and Popescu et al. (submitted) MNRAS.
Le Corre et al. (submitted) PSJ.

Keywords: Asteroids, Hayabusa2, OSIRIS-REx, Ryugu, Bennu

