INITIAL RESULTS OF HAYABUSA2 IMPACT EXPERIMENT AND OBSERVATIONS OF IMPACT EJECTA AND CRATER. K. Ogawa[1,2], M. Arakawa[2], K. Wada[3], T. Kadono[4], K. Shirai[2], K. Ishibashi[3], R. Honda[5], N. Sakatani[1], Y. Shimaki[1], H. Sawada[1], T. Saiki[1], H. Imamura[1], Y. Takagi[6], H. Yano[1], M. Hayakawa[1], C. Okamoto[2], Y. Tsuda[1], S. Nakazawa[1], Y. Iijima[1], N. Hirata[7], T. Toda[1], H. Hayakawa[1], S. Sugita[8], T. Morota[8], S. Kameda[9], E. Tatsumi[10,8], Y. Cho[8], K. Yoshioka[8], Y. Yokota[1], M. Matsuoka[1], M. Yamada[3], T. Kouyama[11], H. Suzuki[12], C. Honda[7], P. Michel[13], [1]Japan Aerospace Exploration Agency, Japan, [2]Kobe University, Japan, [3]Chiba Institute of Technology, Japan, [4]University of Occupational and Environmental Health, Japan, [5]Kochi University, Japan, [6]Aichi Toho University, Japan, [7]The University of Aizu, Japan, [8]The University of Tokyo, Japan, [9]Rikkyo University, Japan, [10]University of La Laguna, Spain, [11]National Institute of Advanced Industrial Science and Technology, Japan, [12]Meiji University, Japan, [13] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, France.

Introduction: Hayabusa2, the Japanese asteroid sample-return explorer, arrived at C-type near-earth asteroid Ryugu in June, 2018. Hayabusa2 then conducted remote-sensing observations at alt. 20 km home position by its onboard instruments with several special operations including low-altitude observations, release of small landers MINERVAs and MASCOT, two times of touch-down and sampling, and the impact experiment operation. Hayabusa2 has succeeded all these operations and departed from Ryugu in November, 2019 for the earth to bring the collected samples back.

Hayabusa2's initial remote-sensing observations have revealed the top-shape and boulder-rich surface of Ryugu. There are many craters on Ryugu but the number densities of small craters are low compared to that of large craters, suggesting relatively young surface age [1]. Similar features were found also on asteroid Bennu by OSIRIS-Rex, the NASA's asteroid sample return mission [2]. For understanding these features relevant to the surface and subsurface evolution process, the surface physical properties, such as the surface layer strength, are key parameters. For example, the surface temperature measurement by the thermal infrared imager TIR onboard Hayabusa2 and the radiometer MARA onboard MASCOT suggested that the boulders are highly porous and have considerably lower strength than meteorites [3]. However, the subsurface condition of Ryugu is still unclear.

The impact experiment on Ryugu was originally planned for excavating and sampling subsurface material. Observations of impact process (growing ejecta curtain) and final crater morphology provide information of the subsurface physical property [4].

Impact Experiment Operation: The impact was made by Small Carry-on Impactor (SCI) onboard Hayabusa2 on April 5, 2019. SCI is a separable, cylindrical unit of a 30-cm size containing explosive of 4.7 kg and a copper plate. The explosion was scheduled at 2400 sec after the separation from the spacecraft, at alt. approximately 250 m while the spacecraft evacuated to the backside of Ryugu. The copper plate was instantly formed by the explosion into a hemispherical shape projectile of 2 kg and was shot at 2 km/s onto Ryugu [5].

For observations of the impact moment, the spacecraft also left Deployable Camera (DCAM3) at a position of about 1-km distance from the impact location. DCAM3 is a 10-cm-scale miniaturized separable camera consisting of two independent camera-and-radio-communication systems, real-time low-resolution camera DCAM3-A [6] and high-resolution scientific camera DCAM3-D [7,8]. DCAM3-D has the image size of 2000 × 2000 pixels and the field of view of 74° × 74º, so that the spatial resolution for the impact location is around 1 m/pixel. DCAM3-D started imaging and radio communication to the spacecraft from –204 sec from the impact time and continued for more than 3 hours with 1 frame/sec at maximum.

Three weeks after the impact the spacecraft started low-altitude crater surveys for the impact site by Optical Navigation Cameras Telescopic/Wide-angle (ONC-T/W), Thermal Infrared Imager (TIR), and Near-Infrared Spectrometer (NIRS3) onboard. The SCI crater was identified in the initial survey operation at alt. 1.7 km, and then more detailed images were taken in subsequent operations at alt. about 300 and 120 m, respectively. Most important images for the crater morphology was taken by ONC-T which has the image size of 1000 × 1000 pixels and the field of view of 6.27º × 6.27º.

Impact Ejecta: DCAM3 operated normally, and succeeded in photographing the ejecta curtain and sending data to the spacecraft (Figure 1). The inverted-truncated-cone shape of the ejecta curtain and its growth indicated that the impact occurred on rather non-cohesive surface, such as sand or pebbles, and not a hard rock, because only high-velocity fragments without an obvious ejecta curtain was expected if the surface layer is cohesive, or a hard rock.

The ejecta curtain in Figure 1 has an asymmetric shape that is hardly explained by an oblique impact, because the impact angle of the projectile was roughly estimated to be > 45º with respect to the local horizontal plane, and it is generally known that a shape of the ejecta curtain is not influenced in such higher angles. In the case of this experiment, the asymmetric shape can be explained by a rough surface or existence of large boulders. It is considered that large boulders closely located at the impact point could interfere the cratering process, that is, they caused the asymmetric ejecta curtain and stopped the crater growth on the half side.

Impact Crater: The SCI crater shown in Figure 2 was identified in ONC-T images by comparing with pre-impact images. The crater rim was also identified around the crater (the dashed curve in Figure 2). The crater size was estimated to be ~18 m as the rim-to-rim diameter. The large two boulders are also found in the crater, and it is considered that these boulders caused the asymmetric growth of the ejecta curtain in Figure 1.

The existence of the elevated rim suggests the crater was formed in the gravity-dominated regime, and not in the strength-dominated regime, according to the cratering theory [9]. Based on the conventional π scaling law [10], the size of the SCI crater is almost similar to a theoretical expectation on a typical sand or pebbles surface. If a small amount of cohesion is considered in the π scaling law, the crater size is expected to be less than 10 m in the configuration of Ryugu, such as in the microgravity.

These crater observation results combined with the ejecta observation by DCAM3 strongly suggest that the surface and subsurface layers on Ryugu consist of sand-like cohesionless materials. This would explain the mobility of the surface layer of Ryugu which causes the low number density of small craters and the present shape of Ryugu.

Further analyses of the ejecta and the crater are ongoing with adding other observational results, such as the existence of sub-craters around the SCI crater which would be formed by impacts of small fragments of SCI explosion. These studies will not only reveal the surface conditions of Ryugu, but also bring us better understanding about the internal structure and evolutional process of small bodies in general.

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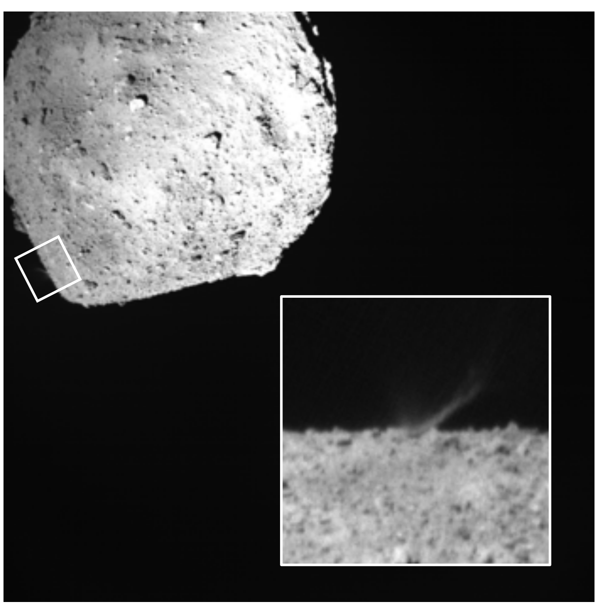

Figure 1: The first image of the impact ejecta taken by DCAM3 at about 3 sec after the impact.

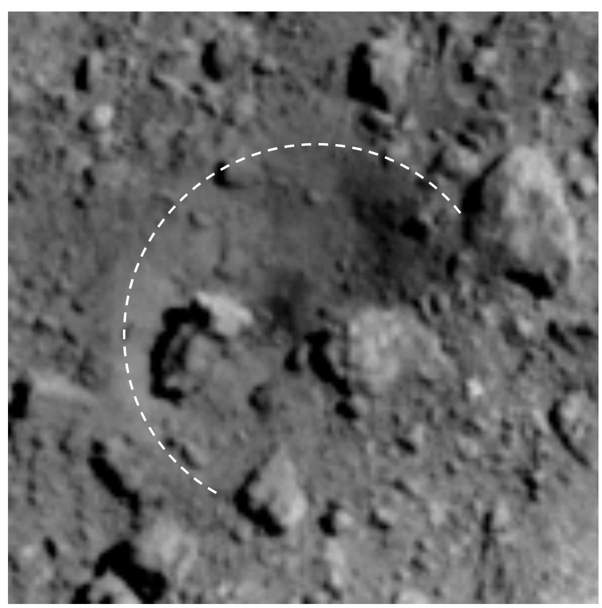

Figure 2: The first image of the artificial crater taken by ONC three weeks after the impact experiment.