**SPACE IMPACT EXPERIMENT ON RYUGU: ARTIFICIAL CRATER.** T. Kadono[1], M. Arakawa[2], K. Wada[3], K. Shirai[4], K. Ogawa[2], N. Sakatani[4], K. Ishibashi[3],Y. Shimaki[4], Y. Takagi[5], H. Yano[4], C. Okamoto[2], M. Hayakawa[4], T. Saiki[4], H. Sawada[4], H. Imamura[4], S. Nakazawa[4], Y. Iijima[4], R. Honda[6], S. Sugita[7], [1]University of Occupational and Environmental Health, [2]Kobe University, [3]Chiba Institute of Technology, [4]Japan Aerospace Exploration Agency, [5]Aichi Toho University, [6]Kochi University, [7]The University of Tokyo.

**Introduction:** The near-earth asteroid 162173 Ryugu was explored by the Japanese spacecraft Hayabusa2 since June 2018, providing the first detailed images of a small asteroid belonging to the C taxonomic class and the entire surface was found to be covered with countless boulders with a maximum size larger than 100 m [1, 2]. The surface regolith layer of Ryugu was expected to have strength originating from cohesion forces among regolith grains under the microgravity condition at about $1 \times 10^{-4}$ m $s^{-2}$, and the maximum strength of the surface layer was estimated theoretically to be 1 kPa [3]. In principle, this surface strength should control the crater formation process under the microgravity condition and reduce the impact crater size drastically compared to the expected size on a strengthless surface [4]. Crater scaling laws used to predict the crater size formed by high velocity impacts of small bodies are necessary in order to construct a crater chronology on asteroid Ryugu and depending on the considered law, the surface age could differ by more than one order of magnitude [1]

A Small Carry-on Impactor (SCI) was equipped with Hayabus2 spacecraft in order to form an artificial impact crater (SCI crater, hereafter) on the surface of Ryugu. The SCI crater enables us to access the asteroid interior for investigating the subsurface properties by remote sensing and for acquiring the subsurface material by active sampling [5, 6]. Furthermore, the SCI impact is the first precious opportunity to study the impact crater formation process under a microgravity environment on a real asteroid surface. Thus, its results can be applied to natural craters on Ryugu directly in order to evaluate the crater chronology and investigate the subsurface structure. Besides these applications, conventional crater scaling laws for the crater size and the ejecta velocity distribution can be verified at these conditions, and the SCI impact is the only one valuable anchor to compare with numerous numerical simulations of the impact cratering processes in a microgravity environment [7].

**Space Impact Experiment:** The SCI instrument is a separable unit of a 30-cm cylinder shape containing explosive of 4.7 kg for acceleration of the projectile [5]. In the impact experiment, SCI was separated from the spacecraft and launched a copper projectile of 2 kg onto Ryugu at 2 km/s to make an artificial crater. The SCI operation was carried out on 5 April, 2019 and was successfully accomplished to form a visible artificial impact crater on Ryugu. The production and evolution of impact ejecta from the surface of Ryugu were also successfully observed by a Deployable CAMera 3 (DCAM3). About 2 weeks after the SCI impact, Hayabusa2 and its Optical Navigation Camera (ONC) looked for the SCI crater at the altitude of 1.7 km, then found it very close to the aiming point at latitude 6.00° N and longitude 303.00° E in the north area of the equatorial ridge. The impact angle was estimated to be approximately 60° measured from the local horizontal surface.

Low-altitude remote-sensing observation tours by the spacecraft were also conducted before and after the impact experiment. Surface maps of images were made by ONC, Thermal Infrared Imager (TIR), and Near Infrared Spectrometer (NIRS3) at 1.7 km altitude, and the images of both tours were compared to identify the newly excavated crater.

**Artificial Crater:** An image of the new crater is shown in Figure 1. This image was taken by ONC-T in the low-altitude operation at 1.7 km altitude. By comparing with images in the pre-impact observation, the excavated topography and surrounding dark splashes were newly found in the post-impact images. A crater rim also appeared as a part of a semicircle in the image.

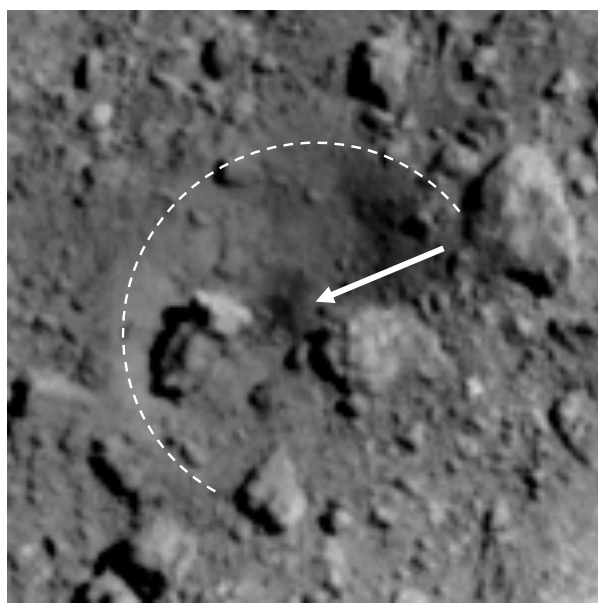

Figure 1: The image of the SCI artificial crater taken by ONC during the low-altitude operation after the impact experiment.

The estimated location of the crater rim is shown as a dashed curve. The deposition rim is a strong evidence for the crater formation occurring in the gravity-dominated regime [8]. The diameter from a point on the rim to an opposite $D_{rim}$ was ~15 m. Using an empirical equation $D = D_{rim}/1.3$, where $D$ is the crater diameter at an initial surface elevation [9], we determine the crater radius of the SCI crater $R = D/2$ to be 6.5 m.

We calculate the SCI crater radius using the conventional $\pi$ scaling law applied for a typical sand surface [9]. We find that the SCI impact crater is about 5% smaller than that calculated for sand. In spite of the difference, it should be formed on a cohesionless surface such as one made of sand, because even a small amount of cohesion limits the crater growth in this microgravity environment and prohibits the crater diameter to be larger than 10 m. Thus, we can reasonably conclude that the surface of Ryugu is composed of sand-like cohesionless materials.

We found a pit close to the impact point on the crater floor (an arrow in Fig. 1). The pit entrance is at a depth of 1.7 m from the initial surface; the diameter and the depth of the pit is >2 m and 0.6 m, respectively. The pit has a conical shape similar to a simple crater in laboratory experiments [8]. The pit might result from the SCI impact on a subsurface layer with a cohesion strength. The cohesion strength of the subsurface layer is estimated by the dynamic pressure generated on the layer, which is caused by the material flow with the particle velocity. We calculated this pressure from the Maxwell's Z-model [9]. Assuming the typical z value of 3 for granular materials, $R = 6.5$ m, a non-cohesive upper layer with a thickness of 1.7 m, and a pit diameter of 2 m formed on a cohesive subsurface layer, the dynamic pressure can be obtained as about 300 Pa at the center of the pit and about 130 Pa at the rim of the pit. Thus, the cohesion strength of the subsurface layer is speculated to be smaller than about 300 Pa and larger than about 130 Pa.

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