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An artificial impact on the asteroid 162173 Ryugu formed a crater in the gravity-dominated regime

Masahiko Arakawa (Kobe University)

Authors：M. Arakawa*, T. Saiki, K. Wada, K. Ogawa, T. Kadono, K. Shirai, H. Sawada, K. Ishibashi, R. Honda, N. Sakatani, Y. Iijima, C. Okamoto, H. Yano, Y. Takagi, M. Hayakawa, P. Michel, M. Jutzi, Y. Shimaki, S. Kimura, Y. Mimasu, T. Toda, H. Imamura, S. Nakazawa, H. Hayakawa, S. Sugita, T. Morota, S. Kameda, E. Tatsumi, Y. Cho, K. Yoshioka, Y. Yokota, M. Matsuoka, M. Yamada, T. Kouyama, C. Honda, Y. Tsuda, S. Watanabe, M. Yoshikawa, S. Tanaka, F. Terui, S. Kikuchi, T. Yamaguchi, N. Ogawa, G. Ono, K. Yoshikawa, T. Takahashi, Y. Takei, A. Fujii, H. Takeuchi, Y. Yamamoto, T. Okada , C. Hirose, S. Hosoda, O. Mori, T. Shimada, S. Soldini, R. Tsukizaki, T. Iwata, M. Ozaki, M. Abe, N. Namiki, K. Kitazato, S. Tachibana, H. Ikeda, N. Hirata, N. Hirata, R. Noguchi, A. Miura

*Corresponding author: Kobe University

Understanding the crater formation process in the Hayabusa2 impactor experiment

Highlights：

- ◆ Crater formed on Ryugu is about 7 times larger than that formed on Earth.
- ◆Ryugu's surface age is young（of order 10^7 years）

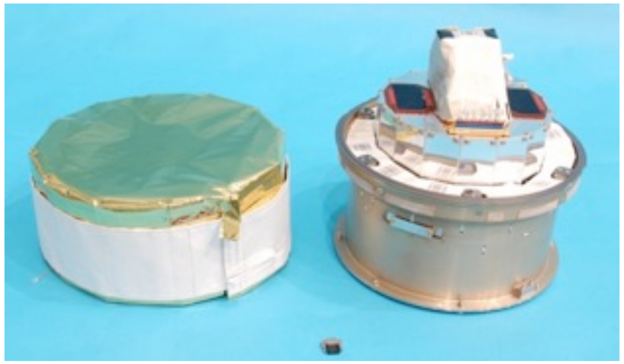
Background & overview

- The growth of impact craters on Ryugu can be limited by either surface strength or surface gravity.
- The surface age of Ryugu is estimated from the size frequency distribution of craters, so the age differs greatly depending on the limiting mechanism for crater growth: the growth is limited by surface strength or limited by surface gravity. This results in estimations for Ryugu's stay in the asteroid belt to vary over an order of magnitude, between 6 million years and 200 million years
- In the collision experiment with the SCI, a semi-circular crater was formed on Ryugu's surface with a dimeter of 14.5m (17.6m at the rim). This is about seven times larger compared to the equivalent experiment on Earth.
- From the shape of the ejecta curtain and SCI crater observed by DCAM3, the growth of the crater is thought to have been restricted by gravity.
- This gives a length of stay for Ryugu in the asteroid belt to be the shortest of the possible estimates at 6.4 – 11.4 million years.
- Ryugu's surface age is likely to be of order 10^7 years old.

SCI, DCAM3：Equipment overview

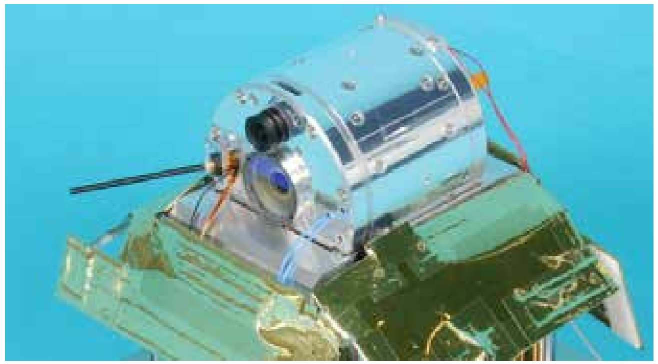
Small Carry-on Impactor

- Copper disc (30 cm) and explosives
- Copper projectile (2 kg, ~ 2 km/s)：hollow spherical shell（13cm diameter）
- World's first experimental device for making artificial craters on asteroids.



Deployable CAMera 3

- Microsatellite：2 optical systems（for science & monitoring）, sensor, digital & analog transmitter, battery.
- Specifications：spatial resolution < 1 m /pixel, shooting speed 1 shot / sec, 74ºx74º field of view.
- In-situ observation of the SCI collision on the surface of asteroid Ryugu.

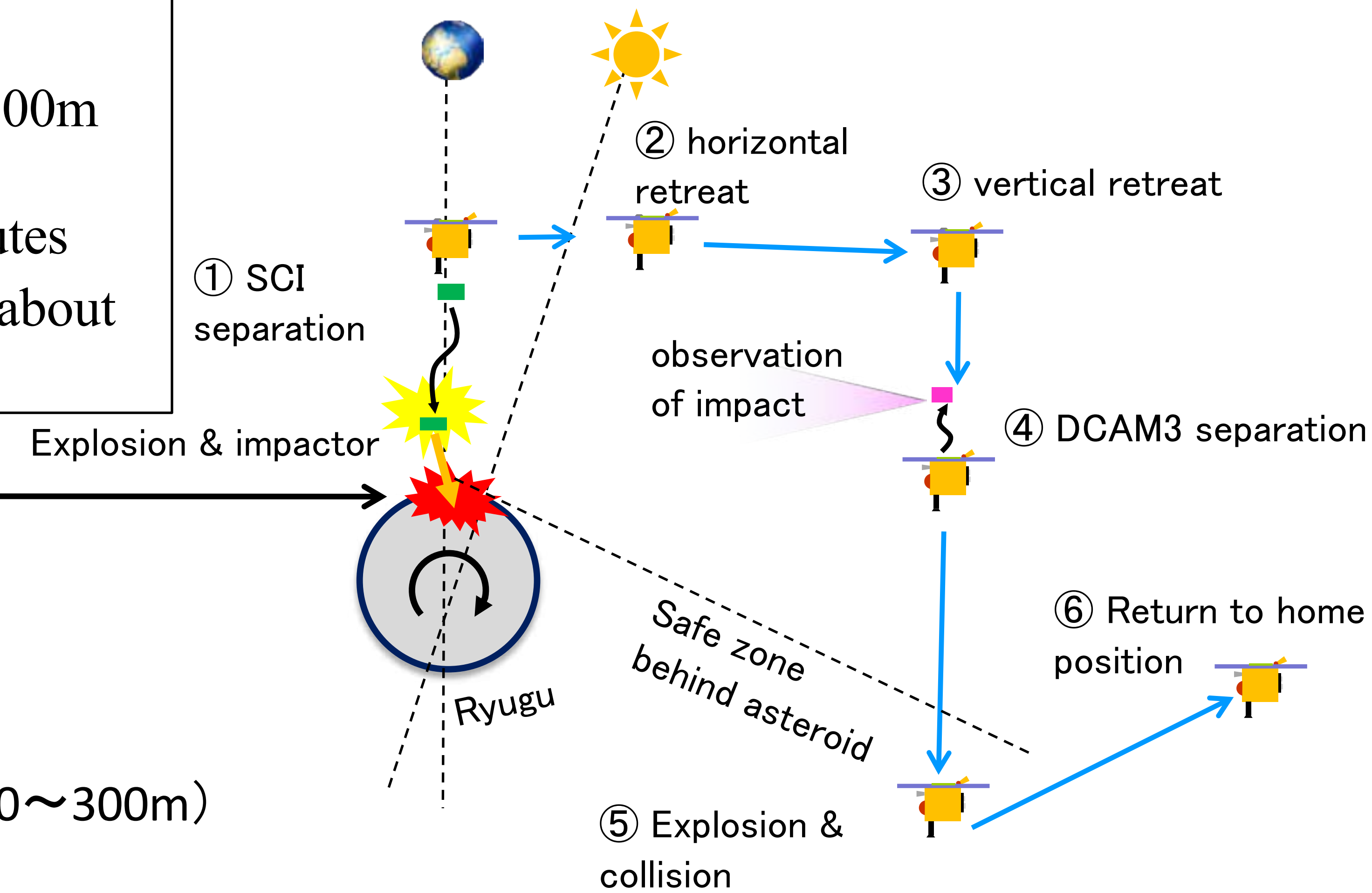


（image credit：JAXA）

SCI, DCAM3：Equipment overview

SCI operation sequence

- SCI separation height is 500m
- From SCI separation to explosion: about 40 minutes
- Return to home position: about 2 weeks



Landed near here later

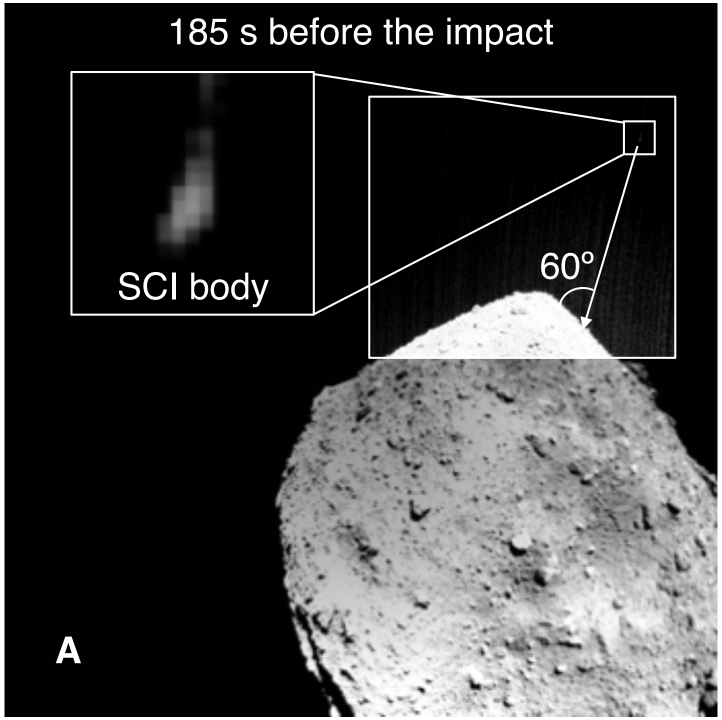
Pinpoint touchdown

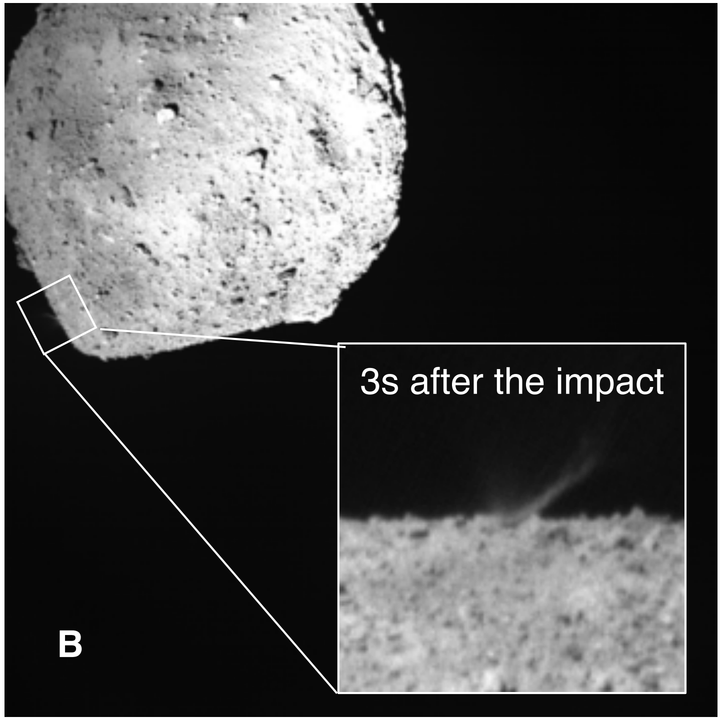
（SCI was exploded at 250～300m）

（image credit：JAXA）

Before & after the collision with DCAM3

- Impact point: 7.9° N, 301.3° E.
- SCI projectile impacted obliquely at an angle of 60° to the surface of Ryugu.





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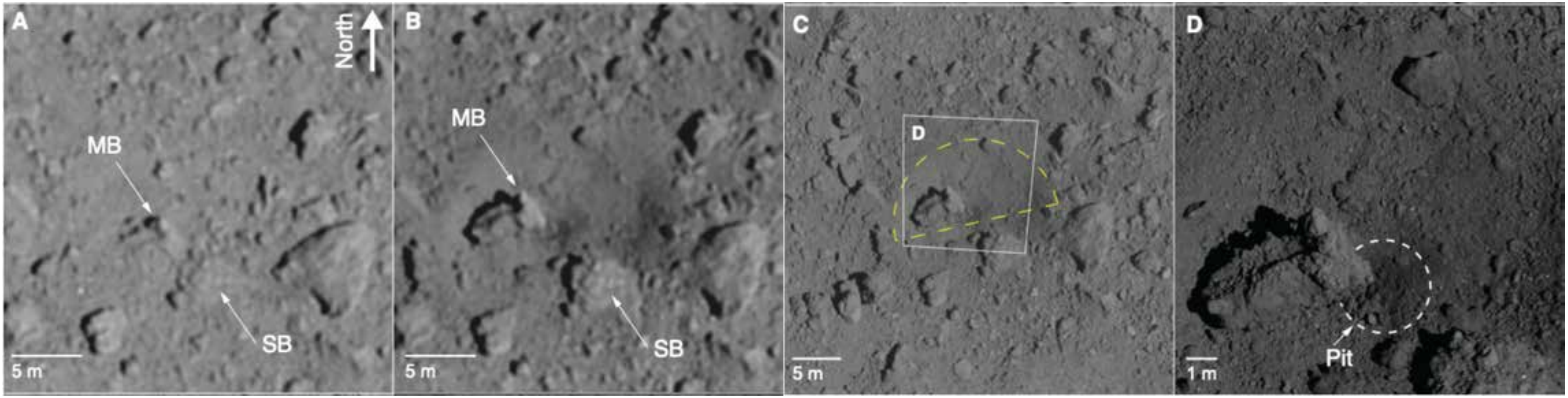
SCI (Omusubi-Kororin) crater

- Impacted between MB（Iijima block 5m）and SB（Okamoto block ）.
- MB moved 3m northwest. Okamoto block was immobile.
- The crater is semi-circular. Southern growth was inhibited by the Okamoto block.
- A pit about 3m in diameter was seen at the eastern end of the Iijima block.



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Comparison before & after the SCI collision

Comparison of images captured before the SCI operation (March 22, 2019) and after the collision (April 25, 2019): animation

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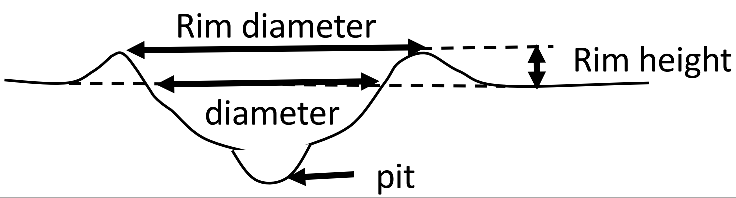
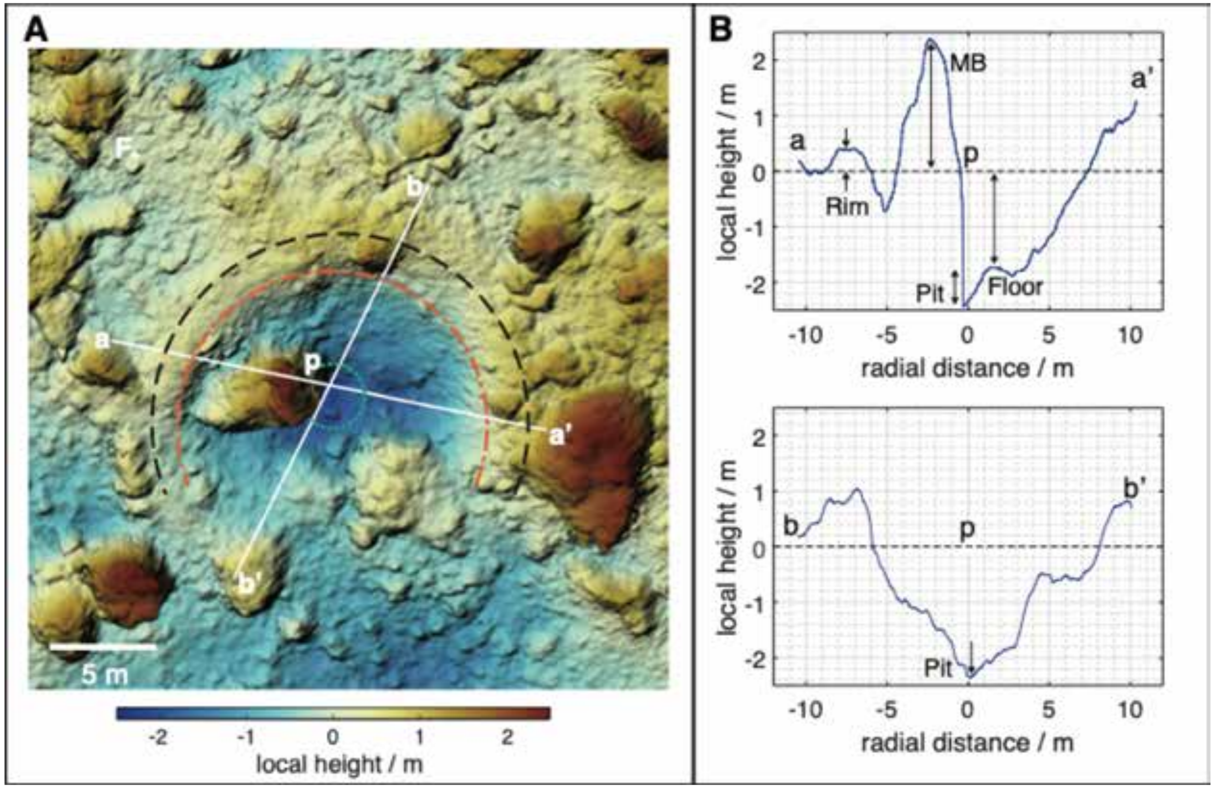
SCI crater shape

- Diameter：14.5±0.8m
  - Crater diameter at 0m height.
- Rim diameter：17.6±0.7m
  - Distance between rim tops
- Pit diameter about 3m、depth 60cm
  - 140 – 670 Pa layer at bottom
- Rim height：40cm
  - Rim consisting of ejecta deposits
- Crater bottom depth
  - Depth from height 0m：1.7m
- Depth from rim top to pit bottom:
  - 2.7m



DEM: Digital Elevation Map



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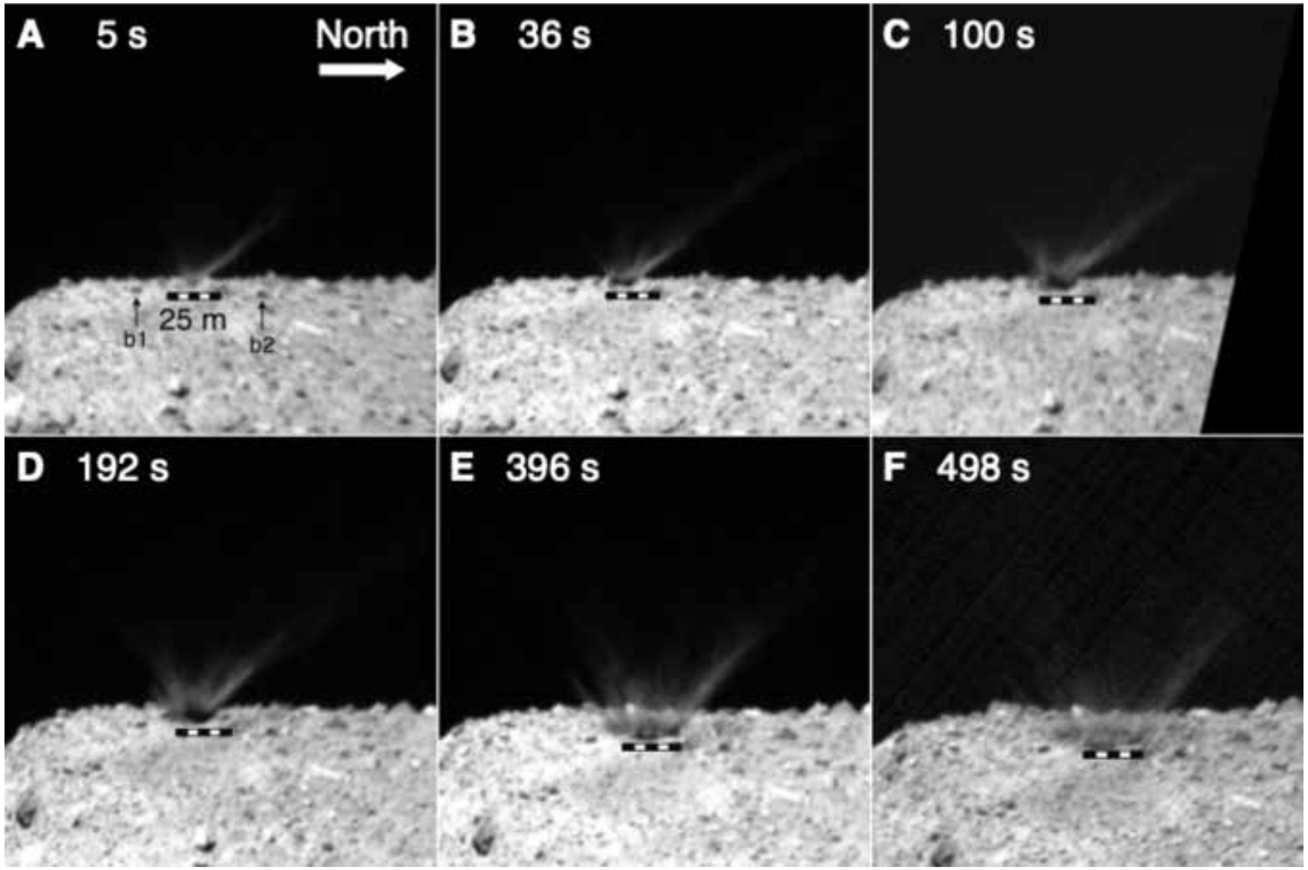
Ejecta curtain

- Ejecta generated in the collision initially spray northward.
- Crater formation, excavation and deposition process, lasts for 500 seconds.
- No separation between the ejecta curtain and ground surface is observed.
- For the first 200 seconds, the crater appears to be growing. After this, the ejecta deposition is occurring.



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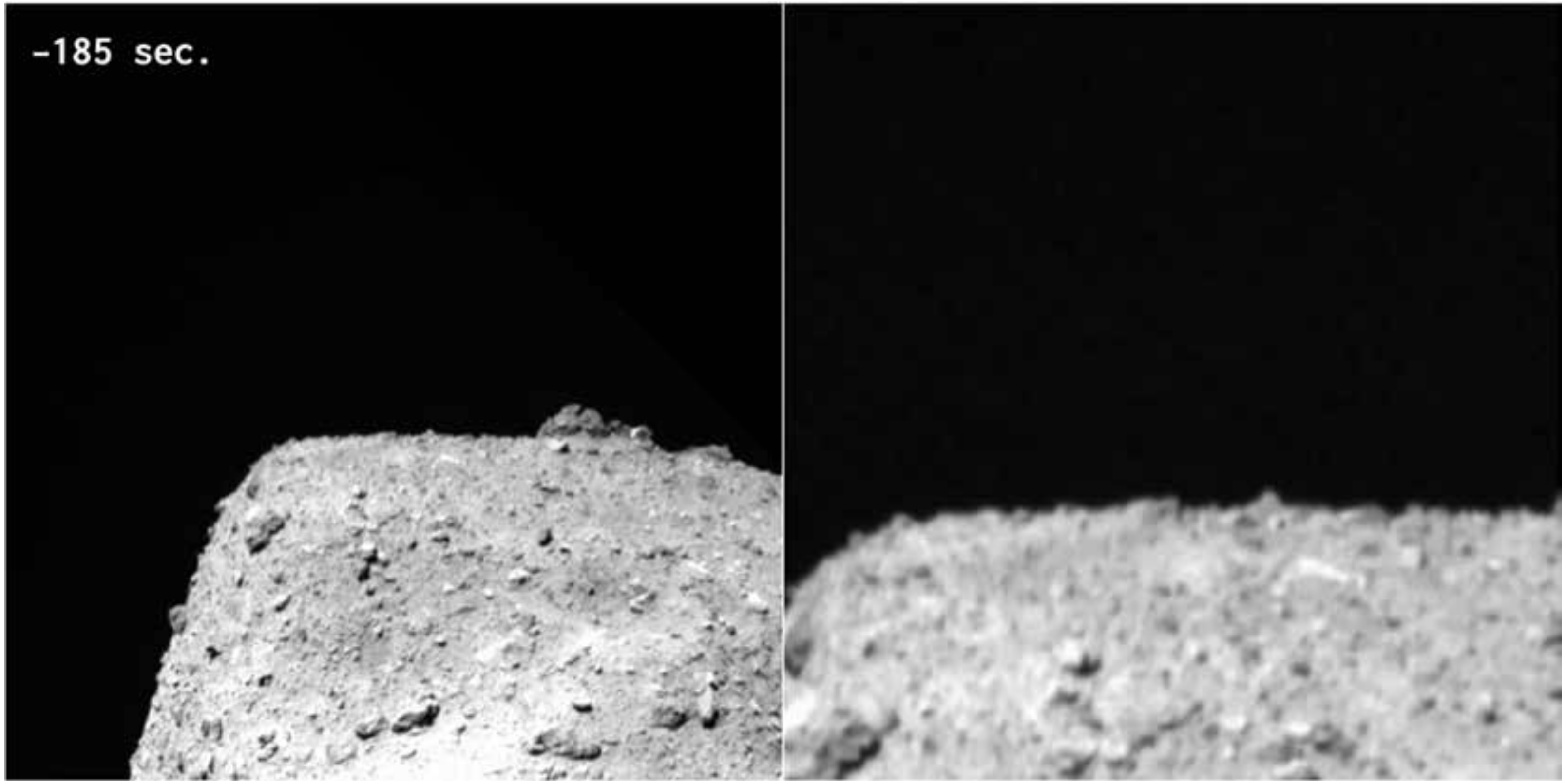
Ejecta curtain (animation)



Ejecta curtain growth and deposition. Animation created using images from 185 seconds before the SCI collision and 3s, 5s, 36s, 100s, 192s, 396s and 489s after collision.

An enlarged image of left animation in the vicinity of the collision point.

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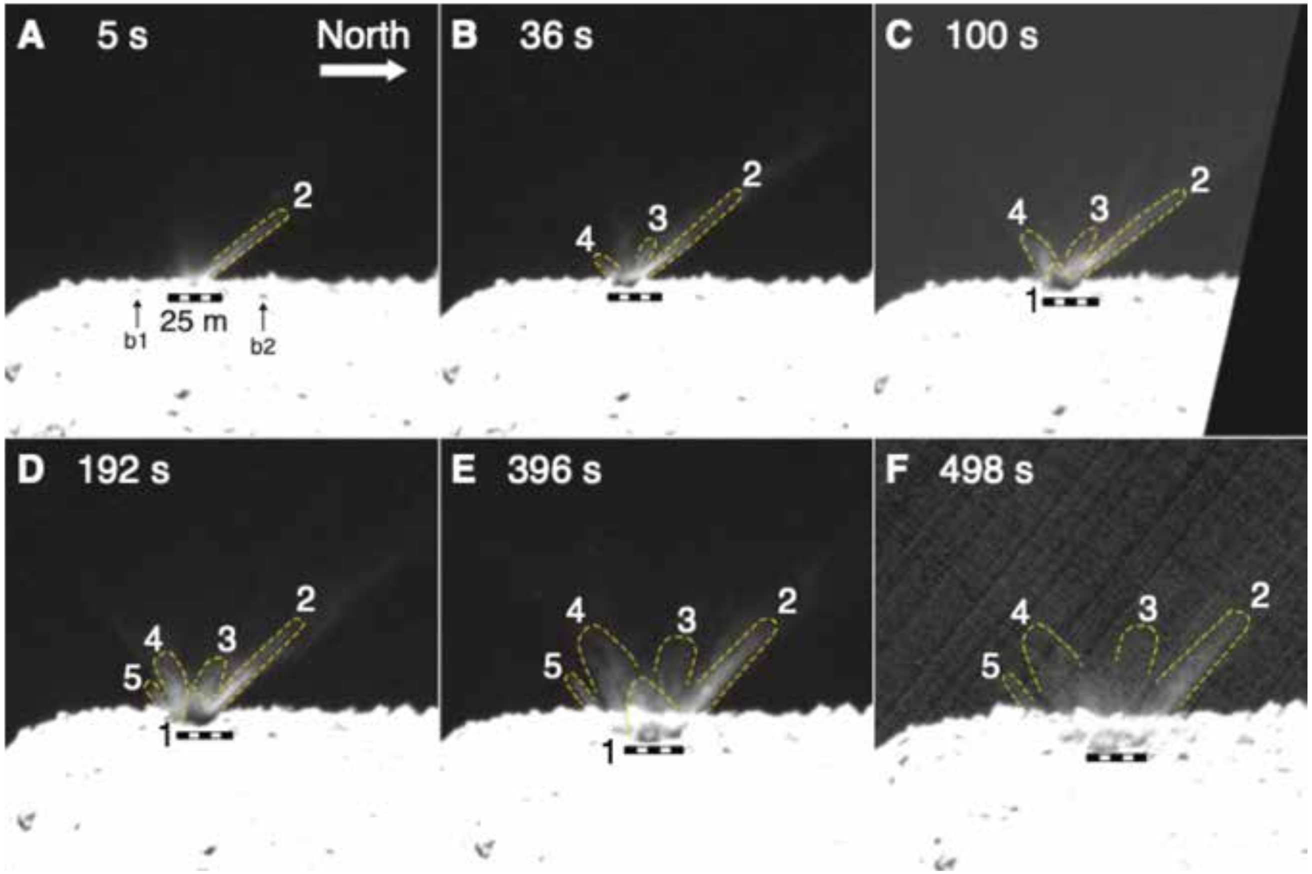
Ejecta curtain

- No ejecta emission is observed on the south side.
  - Okamoto block inhibits crater growth.
- Ejecta sprays outwards in multiple rays.
  - Ejecta rays are separated by large rocks such as the Iijima block.



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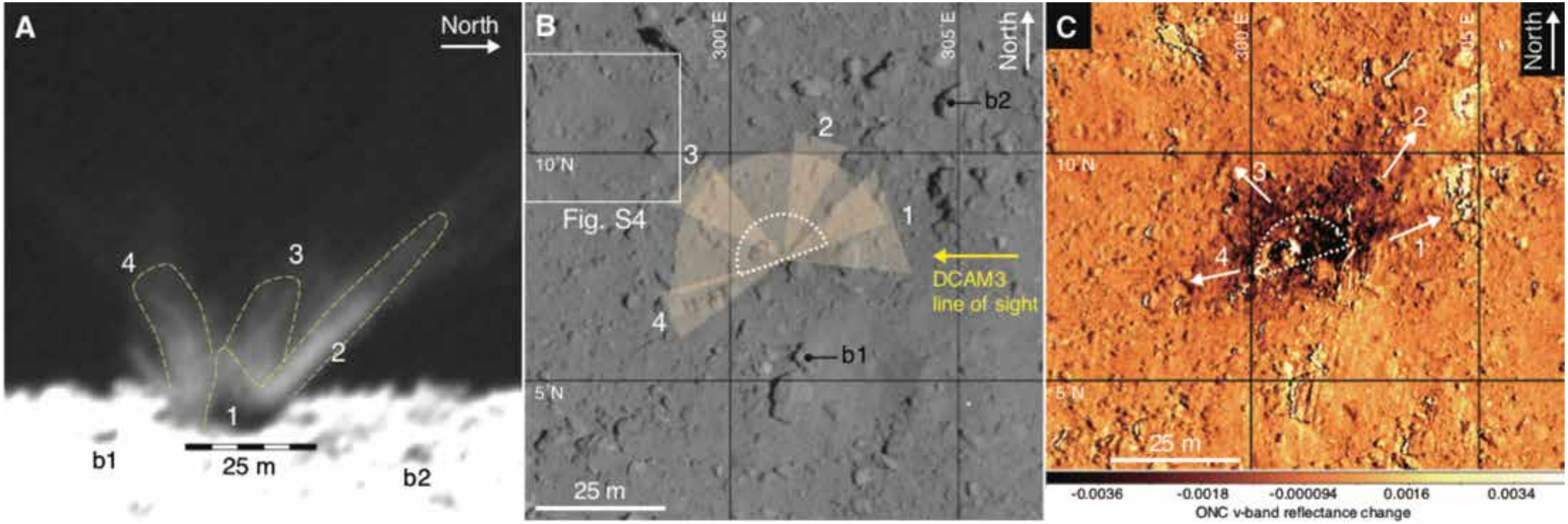
Ejecta deposits

- The distribution of ejecta deposits estimated from the ejecta curtain distribution almost coincides with the distribution in reflectance change seen by the ONC-T.
- Deposits are distributed around the north side of the crater. This appears dark because the reflectivity is lower than the original surface material.



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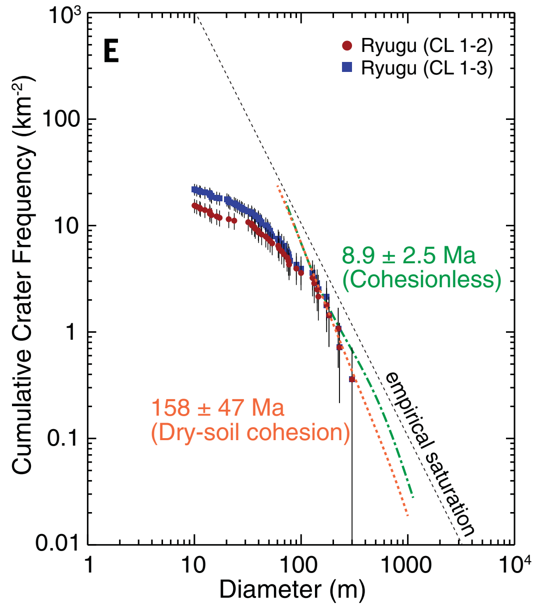
Summary and ripple effect

- The SCI crater can be simulated as a crater forming in sand that lacks strength under microgravity（10^{-5}G）conditions.
  - Crater grows to about 7 times larger than it would if formed on Earth.
  - A deposition rim is formed.
  - Ejecta curtain grows without separating from the ground surface.
- Surface age of Ryugu further narrowed down.
  - According to Sugita et al. (2019), Ryugu's time in the asteroid belt was estimated to within a wide range of about 6 million to about 200 million years. This large uncertainty was due to the unknown strength of Ryugu's surface.
  - The SCI crater revealed the surface of Ryugu has nearly no strength. This result supports the shorter end of the above time period.
  - The short duration that Ryugu has spent in the asteroid belt is an important clue for examining the asteroid's surface age and evolution (see next page).
- These results suggest a need to re-examine crater ages for rubble pile objects such as Ryugu.
- Ejecta appear to have been deposited over the sampling point of TD2 (Uchide-no-kozuchi).

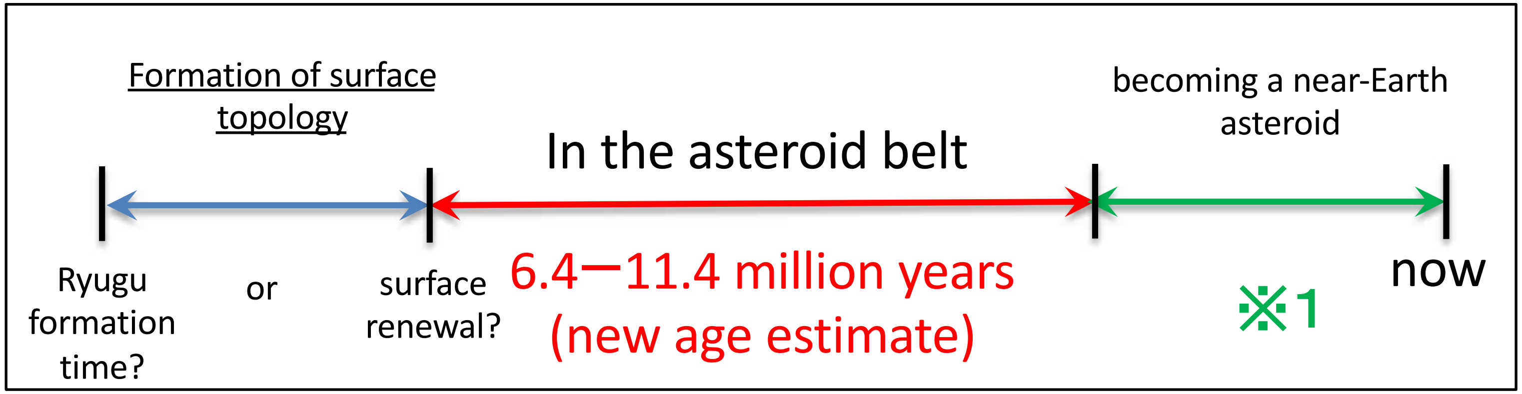
Ma = 100万年



Sugita et al., 2019
Science 19 Apr 2019:
Vol. 364, Issue 6437, eaaw0422
DOI: 10.1126/science.aaw0422

Summary and ripple effect

Surface age of Ryugu



- The surface age of Ryugu is the elapsed time since the formation of the current terrain.
  - There are two theories for this time period: either it is the time since Ryugu's first formation, or it is the period of subsequent evolution after a global resurfacing event.
  - Distinguishing between these two theories is a subject for future research.
- Results from this paper show that Ryugu stayed in the asteroid belt for 6.4 to 11.4 million years after the formation of the current topology.
- Finally, the orbit of Ryugu changed due to the influence of planets such as Jupiter, and it became a near-Earth asteroid.
- ※1: Lifetime of near-Earth asteroids are estimated to be about 10 million years, based on theoretical calculations and astronomical observations.

Summary and ripple effect

Significance of the result: Ryugu stayed in the asteroid belt for 6.4 – 11.4 million years.

- The surface of Ryugu has been found to be close to the youngest value (of order 10^7 years) of the previously assumed estimation range.
- Asteroid surface activity and formation (collisional disruption and reaccumulation) may therefore occur more frequency than previously thought.

Author names

M. Arakawa[1*], T. Saiki[2], K. Wada[3], K. Ogawa[21,1], T. Kadono[4], K. Shirai[2,1], H. Sawada[2], K. Ishibashi[3], R. Honda[5], N. Sakatani[2], Y. Iijima[2 §], C. Okamoto[1 §], H. Yano[2], Y. Takagi[6], M. Hayakawa[2], P. Michel[7], M. Jutzi[8], Y. Shimaki[2], S. Kimura[9], Y. Mimasu[2], T. Toda[2], H. Imamura[2], S. Nakazawa[2], H. Hayakawa[2], S. Sugita[10,3], T. Morota[10], S. Kameda[11], E. Tatsumi[20,12,10], Y. Cho[10], K. Yoshioka[10], Y. Yokota[2,5], M. Matsuoka[2], M. Yamada[3], T. Kouyama[13], C. Honda[14], Y. Tsuda[2], S. Watanabe[15,2], M. Yoshikawa[2,19], S. Tanaka[2,19], F. Terui[2], S. Kikuchi[2], T. Yamaguchi[2†], N. Ogawa[2], G. Ono[16], K. Yoshikawa[16], T. Takahashi[2‡], Y. Takei[16,2], A. Fujii[2], H. Takeuchi[2,19], Y. Yamamoto[2,19], T. Okada[2,10], C. Hirose[16], S. Hosoda[2], O. Mori[2], T. Shimada[2], S. Soldini[17], R. Tsukizaki[2], T. Iwata[2], M. Ozaki[2,19], M. Abe[2,19], N. Namiki[18,19], K. Kitazato[14], S. Tachibana[10], H. Ikeda[16], N. Hirata[14], N. Hirata[1], R. Noguchi[2], A. Miura[2].

Author affiliation

1. Kobe University, Kobe 657-8501, Japan.
2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan.
3. Planetary Exploration Research Center, Chiba Institute of Technology, Narashino 275-0016, Japan.
4. University of Occupational and Environmental Health, Kitakyusyu 807-8555, Japan.
5. Kochi University, Kochi 780-8520, Japan.
6. Aichi Toho University, Nagoya 465-8515, Japan.
7. The Côte d'Azur Observatory, 06304 Nice Cedex 4, France.
8. Physics Institute, University of Bern, NCCR PlanetS, Gesellschaftsstrasse 6, 3012, Bern, Switzerland.
9. Tokyo University of Science, Noda 278-8510, Japan.
10. The University of Tokyo, Tokyo 113-0033, Japan.
11. Rikkyo University, Tokyo 171-8501, Japan.
12. University of La Laguna, 38205 San Cristóbal de La Laguna, Spain.
13. National Institute of Advanced Industrial Science and Technology, Tokyo 135-0064, Japan.
14. The University of Aizu, Aizu-Wakamatsu 965-8580, Japan.
15. Nagoya University, Nagoya 464-8601, Japan.
16. Research and Development Directorate, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan.
17. University of Liverpool, Liverpool L3 5TQ, United Kingdom.
18. National Astronomical Observatory of Japan, Mitaka 181-8588, Japan.
19. SOKENDAI (The Graduate University for Advanced Studies), Hayama 240-0193, Japan.
20. Instituto de Astrofísica de Canarias, La Laguna, Tenerife, E38205, Spain.
21. JAXA Space Exploration Center, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan.

*Corresponding author: E-mail: masahiko.arakawa@penguin.kobe-u.ac.jp

†Current affiliation: Mitsubishi Electric Corporation, Kamakura 247-8520, Japan.

‡Current affiliation: NEC Corporation, 1-10 Nisshin-cho, Fuchu, Tokyo 183-0036, Japan.

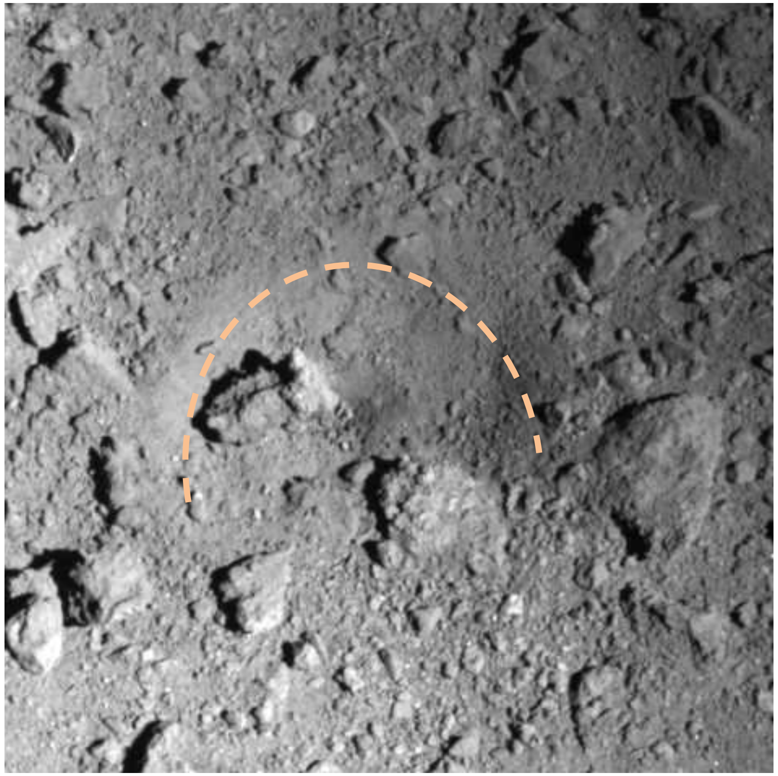
§Deceased.

Reference: Comparison with ground experiments

- Crater grew about 7 times the size as that formed on Earth.

(image credit：JAXA)

Artificial crater formed by ground tests of the SCI. The size is about 2m.



（Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST）

Reference: Artificial crater-related place names

The following nicknames are being used for the area around the artificial crater:

■Artificial crater

Omusubi-Kororin Crater

（SCI Crater）

■Mobile Block

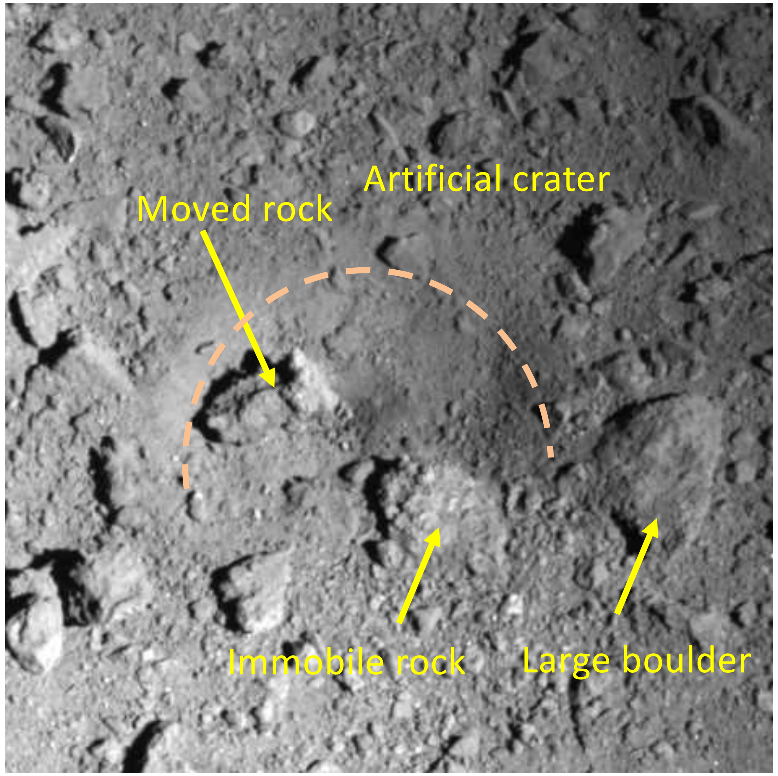
Iijima Block

■Stable Block

Okamoto Block

■Large boulder

Onigiri Boulder



（Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST）