



2022 4 9 23

2022	4
9 23	
9 30	

J P A R C

Science

JAXA	6
2 Phase-2	

Science 2022 9 23

Formation and evolution of carbonaceous asteroid Ryugu: Direct evidence from returned samples

Science

D O I 10.1126/science.abn8671

	2020	12	6	JAXA
			Phase-1	
6			2 Phase-2	
			Phase-2	
6			Phase-2	

JAXA

tomoki.nakamura.a8@tohoku.ac.jp

isas-kouho@ml.jaxa.jp

sci-pr@mail.sci.tohoku.ac.jp

jp-press@general.hokudai.ac.jp

comms@mail2.adm.kyoto-u.ac.jp

koho@jimu.kyushu-u.ac.jp

koho@office.hiroshima-u.ac.jp

J-PARC

press@kek.jp

pr-section@j-parc.jp

kouhou@spring8.or.jp

1 2 3 4 5 6

6

CO₂ 200

3 Ca Al

10 126 4

@J-PARC Cl

CO₂ 2 4

5 25

1

0.9 2 0.2 0.2

4

6

1

CT

@SPring-8

1.79

0.08

³

1.19

30

1

7

46

200

200

300

500

50

100

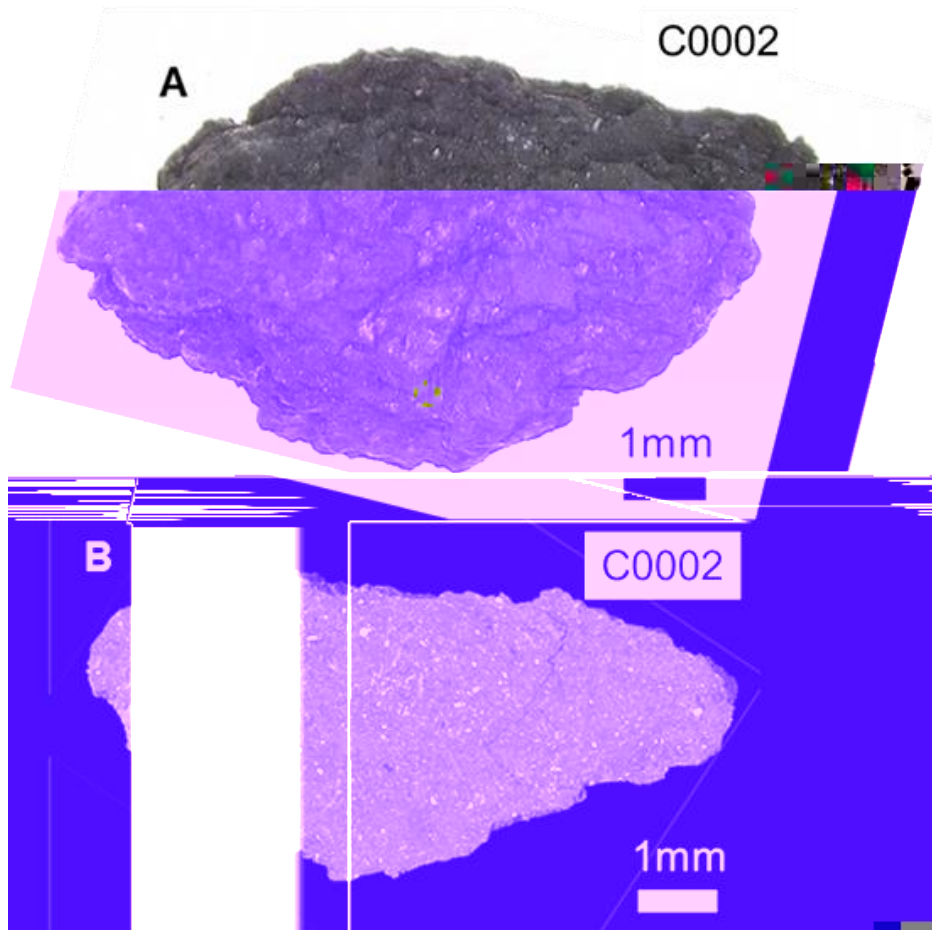
1/10

50

10GPa

0.2

2



© SPring-8

1 A

C0002

B SPring-8

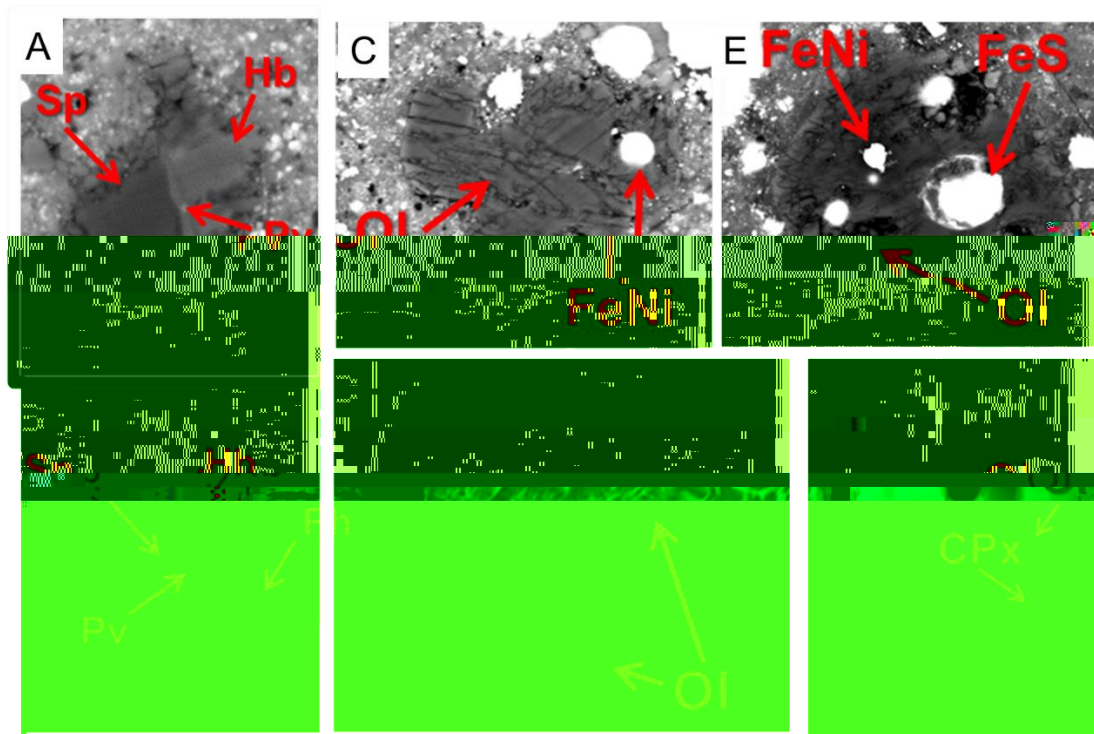
X CT

CT



© MIT

2

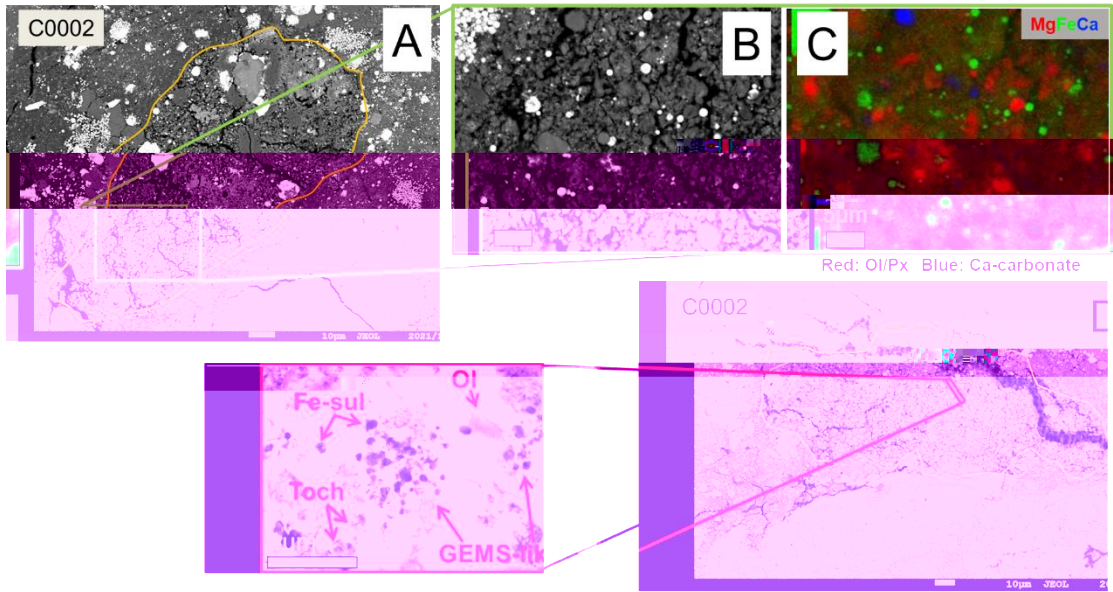


©

3

B) Ca Al B-D 1000 Ol FeNi FeS A

F



©

4 C0002

A

B

C B

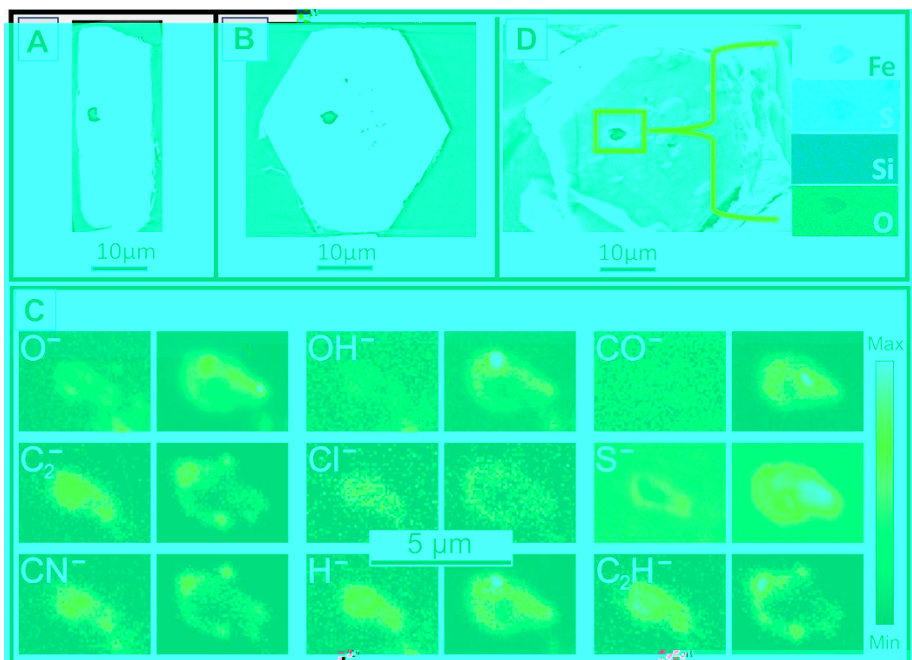
D

E D

1

GEMS-like

Ol



©

NASA/JSC SPring-8

5

6

CO₂

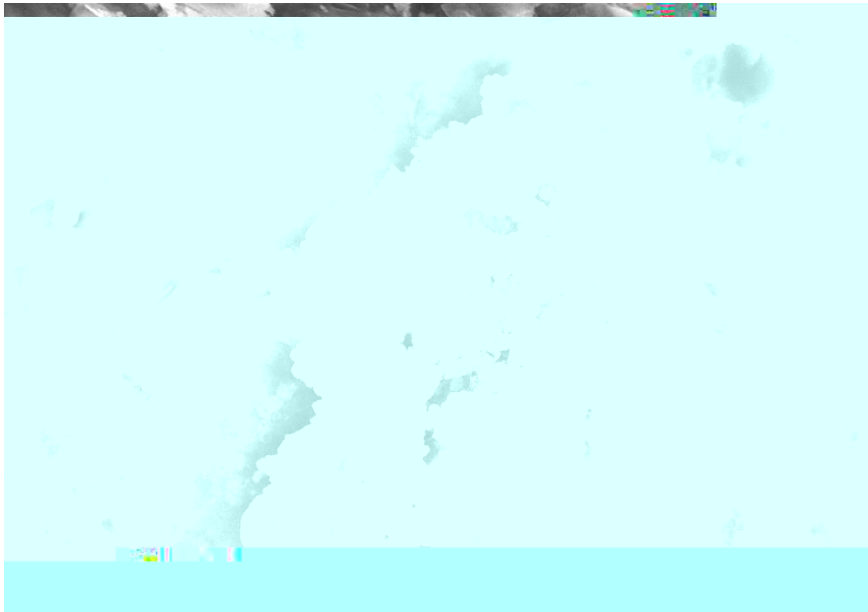
A B

CT

C

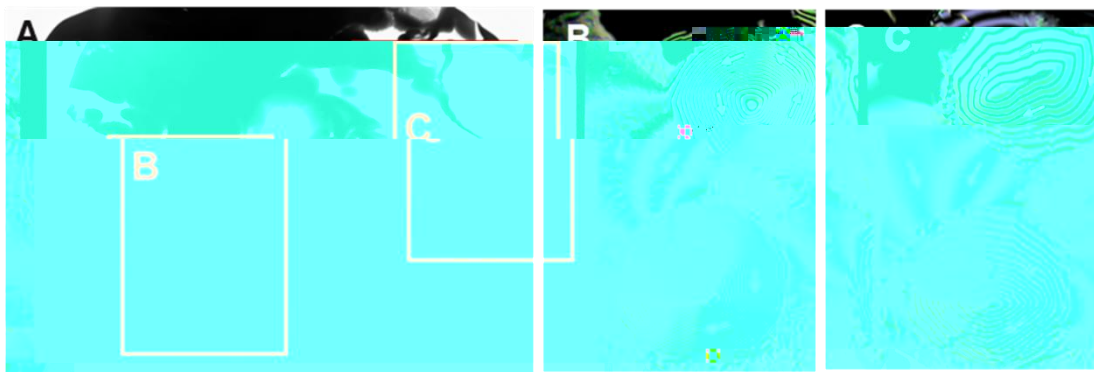
-120

D



©

6



© JFCC

7

Fe_3O_4

A

B C

1 Ca Al

2

100

3

45 6700

4

200

【論文情報】

雑誌名：Science

論文タイトル：Formation and evolution of carbonaceous asteroid Ryugu: Direct evidence from returned samples

著者：T. Nakamura¹, M. Matsumoto¹, K. Amano¹, Y. Enokido¹, M. E. Zolensky², T. Mikouchi³, H. Genda⁴, S. Tanaka^{5,6}, M. Y. Zolotov⁷, K. Kurosawa⁸, S. Wakita⁹, R. Hyodo⁵, H. Nagano¹⁰, D. Nakashima¹, Y. Takahashi^{11,12}, Y. Fujioka¹, M. Kikuri¹, E. Kagawa¹, M. Matsuoka^{13,14}, A. J. Brearley¹⁵, A. Tsuchiyama^{16,17,18}, M. Uesugi¹⁹, J. Matsuno¹⁶, Y. Kimura²⁰, M. Sato¹¹, R. E. Milliken²¹, E. Tatsumi^{22,11}, S. Sugita^{11,8}, T. Hiroi²¹, K. Kitazato²³, D. Brownlee²⁴, D. J. Joswiak²⁴, M. Takahashi¹, K. Ninomiya²⁵, T. Takahashi^{26,27}, T. Osawa²⁸, K. Terada²⁹, F. E. Brenker³⁰, B. J. Tkalcec³⁰, L. Vincze³¹, R. Brunetto³², A. Aléon-Toppiani³², Q. H. S. Chan³³, M. Roskosz³⁴, J.-C. Viennet³⁴, P. Beck³⁵, E. E. Alp³⁶, T. Michikami³⁷, Y. Nagaashi^{38,1}, T. Tsuji^{39,40}, Y. Ino^{41,5}, J. Martinez², J. Han⁴², A. Dolocan⁴³, R. J. Bodnar⁴⁴, M. Tanaka⁴⁵, H. Yoshida¹¹, K. Sugiyama⁴⁶, A. J. King⁴⁷, K. Fukushi⁴⁸, H. Suga⁴⁹, S. Yamashita^{50,51}, T. Kawai¹¹, K. Inoue⁴⁸, A. Nakato⁵, T. Noguchi^{52,53}, F. Vilas⁵⁴, A. R. Hendrix⁵⁴, C. Jaramillo-Correa⁵⁵, D. L. Domingue⁵⁴, G. Dominguez⁵⁶, Z. Gainsforth⁵⁷, C. Engrand⁵⁸, J. Duprat³⁴, S. S. Russell⁴⁷, E. Bonato⁵⁹, C. Ma⁶⁰, T. Kawamoto⁶¹, T. Wada¹, S. Watanabe^{5,26}, R. Endo⁶², S. Enju⁶³, L. Riu⁶⁴, S. Rubino³², P. Tack³¹, S. Takeshita⁶⁵, Y. Takeichi^{50,51,66}, A. Takeuchi¹⁹, A. Takigawa¹¹, D. Takir², T. Tanigaki⁶⁷, A. Taniguchi⁶⁸, K. Tsukamoto¹, T. Yagi⁶⁹, S. Yamada⁷⁰, K. Yamamoto⁷¹, Y. Yamashita⁶⁹, M. Yasutake¹⁹, K. Uesugi¹⁹, I. Umegaki^{72,65}, I. Chiu²⁵, T. Ishizaki⁵, S. Okumura⁵², E. Palomba⁷³, C. Pilorget^{32,74}, S. M. Potin^{13,75}, A. Alasli¹⁰, S. Anada⁷¹, Y. Araki⁷⁶, N. Sakatani^{70,5}, C. Schultz²¹, O. Sekizawa⁴⁹, S. D. Sitzman⁷⁷, K. Sugiura⁴, M. Sun^{17,18,78}, E. Dartois⁷⁹, E. De Pauw³¹, Z. Dionnet³², Z. Djouadi³², G. Falkenberg⁸⁰, R. Fujita¹⁰, T. Fukuma⁸¹, I. R. Gearba⁴³, K. Hagiya⁸², M. Y. Hu³⁶, T. Kato⁷¹, T. Kawamura⁸³, M. Kimura^{50,51}, M. K. Kubo⁸⁴, F. Langenhorst⁸⁵, C. Lantz³², B. Lavina⁸⁶, M. Lindner³⁰, J. Zhao³⁶, B. Vekemans³¹, D. Baklouti³², B. Bazi³¹, F. Borondics⁸⁷, S. Nagasawa^{26,27}, G. Nishiyama¹¹, K. Nitta⁴⁹, J. Mathurin⁸⁸, T. Matsumoto⁵², I. Mitsukawa⁵², H. Miura⁸⁹, A. Miyake⁵², Y. Miyake⁶⁵, H. Yurimoto⁹⁰, R. Okazaki⁹¹, H. Yabuta⁹², H. Naraoka⁹¹, K. Sakamoto⁵, S. Tachibana^{11,5}, H. C. Connolly Jr.⁹³, D. S. Laretta⁹⁴, M. Yoshitake⁵, M. Yoshikawa^{5,6}, K. Yoshikawa⁹⁵, K. Yoshihara⁵, Y. Yokota⁵, K. Yogata⁵, H. Yano^{5,6}, Y. Yamamoto^{5,6}, D. Yamamoto⁵, M. Yamada⁸, T. Yamada⁵, T. Yada⁵, K. Wada⁸, T. Usui^{5,11}, R. Tsukizaki⁵, F. Terui⁹⁶, H. Takeuchi^{5,6}, Y. Takei⁵, A. Iwamae⁹⁷, H. Soejima^{5,97}, K. Shirai⁵, Y. Shimaki⁵, H. Senshu⁸, H. Sawada⁵, T. Saiki⁵, M. Ozaki^{5,6}, G. Ono⁹⁵, T. Okada^{5,98}, N. Ogawa⁵, K. Ogawa⁵, R. Noguchi⁹⁹, H. Noda¹⁰⁰, M. Nishimura⁵, N. Namiki^{100,6}, S. Nakazawa⁵, T. Morota¹¹, A. Miyazaki⁵, A. Miura⁵, Y. Mimasu⁵, K. Matsumoto^{100,6}, K. Kumagai^{5,97}, T. Kouyama¹⁰¹, S. Kikuchi^{8,100}, K. Kawahara⁵, S. Kameda^{70,5}, T. Iwata^{5,6}, Y. Ishihara¹⁰², M. Ishiguro¹⁰³, H. Ikeda⁹⁵, S. Hosoda⁵, R. Honda^{104,105}, C. Honda²³, Y. Hitomi^{5,97}, N. Hirata³⁸, N. Hirata²³, T. Hayashi⁵, M. Hayakawa⁵, K. Hatakeda^{5,97}, S. Furuya¹¹, R. Fukai⁵, A. Fujii⁵, Y. Cho¹¹, M. Arakawa³⁸, M. Abe^{5,6}, S. Watanabe¹⁰⁶, Y. Tsuda⁵.

- ⁴⁴Department of Geoscience, Virginia Tech., Blacksburg VA 24061, USA.
- ⁴⁵Materials Analysis Station, National Institute for Materials Science, Tsukuba 305-0047, Japan.
- ⁴⁶Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan.
- ⁴⁷Department of Earth Science, Natural History Museum, London SW7 5BD, UK.
- ⁴⁸Institute of Nature and Environmental Technology, Kanazawa University, Kanazawa 920-1192, Japan.
- ⁴⁹Spectroscopy Division, Japan Synchrotron Radiation Research Institute, Sayo 679-5198, Japan.
- ⁵⁰Department of Materials Structure Science, The Graduate University for Advanced Studies (SOKENDAI), Tsukuba, Ibaraki 305-0801, Japan.
- ⁵¹Institute of Materials Structure Science, High Energy Accelerator Research Organization, Tsukuba 305-0801, Japan.
- ⁵²Division of Earth and Planetary Sciences, Kyoto University; Kyoto 606-8502, Japan
- ⁵³Faculty of Arts and Science, Kyushu University, Fukuoka 819-0395, Japan.
- ⁵⁴Planetary Science Institute, Tucson AZ 85719, USA.
- ⁵⁵The Pennsylvania State University, University Park, PA 16802, USA.
- ⁵⁶Department of Physics, California State University, San Marcos, CA 92096, USA.
- ⁵⁷Space Sciences Laboratory, University of California, Berkeley, California 94720, USA.
- ⁵⁸Laboratoire de Physique des 2 Infinis Irène Joliot-Curie, Université Paris-Saclay, CNRS, 91405 Orsay, France.
- ⁵⁹Institute for Planetary Research, Deutsches Zentrum für Luftund Raumfahrt, Rutherfordstraße 2 12489 Berlin, Germany.
- ⁶⁰Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena CA 91125, USA.
- ⁶¹ Department of Geosciences, Shizuoka University, Shizuoka 422-8529, Japan.
- ⁶²Department of Materials Science and Engineering, Tokyo Institute of Technology, Tokyo 152-8550, Japan.
- ⁶³Graduate School of Science and Engineering, Ehime University, Matsuyama 790-8577, Japan.
- ⁶⁴European Space Astronomy Centre, 28692 Villanueva de la Cañada, Spain.
- ⁶⁵High Energy Accelerator Research Organization, Tokai 319-1106, Japan.
- ⁶⁶Department of Applied Physics, Osaka University, Suita, 565-0871, Japan
- ⁶⁷Hitachi, Ltd., Hatoyama 350-0395, Japan.
- ⁶⁸Institute for Integrated Radiation and Nuclear Science, Kyoto University, Kumatori 590-0494, Japan.
- ⁶⁹National Metrology Institute of Japan, AIST, Tsukuba 305-8565, Japan.
- ⁷⁰Department of Physics, Rikkyo University, Tokyo 171-8501, Japan.
- ⁷¹Japan Fine Ceramics Center, Nagoya 456-8587, Japan.
- ⁷²Toyota Central Research and Development Laboratories, Inc., Nagakute 480-1192, Japan.
- ⁷³Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, Rome 00133, Italy.
- ⁷⁴Institut Universitaire de France, Paris, France.
- ⁷⁵Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands
- ⁷⁶Department of Physical Sciences, Ritsumeikan University, Shiga 525-0058, Japan.
- ⁷⁷Physical Sciences Laboratory, The Aerospace Corporation, California 90245, USA.
- ⁷⁸University of Chinese Academy of Sciences, Beijing 100049, China.
- ⁷⁹Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, CNRS, 91405 Orsay, France.
- ⁸⁰Deutsches Elektronen-Synchrotron Photon Science, 22603 Hamburg, Germany.
- ⁸¹Nano Life Science Institute (The World Premier International Research Center Initiative), Kanazawa University, 920-1192, Japan.
- ⁸²Graduate School of Life Science, University of Hyogo, Hyogo 678-1297, Japan.
- ⁸³Institut de Physique du Globe de Paris, Université de Paris, Paris 75205, France.
- ⁸⁴Division of Natural Sciences, International Christian University, Mitaka 181-8585, Japan.
- ⁸⁵Institute of Geosciences, Friedrich-Schiller-Universität Jena, 07745 Jena, Germany.
- ⁸⁶Center for Advanced Radiation Sources, The University of Chicago, Chicago, IL 60637, USA.
- ⁸⁷
Yvette Cedex, F-91192, France.
- ⁸⁸Institut Chimie Physique, Université Paris-Saclay, CNRS, 91405 Orsay, France.
- ⁸⁹Graduate School of Science, Nagoya City University, Nagoya 467-8501, Japan.
- ⁹⁰ Department of Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan.

- ⁹¹Department of Earth and Planetary Sciences, Kyushu University, Fukuoka 819-0395, Japan.
- ⁹²Graduate School of Advanced Science and Engineering, Hiroshima University, Higashi-Hiroshima 739-8526, Japan.
- ⁹³Department of Geology, Rowan University, Glassboro NJ 08028, USA.
- ⁹⁴Lunar and Planetary Laboratory, University of Arizona; Tucson AZ 85721, USA.
- ⁹⁵Research and Development Directorate, JAXA, Sagamihara 252-5210, Japan.
- ⁹⁶Department of Mechanical Engineering, Kanagawa Institute of Technology, Atsugi 243-0292, Japan.
- ⁹⁷Marine Works Japan Ltd., Yokosuka 237-0063 Japan.
- ⁹⁸Department of Chemistry, The University of Tokyo, Tokyo 113-0033, Japan.
- ⁹⁹Faculty of Science, Niigata University, Niigata 950-2181, Japan.
- ¹⁰⁰National Astronomical Observatory of Japan, Mitaka 181-8588, Japan.
- ¹⁰¹Digital Architecture Research Center, National Institute of Advanced Industrial Science and Technology, Tokyo 135-0064, Japan.
- ¹⁰²JAXA Space Exploration Center, JAXA, Sagamihara 252-5210, Japan.
- ¹⁰³Department of Physics and Astronomy, Seoul National University, Seoul 08826, Korea.
- ¹⁰⁴Department of Information Science, Kochi University, Kochi 780-8520, Japan
- ¹⁰⁵Center for Data Science, Ehime University, Matsuyama 790-8577, Japan.
- ¹⁰⁶Department of Earth and Environmental Sciences, Nagoya University, Nagoya 464-8601, Japan.

Science

DOI 10.1126/science.abn8671