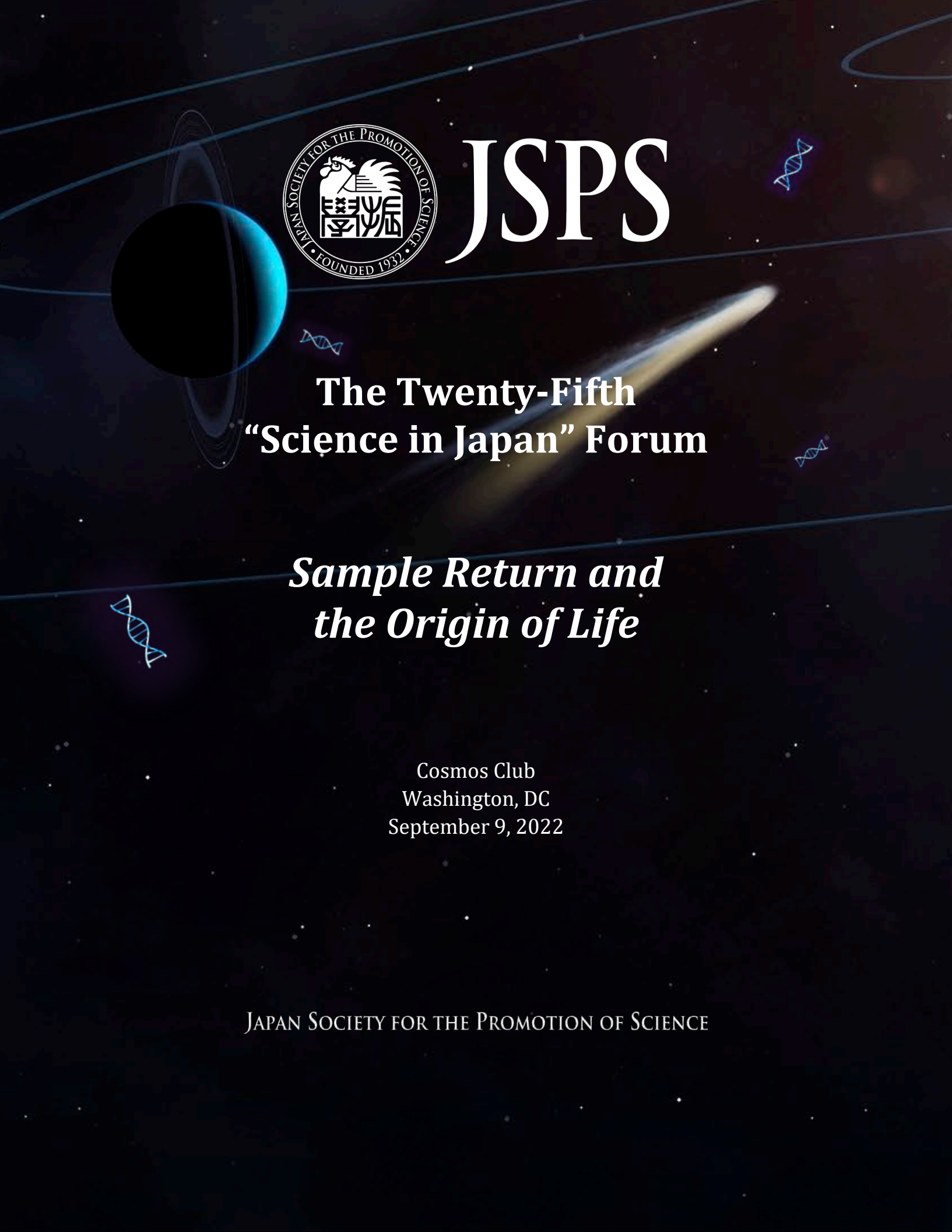

The Twenty-Fifth "Science in Japan" Forum

Sample Return and the Origin of Life

Cosmos Club
Washington, DC
September 9, 2022

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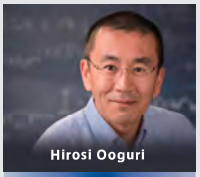
Shin-ichi Orimo

Math-Materials

AIMR
Advanced Institute for Materials Research
Tohoku University



Hirosi Ooguri

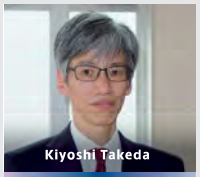
Universe

IPMU
Kavli Institute for the Physics and Mathematics of the Universe
The University of Tokyo

Susumu Kitagawa

Cells & Materials

iCeMS
Institute for Integrated Cell-Material Sciences
Kyoto University



Kiyoshi Takeda

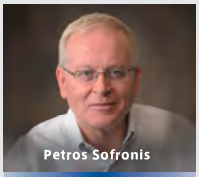
Immunology

WPI Osaka University
iFReC
Immunology Frontier Research Center
Osaka University

Takashi Taniguchi

Nanotechnology

MANA
Nano Revolution for the Future
International Center for Materials Nanoarchitectonics
National Institute for Materials Science



Petros Sofronis

Energy

i²CNER
International Institute for Carbon-Neutral Energy Research
Kyushu University

Masashi Yanagisawa

Sleep

IIIS
International Institute for Integrative Sleep Medicine
University of Tsukuba

Yasuhito Sekine

Earth & Life

ELSI
Earth-Life Science Institute
Tokyo Institute of Technology

Takashi Yoshimura

Molecules

ITbM Nagoya University
Institute of Transformative Bio-Molecules
Nagoya University

Takao K. Hensch

Neurointelligence

IRCN
International Research Center for Neurointelligence
The University of Tokyo

Takeshi Fukuma

Nano Life Science

NanoLSI
WPI KANAZAWA UNIVERSITY
Nano Life Science Institute
Kanazawa University

Satoshi Maeda

Chemical Reaction Design

ICReDD
HOKKAIDO UNIVERSITY
Institute for Chemical Reaction Design and Discovery
Hokkaido University

Mitinori Saitou

Human Biology

ASHBi
WPI Kyoto University
Institute for the Advanced Study of Human Biology
Kyoto University

Masashi Hazumi

Measurement Science

QUP
International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles
WPI research center at KEK
International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles
High Energy Accelerator Research Organization (KEK)

MEXT Ministry of Education, Culture, Sports, Science and Technology-Japan
JSPS Japan Society for the Promotion of Science 日本学術振興会

The Twenty-Fifth
"Science in Japan" Forum

Sample Return and the Origin of Life

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Sponsored by
Japan Society for the Promotion of Science

Co-sponsored by
American Association for the Advancement of Science
American Geophysical Union
U.S. Department of Energy
Earth-Life Science Institute
The International Society for the Study of the Origin of Life
The Japan Aerospace Exploration Agency
Japan Geoscience Union
National Aeronautics and Space Administration
National Science Foundation
US and Canada JSPS AA
World Premier International Research Center Initiative

Agenda

12:00pm - **Registration**

1:00pm - 1:20pm **Opening Remarks**

Kohji Hirata, *Director, Japan Society for the Promotion of Science Washington Office*

David S. Draper, *Deputy Chief Scientist of NASA*

Hitoshi Kuninaka, *Director General of ISAS/JAXA*

Kim Montgomery, *Director of International Affairs and Science Diplomacy of AAAS*

Tetsuya Mizumoto, *Executive Director of JSPS*

1:20pm - 2:20pm **Keynote Speech: The Origin of Life and Sample Return**

Yasuhito Sekine, *Professor, Earth-Life Science Institute, Tokyo Institute of Technology*

Lindsay E. Hays, *Program Scientist, Planetary Science Division, NASA Headquarters, National Aeronautics and Space Administration*

2:20pm - 2:40pm **Coffee Break**

2:40pm - 3:40pm **Session 1: Science of Sample Return**

Shogo Tachibana, *Professor, University of Tokyo*

Harold Connolly Jr., *Founding Chair and Professor, Department of Geology, Rowan University*

3:40pm - 4:00pm **Coffee Break**

4:00pm - 5:00pm **Session 2: Toward the Origin of Life**

George Cody, *Senior Staff Scientist, Earth and Planets Laboratory, Carnegie Institution for Science*

Kosuke Fujishima, *Associate Professor, Earth-Life Science Institute, Tokyo Institute of Technology*

5:00pm - 5:50pm **<u>Session 3: Panel Discussion "Japan-US Collaboration toward the Origin of Life"</u>**

All speakers

Moderator:

Lindsay E. Hays, *Program Scientist, Planetary Science Division, NASA Headquarters, National Aeronautics and Space Administration*

5:50pm - 6:00pm **Closing Remarks**

Koji Aribayashi, *Science Counselor of Embassy of Japan in the United States of America*

Foreword

The “Science-in-Japan” Forum was started in 1996 to be held annually in Washington D.C. by Dr. Masatoshi Koshiba as the Director of the Japan Society for the Promotion of Science (JSPS) Washington Office (WO) to promote the scientific cooperation between Japan and the United States.

The 25th Forum for 2022 is on “Sample Return and the Origin of Life” which was planned originally for June 2020 but has been postponed several times due to COVID-19.

I am glad that this Forum was revived finally and with new aspects. If this Forum had been held as originally planned, we would not have seen the results that we would learn today which were brought in by Hayabusa 2. Furthermore, we are now expecting the successful return of OSIRIS-Rex.

The two projects are competing and collaborating at the same time. This may be a good example of how collaboration and competition are productive in science.

This Forum is co-sponsored by AAAS, AGU, DOE, ELSI, ISSOL, JAXA, JpGU, NASA, NSF, US and Canada JSPS AA, and WPI. It was first conceived by Dr. M. Voytek and Dr. N. Yoshida of ELSI in 2019, followed by advice and assistance by Dr. K. Hirose (Director of ELSI), Dr. S. Watanabe (U. Nagoya), Dr. H. Kuninaka (Director of ISAS), and many others. (The affiliations are as they were at that time.) For the 2022 version, Dr. K. Kurita and Dr. T. Heenatigala of ELSI have collaborated with us as scientific advisers. I would like to express my gratitude to all of them.

I hope all the participants will find the Forum useful and enjoyable.

Kohji Hirata
Director, JSPS Washington Office

Understanding the origin of life through Solar System Explorations

Yasuhito Sekine
Professor, Earth-Life Science Institute (ELSI), Tokyo Institute of Technology
PhD in Earth and Planetary Science

How did life emerge on early Earth? This has been a long-standing question in natural science. Since the Miller-Urey experiment in 1953, the mystery of the origin of life on Earth became a topic that scientists can tackle and deal with. Since then, many previous studies undertook laboratory experiments that simulated early Earth environments and revealed that building materials of life can be formed by multiple abiotic processes. To form primitive life from the building materials, however, these materials need to be functionalized, forming a self-organized dynamic system. Where did the self-organization occur on early Earth? What are the key planetary factors that allow the self-organization and the emergence of life? Specifically, is the presence of atmosphere, wet-dry cycles, or hydrothermal systems necessary for the emergence of life? These questions will not be solved only by investigations of Earth's environments and laboratory experiments.
Recently, Solar System explorations have revealed the presence of habitable environments, where liquid water, organic matter, and chemical energy co-exist(ed), beyond Earth in the Solar System. This includes subsurface oceans of geologically active Europa and Enceladus, surface oceans/lakes on early Mars, and liquid methane oceans on Titan. Europa and Enceladus would have hydrothermal environments on the seafloor; however, there are no thick atmospheres and wet-dry cycles on these moons. On early Mars, wet-dry cycles would be dominated; yet, there would have been no deep oceans. Comparative explorations of these habitable environments beyond Earth will be able to provide insights into how particular planetary environments (the presences of atmosphere, wet-dry cycles, and hydrothermal system) can promote chemical evolution and help self-organization of organic molecules. Our generation could be the one to discover the evidence of life beyond Earth and, at the same time, the one to understand the key planetary factors required for the emergence of life on Earth.

I have been interested in chemistry, environments, and habitability of planets and satellites (including Europa, Enceladus, Titan, Mars, Ceres, Pluto, and Earth) in the Solar System. I have tackled these researches based on laboratory experiments, numerical modeling, and field surveys to interpret observational data obtained by spacecrafts.

Present

Professor, Earth-Life Science Institute (ELSI), Tokyo Institute of Technology

Education

Undergraduate 1997-2001. University of Tokyo, Japan, B.Sc. (Geophysics)
Graduate 2001-2006. University of Tokyo, Japan, Ph.D. (Earth and Planetary Science)
(2005-2006. Visiting Ph.D. student, NASA Ames Research Center, CA, USA)
Supervisor: Prof. Takafumi Matsui

Academic Career

2006-2007. Research Associate, Dept. of Earth & Planetary Science, University of Tokyo
2007- 2011. Assistant Professor, Dept. of Complexity Science & Engineering, University of Tokyo
2011-2014. Lecturer, Dept. of Complexity Science & Engineering, University of Tokyo
2014-2018 Associate Professor, Dept. Earth & Planetary Science, University of Tokyo
2018-present Professor, Earth-Life Science Institute (ELSI), Tokyo Institute of Techonology

Academic awards

2009. Outstanding Young Scientist Award, the Japan Society for Planetary Sciences
2012. Young Researcher Award, Geochemical Research Association, Japan
2016. Young Scientists' Prize, The Commendation for Science & Technology by the Minister of Education, Culture, Sports, Science, and Technology, Japan

Mars Sample Return: Future Planning for Understanding the Past

Lindsay E. Hays
Program Scientist, Planetary Science Division, NASA Headquarters
PhD in Geobiology

The joint NASA and ESA Mars Sample Return Campaign consists of multiple missions intended to be the first to collect and deliver scientifically selected samples from another planet. Currently, the Perseverance rover is operating on the surface of Mars collecting samples, and planning is underway for the missions to bring these back to Earth and for the facility to receive them once they are back. Analyses of these samples would offer unique science benefits that cannot be attained through orbital or landed missions that rely only on remote sensing and *in situ* measurements, respectively, and would address some of the most fundamental questions about the formation and evolution of the solar system, and potentially the origin and early evolution of life. Sample return missions such as OSIRIS-REx and Hayabusa illustrate how returned samples may be the only way to address some questions in planetary science and astrobiology. Many aspects of NASA's history of sample return from planetary bodies, and planetary exploration broadly, will need to be brought together, along with the development of new technologies, in order to see the success of the Mars Sample Return Campaign.

Lindsay Hays has been a Program Scientist in the Planetary Science Division (PSD) at NASA Headquarters since 2017. She is the Deputy Program Scientist for the Astrobiology Program and the Deputy Lead Scientist for Mars Sample Return; she is also the lead Program Officer for the Exobiology research program and the deputy for the Habitable Worlds research program. Dr. Hays' PhD and Postdoctoral research was in organic geochemistry, where she studied lipid biomarkers for environmental conditions at major biological transition points in Earth's history including mass extinction and radiation events. After a one-year managerial postdoctoral fellow at NASA Headquarters, where she served as the Editor-in-Chief for the 2015 Astrobiology Strategy, Dr. Hays moved to JPL and worked as the Sample Return Science System Engineer in the Mars Program Office.

Present

Program Scientist, Planetary Science Division, NASA Headquarters

Education

2001 - 2005 Undergraduate Student in Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Obtained B.Sc.

2005 - 2010 Graduate Student in Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Obtained Ph.D. (Thesis advisor; Dr. Roger Summons)

Academic/Professional Career

2010 - 2013 Post-Doctoral Fellow in Earth and Planetary Sciences
Harvard University (Dr. Ann Pearson's laboratory)

2013 - 2014 Post-Doctoral Management Fellow in Astrobiology Program
NASA Headquarters (Dr. Michael New and Dr. Mary Voytek)

2014 - 2017 Science System Engineer in Mars Program Office
Jet Propulsion Laboratory

2017 - today Program Scientist, Planetary Science Division
NASA Headquarters

Academic/Professional awards

2021 NASA HQ Unsung Hero Award (Washington, DC, US)
2016 JPL Voyager Award (Pasadena, CA, US)
2015 JPL Team Award (Pasadena, CA, US)
2013 NASA Postdoctoral Management Program Fellowship (Washington, DC, US)
2011 Agouron Geobiology Postdoctoral Fellowship (Cambridge, MA, US)

What we have learned from C-type asteroid Ryugu – From an astrobiological perspective

Shogo Tachibana
Professor, UTokyo Organization for Planetary and Space Science, University of Tokyo | Specially Appointed Professor, Institute of Space and Aeronautical Science, JAXA
PhD in cosmochemistry

The JAXA's asteroid sample return mission Hayabusa2 aims to explore C-type near-Earth asteroid (162173) Ryugu to unveil the origin of the Solar System and the Earth's ocean and life through proximity observation and sample analysis. Hayabusa2 collect samples at two surface locations on the asteroid. The spacecraft delivered its reentry capsule to the Earth in December 2020. Returned particles, ~5 g in total, well represent the surface of Ryugu from both spectroscopic and morphological point of views. The samples show the featureless low-reflectance nature in the visible wavelength range, consistent with the surface of Ryugu. The near infrared spectroscopy and spectroscopic imaging found that returned particles show absorption features of hydrated minerals, carbonates, and organic matter. Further detailed sample analysis by the Hayabusa2 initial analysis team has found that Ryugu is most similar to CI carbonaceous chondrites in many aspects. As in CI chondrites, Ryugu samples show an elemental composition well matching the Sun's elemental abundance, suggesting that Ryugu is one of the chemically most pristine samples in the Solar System. Ryugu samples consist mainly of hydrated silicates such as serpentine and saponite associated with carbonates (dolomite and breunnerite), iron sulfide (pyrrhotite), and iron oxide (magnetite), which is also consistent with mineralogy and petrology of CI chondrites that experienced severe aqueous alteration. The volatile concentrations are less than the solar composition but are as high as those in CI chondrites. In this talk I will review and discuss the results of Ryugu sample analysis from an astrobiological perspective.

I am interested in what was responsible for making diverse Solar System planets, including Earth. I have especially aimed at understanding the chemical evolution of the early Solar System by combining laboratory experiments, analysis of extraterrestrial materials, astronomical observation, modeling, and Solar System exploration. My research group has conducted laboratory experiments on (1) evaporation/condensation/gas-solid (melt) reaction of mineral dust and silicate melts in protoplanetary disks, (2) photochemistry of ice in molecular clouds, and (3) mineral-water-organics interaction in small bodies. I have put constraints on physicochemical conditions that early Solar System materials experienced during their evolution prior to planet formation. In order to obtain pristine materials with the geologic context, I have been involved in Hayabusa2 and OSIRIS-REx asteroidal sample return missions. I have worked to set the scientific goal of Hayabusa2, develop the sample acquisition system, and lead the sample analysis. I have also been involved in astronomical observations of metal-bearing gas molecules around an evolved star and a massive proto star candidate and in theoretical modeling of chemical reactions in protoplanetary disks. I believe that these studies open a new frontier in cosmochemistry.

Present

Professor, UTokyo Organization for Planetary and Space Science, Univ. Tokyo
Specially Appointed Professor, Institute of Space and Aeronautical Science, JAXA

Education

1991 - 1995 Undergraduate Student in the Faculty of Science,
Osaka University, Obtained B.Sc.
1995 - 2000 Graduate Student in the Department of Earth and Space, Graduate School of Science, Osaka University, Obtained Ph.D. (Thesis advisor; Dr. Akira. Tsuchiyama)

Academic Career

2000 - 2003 Research Fellow of the Japan Society for the Promotion of Science
2003 - 2012 Research Associate, Department of Earth and Planetary Sciences, Univ. Tokyo
2002 - 2013 Lecturer, Department of Natural History of Sciences, Hokkaido Univ.
2013 - 2017 Associate Professor, Department of Natural History of Sciences, Hokkaido Univ.
2017 - Professor, UTokyo Organization for Planetary and Space Science, Univ. Tokyo
2019 - Specially Appointed Professor, Institute of Space and Aeronautical Science, JAXA

Academic awards

2022 Fellow, The Meteoritical Society
2020 Space Engineering Division Award, Japanese Engineering Society
for the Hayabusa2 Sampler Team
2020 The Geochemical Journal Award – Orthous-Daunay F.-R., Piani L., Flandinet L., Thissen R., Wolters C., Vuitton V., Poch O., Moynier F., Sugawara I., Naraoka H. and Tachibana S. (2019) Ultraviolet-photon fingerprints on chondritic large organic molecules. Geochem. J. 53, 21-32.
2016 The Paul W. Gast Lectureship
2008 The Meteoritical Society Nier Prize
2007 The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, The Young Scientists' Prize
2007 The Mineralogical Society of Japan Award for Young Researchers
2006 The Geochemical Society of Japan Award for Young Researchers
2005 The Japanese Society for Planetary Sciences Award for Young Researchers

OSIRIS-REx: Sample Science and the Geologic Context of the Returned Sample

Harold C. Connolly Jr.
Founding Chair and Professor, Department of Geology, Rowan University
PhD in Geological Sciences

The OSIRIS-REx mission is part of NASA's New Frontiers 3 program and has the main goal of returning to Earth at least 60 g of pristine material from the carbonaceous asteroid, 101955 Bennu. After a survey of the asteroid lasting almost two years, the spacecraft flawlessly collected and safely stowed sample from Bennu in October of 2020, departing for Earth in May of 2021. The spacecraft is on its way to drop-off the precious, rocky material known as regolith now contained within the spacecraft's sample return capsule to the Utah desert in September 2023. The sample analysis team will spend two years characterizing the returned sample to test hypotheses that will illuminate the origin and history of asteroid Bennu, its components, Solar System formation, and provide insight into the possible origins of life. Based on our finding at Bennu, we anticipate that the sample will be rich water and organics and contain other evidence of geological processing within the parent asteroid of Bennu! The talk will provide an overview of the mission, the discoveries made while visiting the asteroid and the relationship of these findings to sample science. The talk will also explain how and why we will analyze the returned sample and highlight how the analysis of the Hayabusa2 sample has helped to shape the OSIRIS-REx sample analysis plan and team culture. The OSIRIS-REx science team is international with significant collaborations with JAXA and the Hayabusa2 team. OSIRIS-REx and Hayabusa2 teams have and continue to exchange scientific and engineering data, lessons learned, and aspects of their cultural systems that focus on improving communicating and maximizing the science finding of each mission.

Harold C. Connolly Jr. is the founding chair and a professor within the Department of Geology at Rowan University. Prior to joining his current university, he was a professor at the City University of New York. He is a research associate at the American Museum of Natural history and a visiting associate at the Lunar and Planetary Laboratory of the University of Arizona. He has also held visiting positions at Hokkaido University and the University of Tokyo. Professor Connolly is a geologist who specializes in problems founded in petrology and geochemistry through the study of primitive planetary meteorites known as chondrites. His research aims to constrain the processes and timing of the formation and evolution of rocky bodies within the Solar System through investigations of such meteorites with an emphasis on linking their formation to astrophysical processes, asteroids, and cosmochemistry. He is the mission sample scientist and co-investigator of the OSIRIS-REx asteroid sample return mission. Professor Connolly is also a co-investigator of the Japan Aerospace Exploration Agency's asteroid sample return mission, Hayabusa2. He has mentored numerous students during his career, from undergraduates to the PhD level, and is committed to educating the next generation of scientists with an emphasis on international collaborations.

Present

Founding Chair and Professor, Department of Geology, Rowan University

Education

1996 Ph.D. in Geological Science, Rutgers University.
Petrology - Geochemistry - Meteoritics - Cosmochemistry
Thesis advisor: Prof. Roger H. Hewins

1991 M.S. in Geological Sciences, Rutgers University.
Thesis advisor: Prof. Roger H. Hewins

1988 B.A. in Geological Sciences, Rutgers University.
Honor thesis advisor (Chondrule formation): Prof. Roger H. Hewins
Research advisor (Devonian paleo-communities): Prof. G. McGhee

Academic Career

2016- Founding Chair and Professor, Department of Geology, Rowan University.

2013-2016 Deputy Executive Officer of the Earth and Environmental Sciences Ph. D. program, The Graduate School of CUNY.

2003- Visiting scientist, Lunar and Planetary Laboratory, University of Arizona.

2001- Research Associate, Department of Earth and Planetary Sciences, American Museum of Natural History

2001-2015 Faculty, Earth and Planetary Sciences, Department of Physical Sciences, Kingsborough Community College, CUNY (Professor 2009-2015).

1998-2001 Research Scientist, Division of Geological and Planetary Sciences, California Institute of Technology.

Academic awards

2014 Elected Fellow of the international Meteoritical Society.
2006 Asteroid 1981 EV19 renamed to Asteroid (6761) Haroldconnolly.
1999 Antarctic Service Medal, issued by the US Congress and Department of Navy.

Studies of the Ancient Organic Chemistry in the early Solar System

George D. Cody
Senior Staff Scientist, Earth and Planets Laboratory, Carnegie Institution for Science
PhD in Geosciences

Carbonaceous Chondritic meteorites constitute some of the most "primitive" Solar System Material that can be studied on Earth. These meteorites are fragments of ancient planetesimals that were too small to differentiate into a mantle and core. Organic carbon, in the form of a complex macromolecular phase (referred to as Insoluble Organic Matter, IOM), is relatively abundant, constituting ~ 2 wt % of a carbonaceous chondrite. Molecular analysis of IOM, primarily through solid state Nuclear Magnetic Resonance (NMR) spectroscopy reveals that considerable information regarding processes that occurred within the planetesimal(s) is revealed in the structure and isotopic composition of IOM. Most notably, it is clear that both long and short hydrothermal processes systematically evolve IOM molecular structure and hydrogen isotopic compositions revealing that after accretion such planetesimals were chemically active for potentially millions of years driven by the heat generated from radioactive decay of certain isotopes (e.g., ^{26}Al). Establishment of persistent dynamic organic reaction networks clearly operated within these planetesimals continuously producing organic molecules that are familiar in extent intermediary metabolism. As such, studies of carbonaceous chondritic planetesimals may serve as a guide towards understanding similar chemistry that presumably occurred on the primitive Earth which would have been a necessary (but not sufficient) prerequisite to life's origins.

George Cody's research focuses on understanding post accretional history of primitive solar System objects, e.g. carbonaceous chondritic meteorites, asteroids and comets as recorded in the organic chemistry residing within these materials. He was a member of the preliminary examination team for the NASA Stardust Mission, a sample return
Mission from Comet Wild2/81P applying Carbon μXANES spectroscopy to characterize organics. He is currently a Deputy Lead on the Insoluble Organic Matter Team of the JAXA Hyabusa II sample return mission from the asteroid Ryugu applying Carbon μXANES spectroscopy and 1H solid state NMR to characterize organics, and he is a member of the Organics Working Group of the NASA OSIRIS-Rex sample return mission from the asteroid Bennu where in 2023 he will be in charge of obtaining ^{13}C and ^{1}H solid state NMR from insoluble organic matter isolated from chondritic particles captured off the surface of Bennu.

Present Senior Research Scientist, Earth and Planets Laboratory, Carnegie Institution for Science

Education

1978 - 1982 Undergraduate Student in the Faculty of Geosciences, The University of Massachusetts, Amherst, B.Sc.

1988 - 1992 Graduate Student in the Department of Geosciences, Department of Geosciences, The Pennsylvania State University, Obtained Ph.D. (Thesis advisors; Drs. Alan Davis and Patrick Hatcher)

Academic Career

1992 - 1995 Post-Doctoral Fellow at the Chemistry Division, Argonne National Laboratory

1995 - 2022 Staff Scientist at the Earth and Planets Laboratory (formerly known as the Geophysical Laboratory), Carnegie Institution for Science

Academic awards

1990 Texaco Fellowship, PSU

1991 Mining and Mineral Resources Fellowship, PSU

1991 Phi Kappa Phi-Graduate Honors Society, PSU

1994 Enrico Fermi Scholar, Argonne National Laboratory

1996 Japanese Society for the Promotion of Science Fellowship, GL

1999 Best Oral Presentation: *Fuel Chemistry at Nanoscales*: Presented at the Hydrocarbon Resources Gordon Conference, Ventura

2010 Distinguished Visiting Scholar, California Institute of Technology

Macromolecular origins of life

Kosuke Fujishima
Associate Professor, Earth-Life Science Institute, Tokyo Institute of Technology
PhD in Systems Biology

One of the big mysteries concerning the origins of life (OoL) is how life came to utilize functional polymers such as protein and RNA/DNA. In modern biology, protein is responsible for maintaining a combination of chemical reactions and cellular structure. In comparison, DNA is a carrier of genetic information, while RNA serves as both an information carrier and catalyst. Further, RNA is the principal constituent of protein synthesis machinery known as the ribosome, suggesting a deep root of RNA-protein coevolution. Previous developments in the OoL research have substantiated the prebiotic emergence of the protein and RNA precursor molecules (amino acids and nucleotides) on early Earth and in space. However, considerable uncertainty still lies between modern biochemistry and prebiotic chemistry. Here, the acceleration of synthetic biology has enabled us to address the narrative of how early hypothetical polymers could gain function during the origin and evolution of life.

In this talk, I will summarize several key OoL studies, including our recent efforts that shed light on the primordial structure and function of early protein and RNA, and further discuss their evolutionary trajectory concerning the early Earth environment.

In my lab, we are currently using various synthetic biology tools and biochemical methods to reconstruct and analyze the properties of primitive proteins, RNAs and their precursors through *in vitro* evolution experiments. We are also working with geochemists to experimentally investigate in which primitive terrestrial and extraterrestrial environments are favorable for producing and activating the precursor molecules to form functional polymers. Our long-term goal is to provide new insight into the evolution/coevolution of primordial macromolecules to understand their contribution towards the origin of life on Earth and beyond.

Present
Associate Professor, Earth-Life Science Institute, Tokyo Institute of Technology

Education
2001 - 2005 Undergraduate Student in the Faculty of Environment and Information, Keio University, Obtained B.Sc.
2005 - 2009 Graduate Student in the Graduate School of Media and Governance, Keio University, Obtained Ph.D. (Thesis advisor; Dr. Masaru Tomita)

Academic Career
2009 - 2011 Post-Doctoral Fellow at the Institute for Advanced Biosciences, Keio University (Dr. Akio Kanai's laboratory)
2011 - 2013 JSPS Overseas Post-Doctoral Fellow at the NASA Ames Research Center (Dr. Lynn Rothschild's laboratory)
2013 - 2015 Assistant Research Scientist at the NASA Ames Research Center (Dr. Lynn Rothschild's laboratory)
2016 - 2018 EON Postdoctoral Fellow at the Earth-Life Science Institute, Tokyo Institute of Technology
2019 - 2020 Specially Appointed Associate Professor at the Earth-Life Science Institute, Tokyo Institute of Technology
2020 - Associate Professor at the Earth-Life Science Institute, Tokyo Institute of Technology

Academic awards
2016 WIRED Audi INNOVATION AWARD 2016
2016 iGEM 2016 Best Measurement project (Advisor of Stanford-Brown joint team)
2015 iGEM 2015 Best Manufacturing project (Advisor of Stanford-Brown joint team)
2012 Best Poster Presentation, Gordon Research Seminar (GRS): Origin of Life, USA
2011 28th Inoue Research Award for Young Scientist, Inoue Foundation for Science, Japan

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