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Ocean world habitability and the origin of life

Geologically-active icy moons around Jupiter and Saturn, such as Europa and Enceladus, are known to possess subsurface oceans beneath the icy crust. According to the in-situ chemical analysis of plume materials erupting from Enceladus' subsurface ocean, the Cassini spacecraft has revealed water chemistry of the ocean – that is, seawater pH is alkaline (pH ~ 10) and Na-Cl-carbonate-rich composition. Planetary habitability can be defined as a planetary-scale system that can develop and sustain ingredients of life—liquid water, bioessential elements, and energy—over geological time. In this regard, Enceladus possesses a habitable world beneath the icy shell. This moon has a global subsurface interacting with a rocky core, shere a wide variety of organic matter and chemical energy supported by hydrothermal activities are available. Among the major bioessential elements for Earth's life, phosphorus (P) is usually the least abundant in natural aqueous systems and has been a limiting nutrient of primary productivity over Earth's history. In ocean worlds, such as Enceladus, in the outer Solar System, there may be a more drastic depletion of P than Earth due to lack of surface lands, possibly limiting the emergence and activity of life similar to the form of Earth's life.

Here we report the discovery of two phosphate-bearing minerals in ice grains emitted by Enceladus based on the analysis by Cassini's Cosmic Dust Analyser. Our observational results are evidence that phosphorus is readily available in Enceladus' ocean, with anomalously high concentrations–at least 100 times higher than Earth's oceans. To understand the causative mechanism of the enrichment of phosphate in Enceladus' seawater, we performed hydrothermal reaction experiments and geochemical modeling. We find that alkaline (pH ~10) and carbonate-rich aqueous environments are essential for the phosphate enrichment, where calcium phosphate minerals are thermodynamically unstable compared to calcium carbonate minerals, releasing phosphate into liquid phase. Such alkaline carbonate-rich aqueous environments are commonly achieved in icy ocean worlds beyond the CO2 snowline of the Solar System. Phosphate could have been also enriched in similar alkaline carbonate-rich aqueous environments on early Earth, where earliest life on Earth might have utilized phosphorus as components of its building materials.

CV

Education

1997-2001 B.Sc. in Geophysics and
2001-2006 Ph.D. in Earth and Planetary Science, University of Tokyo, Japan
Supervisor: Prof. Takafumi Matsui
M.S. Thesis "An experimental study on Fischer-Tropsch catalysis and its implications for impact phenomena and solar nebula chemistry
Ph.D. Thesis "The role of organic haze in the hydrogen cycle on Titan"
2005-2006 Visiting Ph.D. student, NASA Ames Research Center, CA, USA

Professional Experience and Appointments

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 Professor, Earth-Life Science Institute (ELSI), Tokyo Institute of Technology
2022 Director, Earth-Life Science Institute (ELSI), Tokyo Institute of Technology

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
2022 JSPS Prize, Japan Society for the Promotion of Science, Japan

Published Peer review papers

85 peer-reviewed papers have been published, fife selected papers are shown.

Postberg, F., **Y. Sekine**, F. Klenner, C. R. Glein, Z. Zou, B. Abel, et al. "Detection of Phosphates Originating from Enceladus' Ocean" ***Nature*** in press, 2023

Sekine, Y.*, H. Genda*, S. Kamata, T. Funatsu "The Charon-forming giant impact as a source of Pluto's equatorial dark regions" ***Nature Astronomy***, 1, 0031, 1–6, 2017. (* these authors contributed equally on this work.)

Sekine, Y., T. Shibuya, F. Postberg, H.-W. Hsu, K. Suzuki, Y. Masaki, et al. "High-temperature water-rock interactions and hydrothermal environments in the chondrite-like core of Enceladus" ***Nature Communications***, 6: 8604, 1–8, 2015.

Hsu, H-W.*, F. Postberg*, **Y. Sekine***, T. Shibuya, S. Kempf, M. Horanyi, et al. "Ongoing hydrothermal activities within Enceladus" ***Nature***, 519, 207-210, 2015 (* these authors contributed equally contributed on this work.)

Sekine, Y., H. Genda, S. Sugita, T. Kadono, T. Matsui "Replacement and late formation of atmospheric N2 on undifferentiated Titan by impacts" ***Nature Geoscience***, 4, 359–362, 2011.