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Dark energy ecosystem driven by chemical disequilibrium in the earth and even extraterrestrial bodies

Over the past 40 years, researchers have explored deep-sea and subseafloor environments around the globe and studied a number of microbial ecosystems, sometime called as Dark Energy Ecosystems. Multi-omics and interdisciplinary approaches have recently provided new insights into the compositional and functional diversity of microbial life living in the dark world. It is now evident that the most fundamental driving force is chemical disequilibrium at a given habitat, which controls the outline of microbial community, in particular, the magnitude and mode of chemolithotrophic primary production and the subsequent biogeochemical energy and element cycles.

This was originally predicted by a thermodynamic calculation of energy mass balance of chemolithotrophic metabolisms in a simulated deep-sea hydrothermal vent environment. The prediction, called as McCollom and Shock's prediction, has been later justified by a number of microbiological studies in various deep-sea hydrothermal vent environments all over the world. Once the prediction could be realized as a principle, the principle can be applied not only to understanding of dark energy ecosystems other than in deep-sea hydrothermal vents but also to reconstruction of the most ancient ecosystem in the Earth and even to searching the possible extraterrestrial ecosystems in our solar system.

On the other hand, recent geoelectrochemical studies of deep-sea hydrothermal environments have revealed that the chemical disequilibrium can drive not only the chemolithotrophic primary production but also the possible electrotrophic primary production and even abiotic electrosynthesis. They represent a new Dark Energy Ecosystems and may be key processes to origin of earthly life.

CV

EXPERIENCE – APPOINTMENTS

Since April 2019	Director General at Institute for Extra-cutting-edge Science and Technology Avant-garde Research (X-star),
2019	Visiting Professor at Exploratory Research Center on Life and Living Systems (ExCELLS), National Institutes of Natural Sciences (NINS)
2014-2019	Director at Department of Subsurface Geobiological Analysis and Research (D-SUGAR)
2012-2016	Principal Investigator at Earth Life Science Institute, Tokyo Institute for Technology
2012-2014	Visiting Professor at Japan Aerospace Exploration Agency (JAXA)
2005-2014	Program Director at JAMSTEC. Subsurface Geobiology Advanced Research (SUGAR) Project & Precambrian Ecosystem Laboratory, Japan Agency for Marine-Earth Science & Technology (JAMSTEC).
2002-2005	Group Leader at JAMSTEC. Subsurface Geobiology Advanced Research (SUGAR) Project & Precambrian Ecosystem Laboratory, Japan Agency for Marine-Earth Science & Technology (JAMSTEC).
1999-2002	Research Scientist at JAMSTEC. Subsurface Geobiology Advanced Research (SUGAR) Project & Precambrian Ecosystem Laboratory, Japan Agency for Marine-Earth Science & Technology (JAMSTEC).

EXPERIENCE – EDUCATION & PROFESSIONAL PREPARATION

1998-1999	Post-doctoral fellow at Department of Environmental Microbiology, Pacific Northwest National Laboratory (PNNL)
1997-1999	Post-doctoral fellow at JAMSTEC supported by JST
1997-1997	Post-doctoral fellow at Kyoto University supported by JSPS
1995-1997	PhD Division of Applied Biosciences, Graduate School of Agriculture, Kyoto University
1995-1996	Visiting scientist, School of Oceanography, University of Washington
1988-1994	BS and MS, Kyoto University

RESEARCH INTERESTS, KEY WORDS

Astrobiology / Geobiology / Early evolution of Earth and Life / Deep-sea hydrothermal vent / Deep biosphere / Microbial ecology / 'Extreme' habitats / Cultivation / Molecular biology / Relationships between the microbial activities and the biogeochemical cycles / Ecosystem functioning / High-pressure.

POSITIONS OF RESPONSIBILITY and refereeing expertise

Membership in professional societies - administrative responsibilities

- Member of the Editorial Board of Archaea (2005-)
- Member of the Editorial Board of Microbes and Environment (2009-2022)
- Editor-in-chief of Microbes and Environment (2017-2022)
- Reviewer for scientific funding for: NSF Biosciences, NSF Geosciences, ESF Geosciences & National Funding Agency in European countries.

AWARDS

2002 The 1st research promotion award of Japanese Society for Extremophiles
2004 The 1st interdisciplinary research & development award of JAMSTEC

2007 The 6th interdisciplinary research & development award of JAMSTEC
2012 The 8th research promotion award of the Japan Academy
2012 The 8th research award of the Japan Society for Promotion of Science
2012 The grand prix (Scientist) of Change Maker of The Year 2012 (Nikkei BP and Caltier Japan)
2013 The commendation of researcher in JAMSTEC 2012
2014 The commendation of researcher in JAMSTEC 2013
2017 Progress in Earth and Planetary Science (PEPS) The Most Cited Paper Award 2017

SCIENTIFIC PRODUCTION

Representative peer reviewed research papers, selection last 4 years

1. Nunoura, T., Chikaraishi, Y., Izaki, R., Suwa, T., Sato, T., Harada, T., Mori, K., Kato, Y., Miyazaki, M., Shimamura, S., Yanagawa, K., Shuto, A., Ohkouchi, N., Fujita, N., Takaki, Y., Atomi, H., and Takai, K. (2018) A primordial and reversible TCA cycle in a facultatively chemolithoautotrophic thermophile. Science, 359, 559-563.
2. Kitadai, N., Nakamura, R., Yamamoto, M., Takai, K., Li, Y., Yamaguchi, A., Gilbert, A., Ueno, Y., Yoshida, N., and Oono, Y. (2018) Geoelectrochemical CO production: Implications for the autotrophic origin of life. Science Adv., 4, eaao7265.
3. Nunoura, T., Nishizawa, M., Hirai, M., Shimamura, S., Harnvoravongchai, P., Koide, O., Morono, Y., Fukui, T., Inagaki, F., Miyazaki, J., Takaki, Y., Takai, K. (2018) Microbial diversity in sediments from the bottom of the Challenger Deep, the Mariana Trench. Microbes Environ, 33, 186-194.
4. Yamamoto, M., Nakamura, R., Takai, K. (2018) Deep-sea hydrothermal fields as natural power plants. ChemElectroChem, 5, 2162-2166.
5. Igisu, M., Ueno, Y., Takai, K. (2018) FTIR microspectroscopy of carbonaceous matter in ~ 3.5 Ga seafloor hydrothermal deposits in the North Pole area, Western Australia. Prog. Earth Planet. Sci., 5, 85.
6. Takai, K. (2019) Limits of Terrestrial Life and Biosphere. In: Yamagishi A., Kakegawa T., Usui T. (eds), Astrobiology, Springer, Singapore, p. 323-344.
7. Kitadai, N., Nakamura, R., Yamamoto, M., Takai, K., Yoshida, N., Oono, Y. (2019) Metals likely promoted protometabolism in early ocean alkaline hydrothermal systems. Sci. Adv., 5, eaav7848.
8. Okada, S., Chen, C., Watsuji, T., Nishizawa, M., Suzuki, Y., Sano, Y., Bissessur, D., Deguchi, S., Takai, K. (2019) The making of natural iron sulfide nanoparticles in a hot vent snail. Proc. Natl. Acad. Sci. USA, 116, 20376-20381.
9. Imachi, H., Nobu, M. K., Nakahara, N., Morono, Y., Ogawara, M., Takaki, Y., Takano, Y., Uematsu, K., Ikuta, T., Ito, M., Matsui, Y., Miyazaki, M., Murata, K., Saito, Y., Sakai, S., Song, C., Tasumi, E., Yamanaka, Y., Yamaguchi, T., Kamagata, Y., Tamaki, H., Takai, K. (2020) Isolation of an archaeon at the prokaryote–eukaryote interface. Nature, 577, 519–525.
10. Miyazaki, J., Ikuta, T., Watsuji, T., Abe, M., Yamamoto, M., Nakagawa, S., Takaki, Y., Nakamura, K., Takai, K. (2020). Dual energy metabolism of the Campylobacterota endosymbiont in the chemosynthetic snail Alviniconcha marisindica. ISME J., 14, 1273-1289.
11. Wheat, C. G., Seewald, J. S., Takai, K. (2020). Fluid transport and reaction processes within a serpentinite mud volcano: South Chamorro Seamount. Geochim. Cosmochim. Acta, 269, 413-428.

12. Sun, J., Chen, C., Miyamoto, N., Li, R., Sigwart, J. D., Xu, T., Sun, Y., Wong, W. C., Ip, J. C., Zhang, W., Lan, Y., Bissessur, D., Watsuji, T.., Kayama-Watanabe, H., Takaki, Y., Ikeo, K., Fujii, N., Yoshitake, K., Qiu, J..-W., Takai, K., Qian, P. Y. (2020) The Scaly-foot Snail genome and implications for the origins of biomineralised armour. Nature Comm., 11, 1657.
13. Nishizawa, M., Matsui, Y., Suda, K., Saito, T., Shibuya, T., Takai, K., Hasegawa, S., Yano, H. (2020) Experimental simulations of hypervelocity impact penetration of asteroids into the terrestrial ocean and benthic cratering. J. Geophys. Res., 125: e2019JE006291.
14. Kitadai, N., Nakamura, R., Yamamoto, M., Okada, S., Takahagi, W., Nakano, Y., Takahashi, Y., Takai, K., Oono, Y. (2021) Thioester synthesis through geoelectrochemical CO2 fixation on Ni sulfides. Comm. Chem., 4, 1-9.