Prediction of chemolithtrophic living ecosystems in deep-sea hydrothermal vents in the Hadean Earth and the modern Enceladus.

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Introduction: Over the past 35 years, researchers have explored seafloor deep-sea hydrothermal vent environments around the globe and studied a number of microbial ecosystems. Bioinformatics and interdisciplinary geochemistry-microbiology approaches have provided new ideas on the diversity and community composition of microbial life living in deep-sea vents. In particular, recent investigations have revealed that the community structure and productivity of chemolithotrophic microbial communities in the deep-sea hydrothermal environments are controlled primarily by variations in the geochemical composition of hydrothermal fluids. This was originally predicted by a thermodynamic calculation of energy yield potential of various chemolithotrophic metabolisms in a simulated hydrothermal mixing zone. The prediction has been finally justified by the relatively quantitative geomicrobiological characterizations in various deep-sea hydrothermal vent environments all over the world.

Thus, there should be a possible principle that the thermodynamic estimation of chemolithotrophic energy yield potentials could predict the realistic chemolithotrophic living community in any of the deep-sea hydrothermal vent environments in this planet.

Hadean deep-sea hydrothermal systems: Thermdynamic calculations of mixing between Hadean seawater and hydrothermal fluid were carried out to predict distribution of mineral precipitates and redox reactions that could occur in Hadean submarine alkaline hydrothermal systems associated with the serpentinization of ultramafic rocks. The modeling indicates that potential mineral precipitates in the mixing zone (chimney structures and hydrothermal deposits) could consist mainly of iron sulfides but also of ferrous serpentine and brucite, siderite, and ferric iron-bearing minerals such as goethite, hematite and/or magnetite as minor phases. The precipitation of ferric iron-bearing minerals suggests that chemical iron oxidation could be caused by pH shift even under anoxic condition. Hydrogenotrophic methanogenesis and acetogenesis - long considered the most ancient forms of biological energy metabolisms - are able to achieve higher maximum energy yield (>0.5 kJ per kg hydrothermal fluid) than those in the modern serpentinization-associated seafloor hydrothermal systems (e.g., Kairei field). In addition, the recently proposed methanotrophic acetogenesis pathway was thermodynamically investigated. But it is known that methanotrophic acetogenesis would require additional exergonic reactions to compensate the endergonic methane-to-methanol conversion reaction at the oxidative entry to the metabolic pathway. Our calculations support the view that this thermodynamic barrier could be overcome by the reduction of nitrate in seawater at low temperature, as previously suggested. However, the thermodynamic calculations also revealed that the reduction of ferric iron-bearing minerals would occur at the outer margin and within the hydrothermal chimney wall and deposit. The maximum available energy of iron-reducing methanotrophic acetogenesis was calculated to be 0.2-0.3 kJ per kg hydrothermal fluid. These results suggest that iron reduction had the potential to accelerate methanotrophy in tandem with nitrate and that the Hadean hydrothermal mixing zone was energetically more favorable to methanotrophy than previously thought.

Modern Enceradus deep-sea hydrothermal systems: In 2005, a spacecraft Cassini discovered a water vapour jet plume from the sole pole area of the Saturnian moon Enceladus. The chemical composition analyses of Cassini's mass spectrometer strongly suggested that the Enceladus could host certain extent of extraterrestrial ocean beneath the surface ice sheet and possible ocean-rock hydrothermal systems. An experimental study simulating the reaction between chondritic material and alkaline seawater reveals that the formation of silica nanoparticles requires hydrothermal reaction at high temperatures. Based on these findings, we attempt to build a model of possible hydrothermal fluid/rock reactions and bioavailable energy composition in the mixing zones between the hydrothermal fluid and the seawater in the Enceladus subsurface ocean. The results indicate that the pH of fluid should be highly alkaline and H_2 concentration in the fluid is elevated up to several tens mM through the water/rock reaction. The physical and chemical condition of the extraterrestrial ocean environments points that the abundant bioavailable energy is obtained maximally from redox reactions based on CO_2 and H_2 but not from with other electron accepters such as sulfate and nitrate. Our model strongly suggests that the abundant living ecosystem sustained by hydrogenotrophic methanogensis and acetogenesis using planetary inorganic energy sources should be present in the Enceladus hydrothermal vent systems and the ocean.