

海底熱水系の物理・化学的多様性と 化学合成微生物生態系の存在様式

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Physical and Chemical Diversity of Seafloor Hydrothermal Systems and Presentation of Associated Chemolithoautotrophic Ecosystem

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Abstract

Deep-sea hydrothermal vents are among the habitats that host the most diverse microbial communities on the Earth. It is promised that hydrothermal vent microbial communities play a major role in the circulation of energy and materials in the global oceanic and suboceanic environments, and even provide important insights into the origin and early evolution of life on the Earth and extraterrestrial life on other planets and moons. Deep-sea hydrothermal vent ecosystems are strongly dependent on the primary production of symbiotic and free-living chemolithoautotrophic microorganisms that can obtain energy from inorganic substances such as H_2S , CO_2 , H_2 , and CH_4 derived from hydrothermal vent fluids. The diversity and abundance of these energy and carbon sources at hydrothermal vent fluids are, in turn, controlled by subseafloor physical and chemical processes such as fluid-rock interactions and phase-separation and -partition of fluids. Therefore, linkage between rock (magma), hydrothermal fluid, and ecosystem is a key to understanding how deep-sea hydrothermal ecosystems are generated and sustained. In this article, we approach this whole “Rock-Fluid-Ecosystem linkage” with the two separate sub-linkages of “Rock-Fluid linkage” and “Fluid-Ecosystem linkage”, which have not been addressed by the individual research fields of the Geochemistry of Hydrothermal Systems and Hydrothermal Vent Microbiology, respectively. Here, we overview the progress of understanding the “Rock-Fluid” and “Fluid-Ecosystem” linkages, both of which will establish the basis for an integrated “Rock-Fluid-Ecosystem linkage”.

In seafloor hydrothermal systems, three major physical and chemical processes affect hydrothermal fluid chemistry: (1) chemical interactions between rock and hydrothermal fluid, (2) volatile inputs from magmas, and (3) phase-separation and -partition of hydrothermal fluids. The chemistry of hydrothermal fluids is primarily controlled by subseafloor fluid-rock interactions, and chemical behavior during fluid-rock interactions is constrained by phase equilibria among primary and secondary minerals in rocks. Therefore, the chemical compositions of rocks and pressure-temperature conditions of fluid-rock reactions play dominant roles in controlling fluid chemistry. Volatile inputs from magma to hydrothermal fluid are conspicuous in arc-back arc hydrothermal systems, due to the remarkable enrichment of

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volatiles (*e.g.*, H₂O, CO₂, and SO₂) in arc-back arc magmas. Massive CO₂ inputs into hydrothermal fluids result in the oversaturation and segregation of CO₂-rich fluid observed as CO₂ bubbles at hydrothermal vents. At depths greater than 700 m, the segregated CO₂ is transformed into liquid and sometimes clathrate-hydrate with decreasing temperature due to mixing with cold seawater and/or conductive cooling. Magmatic input of SO₂ gas also has an extraordinary impact on fluid chemistry with dissolution reactions such as drastic increases of oxygen fugacity and proton activity. The former results in relatively oxidic and thus hydrogen-poor hydrothermal fluids, and the latter causes the highly acidic nature of this type of hydrothermal fluids. Sharp changes of pH conditions of the fluid, in turn, cause fluid-rock interactions, resulting in unusual compositions of end-member hydrothermal fluids such as considerably high Mg, Al, and SO₄²⁻ concentrations. Heating at the reaction zone and/or depressing during upwelling cause phase-separation of hydrothermal fluid. At pressures and temperatures less than the critical point, boiling the fluid produces a low-Cl vapor, while condensation of high-Cl brine droplets take place above the critical point. During the phase-separation, dissolved gasses and neutral species are selectively partitioned into low-Cl vapor phase. In contrast, charged cations are preferentially distributed to the high-Cl brine phase. The subcritical/supercritical phase separations together with subsequent segregation and/or remixing of vapor and brine produce hydrothermal vent fluids with a wide range of chemical compositions.

The “Fluid-Ecosystem” linkage is much less understood than the “Rock (magma)-Fluid linkage”. Two research strategies have been undertaken: (1) geochemical prediction of diversity and abundance in potential energy and carbon metabolisms based on the thermodynamic calculation of the physical and chemical conditions of the habitats and (2) microbiological characterization of functionally active, metabolically diverse microbial communities associated with hydrothermal fluid chemistry. Preliminary but quite significant relevance between the hydrothermal fluid chemical and microbial components is now being denoted. Here, several examples and speculations are introduced and discussed.

Finally, the future research direction for understanding the integrated “Rock-Fluid-Ecosystem linkage” is presented. We hope this overview will be the first step in studying the geology, geochemistry and microbiology of deep-sea hydrothermal systems for young students and researchers, and for bridging the geo- and bio-sciences related to deep-sea hydrothermal activities. In addition, we hope this article will stimulate interdisciplinary discussions and collaborations within the framework of a new research project called Subseafloor Hydrothermal Fluid Rivers, starting from 2008.

Key words : deep-sea hydrothermal system, Rock-Fluid-Ecosystem linkage, fluid-rock interaction, magmatic input, phase-separation, H₂ concentration, energy and carbon metabolisms, chemolithoautotrophs, microbial communities

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