

Impact-induced hydrothermal systems on early Earth: CH₄ production and the origin of life

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Introduction

Hydrothermal systems would be a promising emergence place of life. However, organic synthesis, including CH₄ formation, from CO₂ are inhibited under hydrothermal conditions even high abundances of H₂ without metallic catalysts [1,2]. On the other hand, recent planetary formation theory suggests occurrences of impacts of differentiated bodies (e.g., metallic small bodies), which would have provided Fe-Ni alloy into the impact crater cavities [3]. Here, we perform both hydrological modelling and hydrothermal experiments to examine whether prebiotic organic synthesis could occur within an impact crater of differentiated bodies on early Earth.

Hydrological Modelling

Using a hydrological model (GETFLOWS), we reproduce hydrothermal groundwater circulations emerged within an impact crater with diameter of ~200 km. Our results suggest that hydrothermal circulations would be closed within the crater cavity when the heat source is 200°C or greater. The experienced temperature of hydrothermal fluids would be ~200°C in the hydrothermal circulations.

Hydrothermal experiments

We conduct hydrothermal experiments using a ¹³CO₂-containing, NaCl solution and a mixture of synthesized basalt and Fe-Ni alloy at 200°C and 300°C, 300 bars. We find the formation of ¹³CH₄ (~a few mM), ¹³C₂H₆, and HCOOH from ¹³CO₂ in the fluids. At alkaline pH controlled by alteration of basalt [1], reactive HCO₃⁻ is reduced to HCOOH using H₂. HCOOH is subsequently hydrogenated on Fe-Ni catalyst to form CH₄. The formation process is similar to the carbon fixation in the methyl branch of the reductive acetyl-CoA pathway. In addition, the rate-limiting step of CH₄ formation is oxidation of Fe metal. Owing to low activation energy of Fe oxidation, CH₄ production occurs effectively even at 200°C.

Combining these results, we suggest that impact-generated hydrothermal systems could have promoted organic synthesis on Hadean Earth.

[1] Shibuya et al. (2013) *Chemical Geology* **359**,1-9, [2] McCollom. (2016) *PNAS* **113**, 49 13965–13970, [3] Kendall and Melosh. (2016) *EPSL* **448** 24-33