Fluid chemistry and mineral interactions as dual interfaces of microbial life in deep-sea vents under high-pressure conditions

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Abstract

Deep-sea vents (DSVs) are among the few environments on Earth where life thrives independently of sunlight, sustained entirely by the chemistry of the hydrothermal fluid and the minerals that precipitate along chimney walls. In these systems, microorganisms do not merely tolerate extreme condition, they rather exploit them, drawing energy and carbon directly from the fluid while actively reshaping the surrounding mineral matrix. Deciphering these two intimately coupled interactions, under the high hydrostatic pressures that prevail in the deep ocean, is central to understanding both the limits of life and the biosignatures it leaves behind.

In this PhD project, carried out within the ANR HOTDOG, we reproduce DSV conditions at lab scale using milli- and micro-fluidic devices built from sapphire (a material that withstands pressures up to 300 bar while remaining optically transparent). A porous microreactor geometry mimics the architecture of hydrothermal chimneys, enabling *in situ* monitoring by Raman spectroscopy and optical microscopy, alongside *ex situ* analyses (gas chromatography, TEM).

To probe fluid-driven metabolism, we cultivated the methanogen *Methanothermococcus okinawensis* under increasing H_2/CO_2 partial pressures (2–50 bar). Methane production rose sharply with pressure (from 14.04 ± 1.12% at 2 bar to 48.06 ± 1.75% at 10 bar, the maximum yield) with no inhibitory effect on growth, demonstrating that pressure amplifies the metabolic exploitation of hydrothermal gases.

To probe mineral interactions, the hyperthermophilic archaeon *Thermococcus barophilus* was incubated with abiotically stable FeS_2 within a microreactor. *In situ* microscopy revealed progressive FeS_2 dissolution over 135 h in the presence of cells (an effect absent in abiotic controls [1]) pointing to an active cell–mineral interaction, possibly related to the biomineralization processes previously described in Thermococcales [2].

Together, these results frame DSV microorganisms as active agents at two interfaces: i) the fluid they metabolize and ii) the mineral they transform. High pressure emerges not as a mere environmental constraint, but as a key parameter shaping both interactions. These findings shed new light on microbial habitability in extreme environments, from the Hadean Earth to potential extraterrestrial settings.

References :
[1] Mansor, M. et al. (2025). Geo-Bio Interfaces, 2, e6. https://doi:10.1180/gbi.2024.9
[2] Truong, C. et al. (2023). Frontiers in Microbiology, 14:1145781. https://doi.org/10.3389/fmicb.2023.1145781

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