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Precipitation of greigite and pyrite by Thermococcales: Ensuring survival in Fe- and S-rich environments

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Abstract

Hydrothermal deep-sea vents, one of the most extreme environments for life on Earth, are iron- and sulfur-rich anaerobic systems. Whereas FeS₂ pyrite is abiotically formed in the interior of active sulfide chimneys at high temperatures (> 250°C), a major stock of FeS₂ pyrite is also produced in the cooler middle layers of the chimneys at lower temperatures (< 150°C) by a still unknown mechanism. *Thermococcales*, a major family of archaea inhabiting these extreme environments, have been shown to rapidly produce abundant quantities of FeS₂ from the hydrothermal fluid at 85°C, suggesting that they may contribute to the formation of “low temperature” FeS₂ pyrite in their ecosystem. In this study, we show that this mechanism, which induces a massive cell mortality, operates in *Thermococcus kodakarensis* only when zero-valent sulfur is directly available as sulfur vesicles. Significant amounts of Fe₃S₄ greigite nanocrystals are then formed extracellularly nucleating on iron-phosphate-bearing extracellular materials presumably resulting from cell lysis. Those pyrite and greigite mineralizations allow the formation of a 3D structure composed of pyrite-mineralized cells and vesicles remnants within a matrix consisting mostly of greigite nanocrystals. Starting from this state, we observe that a new generation of cells grew in this medium a priori not adapted to cell growth. We propose that greigite precipitation on phosphate-loaded former cell materials induces the release of phosphates and organic compounds thus making them available to a few surviving non-mineralized cells hence allowing production of new alive cells. This suggests that biologically induced iron-sulfides mineralization could be part of a survival strategy employed by *Thermococcales* to cope in strongly mineralizing high-temperature hydrothermal environments.

Keywords

Biomining, Pyrite, Greigite, Hyperthermophiles, *Thermococcales*, Adaptation