



## **The biological origin, source and cycling of methane in deep crystalline biosphere of Outokumpu, Finland**

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The deep carbon cycle is controlled by combination of hydrogeochemical and biological processes. Methane is the most abundant gas in Outokumpu bedrock and a 2516 m deep scientific drill hole at the site provides an ideal location to study methane cycling in crystalline biosphere. Methanogenesis is the final step in decomposition of organic matter and is constrained to the domain Archaea. Active carbon dioxide -utilizing methanogens affiliating with *Methanobacterium* have been shown to dominate in Outokumpu at different depths. These chemolithoautotrophic methanogens growing solely on carbon dioxide and hydrogen can act as primary producers supplying substrates for heterotrophic organisms. *Methanobolus* and *Methanosarcina* are heterotrophic methanogens present in the bedrock fluids. Recent discovery of *Methylomonas* -type of a particulate methane monooxygenase gene *pmoA* in Outokumpu provides evidence for methane oxidizers carrying out the transformation of methane to carbon dioxide in the presence of oxygen in crystalline rock environments.

The origin of methane in Outokumpu is still enigmatic. Recently, isotopic analyses have demonstrated that in substrate-limited environments, the traditional separation of biogenic and abiogenic methane can be misleading. Finding the boundary between biotically and abiotically produced methane is exceptionally difficult in crystalline bedrock where potential for both forms is combined with often poorly defined biogeochemical conditions.