Patterns and controls on anaerobic oxidation of methane in extreme environments of varying salinity

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Hypersaline habitats are abundant on the Earth's surface and range from hypersaline lakes to inland seas to deep ocean brine seeps and mud volcanoes. These habitats serve as an analog for life on Early Earth and potentially on extraterrestrial bodies. We studied the microbiology and biogeochemistry of methane and sulfur cycling in six extreme habitats that had different salinities: Mono Lake, an alkaline hypersaline lake; two seafloor brine pools and one seafloor mud volcano in the Gulf of Mexico; and two ice-covered Antarctic lakes. Here, we present a comparison rates of anaerobic oxidation of methane (AOM) and sulfate reduction (SR), along with basic biogeochemistry and microbiology, and show that while AOM occurs at salt content up to ~3 times seawater, above that, rates were substantially diminimished and often below detection. Rates of SR, in contrast, were not negatively impacted by salinity.

Rates of AOM and SR in Lakes Fryxell and Vanda, Antarctica, were measured over four years. At Lake Fryxell, (salt: 6.6 g L^{-1}), AOM and SR rates detectable in waters and sediments but rates were only loosely coupled in deep waters, suggesting a novel electron acceptor for AOM. Rates of AOM and SR in Lake Vanda, Antarctica (salt: >150 g L^{-1}) waters and sediments were extremely low. Rates of SR and AOM in Mono Lake (salt: 90 g L^{-1}) were measured when the lake was meromictic. SR and AOM were tightly coupled during summer and AOM rates were among the highest measured for anoxic waters (up to 1.2 µmol L^{-1} d^{-1}). However, during times of high labile organic matter flux, AOM rates dropped substantially (sometimes below the detection limit) while SR rates increased by a factor of 20. Rates of SR and AOM in a low salinity Gulf of Mexico brine fluid, Alaminos Canyon block 601 (salt: 89 g L^{-1}) were 50-100 and 60-80 nmol L^{-1} d^{-1}, respectively, and were not significantly different, suggesting the two processes were coupled. Rates of SR in two high salinity Gulf of Mexico brine fluids (salt: 120 g L^{-1}), Garden Banks block 425 and Green Canyon block 233, were substantial (from 5 to 50 µmol L^{-1} d^{-1}) while AOM rates were below detection. AOM activity appears to be inhibited at high salinity while SR activity proceeds without inhibition.

Possibility of non-methanogenic methane formation in soils

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Methane is traditionally regarded to be a product of biotic processes, produced by methanogenic bacteria under anoxic conditions. After Keppler *et al*. [1] demonstrated methane formation under oxic conditions in living plants as well as detatched leaves, the question arose if methane formation is also possible from organic matter under oxic conditions in soils or peat and wether it would be biotic or abiotic.

Soil and peat samples have been used in sets of experiments with varying parameters such as temperature, water content and time. To verify the independence of the process from methanogenic bacteria, all experiments were also conducted exemplarily on sets of peat samples sterilised by gamma irradiation. Methane formation was measured in dry samples as well as in samples with varying water content. A strong dependency on the water content could be observed. In a second set of experiments the methane concentration was determined after incubation at different temperatures. The results for the heated soil and peat samples (Fig. 1) resemble those found by Vigano *et al*. [2] for heated plant matter and form a temperature curve typical for abiotic reactions.

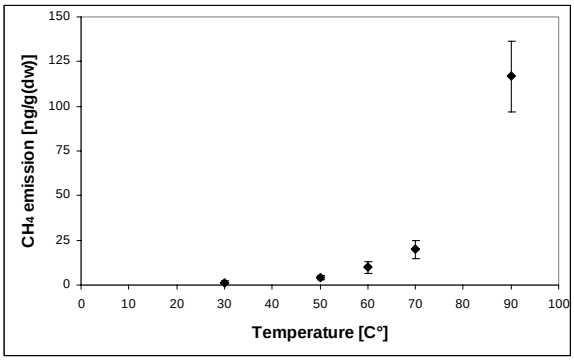

Figure 1. Temperature dependency of CH_4 emission from peat.

For both setups the methane formation from sterile and non-sterile samples was similar.

The total number of results strongly indicates the possibility of non-methanogenic methane formation in soils.

[1] Keppler *et al*. (2006), *Nature* **439**, 187-191. [2] Vigano *et al*. (2008), *Biogeosciences* **5**, 937-947.