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Methanogenesis predominates organic matter mineralization in a ferruginous, non-sulfidic sedimentary environment

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Lake Towuti is a tropical, weakly stratified, 200m deep tectonic lake, with anoxic conditions below 130m water depth. Its catchment is mainly composed of ultramafic rocks and lateritic soils. As a result Lake Towuti sediment is Fe-rich and can contain more than 20 weight percent iron(oxy)hydroxides. Sulfate concentrations in the anoxic bottom water and at the sediment water interface are exceptionally low ($<20\mu$M). Such physical and chemical characteristics lead to a depositional environment partly analogous to those of the ferruginous oceans that persisted throughout the Precambrian eons. Even though these conditions prevailed through much of Earth's history, models of the biogeochemical processes that occurred under these conditions remain largely conceptual, as modern analogue environments are rare. In spring 2015 the Towuti Drilling Project retrieved a $\sim$115 m long sediment core for geomicrobiological investigations. We characterized the biogeochemistry of this ferruginous environment by analyzing cat- and anions dissolved in the pore water and by modeling net reaction rates of elements and compounds involved in microbial organic matter degradation. We further analyzed the concentration and isotopic composition of pore water methane and quantified the total microbial abundance in the sediment.

Lake Towuti's sediment has low concentrations of the electron acceptors nitrate and sulfate. Total microbial abundance in Lake Towuti sediment is relatively high and decreases from 10^8 cells cm^{-3} at the top of the core to 10^5 cells cm^{-3} at $\sim$50m and remains constant below. Given the lack of nitrate and sulfate we suggest that the high microbial abundance is supported by metabolisms like fermentation and methanogenesis. Methane accumulates to $\sim$200 μM over the upper 20 m and appears to remain constant below this depth, even though there is substantial variability that comes from sediment degassing due to pressure loss after core retrieval. Despite relatively high total iron concentrations in Lake Towuti's sediment, modeled rates of methanogenesis exceeded those of all other metabolisms considered, indicating that methanogenesis is the dominant process in microbial organic matter degradation. This implies that the iron that is present in minerals is not readily utilized by microbes; together with the scarcity of sulfate and lack of nitrate this likely indicates that there is no appreciable anaerobic oxidation of methane (AOM). The δ^{13}C values of CH_4 in Lake Towuti sediment range from -73 ‰ to -64 ‰ whereas δD_{CH4} values are very heavy with values between -176 ‰ and -160‰Ṡuch isotopic compositions are characteristic for hydrogenotrophic methanogenesis but do not rule out a contribution from acetoclastic or methylotrophic methanogens. The prevalence of methanogenesis even in this very iron-rich modern environment implies that methanogenesis may play an important role in biogeochemical cycling in ferruginous environments more broadly including in the oceans of the Precambrian eons.