A new microbially explicit model for organic matter degradation in thawing Arctic subsea permafrost

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In a rapidly warming Arctic, permafrost thaw has become a major climate concern. Thawing of permafrost progressively unlocks a vast reservoir of organic matter (OM) that is subsequently subjected to microbial degradation. OM may thus be converted into dissolved inorganic carbon (DIC) and/or methane (CH_4), while nutrients like phosphorus (P) and nitrogen (N) are recycled back into the porewaters. An estimated 2.5 x 10^6 km^2 of permafrost soils has been submerged by rising sea levels since the Last Glacial Maximum. In the coming centuries, the thawing of this so-called subsea permafrost (SSPF) is expected to accelerate due to sea-ice loss and the warming of bottom waters, resulting in an uptake in SSPF OM degradation and consequently, carbon (CH_4, DIC) and nutrient (N, P) production. This will lead to shifts in seafloor carbon and nutrient fluxes, with potentially important, yet unquantified feedbacks on global climate. The magnitudes, evolution and nature of these SSPF-derived fluxes strongly depend on the ability of the microbial community to degrade SSPF OM in its changing habitat (frozen to thawed sediment). Numerical reaction-transport models are ideal tools to disentangle complex and dynamic processes and quantify SSPF-driven carbon and nutrient seafloor fluxes. However, most existing diagenetic models currently do not explicitly resolve microbial biomass dynamics and bioenergetic limitations and are not designed to capture the SSPF evolving habitat.

Here we present a microbially explicit, bioenergetics-informed model for the degradation of thawed SSPF OM. Building on the model concept proposed by Bajracharya *et al.* (2022), we are developing a model that accounts for extracellular hydrolysis of SSPF OM, fermentation of the resulting monomers by fermenting bacteria, and methanogenesis by methanogenic archaea. The microbial community is further divided into active and dormant pools with distinct maintenance energy requirements. Activation of dormant cells is only possible when OM is thawed, and the catabolic energy production of a microbial group exceeds the maintenance energy requirements of the active cells. This model, combined with a transport module and fed with experimental data, will be used to quantify carbon and nutrient seafloor fluxes on the Arctic Shelf in response to SSPF thaw on decadal to centennial timescales.

Reference

Bijendra Man Bajracharya, Christina M. Smeaton, Igor Markelov, Ekaterina Markelova, Chuanhe Lu, Olaf A. Cirpka & Philippe Van Cappellen (2022) Organic Matter Degradation in Energy-Limited Subsurface Environments—A Bioenergetics-Informed Modeling Approach, Geomicrobiology Journal, 39:1, 1-16, DOI: 10.1080/01490451.2021.1998256

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