

Simulating Microbial Energetics, Kinetics, and Competition: Reproducing Ferruginous versus Euxinic Conditions in Meromictic Lakes

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Ferruginous (iron-rich) conditions have been prominent in oceans throughout the Earth's geologic history but now are reliably found only in a handful of permanently stratified lakes. Development of ferruginous, rather than euxinic (sulfide-rich), conditions depend on the outcomes of the competing anaerobic microbial metabolisms of iron reduction and sulfate reduction. We show that observed biogeochemical distributions in the water columns of multiple low-sulfate meromictic lakes from different parts of the world can be reproduced using a reaction-transport model that uses the same set of metabolism-specific microbial parameters. The biomass-explicit model simulates pathway-specific metabolic rates by considering microbial energetics, as well as kinetic and population dynamics factors, and the effects of hydrodynamic regimes. Geochemical results suggest that ferruginous conditions typically develop in lakes for sulfate concentrations below 100 μM . Sulfate reduction and methanogenesis, nevertheless, are ubiquitous even in iron-rich systems, and are observed in microbial surveys. Interestingly, there seems to be a dearth of stably stratified water bodies where sulfate concentrations can persist in the medium-sulfate range of several hundred μM . Rather, when sulfur burial into the sediments becomes iron-limited, sulfate tends to accumulate in the water column to much higher (mM-level) concentrations. A similar mechanism could be suggested to have operated in the variably sulfidic and ferruginous water columns of early oceans. Model simulations also reveal the previously underappreciated role of physical transport in shaping biogeochemical distributions, as minor variations in mixing rates can lead to large variations in microbial abundances.