Exploring the effects of oxidant availability on the early methane cycle

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Despite hints of surface ocean oxygenation as early as ~3 Ga, the ocean remained broadly anoxic throughout the Precambrian. Similarly, the oceanic SO_4^{2-} reservoir, which is the largest reservoir of oxidizing power in the modern ocean, was substantially smaller in deep time. Such scarcity of respiratory electron acceptors potentially allows for an expanded role for methanogenic remineralization pathways—and, possibly, large CH_4 fluxes that could have had important implications for Proterozoic climate stability if biogenic CH_4 evaded oxidation in an oxidant-lean ocean.

We use GENIE, an earth system model of intermediate complexity, to explore the protracted evolution of marine oxidant budgets and the potential links to marine CH_4 fluxes. Our modeling efforts involve several improvements to the CH_4 cycle in GENIE, which previously neglected key anaerobic proceses. Most notably, we have added representations of methanogenesis and anaerobic oxidation of methane coupled to sulfate reduction to the existing biogeochemical module. To assess oxidant controls on marine CH_4 fluxes, we vary the total oceanic oxidizing capcity over several orders of magnitude via adjustments to atmospheric pO_2 and the total oceanic S inventory. We also investigate the steady-state sensitivity of marine CH_4 fluxes to the spatial distribution of oxidants through adjustments to remineralization length scales (effectively, the vertical distribution of respiratory oxidant demand) and ocean circulation parameters affecting the lateral and vertical transport of oxidants.

This work yields exciting insight into the dynamics of CH_4 cycling under the oxidant-deficient conditions that characterized the majority of Earth history and supports further speculation regarding the triggering of Neoproterozoic Snowball Earth events. Although our modeling is cast in the context of the evolution of Proterozoic redox and climate, our GENIE updates may also allow improved exploration of Phanerozoic intervals of reduced oxidant availability that are coincident with proposed perturbations to the CH_4 cycle.