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Surface Ocean Nitrification: Modern Evidence and Neoproterozoic Implications

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Throughout geologic time, fluctuations in nitrogen bioavailability may have influenced the timing and tempo of eukaryotic diversification, with increased nitrate availability in the Tonian (~800 Mya) potentially enabling ecological expansion. In modern oceans, nitrification, the oxidation of ammonia to nitrate, occurs predominantly in low light conditions and proceeds via a two-step pathway mediated largely by ammonia-oxidizing archaea and nitrite-oxidizing bacteria. Competition for nutrients and photoinhibition generally restrict these taxa to deeper waters making vertical mixing an important mechanism for delivering nitrate to the surface ocean in coastal regions. Recent reports, however, suggest that surface nitrification may be more important than previously considered in the modern ocean, with observations of nitrification genes (ammonia monooxygenase (amoA), nitrite oxidoreductase (nxr)) and measurable rates of nitrification in the upper 50 m. However, the lack of paired functional data with isotope measurements leaves uncertainty about whether these nitrifying taxa are transiently transported to the surface ocean or actively mediating nitrification *in situ*. Here, we integrate analyses of the natural abundance of nitrate isotopes ($d^{15}N$ and $d^{18}O$), metaproteomics, and targeted gene quantification to explore whether nitrifiers detected in surface waters were metabolically active. To achieve this, we undertook sampling campaigns in August 2021 and 2022 in the Canadian High Arctic (Nunavut), where we collected marine water samples from Sverdrup Glacier, a site suspected to be influenced by glacially-driven upwelling. We evaluated surface waters for: (1) isotopic signatures consistent with *in situ* nitrate regeneration; (2) expression of key nitrification proteins (i.e., ammonia monooxygenase and nitrite oxidoreductase); and (3) elevated abundances of amoA and nxrB genes encoding these enzymes. Together, these converging signals provide evidence for active *in-situ* surface-ocean nitrification at Sverdrup Glacier. Our findings could complicate conventional interpretations of nitrate limitation in the sedimentary record. In modern nitrate-depleted systems, including the Canadian Arctic, local nitrate regeneration coupled with rapid phytoplankton uptake can decouple production rates from standing concentrations, potentially obscuring evidence of active cycling. If similar dynamics operated in the Neoproterozoic ocean, regenerated nitrate may have been more available than bulk geochemical proxies suggest, representing an underappreciated pathway sustaining nitrate-dependent metabolisms and facilitating eukaryotic ecological diversification.