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Do we really understand nutrient cycling across oxic to ferruginous boundaries?

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Reconstructions of Archean marine nutrient cycling are dependent on the sedimentary pathways that remove nutrients from the water column and archive the ambient abundance of these same nutrients. However, nutrient element behavior with mineral precipitation is often untested in natural aquatic systems that best simulate past oceans, including thermal and light stratification, and relevant microbial communities.

Deming Lake is a meromictic lake in northern Minnesota with low (<1 μM) sulfate in surface water, dissolved iron concentrations that increase from 40 nM to >1 mM at depth, and primary productivity dominated by Cyanobacteria. Dissolved and particulate trace metal data within the Deming Lake water column were collected during three seasonal time points across one year. Net primary productivity rates are dominated by oxygenic photosynthesis vs. anoxygenic pathways, with particulates at active biological depths enriched in major and trace nutrients, indicating the importance of nutrient-type element behavior in particle formation within the oxic-ferruginous boundary where particle scavenging is usually predicted to dominate.

Published Fe isotope data indicates that Fe oxidation and Fe oxide formation primarily occur below the oxycline without extensive preservation of Fe oxides in sediments [1]. Total organic carbon (TOC) contents in these sediments are at a minimum compared to sediments below other water depths, further evidence that Fe oxides remineralize rapidly upon sedimentation. Furthermore, many nutrient elements that are expected to adsorb to Fe oxides don't correlate with authigenic Fe enrichments, and instead show correlations with TOC (P, Co, Cu, Ni, Co, V, Zn).

Direct precipitation of ferrous Fe minerals (carbonates, phosphates) initiates in deeper, anoxic waters. These minerals seem to be the likely hosts for authigenically enriched Fe, and some nutrients (Ca, Mg, P, V, Cu, Zn). However, the correlation between some nutrients and organic carbon persists in sediments, indicating the significance of redistribution of elements throughout the lake with organics, and burial in organics throughout the ferruginous environment.

[1] Heard, Ostrander, Swanner, Rico, & Nielsen (2024),*Geochimica et Cosmochimica Acta* 383, 18-42.