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The maintenance of stable transitional redox states in Lake Zug (Switzerland): Mechanisms and biogeochemical implications

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Respiration is often conceptualized in terms of thermodynamic energy yield of electron acceptors (e.g., O_2 > Mn(IV) & NO_3^- > Fe(III) > SO_4^{2-}), with the corresponding environments characterized by these electron acceptors and their accumulated respiration products [1]. Oxic zones dominate where O_2 supply is sufficient to balance respiration (e.g., most oceanic environments, rivers and many lakes). Despite a range of potential intermediate electron acceptors, two environmental states dominate anoxic waters: (i) euxinic or sulfidic environments characterized by high sulfide concentrations (e.g., restricted marine basins), and (ii) ferruginous environments (e.g., certain anoxic lakes, and Earth's Archean oceans), where relatively high Fe and low SO_4^{2-} availabilities limit water column sulfide accumulation. Consequently, in natural environments, Mn(IV)- or NO_3^--driven respiration is often restricted to transitions between oxic surface waters and ferruginous or euxinic deep waters, with only narrow corresponding 'manganous' or 'nitrogenous' zones.

Lake Zug (Switzerland) is an exception to this, maintaining a thick and persistent manganous zone despite near-constant deepwater anoxia since monitoring began in the 1950s. There is minimal net Fe(III) and SO_4^{2-} reduction apparent throughout almost the entire anoxic zone. In contrast, Mn shows high reactivity across the oxic-anoxic interface. Scanning electron microscopy (SEM) analyses show ubiquitous Mn-rich particles near the oxic-anoxic interface, while particles with appreciable Fe contents are rare, and initial chemical data indicate little transformation of Fe particles throughout anoxic waters. Microstructure profiles suggest mild but steady injection of O_2 into the anoxic zone along with turbulent mixing events. These processes drive supply and modification of dissolved and particulate Mn and N species with implications for both aerobic and anaerobic metabolism [2]. Finally, reactive dissolved Mn, a proxy for dissolved Mn(III), is regularly observed near the redox interface, and seasonally up to 50 m below the oxic-anoxic interface, and may be an important oxidant in deep anoxic waters [3]. Lake Zug, with its absence of abiotic reductants (e.g., Fe(II), H_2S), therefore represents a promising setting to isolate Mn-driven metabolism.

References

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