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Alkalinity Generation During Organic Carbon Remineralization Regulates CO_2 Partitioning and Carbon Retention in Aquatic Environments

GILAD ANTLER

Ben-Gurion University of the Negev

Organic carbon remineralization in aquatic sediments is commonly viewed as a direct source of CO_2 to overlying waters and potentially the atmosphere. This perspective assumes that dissolved inorganic carbon (DIC) production during early diagenesis translates proportionally into CO_2 accumulation and efflux. Yet the stoichiometry of redox reactions governing organic matter degradation also generates alkalinity, fundamentally altering carbonate system equilibria and therefore the fate of respired carbon. Proton consumption during processes such as aerobic respiration, sulfate reduction and iron reduction modifies porewater pH and promotes carbonate mineral dissolution or precipitation, coupling DIC production to sedimentary buffering reactions. Here, we quantify how alkalinity generation during organic matter remineralization modifies CO_2 partitioning and influences net carbon release versus retention across diverse aquatic environments.

Using high-resolution porewater profiles from freshwater lakes, estuaries, and marine sediments, we examine the co-accumulation of DIC and total alkalinity (TA) with depth during early diagenesis. Despite contrasting depositional settings, mineralogies, and redox structures, we observe a consistent and convergent coupling between increases in alkalinity and DIC. The similarity in Alk–DIC slopes across systems indicates that sedimentary carbonate dissolution–precipitation reactions act as a pervasive buffering mechanism rather than a site-specific anomaly. Carbonate dissolution amplifies alkalinity in response to respiration-driven acidification, stabilizing porewater pH and shifting DIC speciation away from free CO_2 toward bicarbonate and carbonate ions. Carbonate system calculations demonstrate that this buffering constrains the fraction of remineralized carbon expressed as aqueous CO_2, limiting its immediate release to atmosphere. The cross-reservoir coherence of Alk–DIC relationships suggests that sedimentary carbonate buffering represents a transferable control on carbon cycling from inland waters to marine basins. Organic carbon breakdown therefore does not scale linearly to CO_2 efflux; instead, carbonate equilibria regulate carbon retention within sediments and modulate carbon–climate feedbacks. Incorporating sedimentary alkalinity generation into carbon cycle assessments will improve estimates of carbon trajectories across aquatic reservoirs and through environmental change.