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Is the major ion composition of seawater a carbon cycle driver?

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The major ion composition of seawater (especially Ca^{2+}, Mg^{2+}, SO_4^{2-}) is often viewed as responding to, rather than driving Earth's long-term carbon cycle, with changes in (e.g.) weathering and seafloor spreading (SFS) forcing coeval changes in atmospheric CO_2 and seawater chemistry. However, it is conceivably possible that these major ions impart a substantial control in and of themselves. For example, changes in the concentration of calcium impact the saturation state of seawater with respect to $CaCO_3$, such that this may have a knock-on effect on the efficiency of calcification and burial. Mg^{2+} and SO_4^{2-} may be similarly important because the concentration of these ions exerts a control on the release of Ca^{2+} in hydrothermal systems. However, addressing the interplay between seawater chemistry and CO_2 has proven challenging, because – notwithstanding the major impact this information has had on the field – fluid inclusion-derived seawater chemistry reconstructions are available from a limited number of time intervals. We address this via the development of carbonate biomineral Na/Ca as a proxy for seawater Ca^{2+}, with the underlying rationale that calcite Na/Ca must be driven by seawater [Ca^{2+}] given the very long Na^+ residence time. By coupling this information with existing reconstructions of seawater elemental ratios (Mg/Ca, Sr/Ca), the complete cation composition of seawater can be derived. We use this information, together with magnesium isotope data from exceptionally well-preserved foraminifera, to explore the relationship between seawater chemistry and atmospheric CO_2 over the Cenozoic and show that these are strongly correlated. Together with carbon cycle box modelling of ocean-atmosphere carbon partitioning, and joint mass-isotope Bayesian inversion modelling of seawater chemistry, we demonstrate that: i) CO_2 can be causally driven by seawater Ca^{2+}, and ii) seawater chemistry changes may be entirely explained by a decrease in both seafloor spreading and reverse weathering. While our modelling cannot unambiguously ascribe CO_2 changes to seawater Ca^{2+} versus (e.g.) the associated SFS degassing decrease, we identify a mechanism by which Ca^{2+} is likely to impact ocean-atmosphere carbon cycle partitioning, and suggest that this acted to amplify the SFS and reverse weathering impacts on the Cenozoic carbon cycle.