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New constraints on the evolution of seawater boron isotope composition and its implications for CO_2

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The chemical history of seawater provides critical insights into Earth's geological processes, ocean habitability, and the long-term carbon cycle, forming a foundation for robust reconstructions of past climate. Boron, a minor dissolved element, plays a key role in marine carbonate chemistry and in the reconstruction of past CO_2 via the boron isotope proxy. Although oceanic boron isotope composition ($\delta^{11}B_{sw}$) is largely homogeneous, it is expected to vary over multi-million-year timescales due to its long residence time of ~10 million years. Knowledge of past $\delta^{11}B_{sw}$ trends is essential for constraining the evolution of CO_2 from boron isotopes and informs fundamental processes such as chemical weathering, authigenic clay formation and oceanic crust alteration. However, to date, the secular evolution of the oceanic boron isotope budget has been difficult to constrain, limiting reliable boron-based pH and CO_2 reconstructions and our understanding of the global boron cycle.

Marine evaporite minerals provide a promising archive for reconstructing $\delta^{11}B_{sw}$ because of their direct origin from seawater. However, the interpretation of their signatures is not straightforward due to the possibility of fractionation during evaporation, crystallisation, and local biogeochemical interactions. Here, we present new insights into boron isotope evolution during evaporite formation from modern evaporitic systems and laboratory experiments, accompanied by new analytical developments for high-precision individual fluid inclusion measurement using laser ablation. Our findings enable us to critically evaluate the evaporite archive and establish a robust interpretative framework for reconstructions from ancient samples. We apply this approach to unravel $\delta^{11}B_{sw}$ during key intervals of the Phanerozoic, revisit the boron cycle, and highlight its implications for understanding long-term CO_2 and climate.