Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.25285

Individual foraminiferal boron isotope and TE/Ca analysis: A promising tool of high-resolution temperature and pH records reconstruction

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Benthic foraminifera have been widely used in past climate reconstructions, and the trace elements and stable isotope composition of their calcitic tests are important geochemical proxies. However, sediment mixing processes and sampling related artefacts can smooth paleoclimate records and reduce signal amplitudes, resulting in interpretation bias in bulk proxy records during abrupt and transient events (e.g. PETM). In situ analysis of individual foraminifera (individual foraminiferal analysis or IFA) has the potential to overcome these limits by enhancing temporal resolution but are associated with an increased geochemical heterogeneity compared to bulk analysis attributed to the combined effects of environmental conditions during ontogeny/calcification and 'vital effects'. Recent advances have enabled the boron isotopic composition ($\delta^{11}B$) of individual benthic foraminifera for the first time, yet the scale of intra- and inter- shell variabilities within individual benthic foraminifera remain uncertain[1-3]. In this study, an improved analytical method using a Neoma MC-ICPMS/MS, which both eliminates an interference from scattered ions of Ca and Ar and improves sensitivity, was used to analyse both Holocene *C. wuellerstorfi* from ODP Site 999 and modern coastal *C. lobatulus* from Western Channel Observatory (WCO) stations in situ $\delta^{11}B$ via laser ablation, paired with B/Ca, Mg/Ca and other TE/Ca ratios by LA-QQQ-ICPMS. Whole individual averages of $\delta^{11}B$ are consistent with bulk analysis by solution (± 0.1‰). Intra-test $\delta^{11}B$ variability of *C. wuellerstorfi* is less than 0.4‰ (2 s.e.) suggesting a minimal vital effect, similar to conclusions from bulk core-top studies[4], and consistent with their stable deep-sea environments. Compared with the 15-years of water-column records of temperature, pH and ΔCO_3^{2-} at WCO station[5], intra-test $\delta^{11}B$, Mg/Ca and B/Ca variabilities of *C. lobatulus* are consistent with the observed seasonal water-column pH and temperature range, and whole individual averages reflect the annual cycle, robustly ground-truthing our multi-proxy IFA methodology.

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