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A seven-million-year multi-proxy geochemical record of planktonic foraminifera *Orbulina universa* from the Mozambique Channel (IODP Site U1476)

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The boron isotope ($\delta^{11}B$) proxy in planktonic foraminifera is widely used to infer past seawater carbonate chemistry, but its interpretation can be complicated by physiological effects, contamination, and biomineralisation processes. Understanding the mechanisms controlling geochemical variability in foraminiferal shells is therefore critical for robust proxy applications. In this study, we present a seven-million-year multi-proxy geochemical record obtained from the planktonic foraminifer *Orbulina universa* from IODP Expedition 361 Site U1476 in the Mozambique Channel. A comprehensive suite of geochemical analyses was conducted, including B/Ca, $\delta^{11}B$, $\delta^{13}C$, $\delta^{18}O$, Mg/Ca, Al/Ca, Sr/Ca, $^{87}Sr/^{86}Sr$, and Ba/Ca.

We identify statistically significant shell size dependencies in $\delta^{11}B$, $\delta^{13}C$, Mg/Ca, and Sr/Ca, exceeding analytical uncertainties, highlighting the importance of size-specific screening to isolate primary signals. Following rigorous geochemical screening, $\delta^{18}O$ and Mg/Ca records exhibit clear glacial–interglacial variability over the past 0.6 Ma, whereas $\delta^{11}B$ shows comparatively muted variability. Despite this, $\delta^{11}B$-derived seawater pCO_2 covaries with atmospheric pCO_2, and the distribution of ΔpCO_2 (seawater minus atmospheric pCO_2) is centered around zero, supporting the potential of *O. universa* $\delta^{11}B$ to record surface ocean carbonate chemistry.

Over longer timescales, Mg/Ca exhibits a pronounced increase over the past seven million years that cannot be explained solely by changes in seawater Mg/Ca, suggesting additional biological or biomineralisation controls. Shell structural analyses using scanning electron microscopy (SEM), X-ray computed tomography (CT), and laser ablation ICP-MS reveal thinning of the spherical chamber between 3.4 and 4.6 Ma and cyclic intra-shell Mg/Ca variability. These observations indicate long-term changes in shell formation processes and magnesium incorporation, which may influence proxy fidelity.

Our results provide new mechanistic insights into the controls on $\delta^{11}B$ and Mg/Ca in *O. universa* and highlight the importance of biomineralisation effects when interpreting long-term geochemical proxy records. These findings improve our understanding of proxy behaviour in planktonic foraminifera and contribute to more reliable applications of biomineral-based proxies in paleoclimate studies.



