

Mechanisms Driving Sub-Micron Proxy Heterogeneity in Biominerals: Lessons From Planktic Foraminifera

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From the pace of the ice ages to carbon cycle changes through time, much of what we know about the past ocean and the ocean's role in climate is based on geochemical proxies recorded in biominerals. Recently developed microanalytical tools like NanoSIMS, ToF-SIMS, and Atom Probe Tomography (APT) provide an unparalleled view of proxy behavior at the sub-micron scale. At this scale, proxies often diverge from a simple relationship with environmental conditions; instead, many biominerals are characterized by small-scale heterogeneity, complicating proxy interpretation. To accurately interpret past records, we need a mechanistic understanding of proxy behavior that can explain this heterogeneity in biominerals and link this variability to environmental records. To solve this problem we use a combination of high-resolution isotope imaging methods, stable-isotope tracers, and live-culture techniques to test the role of two major processes in sub-micron compositional heterogeneity during biomineralization: ion transport and organic-mineral templating.

Focusing on planktic foraminifera, a widely used paleoarchive, we conducted modified pulse chase experiments with a suite of isotope tracers to measure ion transport rates to the site of biomineralization. By varying seawater elemental concentrations during pulse chase experiments, we were able to induce systematic shifts in the ion transport rate. The magnitude of these shifts can be inverted to indirectly measure the elemental composition of the calcifying microenvironment, a key and previously unmeasured parameter affecting skeletal composition. In a set of complementary experiments, we used APT to investigate elemental abundances at the organic-mineral interface in foraminiferal, an approach that will test whether organic templating processes can also drive sub-micron heterogeneity in biominerals. Collectively, the mechanistic understanding of small-scale heterogeneity developed in this study has applications to geochemistry, climate science, and the design of complex biomimetic materials.