

Visualizing Micro-to-Nanoscale Growth in Bimineralic Bivalve Shells: Insights into Amorphous-to-Crystalline Phase Transformation and Implications for Proxy Archives

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Marine bivalve shells record isotope and trace element signatures throughout growth, providing valuable insights into past environments. Structurally, they are biological nanocomposites, integrating inorganic and organic phases into a hierarchically complex architecture. Mineralogically, their inorganic component, calcite or aragonite, forms via stepwise crystallization [1], guided by organic phases, in contrast to abiotic carbonates, which crystallize through simpler processes described by classical crystallization theory [1]. The different formation processes result in distinct differences in mechanical properties [2], elemental composition and matrix effects [3]. A deeper understanding of trace element uptake into the amorphous phase and its transformation is fundamental for more robust proxy reconstructions.

We combine electron microscopy, NanoSIMS isotopic imaging, atom probe tomography (APT), and Photo-induced Force Microscopy (PiFM) to investigate micro- to nanoscale growth in bimineralic *Mytilus galloprovincialis*. Shells were grown in controlled aquaculture experiments with strontium-spiked seawater, creating Sr-labelled shell increments as snapshots of growth. On the mesoscale, we observe distinct differences between the faster-growing outer calcite prism shell layer, which extends the shell, and the slower-growing inner nacreous layer, which thickens the shell. Micron-scale growth and Sr incorporation are visualized by NanoSIMS Sr/Ca and PiFM maps. At atomic and molecular scales, Sr heterogeneities, localized Sr-enriched and Sr-poor regions, suggest an ACC-to-crystalline transformation via localized dissolution and reprecipitation within organically sheathed nanogranules [4]. One of the most important findings is that similar Sr concentrations were incorporated into both aragonite and calcite shell layers despite markedly different partition coefficients, highlighting the crucial role of amorphous precursors in trace element incorporation, as they lack defined partitioning behaviour.

References:

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