A nanoscale look at how shells and coral form reveals that biomineralization is more complex than imagined

March 26 2024, by Lauren Biron

Credit: Dagmara Dombrovska from Pexels

Exactly how does coral make its skeleton, a sea urchin grow a spine, or an abalone form the mother-of-pearl in its shell? A new study at the Advanced Light Source at the Department of Energy's Lawrence

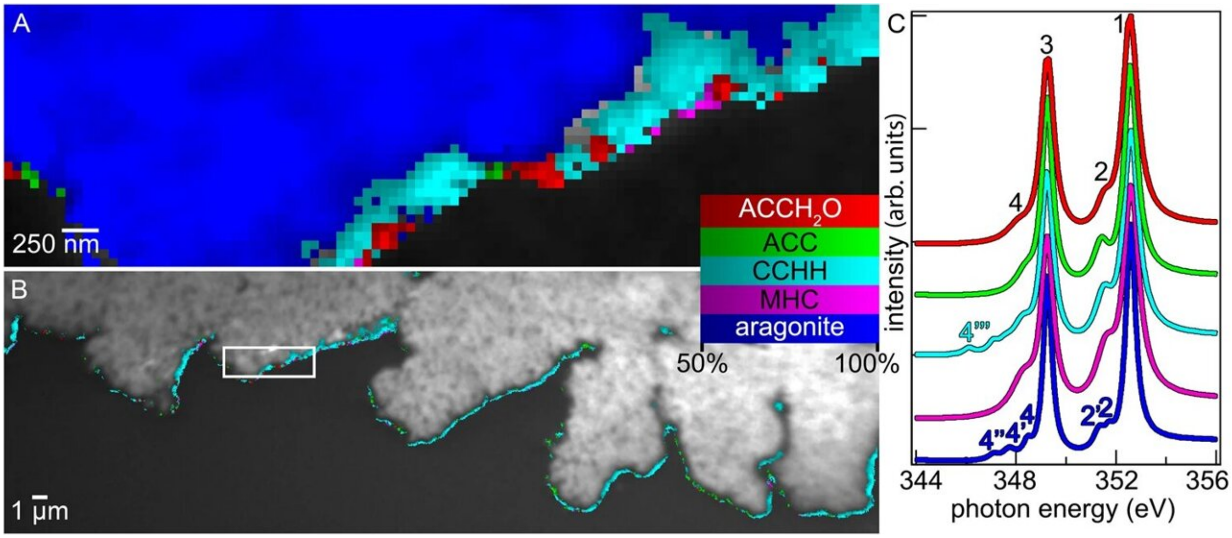
Berkeley National Laboratory (Berkeley Lab) revealed that this process of biomineralization, which sea creatures use to lock carbon away in their bodies, is more complex and diverse than previously thought.

Researchers studied the edges of samples from coral, sea urchins, and mollusks, where temporary building blocks known as "mineral precursors" start to form the new shell or skeleton. There, they found a surprise: Corals and mollusks produced a mineral precursor that had never been observed before in living organisms and had only recently been created synthetically.

They also found variety in the types of building blocks present. Scientists expected to see "amorphous" precursors, minerals that lack a repeating atomic structure. They did—but they also found "crystalline" precursors, minerals that are more structured and orderly. The research is published in the journal *Nature Communications*.

"One fascinating observation is that coral skeletons and mollusk mother-of-pearl form with exactly the same precursors, yet they evolved completely separately from one another," said Pupa Gilbert, a visiting faculty scientist at Berkeley Lab and professor at the University of Wisconsin, Madison. She noted that the two species began making biominerals long after they diverged from one another on the tree of life.

"That's cool because it means making a biomineral that way, with so many precursors, is an evolutionary advantage—energetically, thermodynamically, or some other way," Gilbert said. "As a physicist, I find it fascinating that so much of life, and biology in general, is harnessing the beauty of physics to gain evolutionary advantages."



CCHH on the surface of coral skeleton. CCHH on the surface of a *Stylophora pistillata* coral skeleton. **A**, **B** Grayscale photoelectron image of a coral skeleton (top) with tissue and embedding material (bottom). The box in (**B**) indicates the region magnified in (**A**). In both panels, the colored pixels superimposed on the grayscale micrograph are carbonate Myriad Maps (MMs) of nanoscale mineral phases, displaying only pixels that contained 50% or more of each phase, color coded so red = $ACCH_2O$, green = ACC, cyan = CCHH, magenta = MHC, blue = aragonite, with brighter/darker colors corresponding to greater/lower concentration (see color legend). In (**B**), the aragonite blue pixels are not displayed so the morphology of the skeleton is visible. This area was analyzed in duplicate with consistent results. **C** Ca L-edge x-ray absorption spectra of 5 calcium carbonate phases, acquired from synthetic reference minerals, used for MMs and color-coded as in (**A**), (**B**). The spectra were displaced vertically for clarity. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-46117-x

Scientists also found different proportions of the building blocks present in different species. The surprise mineral precursor, calcium carbonate hemihydrate (CCHH), and another building block (monohydrocalcite, or MHC) were both found in corals and mollusks. But CCHH and MHC only showed up in trace amounts in sea urchin spines—suggesting that different animals take different approaches to biomineralization.

Researchers made the discovery using the Advanced Light Source (ALS), a circular particle accelerator that produces intense beams of light. The ALS can act like a powerful microscope, providing information about the atomic and chemical structure of samples. Scientists used two different techniques to study the surface of the materials and their chemical makeup, revealing the unexpected minerals as well as the variety of building blocks.

"It is tremendously complicated to run these experiments because we have to analyze the samples right away, while they are fresh, to see the precursors as the biominerals are forming," Gilbert said.

"If we wait just one day, we miss these phases that only exist transiently. At Berkeley Lab, we have this unique capability where we can prepare the samples on site and then have access to this fantastic beam and microscopes that are the best in the world and give us the nanoscale resolution and depth sensitivity we need."

To study mineral particles at this minuscule level, researchers also developed a new method called "Myriad Mapping." The technique makes it possible to visualize all the different types and relative concentrations of minerals in one image; previous methods limited researchers to only three types of minerals. The approach may also have applications in other fields ranging from the atomic to the cosmic scale.

Gilbert and her collaborators have ongoing research looking at how the increasing acidity of ocean water affects the way sea creatures make biominerals. Understanding the process is key to predicting how marine life will respond to environmental changes such as more acidic oceans caused by climate change.

More information: Connor A. Schmidt et al, Myriad Mapping of nanoscale minerals reveals calcium carbonate hemihydrate in forming nacre and coral biominerals, *Nature Communications* (2024). DOI: 10.1038/s41467-024-46117-x

Provided by Lawrence Berkeley National Laboratory