BIOMATERIALS:
Reverse Engineering the Ceramic Art of Algae

Ivan Amato*

The glasslike silica laceworks within the cell walls of diatoms are so beautiful they'd be on display in museum cases if only they were thousands of times bigger. No one knows how these tiny algae pull off their bioceramic art, but researchers are closing in on the secret. On page 1129, biochemist Nils Kröger and colleagues at the University of Regensburg in Germany report new clues—silica-forming proteins dubbed silaffins.

Within seconds after they added their first silaffin samples to solutions of silicic acid, a silicon-containing organic compound, Kröger, Rainer Deutzmann, and Manfred Sumper knew they were onto something. Says Kröger: "You suddenly see the precipitate form. The solution gets cloudy"—something that takes hours to happen without silaffins. A scanning electron microscope showed that the precipitate had formed networks of minuscule silica spheres.

Kröger and his colleagues went on to analyze the proteins and show how their structures and chemical features could help catalyze the reaction of silicon-containing molecules into solid silica particles. The researchers "have done a great job of characterizing their proteins," says Galen Stucky of the University of California, Santa Barbara, who last year found what may be compounds with similar functions in silica-making sponges.

Besides helping to explain how diatoms transform dissolved silicon-containing molecules into sturdy solid particles, the finding is also a tantalizing clue for materials scientists who envy biology's
ability to build sophisticated materials at ambient pressures and temperatures. To make any ceramic, from a dinner plate to a toughened drill bit, engineers and artisans now have to mix powders, press them into molds, and fire them in furnaces. There are no furnaces in sight when a developing child infiltrates itself with bone or a diatom drapes itself in silica lace, and materials scientists would like to know how they do it.

The Regensburg group suspected that diatoms make proteins that orchestrate the initial phase of biosilica formation—the growth of tiny silica spheres. For one thing, other researchers had already found organic molecules closely linked to diatom cell walls. After extracting the organic material from their diatom samples, the Regensburg researchers isolated three proteins that could instigate silica precipitation in a test tube—a pair of small, closely related silaffins (1A and 1B) and another larger one, silaffin 2. To begin unraveling how the proteins work, the group determined the amino acid sequence of silaffin-1B and ferreted out a gene from the DNA of the diatom Cylindrotheca fusiformis, which turned out to encode silaffin-1A as well. Kröger says the team also is now working to characterize silaffin 2.

The structures of these proteins harbor clues to the diatoms' silica engineering. The glasslike veil of a newborn diatom takes shape in a "silica deposition vesicle," where conditions are acidic. Both silaffins have an unusual amino acid motif, consisting of bonded pairs of lysines with a string of amine groups grafted on after the protein chain is formed. The researchers say that under acidic conditions, this motif should stimulate silicic acid molecules to form silicon-oxygen bonds, linking them together into silica particles. That might help explain how diatoms form solid silica from ingredients dissolved in their watery environs, but it doesn't explain how the algae coax the silica to form intricate patterns. Kröger conjectures that other features of the proteins could be at work.

Silaffin-1A and -1B both consist mainly of two chemically distinct components, one bearing multiple positive charges and another multiple hydroxy groups. To Kröger, the proteins resemble synthetic block copolymers—polymers in which two distinct segments, each repeated many times, alternate along the molecule. When some copolymers solidify, like segments cluster together, segregating into two separate phases that pattern the material with regions of contrasting chemical properties—somewhat the way drops of oil poured onto a saucer of vinegar form segregated droplets. Kröger wonders whether silaffins might be doing something similar within a diatom's silica deposition vesicle, forming molecular frameworks that then guide the growth of the silica.

However diatoms create their silica patterns, it's a trick materials scientists would like to emulate. "Ceramics are one of those unfulfilled materials we could use lots more of, if only we could get
[them] easily," says materials researcher Paul Calvert of the University of Arizona, Tucson. Adopting biology's kinder, gentler methods could help engineers combine ceramics with other materials that can't take furnace temperatures. Quips Calvert: "You could make something with chocolate feel and a silicon carbide head." Unlikely material combinations, he says, could push forward such projects as "flexible electronics," in which silicon-based electronics are patterned onto polymer sheets. Diatom-like methods for making intricately shaped ceramics might also yield photonic materials, whose internal arrangements of solid and space could select and confine specific wavelengths of light for communication or computing.

The more scientists learn about diatoms' glassy laceworks, the more beautiful they seem.

Ivan Amato is the author of Stuff.