Title
Marine Bio-Nanotechnology: High-performance Materials from Sponge Silicatein

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NEW MARINE PRODUCTS

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Marine Bio-Nanotechnology: High-Performance Materials from Sponge Silicatein

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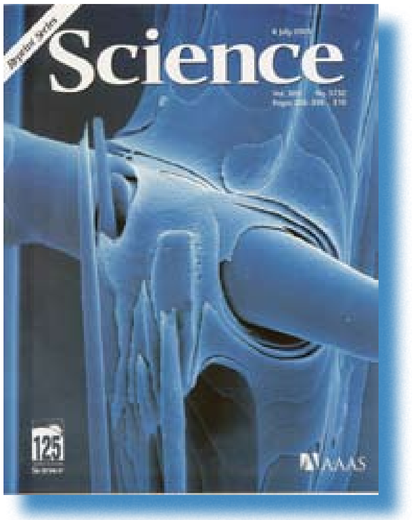

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Summary

Marine sponges produce nanoscale silicon dioxide structures called spicules. In previous California Sea Grant research, UC Santa Barbara professor Daniel Morse and colleagues identified the principal protein responsible for directing spicule construction at the molecular and atomic scale.

They showed that this protein, which they named silicatein, directs the nanofabrication of crystalline forms of several kinds of semiconducting materials, including titanium dioxide, and does so at room temperatures and in the absence of caustic chemicals. (Titanium dioxide is extremely efficient at converting light to electricity and thus has wide use in electronics.)

Because silicatein exists within the biological machinery of living organisms, its ability to operate in mild conditions is not unexpected. However, it is noteworthy in the context of current industrial manufacturing practices, because semiconductors are currently made at extremely high temperatures (in excess of a thousand degrees) and with caustic chemicals.

In ongoing Sea Grant research, Morse and colleagues are using gene cloning, special high-magnification electron microscopes and X-ray analyses to reveal the structures of other proteins involved in directing the synthesis of materials found in the sponge's skeleton. These proteins, or components of these proteins, may one day be anchored on silicon chips and other electronically useful platforms to make high-performance semiconductors and solar energy converters.

Deconstructing the Skeleton of a Marine Sponge

Think of a sponge—not a kitchen sponge, but a marine one. One of those radially symmetric, blob-like creatures stuck on the sea floor. Lacking organs and a body plan of higher life forms, the lowly sponge may seem just barely worthy of its classification in the animal kingdom.

As recent Sea Grant research shows, however, first impressions can be deceiving. Viewed under the intense magnification of a scanning electron microscope, the skeleton of one species of deep-sea sponge reveals itself to be an architectural marvel, an intricately designed glass cage, light-weight yet strong, and so complex that researchers from Lucent Technologies, UC Santa Barbara and the Max Planck Institute of Colloids and Interfaces have spent years deconstructing its structure and elucidating its mechanical properties.

What they have found may lead to new glass materials for everything from thinner optical fibers to safer skyscrapers. The photo [See Fig. 1, next page] is a scanning electron micrograph of the laminated silica cement that binds fibers of the *Euplectella* sponge's skeleton. It was on the cover of the 8 July, 2005 issue of the journal *Science* (reproduced this page). A similar image earned its "photographer," California Sea Grant Trainee James Weaver, a first place in the "Science as Art" competition at the international conference of the Materials Research Society in San Francisco in 2006. As the award's name suggests, these images are more than pretty. They are science, too, and part of a series of images documenting the organizational levels of the sponge's skeleton.

Weaver and Morse, director of the Institute for Collaborative Biotechnologies at UC Santa Barbara and Weaver's thesis advisor, were coauthors on the article in *Science* that described these hierarchical levels. In the article, first-authored by Joanna Aizenberg of Lucent Technologies, researchers show that the skeleton's fundamental building blocks are nanoscale silica spheres [Fig. 1A]. These glassy spheres are deposited around a central protein fiber and then arranged into concentric layers. Each silica layer is separated from its neighbor by a thin layer of protein [Fig. 1B]. This structure, called a spicule, is a composite material that resists cracking and shattering common with windowpanes, cheap drinking glasses and other pure glass objects. Spicules are bundled together, side-by-side (imagine dried spaghetti) [Fig. 1C]. A silica-based cement holds these

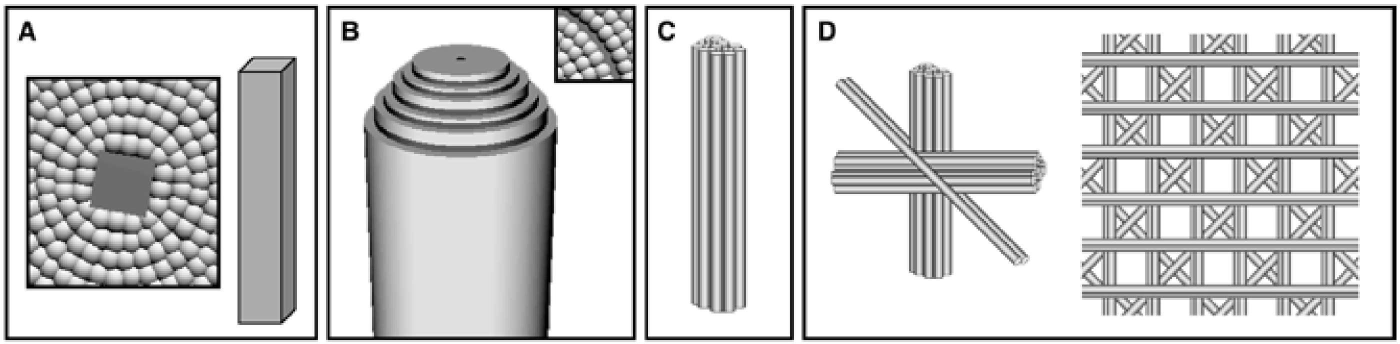

Fig. 1 reprinted with permission from Joanna Aizenberg et al., *Science* 309:275–278 (8 July 2005) ©2005 AAAS.

bundles together. The resulting “beams” are arranged in a cylindrical lattice and reinforced with cross beams, forming the sponge’s macroscopic skeleton [Fig 1D].

“The exceptional mechanical stability of the skeleton arises from the successive hierarchical assembly of the constituent glass from the nanometer to the macroscopic scale,” the authors wrote. “The resultant structure might be regarded as a textbook example in mechanical engineering... (The) hierarchical levels in the sponge skeleton represent major fundamental construction strategies such as laminated structures, fiber reinforced composites, bundled beams and diagonally reinforced square-grid cells, to name a few.”

Safer Windshields and Skyscrapers

A sponge’s skeleton is inspirational to those seeking to develop new materials. The precision of the sponge’s nanofabrication of composite materials exceeds the capabilities of present-day engineering, Morse said. Their glass-like skeletons are amazingly nonbrittle, yet are built with a minimal amount of material. “Sponge technology” may assist in developing thinner optical fibers, better shatterproof glass and safer skyscrapers.

Collaborators

Dow Corning Corporation
Lucent Technologies

Awards

D.E. Morse

2006: Outstanding Research Award, International Abalone Symposium, Chile.

2005: The Kelly Lecturer, Department of Chemistry, Cambridge University, England; the 3M Lecturer, Department of Chemistry and Materials, University of British Columbia, Vancouver, Canada.

J.C. Weaver

2006: First place in “Science as Art” competition, International Conference of the Materials Research Society, San Francisco.

Trainee

James C. Weaver

Selected Publications

Schwenzer, B., K.M. Roth, J.R. Gomm, M. Murr and D.E. Morse. 2006. Kinetically controlled vapor-diffusion synthesis of novel nanostructured metal hydroxide and phosphate films using no organic reagents. *J. Mater. Chem.* 16:401–407.

Thurner, P.J., B. Erikson, Z. Schriock, J. Langan, J. Scott, M. Zhao, J.C. Weaver, G.E. Fantner, P. Turner, J.H. Kindt, G. Schitter, D.E. Morse and P.K. Hansma. 2006. High-speed photography of human trabecular bone during compression *J. Mater. Res.* 21:1093–1100.

Aizenberg, J., J.C. Weaver, M.S. Thanawala, V.C. Sundar, D.E. Morse and P. Fratzi. 2005. Skeleton of *Euplectella* sp.: Structural Hierarchy from the Nanoscale to the Macroscale. *Science* 309:275–278.

Kisailus, D., J.H. Choi, J.C. Weaver, W. Yang and D.E. Morse. 2005. Enzymatic synthesis and nanostructural control of gallium oxide at low temperature. *Advanced Materials* 17:314–318.

Roth, K.M., Y. Zhou, W. Yang and D.E. Morse. 2005. Bifunctional small molecules are biomimetic catalysts for silica synthesis at neutral pH. *J. Amer. Chem. Soc.* 127:325–330.

Wustman B.A., D.E. Morse and J.S. Evans. 2004. Structural characterization of the N-terminal mineral binding domains from the molluscan crystal-modulating biomineralization proteins, AP7 and AP24. *Biopolymers* 74:363–376.

Fantner, G.E., T. Hassenkam, J.S. Kindt, J.C. Weaver, H. Birkedal, L. Pechenik, J.A. Cutroni, G.A.G. Cidade, G.D. Stucky, D.E. Morse and P.K. Hansma. 2005. Sacrificial bonds and hidden length dissipate energy as mineralized fibrils separate during bone fracture. *Nat. Mater.* 4:612–616.

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