Biology and Materials? Part I

Mark Alper

Poets and philosophers have, through the ages, viewed organisms as the embodiment of the mysterious "Vital Force," a unique non-earthly element required for the functioning of life processes.

Biologists have seen, in living organisms, an adaptive, self-reproducing, evolving collection of molecules acting solely according to the laws of chemistry and physics.

Historians speak of the iron or bronze ages and, more recently of the plastics (polymers) and the silicon ages. Materials science departments speak of metals, alloys, ceramics, and perhaps polymers—but not of genes.

The "common man" has, it must be admitted, seen living organisms as a source of useful and important materials—wood for building; cotton, silk, and other fibers for textiles; horn, shell, and bone for tools and weapons; fats for lubricants; fur for clothing

But, in fact, few of us now think of materials when we think of living things. Neither do we think of DNA, protein, and carbohydrates when we think of materials.

No, biologists have not been blackballed by materials scientists, chemists, and physicists. Until recently, they neither understood the processes by which life produces its materials nor even conceived of manipulating those processes to tailor the properties of the materials to our needs. Only within the past few years has the "biological revolution" expanded our understanding of the molecular basis for biological phenomena and our ability to control them. It is only now, for the first time, that one can point to a legitimate field of science based on mimicking, adapting, and controlling biological systems with the goal of producing novel materials with important, unique, and useful properties.

What does biology bring the materials sciences? Unlike the pharmaceutical industry, which sees a very bright future in the discovery of more naturally occurring drugs, the materials community has, in all likelihood, few remaining discoveries of usable biological materials. The emphasis clearly must be on new materials and enhancement of properties. Here, however, the evolutionists ask challenging questions. Nature, they say, has had hundreds of millions of years to perfect biological molecules and structures and optimize them for function. What could a few scientists do to improve on these, and within the time frame of an annual (quarterly) business report or a grant renewal?

Initial studies say that quite a lot can be done to improve on Nature's materials. For one, it appears that many biological systems are not optimized, but simply made "good enough." Simple experiments using tools readily available to living organisms have, for example, led to improvements in the stability and activity of enzymes. Further, biological materials are produced under a very narrow set of conditions. They are synthesized only from those elements that are readily available to a living organism, not toxic to it and readily absorbed by it. Synthetic routes are selected only if they do not involve toxic intermediates and the products made must be deliverable to their site of use. There is, in fact, much that can be improved upon, especially once the synthetic processes are taken out of the organisms and put into the laboratory.

Biology and chemistry have opened a door to this field and the view is promising. Biomaterials is now (at least in the view of its practitioners) one of the most exciting and productive fields of endeavor. It is a new field, however, and there are as yet few true successes. This issue of the *MRS Bulletin*, and also the next, have been designed to provide a survey of some of the exciting questions in the field and examples of some of the research efforts that are being pursued. Even two such issues allow too little space for a complete view, but it is hoped at least a flavor of what is being done can be conveyed.

We have chosen to address four major areas of biomaterials:

- biomineralization,
- proteins as materials,
- enzymes as synthetic tools, and
- materials modeled on self-assembling membranes.

The first two will be addressed in this issue, the next two in the November issue. The discussion of each area begins with a paper describing the current state of knowledge of a relevant biological system, specifically eggshells, silks, natural "plastics," and biological membranes. This description of a natural system is followed by one or two papers presenting work focused on applying what is known about that system to the synthesis of novel, artificial materials. In addition, we have included one or two papers describing new materials modeled on biology that do not fit cleanly into any of the four major areas. The preliminary status of the results betrays the newness of the field, but the nature of the results conveys its excitement.

Acknowledgments

I wish to thank Ms. Marilee Bailey of the Lawrence Berkeley Laboratory Technical Information Department for her work on the cover illustration. Her outstanding combination of artistry and sense of the science is readily apparent in the figure. I also thank Ms. Jeri Edgar who, as usual, saved the day (and in this case, the issue) by handling the administrative aspects of organizing this enterprise for me. I also thank the U.S. Department of Energy, Division of Materials Sciences and also the Division of Energy Biosciences for continued support of our Bio-Materials research program at the Center for Advanced Materials, Lawrence Berkeley Laboratory. □

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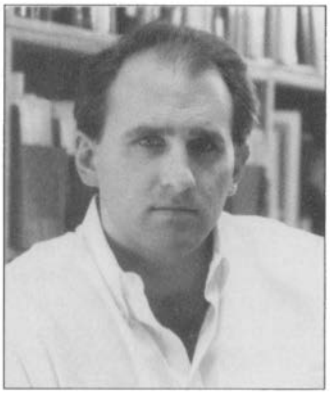
Mark D. Alper

Mark D. Bednarski



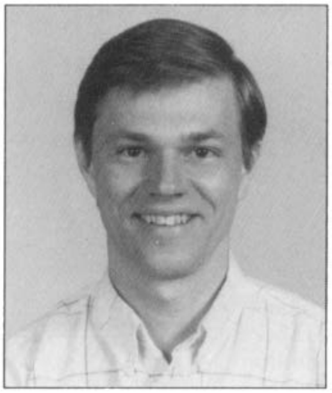
Matthew R. Callstrom

Mark D. Bednarski is a professor in the Chemistry Department at the University of California–Berkeley, and a staff scientist at Lawrence Berkeley Laboratory. He received his PhD degree in chemistry at Yale University in 1987 and was a postdoctoral associate at Harvard University. Bednarski's research group is investigating the synthesis of biocompatible materials and the construction of cell-surface mimics in order to understand the process of biological adhesion. Bednarski has received the American Cancer Society Jr. Faculty Research Award and the National Institute of Health First Award, among other awards.

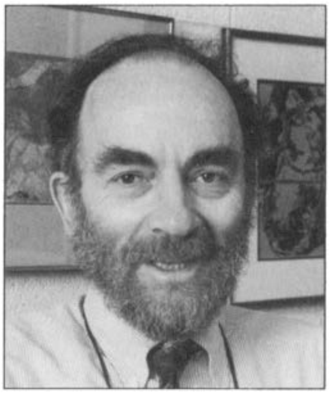
Matthew R. Callstrom, assistant professor of chemistry at Ohio State University, received his BChE from the University of Minnesota in 1983; he received his PhD degree in organic chemistry from the University of Minnesota in 1987 under the guidance of Paul Gassman. Callstrom spent one postdoctoral year with George Whitesides at Harvard University. His research involves the design, synthesis, and study of new materials in two broad areas, doped glassy carbon solids and the chemo- and enzymatic synthesis of carbohydrate-based materials.

Paul Calvert received his BA degree in materials science from Christs College, Cambridge, in 1967 and an unearned MA in 1971. That same year he received his PhD degree in materials engineering, with a thesis on polymer crystallization, from the Massachusetts Institute of Technology. From 1972 to 1988, Calvert was a lecturer in polymer science at Sussex University and afterward came to the University of Arizona, where he recently became a full professor.

Arnold I. Caplan is a professor of biology and the director of the Skeletal Research Center at Case Western Reserve University. The Center comprises faculty and staff from the basic science, engineering, and clinical departments for the purpose of studying skeletal tissues and translating this information into new, innovative healthcare protocols. Caplan received his BS degree in chemistry/chemical engineering from the Illinois Institute of Technology and his PhD degree from Johns Hopkins University Medical School. Widely recognized for his study of the cells and molecules of skeletal tissues in embryos and in repair circumstances in adults, he received the American Association of Orthopaedic Surgeons Kappa Delta Award for his research contributions.



Stephen A. Fossey



Arthur H. Heuer

Joseph Cappello has been senior research director, protein engineering, with Protein Polymer Technologies Inc. since 1988; he is co-inventor of the firm's protein polymer technology. Previously he was research director, molecular design and analysis, at Syntro. Cappello received his BS degree in genetics from the University of California–Davis and his PhD degree in biological chemistry from the University of Cincinnati College of Medicine. His postdoctoral research at Whitehead Institute for Biomedical Research involved bacterial and yeast expression of foreign genes. He was also an American Cancer Society Fellow conducting postdoctoral research on the genetic characterization of cellular differentiation at the Massachusetts Institute of Technology.

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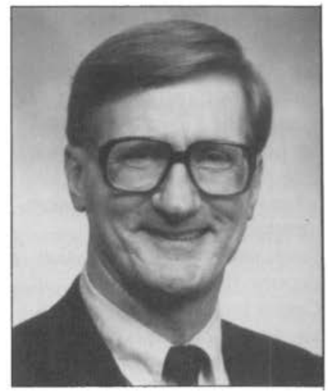

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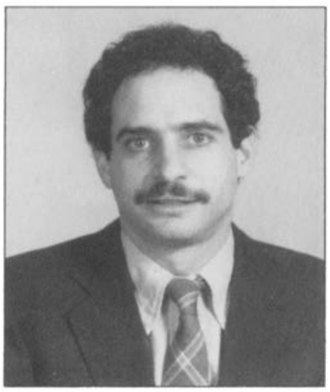

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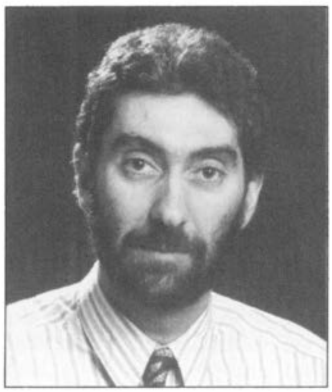

Stephen Mann

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Stephen A. Fossey is a materials research engineer in the Biotechnology Division of the U.S. Army Natick Research, Development & Engineering Center. He received his BS and MS degrees in chemical engineering from the University of Lowell. Fossey recently spent two years on leave in the Chemistry Department at Cornell University, where he began molecular mechanics studies on silk protein. His current research interests include computational modeling of fibrous proteins and polymers.

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David L. Kaplan is the senior scientist for the Biotechnology Division at the U.S. Army Natick Research, Development & Engineering Center, and an adjunct professor in the Chemistry Department at the University of Massachusetts at Lowell. He received his PhD degree from the State University of New York College of Forestry and Syracuse University for his thesis work on the biochemistry of lignin degradation. In addition to the joint program described in this issue of the *MRS Bulletin,* he is involved in a variety of research efforts related to biomolecular materials, including studies on biomineralization, biocatalytic approaches to polymer synthesis, synthesis and degradation of biodegradable polymers, and photodynamic protein assemblies.

Stephen Mann is a professor of chemistry in the School of Chemistry, University of Bath. He received a degree in chemistry at the University of Manchester Institute of Science and Technology and his PhD degree at Oxford University. Before joining the University of Bath, he was a junior research fellow at Keble College. Mann's research interests are in new aspects of inorganic chemistry involving crystalline or amorphous materials synthesized in the presence of organized organic assemblies. Much of his work has been inspired by structural studies of biominerals such as magnetite crystals in magnetotactic bacteria, iron oxide deposition in ferritin, and calcite crystallization in marine coccolithophorids. Mann can be reached at the School of Chemistry, University of Bath, Bath BA2 7AY, United Kingdom.

Charlene M. Mello, a research chemist with the Biotechnology Division at the U.S. Army Natick Research, Development & Engineering Center, received her PhD degree from the University of Massachusetts at Lowell in 1991. Her thesis work involved identification and characterization of the binding of microtubule proteins to centromere DNA sequences. While Mello's primary contributions involve characterization of silk proteins, her research efforts also include the development of environmentally safe markers for genetically engineered microorganisms and appropriate biosensor devices for monitoring and detecting these markers. □