biologists, pharmaceutical chemists, and nutritional chemists dealing with fungi.

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Handbook of Biomineralization

This is the third and most ambitious effort by Edmund Bäuerlein and his co-authors to produce a set of multi-authored books encompassing the vast area of biomineralization in a comprehensive treatment. The first book, *Biomineralization: From Biology to Biotechnology and Medical Application*, appeared in 2000. A revised and enlarged version appeared in 2004 under a similar title. Now, this new three-volume series *Handbook of Biomineralization* assembles the various aspects of the subject under the titles *Biological Aspects and Structure Formation*, *Biomimetic and Bioinspired Chemistry*, and *Medical and Clinical Aspects*. All these books now constitute an important source of information for this rapidly developing and exciting field.

The editors have made a heroic effort to cover all the areas of this vast subject: I am full of admiration for their vast amount of work and for the results that they have achieved. However, this is not really a handbook. A handbook is a compendium of information that is designed to provide comprehensive answers in a certain area. In my opinion it is impossible to achieve such a goal in biomineralization by assembling a collection of manuscripts from different authors. Take, for example, bones and teeth, the two mineralized tissues of medical/clinical importance, which are mainly addressed in the third volume. The subject of teeth is indeed covered systematically, from the formation and structure of teeth to biomechanical design, tooth diseases and treatment, tooth regeneration, and finally tissue engineering of teeth. In contrast, there is no general description of the bone tissue and its structure, of how bone is formed, and what is known about it. That is clearly a significant gap in a series of books that claims to be a handbook of biomineralization.

Biomineralization is concerned with evolution, genetics, molecular biology, cell biology, biochemistry, biomechanics, materials science, chemistry, crystallography, thermodynamics, molecular recognition, structural biology, physiology, and pathology. The *Handbook of Biomineralization* addresses all these aspects. It thus becomes possible, after observing with a bird's-eye view all the enormous amount of work reported here, to identify some of the trends that are developing in the area, especially in recent years.

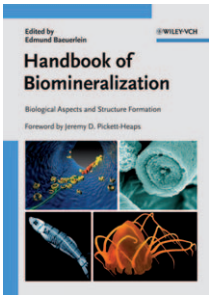
It is extremely satisfying to realize that genetic information is at last becoming available in an area where very little was known, at least in the field of invertebrates, until a very short time ago. There is no doubt in my mind that the genetic information that is emerging will contribute substantially to the advancement of research in the area. Although it is true that genetic factors govern all processes of tissue formation, it is also true that mechanisms of formation will not be fully elucidated on the basis of genetics alone. By definition, biomineralization involves the interface between minerals and biology, and a good understanding of both of these, and of their interplay, is needed.

In the compendium presented here, the highlights are, in my opinion, in the attempts to bridge the gaps between structure, function, morphology, and genetics—a very difficult enterprise indeed, especially because the interface between mineral structures and biological structures, where all the action occurs, is still poorly understood. The articles by Jogler and Schuler on magnetotactic bacteria and by Douglas and co-authors on protein cages touch on these problems and are very interesting.

In the area of carbonate mineralization, where in general much more is known about mechanisms, the gap is bridged more successfully. The chapter by Wilt and Ettensohn covers all aspects of biomineralization of the sea urchin larval skeleton, from development to cell biology, from the gene regulatory network to matrix proteins and their function, from ion and macromolecule transport to skeletal morphogenesis, and from matrix–mineral interactions to structure and mechanism of formation. Marsh takes a similar approach to the description of coccolith calcification. The chapters by Arias on "Egg Shell Growth and Matrix Macromolecules" and by Marin on "Unusually Acidic Proteins" relate the existing information on functional matrix macromolecules within a framework of structure–function relationships.

These efforts represent what is needed to obtain a comprehensive understanding of biomineralization processes. Only then can we properly understand the properties of these fantastically complex and sophisticated materials. It is fascinating to observe how, from this approach, an understanding of the biological design that results in the mechanical properties of the tissues is beginning to emerge (see, e.g., Fratzl and Gupta, Chapter 23 of Vol 1; Zaslansky and Weiner, Chapter 13 of Vol. 3).

I want to conclude with a conceptual consideration. The first article in the series, entitled "Growth and Form: What is the Aim of Biomineralization?", encapsulates the views of Bäuerlein



Handbook of Biomeralization
Edited by Edmund Bäuerlein, Peter Behrens, and Matthias Epple. Wiley-VCH, Weinheim 2007. 1269 pp., hardcover € 499.—
ISBN 978-3527316410

himself, and provides material for constructive thought. In Bäuerlein's view, the major aim of biomineralization is stability. It is questionable whether, in biology, one can assign an aim to a process or to many different processes that are the product of evolution over hundreds of millions of years. I personally doubt that the aim or ultimate product of biomineralization is stability: biomineralization, like most other biological processes, is not about achieving stability, but rather about operating at the edge of instability. Reaching maximum stability, in biological terms, is equivalent to death, because there is no way back from a situation that is at the bottom of the energy well; this is the end of development and evolution. I have no doubt that there are still many surprises to come in the discovery of the strategies that biomineralization evolved, exploiting the subtle interplay between lack of thermodynamic equilibrium in favor of kinetic advantage.

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DOI: 10.1002/anie.200805360

