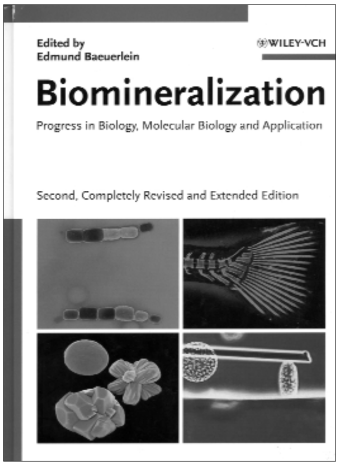

Biomineralization: progress in biology, molecular biology and application

EDMUND BÄUERLEIN (ED.)

2nd edn., 2004, Wiley-VCH,
Weinheim, Germany
361 pp, XXX × XXX cm
Price:
ISBN: 3-527-31065-7

Scientists and engineers have long been inspired by the beautiful structures and properties of the materials formed within living organisms. Biomineralization is the process by which these materials are derived from bioorganic molecules and inorganic solids. It encompasses all the mineral-containing compounds, such as iron oxides and sulfides in bacteria, silicates in diatoms, carbonates in algae, and calcium phosphates and carbonates in vertebrates, used by organisms to fulfill a variety of functions. The second edition of *Biomineralization: progress in biology, molecular biology and application* comes only four years after the first one. The book's 18 chapters supplement information from the previous volume with new content, accounting for over 50% of the text and reflecting the rapid progress that has been achieved within the field in a short span of time.

In Chap. 1 ("Peptides, pre-biotic selection and pre-biotic vesicles"), the book's editor, Edmund Bäuerlein, introduces biomineralization by describing the experiments that showed how, based on their ability to tightly bind metals, several groups of peptides could serve as templates for inorganic nanoparticles. PCR and PCR panning are used to select these peptides from a combinatorial phage display peptide library, thus establishing an important link between molecular biology and materials science.

The book is subsequently organized according to the main biominerals. Chapters 2 through 8 deal with magnetite (Fe_3O_4) and greigite (Fe_3S_4). The biologically induced (uncontrolled formation in the environment from bacterial metabolites) and biologically controlled (within organic matrices or vesicles inside the cell) deposition of magnetic iron minerals by bacteria has been recognized since 1975. Magnetotactic bacteria synthesize magnetosomes, consisting of nanometer-sized magnetite or greigite crystals in intracellular membrane vesicles. These structures allow the bacteria to orient themselves along the lines of the Earth's magnetic field and to maintain their position within the boundary of the oxic-anoxic transition zone. Chapter 2 reviews the characteristics of magnetic minerals in these bacteria and in single-celled eukaryotes, as well as the role iron minerals play in magnetotaxis. Magnetotactic bacteria are resistant to cultivation; thus, alternative methodologies, as outlined in Chap. 3, are needed for their phylogenetic analysis and in situ identification. These include comparative sequence analysis and FISH, or the combination of cultivation and independent rRNA gene retrieval. Chapter 4 is dedicated to an analysis of the magnetosome membrane, the compartment in which substantial amounts of iron accumulate and where an iron mineral is subsequently formed. As one of the fundamental principles governing the formation of inorganic materials in organisms, compartmentalization allows strict control of the process through chemical and spatial partitioning of the mineralizing environment. Yet, how do bacteria synthesize magnetite crystals and regulate their size? Chapter 5 provides answers to these questions, explaining the mechanism behind the enzymatic synthesis of magnetite.

Some microorganisms, such as *Magnetospirillum magneticum*, exhibit relatively less magnetotaxis and are thus referred to as "magnetic" rather than magnetotactic, and their magnetosomes as "bacterial magnetic particles" (BMPs). Chapter 6 uses this microorganism as a model to elucidate the molecular and biotechnological aspects of bacterial magnetite, and describes several studies on the vast potential for the technological application of BMPs.

Biomineralization is also important in the magnetic sensing of animals such as the homing pigeon and the trout, briefly reviewed in Chap. 7. This chapter also surveys the two most plausible hypotheses explaining the physical mechanisms underlying magnetic-field perception. Finally, Chapter 8 describes biomineralization on protein surfaces. For example, the iron-storage protein ferritin belongs to a superfamily of proteins occurring throughout all the kingdoms of life. Ferritin has been extensively characterized, given the increased interest in the protein for nanotechnological applications.

Chapters 9 to 11 shift the focus to hydrated silica (SiO_2) in diatoms. These eukaryotic unicellular algae are ubiquitously present in almost every water habitat and are responsible for an estimated 25% of the net biological primary production on Earth. Diatoms are known for their intricate and ornate silicified cell walls, one of the most outstanding examples of micro- and nanoscale-structured materials in nature. Given the genetic control of the biomineralization process, biogenesis of the diatom cell wall is regarded as a paradigm of controlled production of nanostructured silica. Nevertheless, our understanding of the processes by which diatoms make their cell walls is still very limited. In these three chapters, the state of our knowledge on the development and nanostructure of biosilica is summarized. The roles played by proteins and other organic molecules in the morphogenesis of biolosilica, as well as the mechanism of silicic acid transport and control during cell wall silification are reviewed as well.

The next section is dedicated to calcium carbonates. Although many organisms are capable of calcification, few carry out the reaction in a subcellular compartment and even fewer are genetically capable of controlling the morphology of their calcified products. Coccolithophores, a phylogenetic group of unicellular predominantly phytoflagellates, are an example of the latter. They produce an outer covering of calcitic scales, known as coccoliths, whose morphology is thought to be under genetic control. Biomineralization in coccolithophores is a phenomenon of global importance. The appearance of these organisms in the late Triassic marked the onset of calcium carbonate sedimentation in the deep ocean, a process thought to stabilize the carbon cycle today. This and the role of the coccolith proton pump as a central feature of the ecophysiology of coccolithophores are discussed in Chaps. 12 and 13.

There are also four new chapters on biomineralization in mammals, including humans. Chapter 14, "The zebrafish as a genetic model to study otolith formation," describes how, in order to move and orient themselves in three dimensions, fish have developed a detection system that includes otoliths, composites of inorganic (tiny calcium carbonate crystallites) and organic (fibrous matrix proteins) components. Zebrafish thus provide an opportunity for the in vivo study of their complex interactions.

The following three chapters address calcium phosphates. Chapter 15 describes the means by which pathological calcification could be prevented. In Chapter 16, dentiogenesis as a model for biomineralization is discussed. Chapter 17 reviews the embryonic origins and molecular regulation of bone formation in zebrafish, as an introduction to their use in screening for mutations affecting different aspects of embryonic development, including bone formation.

The last twenty years have witnessed an increasingly profound scientific understanding of the mechanisms underlying the formation of biominerals. Advances in our knowledge have been fueled by the interaction of modern molecular biological techniques with novel solid-state analytical features. Accordingly, the book concludes with a chapter dedicated to the most recent applications of physicochemical methods. These approaches have brought significant gains; however, as the chapter's author, Matthias Epple, explains, equally important are the modern genetic and molecular biological methods that can provide insight into the relationship between the genome and the biominerals formed. In the book's final section, these newer physicochemical methods—infrared (IR) spectroscopy, scanning probe microscopy, synchrotron radiation sources, X-ray microtomography, solid-state nuclear magnetic resonance (NMR) spectroscopy, etc.—are presented in order to encourage scientists from the "biological community" to understand their potential and to stimulate their application, with the goal of bridging the gap between "bioscience" and "materials science."

As Peter Behrens explains in the book's foreword, biomineralization is a fascinating topic that unites the living world with the (not always really) dead one. The ability of the field to connects the living and the mineral world, is mirrored in the fact that it brings together scientists from very diverging fields such as geology, mineralogy, crystallography, medicine, biology, chemistry and biochemistry, and, ultimately, biotechnology.

The book's editor has carefully selected the contributions, focusing on organisms that are most likely to be the targets, in the near future, of genetics and molecular biological investigations. The international team of authors successfully balances descriptive background information with detailed experimental methods. Each section is completed by a wealth of references.

The style of the book is consistently readable and includes several diagrams, drawings, and photographs to illustrate key points. The result is an interdisciplinary must-have account that will prove extremely useful to researchers in a wide range of disciplines, by offering an essential basis for the work to come.

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