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Biomineralization

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until he finds a detail that unravels the whole thing". Many more participants are described. All are sufficiently different to shatter any stereotypes as Gabrielle Walker tells the story of the most hotly contested theory in Earth science today and the scientists, pro and con.

Her final lines: "Theories like the Snowball often languish for decades without being properly probed. They need champions to drag them into the scientific limelight and expose them to scrutiny. They need people like Paul."

Biomineralization

Edited by P. M. Dove, J. J. De Yoreo and S. Weiner
Reviews in Mineralogy & Geochemistry v. 54, 381 p., 2003; Mineralogical Society of America; ISBN 093995066-9
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I am glad that the U.S. Library of Congress, which normally treats earth sciences poorly, saw fit to catalogue the Reviews in Mineralogy & Geochemistry under one number, because not only is that distinctive row of small, white dog-eared paperbacks a point of visual geographic reference, but also a rich source of easy-to-find information on a sweeping array of mineralogical topics. Each volume is crystallized around a short course, and that on biomineralization was delivered prior to the fall 2003 meeting of the American Geophysical Union. This is a series of review papers covering a range of recent developments in the field. It adds to an extensive literature on biomineralization, summarized in a number of fairly recent books, such as those written or edited by B.S.C. Leadbeater and R. Riding (1986), H.A. Lowenstam and S. Weiner (1989), R.E. Crick (1989), S. Mann et al. (1989), K. Simkiss and K. Wilbur (1989), J.G. Carter (1990), E. Bäuerlein (2000) and S. Mann (2001), each of which takes a somewhat different tack. In this book, biomineralization means biologically mediated mineral precipitation, that is, both biologically controlled as well as biologically induced, the latter sometimes referred to as organomineralization. (Organo-mineralization has also been used to denote early diagenetic precipitation triggered by residual organic compounds such as fulvic acids, an area not treated here.) The whole subject is understandably vast and complex.

The introductions of the papers collectively sum up the importance of biomineralization and why geologists should care: organisms—prokaryotic starting nearly 4 billion years ago, eukaryotic barging in for the past half a billion or so—shouldered their way into virtually all geochemical cycles on Earth's surface to the point that most geochemical reactions are really biogeochemical. Organisms are in charge, you better believe it! The grandness and the range of scale, from gross patterns in the rock record to global geochemical cycles to cell metabolism, are captivating. Furthermore, the activities of organisms in bygone eras sequestered minerals that are part of the reservoir re-entering the system via weathering. It is all so simple. The devil is in the details—if you thought chemistry and thermodynamics hurt, try adding organisms to the brew!

This book consists of 12 chapters by an assortment of leading authorities. They are well written and well illustrated and the book is well produced, a tribute to the sponsoring societies. It is ordered, not unnaturally, from the minute to the mega in terms of scale. But if we seek the narrative dimension, the hallmark of geology, we can peek at the final chapters first. A.H. Knoll gives a masterful summary of the evolutionary history of biomineralization, outlining the origins, the phylogeny and fossil record of shells, spicules, endo- and exoskeletons, and so on. He deals with the Neoproterozoic appearances, the "Cambrian explosion", the Ordovician radiations of heavily calcified skeletons, the Permo-Triassic extinction, subsequent recovery as part of the "Mesozoic marine revolution" (the arms race between predators and prey), and the late Mesozoic rise of calcite-secreting coccolithophorids and silica-secreting diatoms. The importance of these events is amplified by P. Van Cappellen who provides an instructive overview of global biogeochemical cycling, the time scale at which its components operate, the size of the reservoirs, their fluxes and their turnover times, and the basic theory behind numerical models. He then delves a little more deeply into the carbon and silica cycles. Both these papers bring the vital perspectives of Deep Time and Whole Earth to the world of biomineralization, showing that biogeochemical pathways have evolved since organisms began to participate, with the backdrop of changing global tectonics. Knoll also touches on the future by reporting the suggestion that the oceans are not well buffered against rapidly rising atmospheric CO_2 levels, meaning that the physiological cost of calcification might become too high for many invertebrate groups to sustain, thereby duplicating past extinction scenarios.

Turning to the more biological, the introductory chapter by the book editors gives us a list of biominerals—much longer than you might imagine—and shows that many groups have evolved the extraordinary feat of being able to extract ions from highly undersaturated environments. The authors outline the mechanisms whereby secretion, active pumping, passive diffusion or gradient diffusion at the cellular level cause nucleation on particulates, on cell surfaces, or genetically programmed precipitation in organic matrices either on or within cells. This introduction is followed by a succinct summary by J.S. Evans of the principles of molecular biology and biochemistry as they pertain to the three categories of macromolecules that are involved in mineral precipitation: proteins, polysaccharides and membrane assemblies. The more thermodynamic background to crystal nucleation and growth is then laid out by J.J. De Yoreo and P.G. Vekilov.

Two chapters by R.B. Frankel and D.A. Bazylinski discuss biologically induced and biologically controlled Fe and Mn mineralization by bacteria. Examples of the former are some Fe sulfides and the 'rusticles' draping the wreck of the *Titanic*, while the latter are the magnetotactic bacteria. Just because these processes involve prokaryotes does not mean they are simple, and the dramatic deterioration of the *Titanic* shows how fast they can operate.

J.R. Young and K. Henriksen describe in detail the crystallography, morphology and process of calcite skeleton formation in coccoliths, tiny but elaborate and highly controlled algal constructions. Similarly, C.C. Perry's chapter on silica biomineralization starts with structural chemistry of SiO_2 and techniques of study, and proceeds to a discussion of sponge spicules and diatoms and the specific proteins thought responsible for silica nucleation. Silica is also precipitated by radiolarians, silicoflagellates, horsetails and grasses.

Animals have obviously devised the most varied and intricate tricks in the biomineralization trade. Invertebrates take the stage in two papers, one by J. Erez on the foraminifera and another by A.L. Cohen and T.A. McConnaughey on scleractinian corals. Erez focuses on recent observations about rates of calcification and fine-scale variations in trace-element composition — geochemists take note! He reports ingenious experiments whereby decalcified specimens are monitored as the cell reconstructs the test. The chapter on corals shows amply why these skeletons are valuable repositories of paleoclimatic information because their rapid growth permits even daily fluctuations in biomineralization rate to be discerned. Cellular processes and the complexities of stable-isotopic composition are reviewed. In both these chapters, the widely held assumption about the primary role of photosymbionts is dispelled: they do not simply enhance the rate of calcium carbonate biomineralization by removing CO_2.

Shell secretion in molluscs has received a great deal of attention in the past. Here, it is dealt with in passing by A. Veis as part of a chapter on compartmentalized precipitation mediated by the collagen matrix in vertebrates. He describes the composition and morphology of collagen molecules and fibrils, how certain proteins induce crystal nucleation, and then how bones, teeth and otoliths are formed.

The lengthy bibliographies attest to the dynamism of the biomineralization field, straddling as it does the domains of geology, biology and chemistry. Technological advancements have obviously paved the way for spectacular improvements in understanding. The next frontier is to assemble the genomic sequences in biomineralizing organisms in order to elucidate the genetic controls on the biochemical processes and how variations manifest themselves in different taxa. This is an excellent book, bursting with information, much of which is quite beyond this reviewer. I can, however, appreciate the majesty of biomineralization in the history and workings of Earth, and marvel at its wondrous artistry I see under the microscope.