Volumes Published in the Series

Progress in Molecular and Subcellular Biology

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W.E.G. Müller and M.A. Grachev (Eds.) |
Lake Baikal, the oldest (>24 million years), deepest (1,637 m) and most voluminous lake on Earth, comprising one-fifth of the world’s unfrozen freshwater, harbors the highest number of known endemic animals in a freshwater lake. Until recently, it remained enigmatic why such a high diversity evolved in this closed and isolated lake. Focusing on sponges (phylum Porifera) as examples, some answers have produced a deeper understanding of the evolutionary forces that have driven this process. The most likely scenarios are outlined in this volume, explaining the high rate of evolution/diversification of Baikalian sponge species, especially focusing on their method of reproduction and their specific habitat with its extreme temperature and particular chemical composition. A further trigger of evolution of the endemic sponges in Lake Baikal may be their sophisticated symbiotic relationship with unicellular autotrophic eukaryotes. As a basis for understanding the exceptional habitat, the geological history of the lake and its surrounding basins is described in greater detail. Another exciting finding is that (almost) all sponge species in Lake Baikal harbor mobile genetic elements (retrotransposons) which have been implicated in the endemic progress during evolution.

It is likewise remarkable that the Baikalian sponges are characterized by a distinct and elaborate body plan which characterizes them as the most subtle freshwater sponges on Earth. The basic characteristics of the body plan construction are given with the main emphasis on the organization, construction, and association of the needle-like skeletal elements, the spicules. It is further highlighted that the basis for the exceptional morphogenetic organization of the sponges in Lake Baikal must be seen in the expression of those genes which result in the synthesis of proteins governing the synthesis of spicules and their associated proteins. In particular, by comparing sponge species in lakes adjacent, but not connected, to Lake Baikal, it became apparent what a high degree of morphological construction their sponges have reached.

The inorganic material from which spicules are made is silica, a material which has recently gained increasing attention. Here, the siliceous sponges in general and the Lake Baikal (siliceous) sponges in particular, are featured for their property to synthesize polymeric silica enzymatically. The key enzyme involved in this process is silicatein which exists in the endemic sponges of Lake Baikal as a family of more than five different members. No other sponge taxon comprises such a high poly-
morphism, thus qualifying the Lake Baikal species as exceptional with respect to their genetic toolkit for silica formation. In order to successfully approach the exploitation of this unique property in a sustainable way, and by applying modern molecular biology and cell biology techniques, the sponge silicateins have been prepared in a recombinant way in bacteria.

Based on these findings, it is now the challenge to apply the process of enzymatic silica formation for the fabrication of biosilica-based materials used, e.g., in biomedicine. A major breakthrough came recently with experiments which showed that silicatein can be immobilized on inorganic matrices as well as on organic polymer layers through a linker molecule, comprising a nitrilotriacetic acid group which binds via nickel ions to histidine-tagged silicatein. The immobilized enzyme catalyzes not only the condensation of biosilica but also, importantly, the formation of structured titania and zirconia nanoparticles from soluble precursors. This finding will surely have a considerable impact for the construction of three-dimensional semiconductors if nanowires can be decorated with such biocatalytically-formed titania and/or zirconia nanoparticles.

The stability of spicules’ biosilica is highly impressive. Besides this property, it is now being investigated whether biosilica has additional properties which are important for biomedical applications: (1) to be biocompatible and (2) to be biodegradable. In this volume, the first approaches to reaching sufficient biocompatibility of biosilica are conceptualized. In order to meet the demands for novel bioactive supports in surgery, orthopedics, and tissue engineering, recombinant silicatein has been applied for the synthesis of silica-containing bioactive surfaces under ambient conditions that do not damage biomolecules such as proteins. In nature, an anabolic reaction is counterbalanced by a catabolic one. This also holds true for enzymatic processes. Driven by this experience, silicatein has been screened for a biosilica-degrading enzyme, which was discovered with silicase. Both silicase and, to a much lesser extent also carbonic anhydrase, allow the decomposition of biosilica, again under ambient conditions.

This volume focuses on state-of-the-art issues of biosilica biochemistry, cell biology, and biotechnology, which allow an estimation of the inherent high economical value that can be attributed to this material. However, the treasures of Lake Baikal are larger; it is a unique place at which (1) evolution in action can be studied, (2) a unique and conserved climate situation exists, which may provide us with early warning markers of the present day global warming process, and (3) solid methane is found, a powerful greenhouse gas that is also a valuable fuel for mechanical and electrical energy generation.

Professor Dr. W.E.G. Müller
Dr. Mikhail A. Grachev (Academician)
Preface to the Series

Recent developments in the applied field of natural products are impressive, and the speed of progress appears to be almost self-accelerating. The results emerging make it obvious that nature provides chemicals, secondary metabolites, of astonishing complexity. It is generally accepted that these natural products offer new potential for human therapy and biopolymer science. The major disciplines which have contributed, and increasingly contribute, to progress in the successful exploitation of this natural richness include molecular biology and cell biology, flanked by chemistry. The organisms of choice, useful for such exploitation, live in the marine environment. They have the longest evolutionary history during which they could develop strategies to fight successfully against invading organisms and to form large multicellular plants and animals in aqueous medium. The first multicellular organisms, the plants, appeared already 1,000 million years ago (Ma), then the fungi emerged and, finally, animals developed (800 Ma).

Focusing on marine animals, the evolutionary oldest phyla, the Porifera, the Cnidaria and the Bryozoa, as sessile filter feeders, are exposed not only to a huge variety of commensal, but also toxic microorganisms, bacteria and fungi. In order to overcome these threats, they developed a panel of defense systems, for example, their immune system, which is closely related to those existing in higher metazoans, the Protostomia and Deuterostomia. In addition, due to this characteristic, they became outstandingly successful during evolution: they developed a chemical defense system which enabled them to fight in a specific manner against invaders. These chemicals are of low molecular weight and of non-proteinaceous nature. Due to the chemical complexity and the presence of asymmetrical atom centers in these compounds, a high diversity of compounds became theoretically possible. In a natural selective process, during evolution, only those compounds were maintained which caused the most potent bioactivity and provided the most powerful protection for the host in which they were synthesized. This means that during evolution nature continuously modified the basic structures and their derivatives for optimal function. In principle, the approach used in combinatorial chemistry is the same, but turned out to be painful and only in few cases successful. In consequence, it is advisable to copy and exploit nature for these strategies to select for bioactive drugs. Besides the mentioned metazoan phyla, other animal phyla, such as the higher evolved animals, the mollusks or tunicates, or certain algal groups, also
produce compounds for their chemical defense which are of interest scientifically and for potential application.

There is, however, one drawback. Usually, the amount of starting material used as a source for the extraction of most bioactive compounds found in marine organisms is minute and, hence, not sufficient for their further application in biomedicine. Furthermore, the constraints of the conventions for the protection of nature limit the commercial exploitation of novel compounds, since only a small number of organisms can be collected from the biotope. Consequently, exploitation must be sustainable, i.e., it should not endanger the equilibrium of the biota in a given ecosystem. However, the protection of biodiversity in nature, in general, and of organisms living in the marine environment, in particular, holds an inherent opportunity if this activity is based on genetic approaches. From the research on molecular biodiversity, benefits for human society emerge which are of obvious commercial value; the transfer of basic scientific achievements to applicable products is the task and the subject of *Marine Molecular Biotechnology*. This discipline uses modern molecular and cell biological techniques for the sustainable production of bioactive compounds and for the improvement of fermentation technologies in bioreactors.

Hence, marine molecular biotechnology is the discipline which strives to define and solve the problems regarding the sustainable exploitation of nature for human health and welfare, through the cooperation between scientists working in marine biology/molecular biology/microbiology and chemistry. Such collaboration is now going on successfully in several laboratories.

It is the aim of this new subset of thematically connected volumes within our series *Progress in Molecular and Subcellular Biology* to provide an actual forum for the exchange of ideas and expertise between colleagues working in this exciting field of *Marine Molecular Biotechnology*. It also aims to disseminate the results to those researchers who are interested in the recent achievements in this area or are just curious to learn how science can help to exploit nature in a sustainable manner for human prosperity.

Werner E.G. Müller
By tradition, both Russia and Germany place a high value on education, research and science. Now more than ever before, education and research are the keys to the economic and social future of all countries. Well-qualified experts enable new insights into the fields of science and research. They have the power to safeguard and strengthen prosperity across the world. If we want to achieve long-term economic growth, we need to give young people the opportunity to acquire valid qualifications.

Scientific cooperation between Russia and Germany is characterized by excellent, long-standing relations. An agreement on scientific and technological cooperation was originally concluded 20 years ago. It was exceptionally successful and opened up numerous opportunities for scientific cooperation. In 2005, the heads of government of the two countries signed a joint declaration on a “Strategic Partnership in Education, Research and Innovation”, thus reiterating their willingness to work together. The aim of the declaration is to give the many existing ties a more strategic orientation. At the same time, it initiate long-term relations between their research institutions and universities.

As part of this strategic partnership, the German-Russian “Joint Lab Baikal” was established in 2005, with the support of the Federal Ministry of Education and Research. It specializes in molecular biology and the sustainable use of endemic sponges in Lake Baikal. The scientific coordinator of the project is Prof. Werner E.G. Müller, head of the Department of Applied Molecular Biology at the University of Mainz’s Institute for Physiological Chemistry. On the Russian side, the project is headed by Prof. Michael A. Grachev, Member of the Russian Academy of Sciences and Director of the Limnology Institute of the Russian Academy of Sciences (Siberian Branch) in Irkutsk.
I am delighted that the latest results of this productive collaboration are being presented in this study – “Biosilica in Evolution, Morphogenesis and Nanobiotechnology. Case Study Lake Baikal“. This is an excellent reflection of the vitality of German-Russian cooperation in the field of research.

Thomas Rachel  
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Biomineralization, in particular biosilicification, has become an exciting source of inspiration for novel bionic approaches. This book describes the exploitation of biomineralization principles which have been perfected by nature all the way through the course of evolution. Harnessing the unique capability of sponges to form silica under ambient conditions enables the industrial production of biosilica in a sustainable way, which opens opportunities for a range of innovative applications and processes including lithography, microelectronics and biomedicine. The strategies described in this book support the objectives of the European Commission’s ‘Nanosciences, Nanotechnologies, Materials and new Production Technologies – NMP’ program by delivering tools to improve the competitiveness, innovation potential and sustainability of European industry. The nanobiotechnology concept promoted by the NMP Thematic priority of the Seventh Framework Program is targeted by using nature as model for new nanotechnology-based processes, and these technologies can contribute to the transformation of European industry from resource-intensive to knowledge-intensive. Some of the most promising perspectives for new technologies stem from the converging interfaces of different disciplines. The novel techniques based on the principles of biomineralization/biosilicification are thus expected to bring about long-term innovation in the rapidly growing field of nanobiotechnology. The international collaboration presented by the European and Russian organizations is a perfect means of establishing lasting cooperation and signifies the partnership activity of the European Research Area on a global scale.

Herbert von Bose
Director

Directorate G: Industrial Technologies
Directorate-General for Research

[The views expressed are purely those of the writer and may not in any circumstances be regarded as stating an official position of the European Commission]
On 11 April 2005, a Joint Declaration on a “Strategic Partnership in Education, Research and Innovation“ was signed by Russian President Vladimir Putin and German Chancellor Gerhard Schröder. The establishment of the Russian - German “Joint Lab Baikal” is an example of the successful implementation of the aims expressed in this document. This joint lab is headed by Dr. Michael A. Grachev, Member of the Russian Academy of Sciences and Director of the Limnology Institute of the Siberian Branch of the Russian Academy of Sciences in Irkutsk and Prof. Dr. Werner E.G. Müller, head of the Department of Applied Molecular Biology at the Institute for Physiological Chemistry of the University of Mainz in Germany.

Lake Baikal is the greatest, deepest and most ancient lake in the world. The endemic sponges inhabiting this lake are important not only for basic science but also for the innovative discipline of nanobiotechnology, as highlighted in this book. This monograph underlines the excellent development in the relations between both countries in the field of science and technology.

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