Cellular Origin, Life in Extreme Habitats and Astrobiology 19

Joseph Seckbach
J. Patrick Kociolek *Editors*

The Diatom World

Springer

THE DIATOM WORLD

Cellular Origin, Life in Extreme Habitats and Astrobiology

Volume 19

Series Editor:

Joseph Seckbach
The Hebrew University of Jerusalem, Israel

For further volumes:
http://www.springer.com/series/5775

The Diatom World

Edited by

Joseph Seckbach
The Hebrew University of Jerusalem, Israel

and

J. Patrick Kociolek
University of Colorado, Boulder, CO, USA

Springer

Editors
Joseph Seckbach
The Hebrew University of Jerusalem
Home address: P.O. Box 1132
90435 Efrat
Israel
seckbach@cc.huji.ac.il

J. Patrick Kociolek
Museum of Natural History and
Department of Ecology and
Evolutionary Biology
University of Colorado
Boulder, CO 80309
USA
patrick.kociolek@colorado.edu

ISSN 1566-0400
ISBN 978-94-007-1326-0 e-ISBN 978-94-007-1327-7
DOI 10.1007/978-94-007-1327-7
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2011932495

TABLE OF CONTENTS

PART 3:
FRESHWATER ECOLOGY

PART 4:
MARINE ECOLOGY

PART 5:
SUMMARY

FOREWORD

The Diatom World

The impact of diatoms on planet Earth is substantial and far reaching, hence "The Diatom World" is an appropriate title for a book describing the attributes of diatoms, with an emphasis on their ecological roles. The large-scale ecological success of diatoms suggests that they have refined their cellular processes for efficient utilization of nutrients and sunlight to a greater extent than most other unicellular algae. The most visible distinguishing feature of diatoms is their silicified cell walls, and because of its uniqueness, it is reasonable to assume that utilization of silica as a structural material is a valuable adaptation. A rich genomic diversity may also contribute to the diatoms' success; diatom genome sequencing has revealed a roughly equal contribution of plant and animal gene homologs, with a relatively high contribution of bacterial genes.

Diatom research impacts a wide variety of areas. Topics included in this book include morphology, phylogeny/evolution, sexuality/breeding, surface colonization and biofilms, infection and toxicity, bio/nanotechnology, extremophilicity, ecology, and endosymbiosis. Systematics is a major point of emphasis in the book. Two factors contribute to the continuing refinement of diatom systematics: (1) the enormous number of species and (2) distinctions between morphological and genetically based markers. The latter is an especially interesting point because although cell wall structure is ultimately genetically derived, the ability of diatoms to make such a diversity of structures "muddles the message" and there is necessarily no strict correspondence between genetic and structural similarity. Sexuality in diatoms is discussed, which includes an exploration of the concept that classical breeding approaches may be useful for diatom research. Diatoms affect the world as biofouling organisms, both in terms of ecological and economic impacts. The diatom silica cell wall has a universal appeal which encompasses aesthetic beauty coupled with an intellectual fascination about how such structures are made. Several chapters touch upon this subject both in terms of comparisons of the final morphology and the process of structure formation. The value of the silicified cell wall is evident for the diatom, but its usefulness for humans is addressed in terms of a possible source of inexpensive nano-structured materials for nanotechnological applications (with an emphasis on optical properties) and as a bioindicator of water quality. The ability of diatoms to colonize environments with extremes of temperature, pH, and salinity is covered in detail. All is not beautiful in the diatom world, even though they live in protective shells, diatoms can be infected by viruses, and toxin production by diatoms has adverse effects on the ecosystem and human health.

Diatoms impact processes on a wide range of scales, from the nanometer-to-micron range at which their silica structures are formed, through the meters-to-kilometers scale on which diatom communities function, and to the global scale carbon fixation and biogeochemistry. Given their participation in so many processes and at such diverse scales, it is indeed a Diatom World.

Mark Hildebrand

Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive,
La Jolla, CA 92093

Biodata of **Mark Hildebrand** author of the ***"Foreword"***

Mark Hildebrand is a Research Professor in the Marine Biology Research Division of Scripps Institution of Oceanography, University of California, San Diego. He received a Ph.D. from the University of Arizona in 1987 and did his postdoctoral work with Benjamin Volcani at SIO. His lab's research is focused mainly on diatoms, in two areas: (1) silicon metabolism and cell wall synthesis and (2) development of diatoms for biofuel production. His work has involved application of molecular techniques to diatoms to clone silicon responsive genes, leading to the identification and characterization of silicon transporters. He contributed to the first determination of a diatom genome sequence (for *Thalassiosira pseudonana*). His lab has performed a proteomic investigation into cell-wall-associated proteins in *T. pseudonana,* a thorough examination of silicon transport processes which led to a mechanistic model for transport function and a new understanding of factors influencing uptake kinetics, and developed a synchronized growth procedure that enables monitoring of cellular processes (transcript and protein levels, cell wall formation, etc.) throughout the entire cell cycle. A publication in Journal of Phycology resulting from the latter work was awarded the Provasoli Award for best publication in the Journal for the year 2007 (Hildebrand et al., 2007, J. Phycol. 43:730). Current research in the lab is focused on applying high-resolution imaging techniques (AFM, SEM, TEM, and fluorescence microscopy) to follow the process of diatom cell wall silicification and to couple these processes with identification of the genes responsible for specific aspects of structure formation, which includes transgenic approaches. In terms of the development of diatoms as organisms for biofuel production, the lab is investigating the effect of different triggers for neutral lipid accumulation coupled with "omics" approaches to understand the underlying regulation involved in controlling carbon partitioning between carbohydrates for growth and neutral lipids for energy storage.

E-mail: **mhildebrand@ucsd.edu**

DIATOMS: GENERAL INTRODUCTION

Diatoms are microscopic unicellular or colonial (in the shape of filaments or ribbons, or tube dwelling) eukaryotic algae. Their cell walls are with silica shells, and they are ubiquitously distributed in aqueous habitats.

Their name is derived from the Greek words (dia) = "through" + (temnein) = "to cut," since their cells are divided in two halves or two box-like parts (frustules or valves). They are one of the most common types of phytoplankton. One can detect them in marine as well as in fresh water habitats, at high and low temperatures, at different pH values, in hypersaline environments, and in brackish water. Diatoms especially play an important role in the oceans where they fix large amounts of carbon dioxide and synthesize carbohydrates that serve as a chief source of zooplankton food in the marine food chain. Bacteria adhere to and influence diatoms' growth.

There are over 1,250 genera of diatoms in the Class Bacillariophyceae. Diatoms are very responsive to environmental changes, and analysis of diatom communities can be used to study long-term changes.

Their exoskeleton is made of nanometer-sized particles of SiO_2 (silicon dioxide] obtained from their ability to "metabolize" silicic acid [$Si(OH)_4$] from the environment and form frustules. These silica "shells" of the cell walls are easily preserved and provide a useful tool for fossil research. Fossil evidence suggests that diatoms originated during, or before, the early Jurassic period (~210 to 144 Mya). It is assumed that these unicellular algae arose from the endocytobiosis of a red alga, which penetrated (or was engulfed) into a single-celled heterotrophic host eukaryotic cell. Their chloroplasts do not accumulate storage carbohydrates, as seen in, for example, the green algae.

Diatoms are often visible to the naked eyes as a golden coating growing on vessels, and they commonly form brown films on aquarium glass or rocks. At higher magnification and especially in the scanning electron microscope, their cells appear very attractive and display extremely beautiful designs and patterns, as shown by several photos in this volume.

Recently, the genome sequences of some diatom species as well as compilations of applied research on diatoms have been published, and the taxonomy of the group has been repeatedly revised in recent years. However, general books on their biology and ecology are few. In the current volume, some of the leaders in diatom research present new information and/or summarize recent research efforts on a wide range of topics, including morphology, nanostructure, morphogenesis, motility, ecophysiology with emphasis on their wide range of habitats and ecological niches, biogeography, taxonomy, molecular evolution and phylogeny,

cryptic and endosymbiontic species, toxic species, viruses of diatoms, and more. However, aesthetical aspects are not forgotten.

It is our hope that the *The Diatom World* will foster greater appreciation and research contributions on this incredibly diverse and fascinating group of organisms. We thank all our authors for their contributions and their patience. A special appreciation is due to the anonymous reviewers who evaluated the chapters of this book.

Acknowledgments

We thank Professors Aharon Oren, Richard Gordon, and David J. Chapman for revising and improving the above introduction to *The Diatom World*.

Joseph Seckbach
The Hebrew University of Jerusalem, Israel

J. Patrick Kociolek
Museum of Natural History and Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309, USA

Biodata of **Joseph Seckbach,** editor of this volume (along with J. Patrick Kociolek) and author of the opening and summary of this volume.

Professor Joseph Seckbach is the founder and chief editor of *Cellular Origins, Life in Extreme Habitats and Astrobiology* ("COLE") www.springer.com/series/5775 book series. He has coedited other volumes, such as the *Proceeding of Endocytobiology VII Conference* (Freiburg, Germany) and the *Proceedings of Algae and Extreme Environments meeting* (Trebon, Czech Republic) (See http://www.schweizerbart.de/pubs/books/bo/novahedwig-051012300-desc.ht). He has edited the recent volume (with Richard Gordon) entitled *Divine Action and Natural Selection: Science, Faith, and Evolution* published by World Scientific Publishing Company (2008) www.worldscibooks.com/lifesci/6998.html.

Dr. Seckbach earned his Ph.D. from the University of Chicago (1965) and did a postdoctorate in the Division of Biology at Caltech, in Pasadena, CA. He was appointed to the faculty of the Hebrew University (Jerusalem, Israel) and spent sabbaticals at UCLA and Harvard University and DAAD-sponsored periods in Tübingen, Germany and at LMU, Munich. Dr Seckbach served at Louisiana State University, Baton Rouge, as the first selected occupant of the Endowed Chair for the Louisiana Sea Grant and Technology transfer.

Beyond editing academic volumes, he has published scientific articles on plant ferritin–phytoferritin, cellular evolution, acidothermophilic algae, and life in extreme environments. He also edited and translated several popular books. Dr. Seckbach is the coauthor, with R. Ikan, of the Hebrew-language *Chemistry Lexicon* (Deveer publisher, Tel Aviv). His recent interest is in the field of enigmatic microorganisms and life in extreme environments.

E-mail: **seckbach@huji.ac.il**

Biodata of Professor **J. Patrick Kociolek** editor and coauthor of two chapters in this volume.

Professor J. Patrick Kociolek is the **coeditor** of this book (COLE volume 19). He received his M.S. (1983) from Bowling Green State University (Ohio, USA), working with Dr. Rex Lowe on the diatom flora of the Great Smoky Mountains (in the Southeastern portion of the USA) , and obtained his Ph.D. (1988) from the University of Michigan (Ann Arbor) in the laboratory of Dr. Eugene F. Stoermer. He spent nearly 20 years as the G Dallas Hanna Chair in Diatom Studies at the California Academy of Sciences, before joining the faculty at the University of Colorado, Boulder. His interests include the taxonomy and systematics of diatoms, as well as developing an understanding of their evolutionary histories and patterns of distribution. He is also interested in developing tools to further research on diatom taxonomy, nomenclature, and ecology. Dr. J. Patrick Kociolek is the author of over 150 peer-reviewed articles and has edited or coedited eight books.

E-mail: **Patrick.Kociolek@Colorado.edu**

LIST OF AUTHORS FOR "THE DIATOM WORLD"

ALBERTANO, PATRIZIA
DEPARTMENT OF BIOLOGY, LBA – LABORATORY OF BIOLOGY OF ALGAE, UNIVERSITY OF ROME "TOR VERGATA", VIA DELLA RICERCA SCIENTIFICA 00133, ROME, ITALY

ALSTER, ALLA
ISRAEL OCEANOGRAPHIC AND LIMNOLOGICAL RESEARCH LTD, THE YIGAL ALLON KINNERET LIMNOLOGICAL LABORATORY, P.O. BOX 447, MIGDAL 14950, ISRAEL

ASHWORTH, MATT
PLANT BIOLOGY GRADUATE PROGRAM, THE UNIVERSITY OF TEXAS AT AUSTIN, 1 UNIVERSITY STATION (A6700) AUSTIN TX, 78712, USA

BĄK, MAŁGORZATA
PALAEOCEANOLOGY UNIT, FACULTY OF GEOSCIENCES, UNIVERSITY OF SZCZECIN, 70-383, SZCZECIN, POLAND

BARGU, SIBEL
DEPARTMENT OF OCEANOGRAPHY AND COASTAL SCIENCES, SCHOOL OF THE COAST AND ENVIRONMENT, LOUISIANA STATE UNIVERSITY, BATON ROUGE, LA 70803, USA

CHAERLE, PETER
SBAE INDUSTRIES NV, HOOIWEGE 40, 9940 SLEIDINGE, BELGIUM

CHEPURNOV, VICTOR A.
SBAE INDUSTRIES NV, HOOIWEGE 40, 9940 SLEIDINGE, BELGIUM

CONGESTRI, ROBERTA
DEPARTMENT OF BIOLOGY, LBA – LABORATORY OF BIOLOGY OF ALGAE, UNIVERSITY OF ROME "TOR VERGATA", VIA DELLA RICERCA SCIENTIFICA, 00133 ROME, ITALY

COX, EILEEN J.
DEPARTMENT OF BOTANY, THE NATURAL HISTORY MUSEUM,
CROMWELL ROAD, LONDON, SW7 5BD, UK
DELL'UOMO, ANTONIO
DEPARTMENT OF ENVIRONMENTAL SCIENCES,
UNIVERSITY OF CAMERINO, VIA PONTONI 5,
I-62032 CAMERINO (MC), ITALY

GELBRECHT, JÖRG
LEIBNIZ INSTITUTE OF FRESHWATER ECOLOGY AND INLAND
FISHERIES, 12587 BERLIN, GERMANY

GORDON, RICHARD
DEPARTMENT OF RADIOLOGY, UNIVERSITY OF MANITOBA,
HSC ROOM GA216, 820 SHERBROOK STREET, WINNIPEG,
MB R3A 1R9, CANADA

JANSEN, ROBERT K.
SECTION OF INTEGRATIVE BIOLOGY, THE UNIVERSITY OF TEXAS
AT AUSTIN, 1 UNIVERSITY STATION (A6700) AUSTIN, TX 78712, USA

KACZMARSKA, IRENA
DEPARTMENT OF BIOLOGY, MOUNT ALLISON UNIVERSITY,
63B YORK ST., SACKVILLE, NB E4L 1G7, CANADA

KARSTEN, ULF
INSTITUTE OF BIOLOGICAL SCIENCES, APPLIED ECOLOGY,
UNIVERSITY OF ROSTOCK, D-18057 ROSTOCK, GERMANY

KOCIOLEK, J. PATRICK
MUSEUM OF NATURAL HISTORY AND DEPARTMENT
OF ECOLOGY AND EVOLUTIONARY BIOLOGY,
UNIVERSITY OF COLORADO, BOULDER, CO 80309, USA

LANGE-BERTALOT, HORST
J.W. GOETHE-UNIVERSITÄT, FRANKFURT, GERMANY

LEE, JOHN J.
CITY COLLEGE OF CITY UNIVERSITY OF NEW YORK,
CONVENT AVE @ 138 ST, NEW YORK, NY 10031, USA

LOWE, REX
DEPARTMENT OF BIOLOGICAL SCIENCES, BOWLING GREEN STATE
UNIVERSITY, BOWLING GREEN, OHIO 43403, USA

MANN, DAVID G.
ROYAL BOTANIC GARDEN EDINBURGH, INVERLEITH ROW
EDINBURGH EH3 5LR, SCOTLAND, UK

MEDLIN, LINDA K.
UPMC UNIV PARIS 06/CNRS, UMR 7621, LOMIC, OBSERVATOIRE
OCÉANOLOGIQUE, F-66651 BANYULS/MER, FRANCE
CNRS, UMR 7621, LOMIC, OBSERVATOIRE OCÉANOLOGIQUE,
F-66651 BANYULS/MER, FRANCE

NAGASAKI, KEIZO
NATIONAL RESEARCH INSTITUTE OF FISHERIES
AND ENVIRONMENT OF THE INLAND SEA,
FISHERIES RESEARCH AGENCY, 2-17-5 MARUISHI
HATSUKAICHI, HIROSHIMA 739-0452, JAPAN

NAGY, STEPHEN S.
MONTANA DIATOMS, P.O. BOX 5714, HELENA, MT 59604-5714, USA

NAKOV, TEOFIL
PLANT BIOLOGY GRADUATE PROGRAM,
THE UNIVERSITY OF TEXAS AT AUSTIN,
1 UNIVERSITY STATION (A6700), AUSTIN, TX 78712, USA

NIKULINA, TATIANA V.
LABORATORY OF FRESHWATER COMMUNITIES,
INSTITUTE OF BIOLOGY AND SOIL SCIENCES, RUSSIAN ACADEMY
OF SCIENCES, FAR EAST BRANCH, 100 LETIYA VLADIVOSTOKA
AVENUE, 159, VLADIVOSTOK 690022, RUSSIA

OZHAN, KORAY
DEPARTMENT OF OCEANOGRAPHY AND COASTAL SCIENCES,
SCHOOL OF THE COAST AND ENVIRONMENT, LOUISIANA STATE
UNIVERSITY, BATON ROUGE, LA 70803, USA

POTAPOVA, MARINA
THE ACADEMY OF NATURAL SCIENCES, 1900 BENJAMIN
FRANKLIN PARKWAY, PHILADELPHIA, PA 19103, USA

RADZIEJEWSKA, TERESA
PALAEOCEANOLOGY UNIT, FACULTY OF GEOSCIENCES,
UNIVERSITY OF SZCZECIN, 70-383, SZCZECIN, POLAND

ROEF, LUC
SBAE INDUSTRIES NV, HOOIWEGE 40, 9940 SLEIDINGE, BELGIUM

RUCK, ELIZABETH
PLANT BIOLOGY GRADUATE PROGRAM,
THE UNIVERSITY OF TEXAS AT AUSTIN,
1 UNIVERSITY STATION (A6700) AUSTIN, TX 78712, USA

RÜDIGER, FRANZISKA
INSTITUTE OF BIOLOGICAL SCIENCES, APPLIED ECOLOGY,
UNIVERSITY OF ROSTOCK, D-18057 ROSTOCK, GERMANY

SCHLIE, CAROLIN
INSTITUTE OF BIOLOGICAL SCIENCES, APPLIED ECOLOGY,
UNIVERSITY OF ROSTOCK, D-18057 ROSTOCK, GERMANY

SCHUMANN, RHENA
INSTITUTE OF BIOLOGICAL SCIENCES, APPLIED ECOLOGY,
UNIVERSITY OF ROSTOCK, D-18057 ROSTOCK, GERMANY

SECKBACH, JOESPEH
HEBREW UNIVERSITY OF JERUSALEM, ISRAEL

SMITH, EMILY
DEPARTMENT OF OCEANOGRAPHY AND COASTAL SCIENCES,
SCHOOL OF THE COAST AND ENVIRONMENT, LOUISIANA STATE
UNIVERSITY, BATON ROUGE, LA 70803, USA

THERIOT, EDWARD C.
TEXAS NATURAL SCIENCE CENTER, UNIVERSITY OF TEXAS,
2400 TRINITY STREET, AUSTIN, TX 78619, USA
SECTION OF INTEGRATIVE BIOLOGY, THE UNIVERSITY OF TEXAS
AT AUSTIN, 1 UNIVERSITY STATION (A6700), AUSTIN, TX 78712, USA

TIFFANY, MARY ANN
DEPARTMENT OF BIOLOGY, SAN DIEGO STATE UNIVERSITY,
5500 CAMPANILE DRIVE, SAN DIEGO, CA 92182, USA

TOMARU, YUJI
NATIONAL RESEARCH INSTITUTE OF FISHERIES
AND ENVIRONMENT OF THE INLAND SEA,
FISHERIES RESEARCH AGENCY, 2-17-5 MARUISHI, HATSUKAICHI
HIROSHIMA 739-0452, JAPAN

TORRISI, MARIACRISTINA
DEPARTMENT OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF CAMERINO, VIA PONTONI 5, I-62032 CAMERINO (MC), ITALY

TOWNLEY, HELEN E.
DEPARTMENT OF ENGINEERING SCIENCE, OXFORD UNIVERSITY, PARKS ROAD, OXFORD OX1 3PJ, UK

VAN MEIRHAEGHE, ANNEMIEKE
SBAE INDUSTRIES NV, HOOIWEGE 40, 9940 SLEIDINGE, BELGIUM

VANHOUTTE, KOEN
SBAE INDUSTRIES NV, HOOIWEGE 40, 9940 SLEIDINGE, BELGIUM

VILLAC, MARIA CÉLIA
DEPARTMENT OF BIOLOGY, MOUNT ALLISON UNIVERSITY, 63B YORK ST, SACKVILLE, NB E4L 1G7, CANADA

WAWRZYNIAK-WYDROWSKA, BRYGIDA
PALAEOCEANOLOGY UNIT, FACULTY OF GEOSCIENCES, UNIVERSITY OF SZCZECIN, 70-383, SZCZECIN, POLAND

WILLIAMS, DAVID M.
BOTANY DEPARTMENT, THE NATURAL HISTORY MUSEUM, CROMWELL ROAD, LONDON SW7 5BD, UK

WITKOWSKI, ANDRZEJ
PALAEOCEANOLOGY UNIT, FACULTY OF GEOSCIENCES, UNIVERSITY OF SZCZECIN, 70-383 SZCZECIN, POLAND

WOELFEL, JANA
INSTITUTE OF BIOLOGICAL SCIENCES, APPLIED ECOLOGY, UNIVERSITY OF ROSTOCK, D-18057 ROSTOCK, GERMANY

YEHOSHUA, YARON
THE MINA AND EVERARD GOODMAN FACULTY OF LIFE SCIENCES, BAR-ILAN UNIVERSITY, 52900 RAMAT GAN, ISRAEL

ACKNOWLEDGMENTS

We thank our authors for the contributions and patience and are grateful to the reviewers for their careful review of the chapters. We wish to acknowledge all of our colleagues who assisted us with their good advice for this volume, among them are: Aharon Oren, Assaf Vardi, David Chapman, Helga Stan-Lotter, Mark Hildebrand, Maud M. Walsh, Richard Gordon, Russell Chapman, and Scott Balogh. If any other name has been omitted, we apologize for the oversight. Special appreciation is due to Melanie van OverBeek and Maryse Walsh (Springer, Dordrecht, NL) for their cooperation with all the COLE books. Last but not least, the senior author (JS) is grateful to his wife, Fern Seckbach, for her patience, understanding, and assistance during the compiling of this book (and other volumes in the series).

Joseph Seckbach
The Hebrew University of Jerusalem, Israel

J. Patrick Kociolek
Museum of Natural History and Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309, USA

Biodata of **Stephen S. Nagy** author of "***Collecting, Cleaning, Mounting, and Photographing Diatoms***."

Stephen S. Nagy, M.D. is an amateur diatomist, microscopist, and photomicrographer, and is a Diplomate of the American Board of Psychiatry and Neurology in Adult Psychiatry. He lives and practices in Helena, Montana. Dr. Nagy obtained his Medical Doctor degree at The Medical College of Pennsylvania in 1977, and passed his Adult Psychiatry Boards in 1982. He became fascinated by diatoms in road cuts when living in Klamath Falls, Oregon and wondered what the chalky deposits around town actually were. He learned to clean diatoms and to make exhibition mounts of them from his mentor, Klaus Dieter Kemp of Somerset County, UK, by telephone and email over many years apprenticeship. From the start his interest was in learning the practical craft of a diatomist, being able to make a selected diatom mount of high quality, and not pursuing this interest as an academic study. He has successfully arranged 300 diatoms on a single microscope slide. Dr. Nagy has been recognized for his photomicrographs of diatoms cleaned and mounted by him, and of other microscopic objects, in the Nikon Small World Photomicrography Competition (placing tenth in 2007), and in the Olympus Bioscapes International Digital Imaging Competition (placing third in 2008). He has had other images judged to be in the top 100 photos of each competition since 2005, and these photos may be viewed online at the respective contest Web sites.

E-mail: **snagymd@pol.net**

J. Seckbach and J.P. Kociolek (eds.), *The Diatom World*,
Cellular Origin, Life in Extreme Habitats and Astrobiology 19, 1–18
DOI 10.1007/978-94-007-1327-7_1, © Springer Science+Business Media B.V. 2011

COLLECTING, CLEANING, MOUNTING, AND PHOTOGRAPHING DIATOMS

STEPHEN S. NAGY
Montana Diatoms, P.O. Box 5714, Helena, MT 59604-5714, USA

1. Introduction

Our beautiful world surrounds us with diatoms, but because they are at or below the limit of resolution of the naked eye, we can literally swim through them and never know that they are there. When people first learn about diatoms, they are amazed that diatoms exist, and then fascinated to find out how to locate and collect them. How can one collect something that one cannot see? One clue to the presence of diatoms is the color of the photosynthetic pigments in live diatoms, which ranges from a golden brown through a brownish olive drab to dark brown, and the typically mucoid appearance of a colony of diatoms. In life, one is essentially looking for golden-brown slime.

The places most collectors look are in freshwater, such as streams or lakes, in brackish or marine waters, and in fossil sites. A problem in collecting is that particles in soils, and silts in marine settings, can approximate the size of diatoms, so that the goal in collecting is to acquire a clean sample without significant contaminants that are difficult to separate. As a consequence, one searches as much as possible for diatoms that are not in contact with mud or silt. Each of these sample types requires a slightly different approach.

2. Collecting in Freshwater

In freshwater settings, the simplest approach to collecting diatoms is to obtain samples of stalked multicellular green algae (or aquatic weeds) that grow on the bottom of the stream or lake. These freshwater green algae are regularly covered with a forest of diatoms, and if the green algae are placed into a zip lock plastic bag and shaken, pummeled, and agitated, the water in the bag will rapidly become a cloudy golden-brown or olive-drab color, as the diatoms are released from the weed and become suspended in the solution. The water is poured into a vertical glass cylinder through a coarse sieve to hold back the green algae, and the diatoms are allowed to settle to the bottom of the cylinder over hours or overnight. This process can be repeated about four or five times to extract additional diatoms

from the same sample of green algae with little or no loss of production each time, and there is no damage to the diatom frustules.

There are some other simple collection techniques for freshwater diatoms. Diatoms tend to prefer cold water that is not in direct sunlight, so that the undersides of lily pads, or the damp concrete in the shadow of a bridge, are more likely to have interesting samples than specimens resulting from a search in the sunlight. Some diatoms grow in a sheath around plant stems of rushes, and these diatoms can be stripped off by hand. Other species may grow as a shiny or glossy coating on rocks or on wood exposed to splashing water, appearing like a mucus growth with the characteristic color. Still others may grow in microscopic, essentially colorless tubes, or on the end of tubes, and the whole colony appears like a dirty off-white cotton mop attached to rocks in the river. The most notorious of these is *Didymosphenia geminata* Lyngbye (Schmidt) which was once thought to be rare and limited to high alpine settings with very clean waters. But this beautiful diatom (Fig. 1) has now been renamed by the public as "Rock Snot" as it has been transported by the felt soles of fly fishermen to streams around the world; it has been found to be a highly invasive species that can grow to cover the bottom of a stream and kill normal insect and plant life. *Didymosphenia* grows at the end of a colorless stalk, and the colony can have the appearance of a dirty sheep's fleece on rocks under water. Other *Cymbella* species grow within tiny tubes, and can

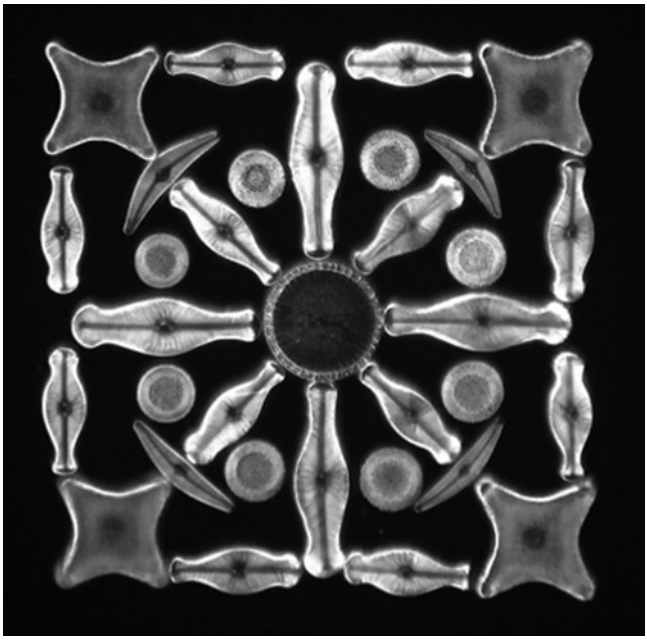

Figure 1. An ornate square of arranged diatoms by the author, which includes freshwater and marine diatoms. Didymosphenia forms the main spokes of the arrangement and has a shape similar to a classic bottle of Coca-Cola (Photo copyright retained by author).

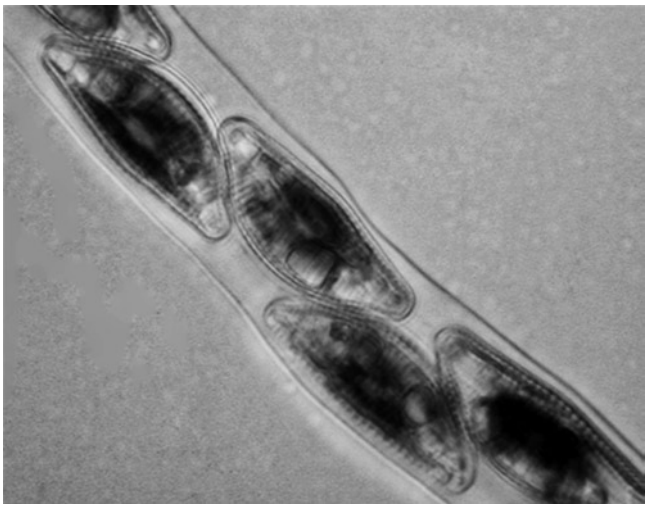

Figure 2. Cymbella prostrata var auerswaldii (Rabenhorst) Reimer growing in a tube (Photo copyright retained by author).

have a similar appearance to the naked eye, that of an off-white or gray mass that appears like a bunch of soft, depigmented green algae (Fig. 2). Under the microscope in a wet mount, the living diatoms line up within these tubes like beans in a pod. Other freshwater diatoms grow as single cells, and can be found between the pebbles on the bottom of slow-moving waters as a fine brown or golden-brown dust. If there is a river with a constant stream flow, there can be a layer of sediment on the tops or upstream surfaces of underwater rocks, which includes accumulations of single diatoms, and this material can be collected with a turkey baster or other suction device, and allowed to settle in a cylinder as above.

3. Collecting in Brackish and Marine Waters

Diatoms in the ocean are both colonial and free living, and are somewhat more challenging to collect in any quantity than diatoms in freshwater settings. Growth of marine algae that do not have a shiny or smooth surface may be sources of diatoms, similar to the freshwater technique described above. Often these will grow on buoys or on anchor lines, or on the surfaces of wood or plastic that are in contact with the sea for a prolonged period of time. A traditional source of exotic diatoms is washings from the surfaces of marine shells, such as the Conch, and a newly harvested shell can produce extraordinary specimens by simply brushing the surface of the shell with a toothbrush swished in water, and repeatedly rinsed in a collecting bottle as the brush color changes to brown, stained with living diatoms. Free-living marine diatoms can settle onto the surface of rocks or the sand under water, and a collection of sediment or “dust” from the upper surface

of rocks in an area where the water is quiet can provide a lovely marine sample. A sample of sand from the surface of a flat as the tide has receded can include a collection of larger sand granules and smaller diatoms, which need to be rinsed and released from the sand grains. Sediment adhering to a marine anchor can be treated in the same way. Of course, the traditional technique for collecting planktonic species is to tow a very fine funnel-shaped net behind a boat at slow speeds, which is beyond the realm of possibility for most individuals with a casual interest in diatoms. There are other diatoms that grow between the grains of mud or sand, such as *Pleurosigma angulatum* (Queckett) W. Smith, which finds its way to the surface of the sand at low tide, appearing as a brownish color on moist sand when compared to adjacent areas. These diatoms and some substrate can be gently scraped off of the material underneath using a credit card or other small piece of plastic. The diatoms and the sand can be placed in a shallow dish, moistened with seawater, and covered with a muslin handkerchief, and at the next low tide the *Pleurosigma* will find their way through the handkerchief to the upper surface of the handkerchief, where they can be removed easily with a sable brush.

4. Collecting Fossil Diatoms

There are sites around the world where diatoms fell as sediment out of marine or freshwater bodies of water over time, and formed deep concretions on the bottom. Over time, the organic material decomposed and the diatom frustules were pressed together, resulting in diatomaceous earth, or diatomite. Perhaps, the most famous location to diatomists are the deposits at Oamaru, New Zealand, a marine deposit with extinct and exotically unique forms unlike those found anywhere else in the world. Additional sites of some notoriety include: the freshwater deposits at Terrebonne, Oregon, on the eastern slope of the Cascade Mountains north of Bend, Oregon on the banks of the Deschutes River. These deposits are quite loosely packed, appear as white layers in road cuts near the Deschutes River, and appear to be composed of about 97% unbroken frustules. There are freshwater fossil deposits in Klamath Falls, Oregon, well known to Victorian diatomists as the source of varied freshwater species which form brilliant white, hard chalky deposits throughout the Klamath basin, the site of an ancient lake which preceded the formation of the Cascade Mountains. This diatomite or diatomaceous earth is much more densely compressed and is actually used as chalk by children growing up there to draw hopscotch courts on the pavement of driveways.

Marine deposits at Lompoc, California have long been the site of commercial extraction and production for industrial use for many years. A much smaller deposit of marine diatoms near Dunkirk, Maryland was once a source of diatomite on the US East Coast, featuring exotic extinct diatoms and some diatoms which are still living, perhaps most famous for the large numbers of the beautiful centric form, *Actinoptychus heliopelta* Grunow. Outside of the USA, sites of notoriety include freshwater deposits from Toome Bridge, Ireland, and marine deposits from Szent Peter, Hungary, the exact location of which appears to have

Figure 3. The light band is fossil freshwater diatomaceous earth next to Highway 97 at Klamath Falls, Oregon. This diatomite is estimated to be 1.5 million years old. The columnar basalt is thought to have appeared at the time that the Cascade Mountains were formed, ending the life of the lake that produced the diatoms (Photo copyright retained by author).

been lost as national boundaries changed during the Second World War, and which may have been nearly completely extracted, used in the preparation of dynamite during this conflict. Additional marine fossil deposits are located at Mors, Jutland, Denmark, which is so heavily compressed that many valves are fractured, and at additional sites in France and in Russia.

The diatomite in these fossil deposits can range from white to tan-colored to green deposits, which may be found at road cuts as exposed strata, ranging in texture from friable, easily crumbled material to specimens that appear to be quite dense and hard. They are typically compressed to break and form fragments of diatoms, interspersed with whole forms and with mineral deposits that approximate the size of the frustules of the diatoms. If very dense, the diatoms may be cemented together with calcium carbonate and other minerals leached and condensed around the diatoms. It is typically impossible to determine if a deposit is silt or diatoms without looking at a bit of the specimen through the microscope (Fig. 3).

5. Cleaning Diatoms

The goal of cleaning diatom samples is to have as a final product a sparkling white suspension of diatom frustules, valves, and girdle bands in distilled water, free of diatom fragments and contaminating sediments, so that a single diatom valve can be examined accurately. This suspension can be made into a strew slide, placing a drop

onto a glass coverslip or glass slide, which is then allowed to dry without heat, which will tend to make the diatoms clump or form lines. When the drop dries, if the diatoms are clean and without any chemical residue remaining in the solution, they will not be adherent to the glass and may be lifted off to make selected slides. Or, once the strew is made, the slide can be heated to glowing red in order to sinter these small bits of nature's glass onto the surface of the coverslip and then covered with a tiny drop of high refractive-index mountant (Naphrax, Zrax, Styrax, or Hyrax) and coverslip for subsequent examination. In practice, it is sometimes simple and at other times quite difficult to obtain a specimen of this degree of cleanliness, depending upon the extent of contaminants present in the sample.

All fossil deposits must be broken up without damaging the frustules, which precludes a mechanical approach of crushing. The simplest technique is to repeat multiple cycles of freezing and thawing in fresh water until the sample breaks into dust. This may take as few as 3 cycles or as many as 50 or more freeze–thaw cycles.

The next step in cleaning both recent and fossil forms involves the neutralization and removal of carbonates, which is best done with the addition of hydrochloric acid or nitric acid and gentle heat. (Diatoms are remarkably stable in strong acids, but are dissolved by alkalis.) In some cases, such as in cleaning the tubular forms (Cymbella and Didymosphenia) mentioned above, the mass of tubular material simply disappears in contact with this acid with a dramatic "whoosh!" However, in cases of fossil material steeped in carbonates, the diatom suspension may show little if any reaction to the acid, and may require prolonged low heat to extract the carbonates, which typically leach out creating a yellow or tan color in the acid solution. Some fossil samples that I have worked on have required treatment with multiple changes of hydrochloric acid, and heat applied for days before the carbonates are removed adequately. This acid must be washed free and removed completely before any next step can occur.

There have been cold or warm processing techniques described involving solutions of hydrogen peroxide, bleach, or a mixture of dilute sulfuric acid and crystalline potassium permanganate, but each of these has drawbacks. High-concentration hydrogen peroxide can damage the delicate sieve plates present in diatoms (K.A. Kemp, 2005, Scanning electron microscope observation by Frank E. Round of sieve plates cleaned with peroxide, Personal communication), and these techniques are significantly less effective, but also less dangerous, than hot processing with concentrated sulfuric acid using added potassium chlorate.

In the hot-acid technique, the sample is heated in a Pyrex beaker over a burner with concentrated sulfuric acid added to a moist solution of diatoms and water, which will boil until all water is driven from the specimen, leaving the sample in fuming sulfuric acid. The addition of this acid will convert recent samples, and some fossil samples, to a black color, reflecting the oxidation of organic elements to carbon. Then, very carefully, small spatulas of crystalline potassium chlorate, a strong oxidizing agent, are added to the sample under continuing intense heat until the color changes to a dark brown, then tan, and finally to a white or pale yellow color, at which point heat may be discontinued and the sample allowed to cool. When the beaker is no longer hot, a very small amount of distilled water from a