

ENCYCLOPEDIA *of*  
GEOBIOLOGY

# Encyclopedia of Earth Sciences Series

## ENCYCLOPEDIA OF GEOBIOLOGY

### Volume Editors

Joachim Reitner is Professor of Paleontology, Head of the Department of Geobiology, and Managing Director of the Museum, Collections and Geopark, at the University of Göttingen, Germany. He is also Editor-in-Chief of Lecture Notes in Earth Sciences (Springer), Co-Editor of Facies (Springer), and Associate Editor of the Geomicrobiology Journal (Taylor & Francis). Dr. Reitner's research focuses on the interplay between organisms and their metabolic processes with various abiotic parameters. Many geological processes can be understood as geo-physiological processes, allowing chemical reactions to proceed that would never occur under standard thermodynamic conditions. Therefore, a major thrust of Dr. Reitner's research is the investigation of the evolution of these processes, which are visible in biosignatures and biomineralization patterns, and in their interaction with biogeochemical cycles. Among his many honors and accolades, Dr. Reitner is the recipient of the G. W. Leibniz Award from the Deutsche Forschungsgemeinschaft.

Volker Thiel is Professor of Organic Geochemistry in the Geoscience Center at the University of Göttingen, Germany. Dr. Thiel has been involved in geobiological research for some 15 years, with a focus on the use of organic molecules as chemical tracers (biomarkers) for biogeochemical pathways. His research interests include lipid biomarkers as indicators for biogeochemical processes, molecular fossils, biological formation, and turnover of methane, and microbial control on mineral formation. The results of his studies have significantly contributed to the characterization of microbial processes associated with methane turnover in modern and ancient environments. Much of Dr. Thiel's current work is devoted to new approaches to enhance the spatial resolution of biomarker analysis in geobiological systems. He is member of the Editorial Board of the journal Geobiology (Wiley-Blackwell).

### Editorial Board

Hans-Joachim Fritz  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidtstr.3  
37077 Göttingen  
Germany

Andreas Kappler  
Center for Applied Geoscience (ZAG)  
Sigwartstraße 10  
72076 Tübingen  
Germany

Kurt O. Konhauser  
Department of Earth and Atmospheric Sciences  
University of Alberta, Edmonton  
Alberta, T6G 2E3  
Canada

Pamela Reid  
Rosenstiel School of Marine and Atmospheric Science  
University of Miami  
4600 Rickenbacker Cswy  
Miami FL 33149  
USA

Xingliang Zhang  
Department of Geology  
Northwest University  
Xian 710069  
China

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ENCYCLOPEDIA OF EARTH SCIENCES SERIES

# ENCYCLOPEDIA *of* GEOBIOLOGY

*edited by*

**JOACHIM REITNER**

**VOLKER THIEL**

*University of Göttingen*

*Germany*

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## Contributors

Alexander V. Altenbach  
Ludwig-Maximilians-University Munich  
Richard-Wagner-Str. 10  
80333 Munich  
Germany  
altenbach@lmu.de

Ariel D. Anbar  
School of Earth and Space Exploration  
and Department of Chemistry and Biochemistry  
Arizona State University  
Tempe, AZ  
USA  
anbar@asu.edu

Andreas J. Andersson  
Bermuda Institute of Ocean Sciences  
17 Biological Station  
Ferry Reach, St. George's  
Bermuda

Gernot Arp  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
garp@gwdg.de

Roman Aubrecht  
Department of Geology and Paleontology  
Faculty of Natural Sciences  
Comenius University  
Mlynská dolina-G  
842 15 Bratislava  
Slovakia  
Aubrecht@fns.uniba.sk

Christina Beimforde  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
christina.beimforde@geo.uni-goettingen.de

Giovanna Bianconi  
Department of Agrobiologia and Agrochemistry  
University of Tuscia  
Viterbo  
Italy  
giovannabianconi@libero.it

Jens Boenigk  
Institute for Limnology  
Austrian Academy of Sciences  
Mondseestr. 9  
5310 Mondsee  
Austria  
jens.boenigk@oeaw.ac.at

Antje Boetius  
Department of Molecular Ecology  
Max Planck Institute for Marine Microbiology  
Celsiusstrasse 1  
28359 Bremen  
Germany  
aboetius@mpi-bremen.de

Tanja Bosak  
Department of Earth  
Atmospheric and Planetary Sciences  
Massachusetts Institute of Technology  
Cambridge, MA 02139  
USA  
tbosak@mit.edu

Michael E. Böttcher  
Geochemistry & Stable Isotope Geochemistry  
Marine Geology Section  
Leibniz Institute for Baltic Sea Research  
18119 Warnemünde  
Germany  
michael.boettcher@io-warnemuende.de

Nicole Brinkmann  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
nbrinkm@uni-goettingen.de

Jochen J. Brocks  
Research School of Earth Sciences  
The Australian National University  
Building 61, Mills Road  
Canberra, ACT 0200  
Australia  
jochen.brocks@anu.edu.au

Burkhard Büdel  
Plant Ecology and Systematics  
Department of Biology  
University of Kaiserslautern  
P.O. Box 3049  
67653 Kaiserslautern  
Germany  
buedel@rhrk.uni-kl.de

Helmut Bürgmann  
Department of Surface Waters  
Eawag, Swiss Federal Institute of Aquatic Science and  
Technology  
Seestrasse 79  
6047 Kastanienbaum  
Switzerland  
Helmut.Buergmann@eawag.ch

Alison Butler  
Department of Chemistry  
University of California  
Santa Barbara, CA 93106-9510  
USA  
butler@chem.ucsb.edu

Francesco Canganella  
Department of Agrobiological and Agrochemistry  
University of Tuscia  
Viterbo  
Italy  
canganella@unitus.it

Elizabeth A. Canuel  
College of William and Mary  
Virginia Institute of Marine Science  
P.O. Box 1346  
Gloucester Point, VA 23062  
USA  
ecanuel@vims.edu

Barbara Cavalazzi  
Centre de Biophysique Moléculaire CNRS  
Université de Orléans  
Rue Charles Sadron  
45071 Orléans  
France

Zhe Chen  
State Key Laboratory of Palaeobiology and Stratigraphy  
Chinese Academy of Sciences  
210008 Nanjing  
China

Charles S. Cockell  
Planetary and Space Sciences Research Institute  
Open University  
Milton Keynes, MK7 6AA  
UK  
c.s.cockell@open.ac.uk

Heribert Cypionka  
University of Oldenburg  
26111 Oldenburg  
Germany  
cypionka@icbm.de

Sharmishtha Dattagupta  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
sdattag@uni-goettingen.de

Dirk de Beer  
Microsensor Research Group  
Max Planck Institute for Marine Microbiology  
Celsiusstrasse 1  
28359 Bremen  
Germany  
dbeer@mpi-bremen.de

Alan W. Decho  
Department of Environmental Health Sciences  
Arnold School of Public Health  
University of South Carolina  
Columbia, SC 29208  
USA  
awdecho@mailbox.sc.edu

Christian Défarge  
Institut des Sciences de la Terre d'Orléans  
Unité Mixte de Recherche 6113  
Université d'Orléans  
and  
Université François-Rabelais de Tours  
Ecole Polytechnique de l'Université d'Orléans  
8 rue Léonard de Vinci  
45072 Orléans  
France  
Christian.Defarge@univ-orleans.fr

Thomas Dieing  
Wissenschaftliche Instrumente und Technologie GmbH  
Lise-Meitner-Strasse 6  
89081 Ulm  
Germany  
thomas.dieing@witec.de

Martin Dietzel  
Institute of Applied Geosciences  
Graz University of Technology  
8010 Graz  
Austria  
martin.dietzel@tugraz.at

Harold L. Drake  
Department of Ecological Microbiology  
University of Bayreuth  
95440 Bayreuth  
Germany  
hld@uni-bayreuth.de

Mary L. Droser  
Department of Earth Sciences  
University of California  
Riverside, CA 92521  
USA  
mary.droser@ucr.edu

Gregory K. Druschel  
Department of Geology  
University of Vermont  
321 Delehanty Hall  
180 Colchester Ave.  
Burlington, VT 05405  
USA  
Gregory.Druschel@uvm.edu

Christophe Dupraz  
Center for Integrative Geosciences – Marine Sciences  
University of Connecticut  
354 Mansfield Road  
Storrs, CT 06269-2045  
USA  
christophe.dupraz@uconn.edu

Hermann Ehrlich  
Biomaterials, Biocomposites & Biomimetics Group  
Institute of Bioanalytical Chemistry  
Dresden University of Technology  
Bergstr. 66  
1062 Dresden  
Germany  
Hermann.Ehrlich@mailbox.tu-dresden.de

Anton Eisenhauer  
IFM-GEOMAR  
Leibniz-Institut für Meereswissenschaften  
Christian Albrechts Universität zu Kiel  
Wischhofstr. 1-3  
24148 Kiel  
Germany  
aeisenhauer@ifm-geomar.de

David Emerson  
Bigelow Laboratory for Ocean Sciences  
West Boothbay Harbor, ME 04575  
USA  
demerson@bigelow.org

Annette S. Engel  
Department of Geology and Geophysics  
Louisiana State University  
E235 Howe-Russell Geoscience Complex  
Baton Rouge, LA 70803  
USA  
aengel@geol.lsu.edu

Jiasong Fang  
College of Natural and Computational Sciences  
Hawaii Pacific University  
Kaneohe, HI 96744  
USA  
jsfang@hpu.edu

Jack D. Farmer  
School of Earth and Space Exploration  
Arizona State University  
Tempe, AZ  
USA  
jfarmer@asu.edu

Sergiu Fendrihan  
Bioresource Center and Advanced Research Association  
Aleea Istru nr. 2C, bloc A14B sc. 8, et. 2, apt. 113, sect. 6  
061912 Bucharest  
Romania  
ecologos23@yahoo.com; sergiu.fendrihan@rbc.ro

Gerta Fleissner  
Institute for Cell Biology and Neurosciences  
Goethe-University Frankfurt  
Siesmayerstr. 70  
60323 Frankfurt a. M.  
Germany  
fleissner@bio.uni-frankfurt.de

Guenther Fleissner  
Institute for Cell Biology and Neurosciences  
Goethe-University Frankfurt  
Siesmayerstr. 70  
60323 Frankfurt a. M.  
Germany  
fleissner@bio.uni-frankfurt.de

Gilberto E. Flores  
Department of Biology  
Portland State University  
1719 SW 10th Avenue  
Portland, OR 97207  
USA  
floresg@pdx.edu

Karl B. Föllmi  
Institute of Geology and Paleontology  
University of Lausanne  
2015 Lausanne  
Switzerland  
karl.foellmi@unil.ch

David A. Fowle  
Department of Earth and Atmospheric Sciences  
University of Alberta  
Edmonton, Alberta T6G 2E3  
Canada  
fowle@ku.edu

Thomas Friedl  
Albrecht-von-Haller-Institute for Plant Sciences  
University of Göttingen  
Untere Karspüle 2  
37073 Göttingen  
Germany  
tfriedl@uni-goettingen.de

Michael W. Friedrich  
Microbial Ecophysiology  
Faculty of Biology/Chemistry  
University of Bremen  
28359 Bremen  
Germany  
Michael.friedrich@uni-bremen.de

Hans-Joachim Fritz  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidstr. 3  
37077 Göttingen  
Germany  
hj.fritz@bio.uni-goettingen.de

Geoffrey M. Gadd  
Division of Molecular Microbiology  
College of Life Sciences  
University of Dundee  
Dundee DD1 5EH  
Scotland  
UK  
g.m.gadd@dundee.ac.uk

James G. Gehling  
South Australian Museum  
Adelaide, SA 5000  
Australia  
gehling.jim@saugov.sa.gov.au

David A. Gilichinsky  
Institute of Physicochemical & Biological Problems in  
Soil Science  
Russian Academy of Sciences  
Pushchino  
Russia  
gilichin@online.stack.net

Murray K. Gingras  
Department of Earth and Atmospheric Sciences  
University of Alberta  
Edmonton, Alberta T6G 2E3  
Canada  
murray.gingras@gmail.com

Eberhard Gischler  
Institut für Geowissenschaften  
Facheinheit Paläontologie  
J.W. Goethe-Universität  
Altenhöferallee 1  
60438 Frankfurt am Main  
Germany  
gischler@em.uni-frankfurt.de

Susan Glasauer  
Department of Land Resource Science  
University of Guelph  
Guelph, Ontario N1G 2W1  
Canada  
glasauer@uoguelph.ca



Stjepko Golubic  
Department of Biology  
Boston University  
5 Cummington Street  
Boston, MA 02215  
USA  
Golubic@bu.edu

Michael Gudo  
Morphisto Evolutionsforschung und Anwendung GmbH  
Institut für Evolutionswissenschaften  
Weismüllerstr. 45  
60314 Frankfurt am Main  
Germany  
mgudo@morphisto.de

Maria T. González-Muñoz  
Departamento de Mineralogía y Petrología  
Universidad de Granada  
Fuentenueva s/n  
18002 Granada  
Spain  
mgonzale@ugr.es

Bent T. Hansen  
Department of Isotope Geology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
bhansen@gwdg.de

Georges E. Gorin  
Department of Geology-Paleontology  
University of Geneva  
13 rue des Maraîchers  
1205 Geneva  
Switzerland  
georges.gorin@unige.ch

Amber K. Hardison  
College of William and Mary  
Virginia Institute of Marine Science  
P.O. Box 1346  
Gloucester Point, VA 23062  
USA  
amber@vims.edu

Dmitriy Grazhdankin  
Division of Precambrian and Cambrian Paleontology and  
Stratigraphy  
Russian Academy of Sciences  
Prospekt Akademika Koptyga 3  
Novosibirsk 630090  
Russia  
dima.grazhdankin@gmail.com

Christine Heim  
Geobiology Group  
Geoscience Centre  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
cheim@gwdg.de

Kliti Grice  
WA Organic and Isotope Geochemistry Centre  
Department of Applied Chemistry  
Curtin University of Technology  
Perth, WA 6845  
Australia  
K.Grice@curtin.edu.au

Jochen Hoefs  
Department of Isotope Geology  
University of Göttingen  
Goldschmidtstr. 1  
37077 Göttingen  
Germany  
jhoefs@gwdg.de

Alexander Grunau  
Department of Microbiology  
Institute of Plant Biology  
University of Zurich  
Winterthurerstrasse 190  
8057 Zurich  
Switzerland  
alexander.grunau@access.uzh.ch

Tori M. Hoehler  
Exobiology Branch  
NASA-Ames Research Center  
Mail Stop 239-4  
Moffett Field, CA 94035  
USA  
tori.m.hoehler@nasa.gov

Paul F. Hoffman  
Department of Earth & Planetary Sciences  
Harvard University  
Cambridge, MA  
USA  
hoffman@eps.harvard.edu

Friederike Hoffmann  
Sars International Centre for Marine Molecular Biology  
5008 Bergen  
Norway  
fhoffman@mpi-bremen.de

Veit-Enno Hoffmann  
Department of Sedimentology  
and Environmental Geology  
University of Göttingen  
37077 Göttingen  
Germany  
info@goldwelten.de

Beda A. Hofmann  
Earth Science Department  
Natural History Museum Bern  
Bernastrasse 15  
3005 Bern  
Switzerland  
beda.hofmann@geo.unibe.ch

Vanessa V. Homann  
Department of Chemistry  
University of California  
Santa Barbara, CA 93106-9510  
USA  
vhomann@chem.ucsb.edu

Michael Hoppert  
Institut für Mikrobiologie und Genetik  
University of Göttingen  
Grisebachstraße 8  
37077 Göttingen  
Germany  
mhopper@gwdg.de

Daniel J. Jackson  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
djackso@uni-goettingen.de

Robert G. Jenkins  
Faculty of Education and Human Sciences  
Yokohama National University  
79-1 Tokiwadai  
Hodogaya-ku  
Yokohama City 240-8501  
Japan  
robertgj@ynu.ac.jp

Sören Jensen  
Area de Paleontología  
Universidad de Extremadura  
06006 Badajoz  
Spain  
soren@unex.es

Concepción Jimenez-Lopez  
Departamento de Mineralogía y Petrología  
Universidad de Granada  
Fuentenueva s/n  
18002 Granada  
Spain  
cjl@ugr.es

Brian Jones  
Department of Earth and Atmospheric Sciences  
University of Alberta  
1-26 Earth Sciences Building  
Edmonton, Alberta T6G 2E3  
Canada  
Brian.Jones@ualberta.ca

Akihiro Kano  
Department of Evolution of the Earth and the  
Environment  
Graduate School of Social and Cultural Studies  
Kyushu University  
Fukuoka 819-0395  
Japan  
kano@scs.kyushu-u.ac.jp

Andreas Kappler  
Geomicrobiology Group  
Center for Applied Geoscience  
University of Tübingen  
Sigwartstrasse 10  
72072 Tübingen  
Germany  
andreas.kappler@uni-tuebingen.de

Sabine Kasten  
Alfred Wegener Institute for Polar and Marine Research  
Am Handelshafen 12  
27570 Bremerhaven  
Germany  
Sabine.Kasten@awi.de

Jozef Kazmierczak  
Institute of Paleobiology  
Polish Academy of Sciences  
ul. Twarda 51/55  
00-818 Warszawa  
Poland  
jkaz@twarda.pan.pl

Stephan Kempe  
Department of Physical Geology and Global Cycles  
Institute for Applied Geosciences  
University of Technology  
Schnittspahnstr. 9  
64287 Darmstadt  
Germany  
kempe@geo.tu-darmstadt.de

Paul A. Kenward  
Department of Geology  
University of Kansas  
Lawrence, KS 66045-7613  
USA  
pk1@ku.edu

Steffen Kiel  
Geoscience Center  
Geobiology Group  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
skiel@gwdg.de

L. Paul Knauth  
Arizona State University  
Box 871404  
Tempe, AZ 85287-1404  
USA  
Knauth@asu.edu

Katrin Knittel  
Department of Molecular Ecology  
Max Planck Institute for Marine Microbiology  
Celsiusstrasse 1  
28359 Bremen  
Germany  
kknittel@mpi-bremen.de

Kurt O. Konhauser  
Department of Earth and Atmospheric Sciences  
University of Alberta  
Edmonton, Alberta T6G 2E3  
Canada  
kurtk@ualberta.ca

Erika Kothe  
Institute of Microbiology  
Friedrich Schiller University Jena  
Neugasse 25  
07743 Jena  
Germany  
erika.kothe@uni-jena.de

Stephan M. Kraemer  
Department of Environmental Geosciences  
University of Vienna  
1090 Vienna  
Austria  
stephan.kraemer@univie.ac.at

Martin Krüger  
Geomicrobiology  
Federal Institute for Geosciences and Natural Resources  
Stilleweg 2  
30655 Hannover  
Germany  
Martin.Krueger@bgr.de

Kirsten Küsel  
Institute of Ecology  
Friedrich Schiller University Jena  
07743 Jena  
Germany  
Kirsten.Kuesel@uni-jena.de

Matthias Labrenz  
IOW-Leibniz Institute for Baltic Sea Research  
Section Biology  
Seestrasse 15  
18119 Rostock-Warnemuende  
Germany  
matthias.labrenz@io-warnemuende.de

Jukka Lausmaa  
SP Technical Research Institute of Sweden  
Chemistry and Materials Technology  
Box 857, SE-501 15 Borås  
Sweden  
jukka.lausmaa@sp.se

Natuschka M. Lee  
Department of Microbiology  
Technical University of Munich  
Emil-Ramann-Str. 4  
85354 Freising-Weihenstephan  
Germany  
nlee@microbial-systems-ecology.de

Guoxiang Li  
State Key Laboratory of Palaeobiology  
and Stratigraphy  
Chinese Academy of Sciences  
210008 Nanjing  
China  
gxli@nigpas.ac.cn

Zheng-Xiang Li  
Department of Applied Geology  
Curtin University of Technology  
GPO Box U1987  
Perth, WA 6845  
Australia  
z.li@curtin.edu.au

Volker Liebetrau  
Leibniz Institute of Marine Sciences  
IFM-GEOMAR  
Research Division 2: Marine Biogeochemistry  
Wischhofstr. 1-3  
24148 Kiel  
Germany  
vliebetrau@ifm-geomar.de

Wolfgang Liebl  
Department of Microbiology  
Technische Universität München  
Emil-Ramann-Str. 4  
85354 Freising-Weihenstephan  
Germany  
wliebl@wzw.tum.de

Carol D. Litchfield  
Department of Environmental Science & Policy  
George Mason University  
10900 University Boulevard  
Manassas, VA 20110  
USA  
clitchfi@gmu.edu

Frank E. Löffler  
Department of Microbiology and  
Department of Civil and Environmental Engineering  
University of Tennessee  
Knoxville, TN 37996  
USA  
frank.loeffler@utk.edu

Fred T. Mackenzie  
Department of Oceanography  
School of Ocean and Earth Science and Technology  
University of Hawaii  
Honolulu, HI 96822  
USA  
fredm@soest.hawaii.edu

Joseph G. Meert  
Geological Sciences  
University of Florida  
274 Williamson Hall  
Gainesville, FL  
USA  
jmeert@geology.ufl.edu; jmeert@bellsouth.net

Daniela B. Meisinger  
Department of Microbiology  
Technical University of Munich  
85354 Freising-Weihenstephan  
Germany  
daniela.meisinger@microbial-systems-ecology.de

Kathrin I. Mohr  
Albrecht-von-Haller-Institute for Plant Sciences  
University of Göttingen  
Untere Karspüle 2  
37073 Göttingen  
Germany  
and  
Helmholtz Centre for Infection Research  
Braunschweig  
Germany  
kathrin.mohr@helmholtz-hzi.de

D. Kirk Nordstrom  
U.S. Geological Survey  
3215 Marine St.  
Boulder, CO 80303  
USA  
dkn@usgs.gov

Ronald S. Oremland  
Water Resources Division, MS 480  
United States Geological Survey  
345 Middlefield Road  
Menlo Park, CA 94025  
USA  
roremlan@usgs.gov

Wolfgang Oschmann  
Geologie und Paläontologie  
University of Frankfurt  
Senckenberganlage 32  
60325 Frankfurt  
Germany  
oschmann@em.uni-frankfurt.de

Muriel Paction  
Geological Institute  
ETH Zurich  
Sonneggstrasse 5  
8092 Zurich  
Switzerland  
muriel.paction@erdw.ethz.ch

Karsten Pedersen  
Department of Cell and Molecular Microbiology  
Göteborg University  
Box 462  
405 30 Göteborg  
Sweden  
karsten.pedersen@cmb.gu.se

Randall S. Perry  
Department of Earth Science and Engineering  
Imperial College  
London  
UK  
r.perry@imperial.ac.uk

Steven T. Petsch  
Department of Geosciences  
University of Massachusetts Amherst  
Amherst, MA 01003  
USA  
spetsch@geo.umass.edu

Thomas Pommier  
Microbial Ecology Centre  
UMR 5557 CNRS-Université Lyon 1; USC 1193 INRA  
CNRS-Université Lyon  
43 bd du 11 November 1918  
69622 Villeurbanne  
France  
thomas.pommier@univ-lyon1.fr

Hubertus Porada  
Geoscience Centre  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
hporada@gwdg.de

Mihály Pósfai  
Department of Earth and Environmental Sciences  
University of Pannonia  
P.O. Box 158  
8200 Veszprém  
Hungary  
mihaly.posfai@gmail.com

Nicole R. Posth  
Geomicrobiology Group  
Center for Applied Geoscience  
University of Tübingen  
Sigwartstrasse 10  
72072 Tübingen  
Germany  
nicole.posth@uni-tuebingen.de

Brian R. Pratt  
Department of Geological Sciences  
University of Saskatchewan  
Saskatoon, SK S7N 5E2  
Canada  
brian.pratt@usask.ca

Nadia-Valérie Quéric  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
nqueric@uni-goettingen.de

Gudrun Radtke  
Hessisches Landesamt für Umwelt und Geologie  
Rheingaustr. 186  
65203 Wiesbaden  
Germany  
Gudrun.Radtke@hlug.hessen.de

Eugenio Ragazzi  
Department of Pharmacology and Anaesthesiology  
University of Padova  
35131 Padova  
Italy  
eugenio.ragazzi@unipd.it

Kristina Rathsack  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
kraths@uni-goettingen.de

Douglas Eric Rawlings  
Department of Microbiology  
University of Stellenbosch  
Private Bag X1  
Matieland 7602  
South Africa  
der@sun.ac.za

R. Pamela Reid  
Marine Geology and Geophysics – RSMAS  
University of Miami  
4600 Rickenbacker Causeway  
Miami, FL 33149  
USA  
preid@rsmas.miami.edu

Andreas Reimer  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
areimer@gwdg.de

Joachim Reitner  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
jreitne@gwdg.de

Robin W. Renaut  
Department of Geological Sciences  
University of Saskatchewan  
Saskatoon, SK S7N 5E2  
Canada  
robin.renaut@usask.ca

Anna-Louise Reysenbach  
Department of Biology  
Portland State University  
246 Science Building 2  
1719 SW 10th Avenue  
Portland, OR 97207  
USA  
reysenbacha@pdx.edu

Robert Riding  
Department of Earth and Planetary Sciences  
University of Tennessee  
1412 Circle Drive  
Knoxville, TN 37996  
USA  
riding@cardiff.ac.uk

Kathrin Riedel  
Department of Microbiology  
Institute of Plant Biology  
University of Zurich  
Winterthurerstrasse 190  
8057 Zurich  
Switzerland  
kriedel@botinst.uzh.ch

Elizaveta M. Rivkina  
Institute of Physicochemical & Biological Problems in  
Soil Science  
Russian Academy of Sciences  
Pushchino  
Russia  
rivkina@issp.serpukhov.su

Jennifer A. Roberts  
Department of Geology  
University of Kansas  
Lawrence, KS 66045-7613  
USA  
jenrob@ku.edu

Manuel Rodriguez-Gallego  
Departamento de Mineralogía y Petrología  
Universidad de Granada  
Fuentenueva s/n  
18002 Granada  
Spain  
mrgalleg@ugr.es

Marta Rodríguez-Martínez  
Departamento de Geología  
Facultad de Biología  
Universidad de Alcalá  
28871 Alcalá de Henares, Madrid  
Spain  
marta.rodriguez@uah.es

Carlos Rodriguez-Navarro  
Departamento de Mineralogía y Petrología  
Universidad de Granada  
Fuentenueva s/n  
18002 Granada  
Spain  
carlosrn@ugr.es

Michael Rothballe  
Department Microbe-Plant Interactions  
Helmholtz Zentrum München  
German Research Center for Environmental  
Health (GmbH)  
85764 Neuherberg  
Germany  
rothballe@helmholtz-muenchen.de

Michael J. Russell  
Planetary Science & Life Detection  
Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive  
Pasadena, CA 91109-8099  
USA  
mrussell@jpl.nasa.gov

Jürgen Schieber  
Department of Geological Sciences  
Indiana University  
1001 E 10th Str  
Bloomington, IN 47405-1405  
USA  
jschiebe@indiana.edu

Bernhard Schink  
Department of Biology  
University of Konstanz  
Konstanz  
Germany  
bernhard.schink@uni-konstanz.de

Marie-Lise Schläppy  
Max Planck Institute for Marine Microbiology  
Bremen  
Germany  
mlschlae@mpi-bremen.de

Michael Schmid  
Department Microbe-Plant Interactions  
Helmholtz Zentrum München  
German Research Center for Environmental  
Health (GmbH)  
85764 Neuherberg  
Germany  
michael.schmid@helmholtz-muenchen.de

Alexander R. Schmidt  
Courant Research, Centre Geobiology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
alexander.schmidt@geo.uni-goettingen.de

Kerstin Schmidt  
Institut für Ökologie  
Friedrich-Schiller-Universität Jena  
Dornburger Str. 159  
07743 Jena  
Germany  
kerstinschmidtjena@web.de

Carsten J. Schubert  
Eawag, Swiss Federal Institute of Aquatic Science  
and Technology  
Seestrasse 79  
6047 Kastanienbaum  
Switzerland  
carsten.schubert@eawag.ch

Heide N. Schulz-Vogt  
Max Planck Institute for Marine Microbiology  
Celsiusstr. 1  
28359 Bremen  
Germany  
hschulz@mpi-bremen.de

Mark A. Sephton  
Department of Earth Science and Engineering  
Imperial College London  
London SW7 2AZ  
UK  
m.a.sephton@imperial.ac.uk

Silke Severmann  
Institute of Marine and Coastal Sciences and Department  
of Earth and Planetary Sciences  
Rutgers University  
71 Dudley Road  
New Brunswick, NJ  
USA  
silke@marine.rutgers.edu

Meinhard Simon  
Institute for Chemistry and Biology of the Marine  
Environment  
University of Oldenburg  
26111 Oldenburg  
Germany  
m.simon@icbm.de

Peter Sjövall  
SP Technical Research Institute of Sweden  
Chemistry and Materials Technology  
Borås  
Sweden  
peter.sjovall@sp.se

Helga Stan-Lotter  
Division of Molecular Biology  
Department of Microbiology  
University of Salzburg  
Billrothstr. 11  
5020 Salzburg  
Austria  
helga.stan-lotter@sbg.ac.at

John F. Stolz  
Bayer School of Natural & Environmental Sciences  
Department of Biological Sciences  
Duquesne University  
600 Forbes Avenue  
Pittsburgh, PA 15282  
USA  
stolz@duq.edu

Kristina L. Straub  
Biogeochemie/Umweltgeowissenschaften  
University of Vienna  
Althanstr. 14  
1090 Vienna  
Austria  
kristina.straub@univie.ac.at

Volker Thiel  
Geobiology Group  
Geoscience Center  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
vthiel@gwdg.de

Ingunn H. Thorseth  
Centre of Geobiology and Department of Earth Science  
University of Bergen  
Allegaten 41  
5007 Bergen  
Norway  
Ingunn.Thorseth@geo.uib.no

Jan Toporski  
Wissenschaftliche Instrumente und Technologie GmbH  
Lise-Meitner-Strasse 6  
89081 Ulm  
Germany  
jan.toporski@witec.de

Aline Tribollet  
Institut de Recherche pour le Développement  
BP A5  
98848 Nouméa, Nouvelle-Calédonie  
France  
aline@hawaii.edu

Eric P. Verrecchia  
Institut de Géologie et Paléontologie  
Université de Lausanne  
Anthropole  
1015 Lausanne  
Switzerland  
eric.verrecchia@unil.ch

Pieter T. Visscher  
Center for Integrative Geosciences – Marine Sciences  
University of Connecticut  
354 Mansfield Road  
Storrs, CT 06269-2045  
USA  
pieter.visscher@uconn.edu

Walter Vortisch  
Prospektion und Angewandte Sedimentologie  
Department für Angewandte Geowissenschaften und  
Geophysik  
Montanuniversität Leoben  
Leoben  
Austria  
Walter.Vortisch@unileoben.ac.at

Lesley A. Warren  
School of Geography and Earth Sciences  
McMaster University  
Hamilton, ON  
Canada  
warrenl@mcmaster.ca

Bettina Weber  
Plant Ecology and Systematics  
Department of Biology  
University of Kaiserslautern  
P.O. Box 3049  
67653 Kaiserslautern  
Germany  
weberb@rhrk.uni-kl.de

Frances Westall  
Centre de Biophysique Moléculaire CNRS  
Université de Orléans  
Rue Charles Sadron  
45071 Orléans  
France  
westall@cnrs-orleans.fr

Frank Wiese  
Courant Research Centre Geobiology  
University of Göttingen  
Goldschmidtstr. 3  
37077 Göttingen  
Germany  
frwiese@snaifu.de

Gert Wörheide  
Department of Earth & Environmental Sciences  
Palaeontology and Geobiology  
Ludwig-Maximilians-Universität München  
Richard-Wagner-Str. 10  
80333 München  
Germany  
woerheide@lmu.de

Christoph Wrede  
Institut für Mikrobiologie und Genetik  
University of Göttingen  
Göttingen  
Germany  
cwrede@gwdg.de

Li Zhang  
Faculty of Earth Sciences  
China University of Geosciences  
Wuhan, Hubei 430074  
China  
Lizhang@cug.edu.cn



Maoyan Zhu  
State Key Laboratory of Palaeobiology and Stratigraphy  
Chinese Academy of Sciences  
210008 Nanjing  
China  
myzhu@nlgpas.ac.cn

Frank Zielinski  
Department of Environmental Microbiology  
Biotrophic Plant-Microbe Interactions  
Helmholtz Centre for Environmental Research (UFZ)  
Permoserstr. 15  
04318 Leipzig  
Germany  
frank.zielinski@ufz.de



## Preface

Geobiology is a highly cross-disciplinary field that explores the present and past relationships that life has with non-living matter. “Biosphere meets Geosphere” perhaps most parsimoniously describes the fundamental concept of Geobiology. In 1991, Peter Westbroek, a Dutch paleontologist and influential protagonist of Geobiology defined the field in a book entitled “Life as a Geological Force: Dynamics of the Earth”, thus motivating a new way of thinking in the geosciences. His fundamental work on processes of biomineralization in coccolithophorid algae (Westbroek and de Jong, 1983) greatly contributed to the understanding of metabolic processes controlling mineral formation. Westbroek’s thinking was influenced by James Lovelock’s Gaia concept (Lovelock, 1988) which advocated the importance of biological processes with regard to global change over time. Other early pioneers of the Geobiology concept were the Russian scientist Georgy Adamovich Nadson (1903), who recognised microorganisms as geological agents, and the Swiss geologists Johannes Neher and Ernst Rohrer who discovered the role of microbes in dolomite formation (Neher and Rohrer 1958) and their presence in the deep biosphere of crystalline rocks (Neher and Rohrer 1959). In 1971, the German geoscientist Gerd Lüttig introduced a new discipline that merged aspects of geology and biology and called it “Lithobiontik”. This was the first time that research on geological and biological interactions received a well-founded definition:

*“Die Erdgeschichte ist umschreibbar als eine ständige Auseinandersetzung zwischen Gesteinswelt (lithos) und Lebewelt (bios). Die Gesamtheit der entsprechenden Vorgänge zu erforschen, ist Aufgabe der Lithobiontik, einer Forschungsrichtung im Grenzgebiet zwischen Geologie und Biologie.” — Earth history can be described as a permanent interaction between the geosphere (lithos) and life processes (bios). To investigate these processes is the mission of Lithobiontics, a new research discipline between Geology and Biology.*

Kenneth Nealson and William Ghiorse colleagues provided, in a conceptual review written for the American Academy of Microbiology (Nealson et al. 2001), a modern and concise perception of Geobiology as “Exploring the interface between the Biosphere and the Geosphere”.

The interplay between biological and geological processes has shaped the Earth and driven the evolution of its biodiversity from the early dawn of life, some four billion years ago. Since then, organisms have been responding to a changing global environment and in turn, have themselves altered the chemical and physical settings on our planet. Geobiology strives to identify these cause-and-effect chains in both modern environments and the geological record. Its goal is to provide, on different time and spatial scales, an ‘organismic’ biological perspective on Earth’s environmental evolution (Knoll and Hayes, 1997).

Shifting their focus from traditional morphological studies made by paleontologists, geobiologists continue to develop their ability to relevant chemical and molecular signatures within living and non-living materials, and to interpret these signatures to better understand the geological record and better predict our course into the future. A key issue in most geobiological studies is the elucidation of ancient environmental states, and to understand the evolution of biological processes and their geological consequences. Meaningful signatures that reveal such processes are not limited to visible remains, but also encompass for instance, organic molecules, minerals, petrofabrics and isotope patterns. Organisms may alter their chemical environment, thereby giving rise to the production or destruction of minerals, rocks, atmospheric gases and even fossil fuels. An understanding of these processes creates enormous potential with respect to issues of environment protection, public health, energy and resource management. Geobiological research and

education is therefore rapidly growing, with topics becoming more common in University and High School curricula. With Geobiology issues including many spectacular aspects (e.g., early life, deep biosphere, gas hydrates, black smokers etc.), public interest also increases concomitantly.

Moving beyond the borders of classical core disciplines, scientists from a broad range of disciplines are actively involved in geobiological studies. There is no common perception of a ‘typical’ geobiologist, but as an underlying requirement, scientists need to adapt concepts and utilize methodologies from other disciplines to exploit the full potential of Geobiology. Fields united under the umbrella of geobiology include, but are not limited to: geology and paleontology, mineralogy, microbiology, molecular biology, genomics, organic and inorganic geochemistry, oceanography, astrobiology and (paleo)ecology. This incomplete list provides an impression of the implications of geobiological research, and that the super-discipline of Geobiology is ‘greater than the sum of its parts’ (Nealson et al. 2001).

The *Encyclopedia of Geobiology* was compiled to provide clear explanations of current geobiological topics. It is not structured as a student textbook, but rather to quickly access particular terms and concepts in self-contained entries. We hope that this volume will also tempt the casual reader to browse and become curious about the different facets and foci of Geobiology - following the philosophy of the late Founding Series Editor, Rhodes Fairbridge, we will be most content if an original discovery may emerge from perusing a variety of entries.

We are thankful to our authors, both distinguished ‘old hands’ and young researchers from five continents, who have synthesized the particular subdisciplines for this volume. The preparation of this book was greatly aided by the input we received from our Editorial Board members Hans-Joachim Fritz, Andreas Kappler, Kurt Konhauser,

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The Editors-In-Chief  
Joachim Reitner  
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## References

- Knoll, A. H., and Hayes, J. M., 2000. Geobiology: problems and prospects. In Lane, R. H., Steining, F. F., Kaesler, R. L., Ziegler, W., Lipps, J. (eds.), *Fossils and the Future - Paleontology in the 21st Century*. Senckenberg-Buch Nr. 74, Frankfurt a. M.: Kramer, pp. 149–153.
- Lovelock, J. E., 1988. *The Ages of Gaia*. New York: Norton.
- Lüttig, G., 1971. Lithobiontik – Aufgabengebiet, Tätigkeiten, zukünftige Ziele (*Lithobiontics – scope, activities, future goals*). *Geol Jb (in German)*, **89**, 575–582.
- Nadson, G. A., 1903. Mikroorganismi kak geologitsheskie dieiateli (*Microorganisms as geological agents*). I. Tr. Komisii Isslect. Min. Vodg. Slavyanskaya (in Russian), St. Petersburg, 1–98.
- Nealson, K., Ghiorse, W. A., Strauss, E., 2001. Geobiology: Exploring the Interface Between the Biosphere and the Geosphere. Washington, D.C., American Academy of Microbiology, 16 p.; available online at: <http://academy.asm.org/index.php/colloquia-reports/browse-all/227-geobiology-exploring-the-interface-between-the-biosphere-and-the-geosphere-2001-b>.
- Neher, J., and Rohrer, E., 1958. Dolomitbildung unter Mitwirkung von Bakterien (*Dolomite formation involving bacteria*). *Eclogae Geol Helv (in German)*, **51**, 213–215.
- Neher, J., and Rohrer, E., 1959. Bakterien in tieferliegenden Gesteinslagen (*Bacteria in deeper rock layers*). *Eclogae Geol Helv (in German)*, **52**, 619–625.
- Westbroek, P., 1991. *Life as a Geological Force – Dynamics of the Earth*. New York: W.W.N. Norton.
- Westbroek, P., 1983. Biological metal accumulation and biomineralization in a geological perspectives. In Westbroek P. and de Jong, W. E. (eds.), *Biological Metal Accumulation and Biomineralization in a Geological Perspective*, Dordrecht: Reidel, pp. 1–11.