

GEOMICROBIOLOGY

Fourth Edition, Revised and Expanded

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To my former students,
from whom I have learned as much
as I hope they have learned from me.

Preface to the Fourth Edition

The field of geomicrobiology has been receiving wider recognition than ever before among environmental microbiologists and earth scientists since the first appearance of the third edition of this book in November 1995. This is happening because of an ever-increasing awareness of the influence of microbial activity in shaping the habitable part of our planet. The pace of research on various aspects of geomicrobiology in the last few years has significantly accelerated and produced new discoveries of geomicrobial phenomena and yielded new insights into previously established phenomena. The topic of geomicrobiology was specifically addressed in the program of recent annual meetings of the American Society of Microbiology (ASM) and, since the year 2000, has been allotted a special section in the table of contents of the journal *Applied and Environmental Microbiology*, published by ASM. A journal exclusively devoted to the subject, the *Geomicrobiology Journal*, has been published independently of ASM since 1978. The timely publication of *Geomicrobiology: Fourth Edition, Revised and Expanded*, puts the new advances in the field in perspective.

This fourth edition incorporates the important new findings of geomicrobial significance of the last five years. Some of these findings were made by the

application of new physical and biological analytical techniques. They enlarged our concept of the total size of the microbial habitat enormously because living microorganisms have been detected below the Earth's surface at significantly greater depths than heretofore. They have also expanded our understanding of the great diversity among the microbes in all the habitable parts of the Earth. Intensive investigations are ongoing to determine the interrelationships among the microorganisms in these habitats and the nature of their activities from a geomicrobial standpoint. This edition reflects some modifications in the thinking about the origin of life on Earth and its early evolution, but a divergence of views remains.

In regard to specific geomicrobial processes, the fourth edition reflects the increase in our understanding of the microbial weathering of rocks and minerals. It contains a new chapter that deals with a probable role of microbes in the formation of bauxites. The chapters on iron and manganese incorporate the latest findings in regard to the physiology of microbial oxidation and reduction of ionic forms of these metals and some of their minerals and the diversity of the organisms involved. They also contain a more extensive discussion of the microbial role in anaerobic biodegradation of organic carbon than in earlier editions. The chapters dealing with sulfur, arsenic, and selenium compounds incorporate the latest findings with regard to microbial oxidation and/or reduction of corresponding forms of these elements. The section on microbial metal sulfide oxidation in [Chapter 19](#) has been extensively modified. It reflects the important recent discovery that acidophilic *Thiobacillus ferrooxidans* (recently renamed *Acidithiobacillus ferrooxidans*) seems to be a secondary rather than a primary player in mobilizing metal from metal sulfide ores in heap-, dump-, and in situ leaching and in generating acid mine drainage, at least in more advanced stages. This chapter also examines a current controversy concerning the mechanism by which acidophilic iron bacteria oxidize metal sulfides. New references have been added to the chapter on the geomicrobiology of fossil fuels.

The chief aim of the fourth edition of *Geomicrobiology*, like that of the earlier editions, is to serve as an introduction to the subject and to be of use as a text as well as an up-to-date reference book. The book includes discussion of the older literature as well as the recent literature, which is important for an appreciation of the development of the different areas of geomicrobiology. As in the earlier editions, the reference lists at the end of each chapter are not exhaustive but include the literature I deem most important. Related literature can be located by cross-referencing. As in previous editions, a glossary is included to provide definitions of scientific terms that may be unfamiliar to some readers.

I have retained some of the drawings prepared by Stephen Chiang for the first edition. A few illustrations from the third edition have been replaced, and a few entirely new ones have been added. I am indebted to a number of persons and publishers for making available original photographs or allowing reproduction of

previously published material. They are acknowledged in the legends of the individual illustrations.

I owe thanks to Donna Bedard for very helpful comments on the molecular aspects discussed in [Chapter 7](#). My thanks also go to Jill Banfield, Katarina Edwards, and Francisco F. Roberto for reading [Chapter 19](#), and to Ronald Oremland for reading [Chapters 13](#) and [20](#). I am indebted to Sigal Lechno-Yossef for help with the digital photomicrography setup in the biology department.

The continued belief of Marcel Dekker, Inc., in the importance of this book has encouraged me greatly in preparing this fourth edition. Special thanks go to Sandra Beberman, Vice President, Medical Division; Michael Deters and Moraima Suarez, Production Editors; and the editorial staff.

Responsibility for the presentation and interpretation of the subject matter in this edition rests entirely with me.

Henry Lutz Ehrlich

Preface to the Third Edition

The need for a third edition of *Geomicrobiology* has arisen because of some important advances in the field since the second edition. Of particular significance are advances in the areas of subsurface microbiology as it relates to groundwater, carbonate deposition, rock weathering, methylmercury formation, oxidation and reduction of iron and manganese, chromate reduction, oxidation and reduction of molybdenum, reduction of vanadate (V) and uranium (VI), oxidation and reduction of sulfur compounds, reduction of selenate and selenite, methanogenesis, microbial attack of coal, and degradation of hydrocarbons. These advances have been integrated into the treatment of these subjects. The chapter dealing with the biochemistry and physiology of geomicrobial processes has been updated to convey the basis for our current understanding of how and why microbes are involved in these processes.

Because this book is meant to serve as a reference as well as a textbook, very little material from the second edition has been eliminated. By retaining this information, an overview of the growth of the field of geomicrobiology since its inception is retained. It enables newcomers to learn what has been accomplished in the field and to gain an introduction to the literature. The literature citations on

the different subjects are not exhaustive, but include the most important ones, making it possible to locate other works by cross-referencing. As in the previous editions, a glossary is included to aid in the definition of unfamiliar scientific terms.

In preparing this edition, I have retained some of the line drawings prepared by Stephen Chiang for the first edition that were also included in the second edition. Some other illustrations from the second edition have been replaced, and a few entirely new illustrations have been included. I am indebted to a number of persons and publishers for making available original photographs or allowing reproduction of previously published material. They are acknowledged in the legends of the individual illustrations.

I wish to thank Marcel Dekker, Inc., for their continued belief in the importance of this book by encouraging the preparation of this third edition. I want to express special thanks to Bradley Benedict, Assistant Production Editor, and the editorial staff for their assistance in preparing this edition.

Responsibility for the presentation and interpretation of the subject matter in this edition rests entirely with me.

Henry Lutz Ehrlich

Preface to the Second Edition

As in the first edition of this book, geomicrobiology is presented as a field distinct from microbial ecology and microbial biogeochemistry. The stress remains on examination of specific geomicrobial processes, microorganisms responsible for them, and the pertinence of these processes to geology.

Most chapters from the earlier edition have been extensively revised and updated. As far as possible, new discoveries related to geomicrobiology reported by various investigators since the writing of the first edition have been integrated into the new edition. Two new chapters have been added, one on the geomicrobiology of nitrogen and the other on the geomicrobiology of chromium. The second chapter of the first edition has been divided into two to allow for a more concise development of the two topics: Earth as microbial habitat and the origin of microbial life on Earth.

In the new edition, [Chapters 2–6](#) are intended to provide the background needed for understanding the succeeding chapters, which deal with specific aspects of geomicrobiology. An understanding of microbial physiology and biochemistry is very important for a full appreciation of how specific microbes

can act as geomicrobial agents. For this reason, [Chapter 6](#) was extensively revised from its antecedent, [Chapter 5](#), in the first edition.

Like its predecessor, the present edition is meant to serve not only as a text, but also as a general introduction and guide to the geomicrobial literature for microbiologists, ecologists, geologists, environmental engineers, mining engineers, and others interested in the subject. The literature citations are not intended to be exhaustive, but cross-referencing, especially in cited review articles, should lead the reader to many other pertinent references not mentioned in this book.

Some of the revisions in this edition, especially those relating to bioenergetics, were significantly influenced by a number of stimulating informal discussions with my colleague and research collaborator John C. Salerno.

In preparing this edition, I have retained some of the line drawings by Stephen Chiang. I have, however, replaced many of the other illustrations, and added some new ones that I prepared on a Macintosh Plus computer with Cricket Draw and Cricket Graph applications. I wish to thank the Voorhees Computer Center of Rensselaer Polytechnic Institute for allowing me to use the Laser Printer Facility and George Clarkson for making the necessary arrangements. Once again, I am indebted to a number of persons and publishers for making available original photographs or allowing reproduction of previously published material. They are acknowledged in the legends of the individual illustrations.

I wish to thank Marcel Dekker, Inc., for deeming the subject matter of this book of sufficient continued importance to publish this second edition. Special thanks go to Judith DeCamp, Production Editor, and the editorial staff for their help in bringing this edition to fruition.

Responsibility for the presentation and interpretation of the subject matter in this edition rests entirely with me.

Henry Lutz Ehrlich

Preface to the First Edition

This book deals with geomicrobiology as distinct from microbial ecology and microbial biogeochemistry. Although these fields overlap to some degree, each emphasizes different topics (see [Chapter 1](#)). A reader of this book should not, therefore, expect to find extensive discussions of ecosystems, food chains, nutritional cycles, mass transfer, or man-made pollution problems as such, because these topics are not at the heart of geomicrobiology. Geomicrobiology is the study of the role that microbes play or have played in specific geological processes.

This book arose out of a strong need I felt in teaching a course in geomicrobiology. As of this writing, no single text is available that deals with the group of topics presented in this book. Previously, students in my geomicrobiology course needed to be referred to the many primary publications on the various topics. These publications are very numerous and are scattered among a plethora of journals and books that are often not readily available. Some are written in languages other than English. This book is an attempt to glean the basic geomicrobial principles from this literature and to illustrate these principles with many different examples.

Some readers of this book will have a stronger background in Earth and marine science than in microbial physiology, while others will have a stronger background in microbial physiology than in Earth and marine sciences. To enable all these readers to place the geomicrobial discussions in the later chapters in proper context, the introductory [Chapters 2–5](#) were written. They are not meant to be definitive treatises on their subjects, and as a result any one of them will appear elementary to a person already knowledgeable in its field. However, I have found the material in these chapters to be essential in teaching my students.

As for the rest of the book, [Chapter 6](#) summarizes the methods used in geomicrobiology, and [Chapters 7–17](#) examine specific geomicrobial activities in relation to geologically important classes of substance or elements. A single basic theme pervades these last 11 chapters: biooxidation and bioreduction and/or bioprecipitation and biosolution. This may seem an unnecessary reiteration of a common set of principles, but closer examination will show that the manifestations of these principles in different geomicrobial phenomena differ so strikingly as to require separate examination. In discussing geomicrobial processes, I have tended to emphasize the physiological more than the geological aspects. This is in part because the former is my own area of greater expertise, but also, and more importantly, because I feel that the physiological and biochemical nature of geomicrobial processes has to be understood to fully appreciate why some microbes are capable of these activities.

In citing microorganisms in the text, the names employed by the investigators whose work is described are used. In the case of bacteria, these names may have subsequently changed. The currently used names of the bacteria may be found by referring to *Bergey's Manual of Determinative Bacteriology* (8th edition, edited by R. E. Buchanan and N. E. Gibbons, 1974, Williams and Wilkins, Baltimore) and to the *Index Bergeyana* (R. E. Buchanan, J. G. Holt, and E. F. Lessel, 1966, Williams and Wilkins, Baltimore). In some instances, however, it may be impossible to find a bacterial organism listed in the *Manual* or the *Index* because the organism was never sufficiently described to achieve taxonomic status. The current names of renamed bacteria may also be found in the index of organisms at the end of this book.

It is hoped that this book will serve not only as a text but also as an introduction and guide to the geomicrobiological literature for microbiologists, ecologists, geologists, environmental engineers, and others interested in the subject.

The preparation of this book was greatly aided by discussion with, and review of the manuscript by, Galen E. Jones, R. Schweisfurth, William C. Ghiorse, Edward J. Arcuri, Paul A. LaRock, and many students in my geomicrobiology course. Responsibility for the presentation and interpretation of the subject matter as found in this book rests, however, entirely with me. I am indebted to a number of persons and publishers for making available original

photographs or allowing reproduction of previously published material for illustration. They are acknowledged in the legends of the individual illustrations. I wish to thank Stephen Chiang for his preparation of finished line drawings from the crude sketches I furnished. I also wish to thank the editorial staff of Marcel Dekker, Inc., for their help in readying my manuscript for publication.

Henry Lutz Ehrlich

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