
Contents

<i>Preface to the Fourth Edition</i>	v
<i>Preface to the Third Edition</i>	ix
<i>Preface to the Second Edition</i>	xi
<i>Preface to the First Edition</i>	xiii

1. Introduction	1
References	4
2. The Earth as a Microbial Habitat	7
2.1 Geologically Important Features	7
2.2 The Biosphere	12
2.3 Summary	16
References	16

3. The Origin of Life and Its Early History	21
3.1 The Beginnings	21
3.2 Evolution of Life Through the Precambrian: Biological and Biochemical Benchmarks	28
3.3 The Evidence	38
3.4 Summary	43
References	44
4. The Lithosphere as a Microbial Habitat	49
4.1 Rock and Minerals	49
4.2 Mineral Soil	51
4.3 Organic Soils	65
4.4 The Deep Subsurface	65
4.5 Summary	67
References	68
5. The Hydrosphere as a Microbial Habitat	73
5.1 The Oceans	73
5.2 Freshwater Lakes	95
5.3 Rivers	102
5.4 Groundwaters	103
5.5 Summary	108
References	109
6. Geomicrobial Processes: A Physiological and Biochemical Overview	117
6.1 Types of Geomicrobial Agents	117
6.2 Geomicrobially Important Physiological Groups of Prokaryotes	119
6.3 Role of Microbes in Inorganic Conversions in the Lithosphere and Hydrosphere	121
6.4 Types of Microbial Activities Influencing Geological Processes	122
6.5 Microbes as Catalysts of Geochemical Processes	123
6.6 Microbial Mineralization of Organic Matter	142
6.7 Microbial Products of Metabolism That Can Cause Geomicrobial Transformations	144
6.8 Physical Parameters That Influence Geomicrobial Activity	144
6.9 Summary	147
References	148

7. Methods in Geomicrobiology	153
7.1 Introduction	153
7.2 Detection and Isolation of Geomicrobially Active Organisms	155
7.3 In Situ Study of Past Geomicrobial Activity	164
7.4 In Situ Study of Ongoing Geomicrobial Activity	166
7.5 Laboratory Reconstruction of Geomicrobial Processes in Nature	168
7.6 Quantitative Study of Growth on Surfaces	172
7.7 Test for Distinguishing Between Enzymatic and Nonenzymatic Geomicrobial Activity	176
7.8 Study of Reaction Products of a Geomicrobial Transformation	176
7.9 Summary	177
References	177
8. Microbial Formation and Degradation of Carbonates	183
8.1 Distribution of Carbon in the Earth's Crust	183
8.2 Biological Carbonate Deposition	184
8.3 Biodegradation of Carbonates	212
8.4 Biological Carbonate Formation and Degradation and the Carbon Cycle	218
8.5 Summary	220
References	221
9. Geomicrobial Interactions with Silicon	229
9.1 Distribution and Some Chemical Properties	229
9.2 Biologically Important Properties of Silicon and Its Compounds	231
9.3 Bioconcentration of Silicon	233
9.4 Biomobilization of Silicon and Other Constituents of Silicates (Bioweathering)	239
9.5 Role of Microbes in the Silicon Cycle	245
9.6 Summary	247
References	247
10. Geomicrobiology of Aluminum: Microbes and Bauxite	255
10.1 Introduction	255
10.2 Microbial Role in Bauxite Formation	256
10.3 Summary	263
References	264

11. Geomicrobial Interactions with Phosphorus	267
11.1 Biological Importance of Phosphorus	267
11.2 Occurrence in the Earth's Crust	268
11.3 Conversion of Organic into Inorganic Phosphorus and the Synthesis of Phosphate Esters	268
11.4 Assimilation of Phosphorus	270
11.5 Microbial Solubilization of Phosphate Minerals	271
11.6 Microbial Phosphate Immobilization	274
11.7 Microbial Reduction of Oxidized Forms of Phosphorus	278
11.8 Microbial Oxidation of Reduced Forms of Phosphorus	280
11.9 Microbial Role in the Phosphorus Cycle	281
11.10 Summary	283
References	283
12. Geomicrobially Important Interactions with Nitrogen	289
12.1 Nitrogen in the Biosphere	289
12.2 Microbial Interactions with Nitrogen	290
12.3 Microbial Role in the Nitrogen Cycle	297
12.4 Summary	298
References	299
13. Geomicrobial Interactions with Arsenic and Antimony	303
13.1 Introduction	303
13.2 Arsenic	303
13.3 Antimony	317
13.4 Summary	319
References	320
14. Geomicrobiology of Mercury	327
14.1 Introduction	327
14.2 Distribution of Mercury in the Earth's Crust	328
14.3 Anthropogenic Mercury	328
14.4 Mercury in the Environment	329
14.5 Specific Microbial Interactions with Mercury	330
14.6 Genetic Control of Mercury Transformations	335
14.7 Environmental Significance of Microbial Mercury Transformations	336
14.8 A Mercury Cycle	337
14.9 Summary	338
References	339

15. Geomicrobiology of Iron	345
15.1 Iron Distribution in the Earth's Crust	345
15.2 Geochemically Important Properties	345
15.3 Biological Importance of Iron	347
15.4 Iron as Energy Source for Bacteria	349
15.5 Anaerobic Oxidation of Ferrous Iron	376
15.6 Iron(III) as Terminal Electron Acceptor in Bacterial Respiration	377
15.7 Nonenzymatic Oxidation of Ferrous Iron and Reduction of Ferric Iron by Microbes	393
15.8 Microbial Precipitation of Iron	395
15.9 The Concept of Iron Bacteria	397
15.10 Sedimentary Iron Deposits of Putative Biogenic Origin	398
15.11 Microbial Mobilization of Iron from Minerals in Ore, Soil, and Sediments	403
15.12 Microbes and the Iron Cycle	404
15.13 Summary	406
References	408
16. Geomicrobiology of Manganese	429
16.1 Occurrence of Manganese in the Earth's Crust	429
16.2 Geochemically Important Properties of Manganese	430
16.3 Biological Importance of Manganese	431
16.4 Manganese-Oxidizing and -Reducing Bacteria and Fungi	431
16.5 Bio-oxidation of Manganese	435
16.6 Bioreduction of Manganese	447
16.7 Bioaccumulation of Manganese	459
16.8 Microbial Manganese Deposition in Soil and on Rocks	463
16.9 Microbial Manganese Deposition in Freshwater Environments	468
16.10 Microbial Manganese Deposition in Marine Environments	477
16.11 Microbial Mobilization of Manganese in Soils and Ores	496
16.12 Microbial Mobilization of Manganese in Freshwater Environments	499
16.13 Microbial Mobilization of Manganese in Marine Environments	500
16.14 Microbial Manganese Reduction and Mineralization of Organic Matter	503
16.15 Microbial Role in the Manganese Cycle in Nature	503
16.16 Summary	507
References	508

17. Geomicrobial Interactions with Chromium, Molybdenum, Vanadium, Uranium, and Polonium	529
17.1 Microbial Interactions with Chromium	529
17.2 Microbial Interaction with Molybdenum	536
17.3 Microbial Interaction with Vanadium	537
17.4 Microbial Interaction with Uranium	539
17.5 Bacterial Interaction with Polonium	541
17.6 Summary	541
References	542
18. Geomicrobiology of Sulfur	549
18.1 Occurrence of Sulfur in the Earth's Crust	549
18.2 Geochemically Important Properties of Sulfur	550
18.3 Biological Importance of Sulfur	551
18.4 Mineralization of Organic Sulfur Compounds	551
18.5 Sulfur Assimilation	552
18.6 Geomicrobially Important Types of Bacteria That React with Sulfur and Sulfur Compounds	553
18.7 Physiology and Biochemistry of Microbial Oxidation of Reduced Forms of Sulfur	562
18.8 Autotrophic and Mixotrophic Growth on Reduced Forms of Sulfur	573
18.9 Anaerobic Respiration Using Oxidized Forms of Sulfur as Electron Acceptors	577
18.10 Autotrophy, Mixotrophy, and Heterotrophy Among Sulfate-Reducing Bacteria	585
18.11 Biodeposition of Native Sulfur	587
18.12 Microbial Role in the Sulfur Cycle	601
18.13 Summary	602
References	603
19. Biogenesis and Biodegradation of Sulfide Minerals at the Earth's Surface	621
19.1 Introduction	621
19.2 Natural Origins of Metal Sulfides	622
19.3 Principles of Metal Sulfide Formation	626
19.4 Laboratory Evidence in Support of Biogenesis of Metal Sulfides	627
19.5 Bio-oxidation of Metal Sulfides	630
19.6 Bioleaching of Metal Sulfide and Uraninite Ores	642

19.7	Bioextraction of Metal Sulfide Ores by Complexation	651
19.8	Formation of Acid Coal Mine Drainage	652
19.9	Summary	657
	References	657
20.	Geomicrobiology of Selenium and Tellurium	669
20.1	Occurrence in the Earth's Crust	669
20.2	Biological Importance	669
20.3	Toxicity of Selenium and Tellurium	670
20.4	Bio-oxidation of Reduced Forms of Selenium	671
20.5	Bioreduction of Oxidized Selenium Compounds	672
20.6	Selenium Cycle	676
20.7	Bio-oxidation of Reduced Forms of Tellurium	676
20.8	Bioreduction of Oxidized Forms of Tellurium	677
20.9	Summary	678
	References	678
21.	Geomicrobiology of Fossil Fuels	683
21.1	Introduction	683
21.2	Natural Abundance of Fossil Fuels	683
21.3	Methane	685
21.4	Peat	699
21.5	Coal	702
21.6	Petroleum	706
21.7	Summary	717
	References	719
	<i>Glossary</i>	733
	<i>Index</i>	749