

Contents

ABOUT THE EDITORS — v

HISTORICAL DEVELOPMENT
AND PERSPECTIVES OF THE SERIES — vii

PREFACE TO VOLUME 21 — ix

CONTRIBUTORS TO VOLUME 21 — xix

TITLES OF VOLUMES 1–44 IN THE
METAL IONS IN BIOLOGICAL SYSTEMS SERIES — xxiii

CONTENTS OF VOLUMES IN THE
METAL IONS IN LIFE SCIENCES SERIES — xxv

Martha E. Sosa Torres and Peter M. H. Kroneck

1 INTRODUCTION: FROM ROCKS TO LIVING CELLS — 1

Abstract — 1

1. Introduction: From Microbes to Metalloenzymes — 2
2. Early Life Chemistry and Catalysts: Can We Find Their Traces in Rocks? — 8
3. The Great Oxidation Event — 15
4. Calcium in Redox Enzymes — 18
5. Outlook and Future Directions — 23

Acknowledgments — 24

Abbreviations and Definitions — 24

References — 24

Bernhard Schink

2 MICROBES: MASTERS OF THE GLOBAL ELEMENT CYCLES — 33

Abstract — 34

1. Introduction: Microbes as Catalysts — 34
2. The Biochemical “Redox Tower” — 36

3. Redox Reactions with Metals — **39**
4. Activation of Inert Substrates — **42**
5. Combination of Endergonic and Exergonic Reactions — **44**
6. Autocatalytic Adjustment of Catalytic Capacity — **47**
7. Specificities and Limits of Enzyme-Catalyzed Reactions — **50**
8. Consequences of Microbial Redox Activities — **51**
9. Conclusions — **54**
- Acknowledgments — **54**
- Abbreviations — **55**
- References — **55**

Shawn E. McGlynn

- 3 BIOLOGICAL ISOTOPE FRACTIONATION AND EARTH HISTORY: FROM ENZYMES, TO CELLS, TO ECOSYSTEMS — 59**
- Abstract — **60**
1. Earth History and Stable Isotope Biogeochemistry — **60**
2. A Stable Isotope Primer: The ‘Language’ of Isotope Fractionation — **61**
3. An Enzyme Primer: The ‘Language’ of Enzyme Kinetics — **65**
4. Enzymatic Stable Isotope Fractionation: Enzymes Are not Irreversible Catalysts — **69**
5. Metabolic Stable Isotope Fractionation: Organisms Are not Enzymes — **72**
6. Ecological Stable Isotope Fractionation: Ecosystems Are not Organisms — **75**
7. Ways Forward and Future Issues — **76**
- Acknowledgments — **76**
- Abbreviations — **76**
- References — **77**

Jiyao Yu, Shefali Harankhedkar, Arielle Nabatilan, and Christoph J. Fahrni

- 4 IMAGING TRACE METALS IN BIOLOGICAL SYSTEMS — 81**
- Abstract — **82**
1. Introduction — **82**
2. Synchrotron X-Ray Fluorescence Elemental Imaging — **84**
3. Mass Spectrometry-Based Imaging Techniques — **97**
4. Fluorescence Imaging with Metal-Ion Selective Probes — **101**
5. Magnetic Resonance Imaging — **121**
6. Conclusions — **127**
- Acknowledgments — **128**
- Abbreviations and Definitions — **129**
- References — **130**

Simon Duval, Kilian Zuchan, Frauke Baymann, Barbara Schoepp-Cothenet, Elbert Branscomb, Michael J. Russell, and Wolfgang Nitschke

5 MINERALS AND THE EMERGENCE OF LIFE — 135

Abstract — **136**

1. Back to the (Thermodynamic) Roots of Life — **136**
2. The Top-Down Approach: What Can We Learn from Extant Life? — **140**
3. Structural Affinities Between Catalytic Centers in Metalloenzymes and Specific Minerals — **144**
4. Mineral-Catalyzed Reactions Pertinent to Emergence of Life Scenarios — **145**
5. Catalysis and Disequilibrium Converters, Metals, and Quinones/Flavins: An Attempt at Disentangling the Knot — **148**
6. Additional Levels of Complexity: Layered (Clay-Like) Minerals — **149**
7. Conclusion — **153**

Acknowledgments — **154**

Abbreviations and Definitions — **154**

References — **155**

René Uebe and Dirk Schüler

6 THE FORMATION OF IRON BIOMINERALS IN MAGNETOTACTIC BACTERIA — 159

Abstract — **160**

1. Introduction — **160**
2. Phylogenetic and Morphological Diversity of Magnetotactic Bacteria — **161**
3. Structure and Biomineralization of Magnetosomes — **162**
4. Environmental and Biogeochemical Implications of Magnetosome Biomineralization — **169**

Acknowledgments — **177**

Abbreviations — **177**

References — **178**

Stefanie Becker, Allison M. L. Enright, and Andreas Kappler

7 LIVING ON IRON — 185

Abstract — **186**

1. Introduction — **186**
2. Microbial Growth by Oxidizing Iron(II) — **188**
3. Microbial Growth by Reduction of Iron(III) — **208**
4. Applications and Consequences — **214**
5. Outlook and Future Directions — **216**

Acknowledgments — **216**

Abbreviations and Definitions — **217**

References — **217**

Inês B. Trindade, Catarina M. Paquete, and Ricardo O. Louro

8 EXTRACELLULAR REDOX CHEMISTRY — 229

Abstract — **230**

1. Introduction — **230**
2. Assimilatory Redox Chemistry: Scavenging for Metals — **231**
3. Dissimilatory Redox Chemistry: Powering the Metabolism with Metals — **245**
4. Health-Related Applications — **255**
5. Environmental Applications — **256**
6. Biotechnological Applications — **258**
7. General Conclusions — **258**

Acknowledgments — **259**

Abbreviations and Definitions — **259**

References — **260**

Zhiguang Xiao and Anthony G. Wedd

9 COPING WITH TOXIC METALS — 271

Abstract — **272**

1. Introduction — **272**
2. Group 5 Element Vanadium — **277**
3. Group 6 Element Chromium — **278**
4. Group 6 Elements Molybdenum and Tungsten — **278**
5. Group 7 Element Manganese — **279**
6. Group 8 Element Iron — **279**
7. Group 9 Element Cobalt — **281**
8. Group 10 Element Nickel — **281**
9. Group 11 Element Copper — **282**
10. Group 11 Element Silver — **285**
11. Group 11 Element Gold — **285**
12. Group 12 Element Zinc — **286**
13. Group 12 Element Cadmium — **288**
14. Group 12 Element Mercury — **289**
15. Group 13 Element Aluminum — **290**
16. Group 13 Element Thallium — **290**
17. Group 14 Element Lead — **291**
18. Group 15 Element Arsenic — **291**
19. Group 15 Element Bismuth — **291**
20. General Conclusions — **292**

Acknowledgments — **292**

Abbreviations — **292**

References — **292**

Lena J. Daumann and Huub J. M. Op den Camp

10 THE BIOCHEMISTRY OF RARE EARTH ELEMENTS — 299

Abstract — **300**

1. Introduction: Properties of Rare Earth Elements — **300**

2. Selected Uses of Rare Earth Elements in Biochemistry Research — **302**
3. Applications of Rare Earth Elements in Medicine — **305**
4. Other Applications of Rare Earth Elements — **307**
5. Importance of Rare Earth Elements for Bacteria — **312**
6. Future Developments and Applications — **318**
- Acknowledgments — **319**
- Abbreviations — **319**
- References — **319**

SUBJECT INDEX — **325**