

Contents

Introduction	xi
Ernesto DI MAURO	
Chapter 1. The Emergence of Life-Nurturing Conditions in the Universe	1
Juan VLADILO	
1.1. Defining properties of life	1
1.1.1. Implications of the defining properties	2
1.2. Life-supporting conditions and environments	5
1.2.1. Chemical ingredients	6
1.2.2. Physical conditions	7
1.2.3. Habitable worlds	9
1.3. Setting the stage for chemistry and life in the Universe	10
1.3.1. Births of the laws of chemistry	10
1.3.2. Production of chemical elements	11
1.3.3. Assemblage of prebiotic molecules	12
1.3.4. Origin of water	14
1.3.5. Appearance of rocky planets	15
1.4. The habitable Universe	16
1.4.1. Circumstellar habitable zones	17
1.4.2. Galactic habitable zones	19
1.5. Planetary environments suitable for the origin of life	20
1.5.1. Abiogenesis on planetary surfaces	20
1.5.2. Abiogenesis in the oceans	22

1.5.3. Implications for the search for life outside Earth	23
1.6. The quest for inhabited worlds	23
1.7. References	24
Chapter 2. Chirality and the Origins of Life	31
Guillaume LESEIGNEUR and Uwe MEIERHENRICH	
2.1. Introduction to chirality.	32
2.2. The asymmetry of life.	35
2.3. The origin of homochirality	37
2.3.1. Stochastic theories	37
2.3.2. Deterministic theories	38
2.4. Space missions and the search for life and its origins	41
2.4.1. Rosetta	43
2.4.2. ExoMars	45
2.5. References	48
Chapter 3. The Role of Formamide in Prebiotic Chemistry	55
Raffaele SALADINO, Giovanna COSTANZO and Bruno Mattia BIZZARRI	
3.1. Introduction.	55
3.2. Effect of minerals and self-organization in the prebiotic chemistry of formamide	57
3.2.1. Surface catalysis and geochemical scenarios	57
3.2.2. Chemomimesis, circularity and thermodynamic niches	59
3.2.3. Nucleosides phosphorylation	62
3.3. Continuity and mineral complexity.	63
3.4. Energy-driven selectivity.	67
3.5. References	68
Chapter 4. A Praise of Imperfection: Emergence and Evolution of Metabolism	79
Juli PERETÓ	
4.1. From Darwin to Jacob: perfection does not exist.	79
4.2. Protometabolic networks	82
4.3. Enzyme promiscuity and metabolic innovation.	86
4.4. Promiscuity, moonlighting and the essence of life.	91
4.5. Acknowledgments.	93
4.6. References	93

Chapter 5. Viruses, Viroids and the Origins of Life	99
David DEAMER and Marie-Christine MAUREL	
5.1. How were viruses discovered? A brief history	100
5.2. Viral diversity	101
5.3. Viral structure and function	103
5.4. Viruses and mammalian genomes	106
5.5. Role of viruses in human evolution, health and disease	107
5.6. Viroids may be a link to ancient evolutionary pathways	108
5.7. Origin and evolution of viroids	109
5.8. Conclusion	111
5.9. References	112
Chapter 6. Is the Heterotrophic Theory of the Origin of Life Still Valid?	117
Antonio LAZCANO	
6.1. Introduction.	117
6.2. The roaring 20s	118
6.3. Coacervates as models of precellular structures	121
6.4. Precellular evolution and the emergence of cells.	123
6.5. Final remarks: does Oparin still matter?	128
6.6. Acknowledgments.	130
6.7. References	130
Chapter 7. Making Biochemistry-Free (Generalized) Life in a Test Tube.	135
Juan PÉREZ-MERCADER	
7.1. Summary	135
7.2. Introduction and background	136
7.3. Laboratory implementation of an artificial autonomous, and self-organized functional system	140
7.4. More physics and chemistry working together: phoenix, self-reproduction via spores, population growth and chemotaxis	144
7.5. Discussion and conclusions	152
7.6. Acknowledgments.	153
7.7. Appendices: Some additional emergent features in PISA “powered” synthetic biochemistry free protocells.	154
7.7.1. Chemotactic behavior	154
7.7.2. Adaptive behavior and click-PISA	155

7.7.3. Competitive exclusion principle and iniferter PISA	156
7.7.4. PISA and its control by chemical automata	156
7.7.5. Integrating PISA and information control with the Belousov–Zhabotinsky chemical reaction	157
7.8. References	159

Chapter 8. Hydrothermalism for the Chemical Evolution Toward the Simplest Life-Like System on the Hadean Earth

Kunio KAWAMURA

8.1. Introduction.	163
8.1.1. Realistic life-like systems on the Hadean Earth	163
8.1.2. Water in universe	165
8.1.3. Two-gene hypothesis, minerals and high temperature	168
8.2. Hydrothermal environment for the chemical evolution of biomolecules	170
8.2.1. As an energy source	170
8.2.2. Temperature and pressure	171
8.2.3. Biochemical interactions.	172
8.2.4. Minerals and the thermodynamically open system	174
8.3. Hydrothermal methodologies regarding the origin-of-life study.	175
8.3.1. Technical background of research tools for hydrothermal reactions.	175
8.3.2. Recent development using flow system.	176
8.4. RNA world versus hydrothermalism	178
8.4.1. Stability and accumulation of RNA	178
8.4.2. RNA-based life-like system under hydrothermal environments	182
8.5. Future outlook and conclusions	185
8.6. Acknowledgments.	186
8.7. References	186

Chapter 9. Studies in Mineral-Assisted Protometabolisms

Jean-François LAMBERT, Louis TER-OVANESSIAN and

Marie-Christine MAUREL

9.1. Metabolism, protometabolism and minerals	193
9.2. Adsorption on mineral surfaces	196
9.2.1. Adsorption mechanisms	196
9.2.2. Adsorption selectivities	197

9.3. Mineral surfaces and reaction thermodynamics	198
9.3.1. Minerals as reagents	198
9.3.2. Concentrating reagents from the solution	199
9.3.3. Altering free enthalpies of reaction	201
9.3.4. Platforms to capture free energy from macroscopic sources (space gradients and time fluctuations)	202
9.4. Minerals and reaction kinetics: heterogeneous catalysis	204
9.4.1. Lessons from industrial heterogeneous catalysis.	204
9.4.2. What can heterogeneous catalysts do?.	205
9.4.3. Reaction selectivity	206
9.5. A case study: primordial synthesis of pyrimidines	207
9.6. Conclusion	209
9.7. References	210
Chapter 10. A Rationale for the Evolution of the Genetic Code in Relation to the Stability of RNA and Protein Structures . .	217
Andrew TRAVERS	
10.1. Introduction	217
10.2. Codon–anticodon recognition	218
10.3. Concluding remarks	226
10.4. Acknowledgments	226
10.5. References.	226
List of Authors	231
Index	233