

Contents

Author Biography	xi
Foreword	xiii
Acknowledgements	xv
1 Introduction	1
References	7
2 The Great Cooling	8
2.1 The Founding Fathers	8
2.2 Charles Lyell, 'Father of Palaeoclimatology'	12
2.3 Agassiz Discovers the Ice Age	17
2.4 Lyell Defends Icebergs	20
References	25
3 Ice Age Cycles	28
3.1 The Astronomical Theory of Climate Change	28
3.2 James Croll Develops the Theory	29
3.3 Lyell Responds	32
3.4 Croll Defends his Position	33
3.5 Even More Ancient Ice Ages	34
3.6 Not Everyone Agrees	34
References	35
4 Trace Gases Warm the Planet	37
4.1 De Saussure's Hot Box	37
4.2 William Herschel's Accidental Discovery	37
4.3 Discovering Carbon Dioxide	38
4.4 Fourier, the 'Newton of Heat', Discovers the 'Greenhouse Effect'	39
4.5 Tyndall Shows How the 'Greenhouse Effect' Works	40
4.6 Arrhenius Calculates How CO ₂ Affects Air Temperature	43
4.7 Chamberlin's Theory of Gases and Ice Ages	45
References	49
5 Moving Continents and Dating Rocks	51
5.1 The Continents Drift	51
5.2 The Seafloor Spreads	56
5.3 The Dating Game	61

5.4	Base Maps for Palaeoclimatology	62
5.5	The Evolution of the Modern World	65
	References	68
6	Mapping Past Climates	71
6.1	Climate Indicators	71
6.2	Palaeoclimatologists Get to Work	72
6.3	Palaeomagneticians Enter the Field	75
6.4	Oxygen Isotopes to the Rescue	77
6.5	Cycles and Astronomy	78
6.6	Pangaea Palaeoclimates (Carboniferous, Permian, Triassic)	81
6.7	Post-Break-Up Palaeoclimates (Jurassic, Cretaceous)	87
6.8	Numerical Models Make their Appearance	94
6.9	From Wegener to Barron	98
	References	99
7	Into the Icehouse	105
7.1	Climate Clues from the Deep Ocean	105
7.2	Palaeoceanography	106
7.3	The World's Freezer	111
7.4	The Drill Bit Turns	114
7.5	Global Cooling	119
7.6	Arctic Glaciation	125
	References	127
8	The Greenhouse Gas Theory Matures	132
8.1	CO ₂ in the Atmosphere and Ocean (1930–1955)	132
8.2	CO ₂ in the Atmosphere and Ocean (1955–1979)	133
8.3	CO ₂ in the Atmosphere and Ocean (1979–1983)	141
8.4	Biogeochemistry: The Merging of Physics and Biology	144
8.5	The Carbon Cycle	145
8.6	Oceanic Carbon	147
8.7	Measuring CO ₂ in the Oceans	148
8.8	A Growing International Emphasis	149
8.9	Reflection on Developments	150
	References	152
9	Measuring and Modelling CO₂ Back through Time	156
9.1	CO ₂ : The Palaeoclimate Perspective	156
9.2	Fossil CO ₂	157
9.3	Measuring CO ₂ Back through Time	159
9.4	Modelling CO ₂ and Climate	165
9.5	The Critics Gather	168
	References	176
10	The Pulse of the Earth	181
10.1	Climate Cycles and Tectonic Forces	181
10.2	Ocean Chemistry	188
10.3	Black Shales	190

10.4	Sea Level	193
10.5	Biogeochemical Cycles, Gaia and Cybertectonic Earth	194
10.6	Meteorite Impacts	196
10.7	Massive Volcanic Eruptions	199
	References	203
11	Numerical Climate Models and Case Histories	207
11.1	CO ₂ and General Circulation Models	207
11.2	CO ₂ and Climate in the Early Cenozoic	211
11.3	The First Great Ice Sheet	215
11.4	Hyperthermal Events	218
11.5	Case History: The Palaeocene–Eocene Boundary	219
11.6	CO ₂ and Climate in the Late Cenozoic	222
11.7	Case History: The Pliocene	226
	References	234
12	Solving the Ice Age Mystery: The Deep-Ocean Solution	240
12.1	Astronomical Drivers	240
12.2	An Ice Age Climate Signal Emerges from the Deep Ocean	242
12.3	The Ice Age CO ₂ Signal Hidden on the Deep-Sea Floor	248
12.4	Flip-Flops in the Conveyor	249
12.5	A Surprise Millennial Signal Emerges	251
12.6	Ice Age Productivity	253
12.7	Observations on Deglaciation and Past Interglacials	254
12.8	Sea Level	256
	References	259
13	Solving the Ice Age Mystery: The Ice Core Tale	264
13.1	The Great Ice Sheets	264
13.2	The Greenland Story	264
13.3	Antarctic Ice	266
13.4	Seesaws	270
13.5	CO ₂ in the Ice Age Atmosphere	273
13.6	The Ultimate Climate Flicker: The Younger Dryas Event	279
13.7	Problems in the Milankovitch Garden	280
13.8	The Mechanics of Change	282
	References	296
14	The Holocene Interglacial	302
14.1	Holocene Climate Change	302
14.2	The Role of Greenhouse Gases: Carbon Dioxide and Methane	311
14.3	Climate Variability	315
	References	320
15	Medieval Warming, the Little Ice Age and the Sun	324
15.1	Solar Activity and Cosmic Rays	324
15.2	Solar Cycles in the Geological Record	327
15.3	The Medieval Warm Period and the Little Ice Age	330
15.4	The End of the Little Ice Age	340

15.5 The Hockey Stick Controversy	347
15.6 Sea Level	353
References	358
16 Putting It All Together	365
16.1 A Fast-Evolving Subject	365
16.2 Natural Envelopes of Climate Change	366
16.3 Evolving Knowledge	367
16.4 Where is Climate Headed?	373
16.5 Some Final Remarks	375
16.6 What Can Be Done?	377
References	379
Appendix A: Further Reading	381
Appendix B: List of Figure Sources and Attributions	383
Index	389