

# ISOTOPES AND CLIMATES

## Preface

ROBERT BOWEN

*Professor of Geology, Institute of Geology and Palaeontology,  
Westfälische-Wilhelms University, Münster, Federal Republic of  
Germany*



ELSEVIER APPLIED SCIENCE

LONDON and NEW YORK



# Contents

<b>Preface</b>	v
<b>Acknowledgements</b>	vii
<b>Geologic Time Scales</b>	xiv
<b>Introduction</b>	1
<b>Chapter 1 THE BIG HEAT?</b>	11
1 The greenhouse effect and depletion of the ozone layer	11
2 Ice and its isotopes	17
3 Combustion of fossil fuels and rising levels of greenhouse gases in the atmosphere	19
4 What must be done?	23
5 The little ice age and other short-term climatic trends	28
6 Astronomical cycles and long-term climatic trends	29
7 The radioactive isotope of carbon	30
8 Radioactive and stable isotopes in ice cores and the spectral analysis of high-frequency climatic cycles	32
9 The present interglacial (?) episode	34
10 How a cooling trend is turning into a warming one	36
11 Isotopes and investigations of climates past, present and future	37
<b>Chapter 2 ISOTOPES AND CLIMATES NOW AND IN THE PAST</b>	43
1 Isotopes	43
2 Determination of isotopic compositions	46
3 Mass spectrometry	47
4 Inlet system	47
5 Ion source	49
6 Mass analyser	51
7 Ion collectors	53



8	$\delta$ -values	56
9	Isotope reference standards	57
10	Oxygen	58
11	Hydrogen	61
12	Normalization of oxygen and hydrogen isotope data	62
13	Oxygen isotope ratios	63
14	Hydrogen isotope ratios	66
15	Carbon	68
16	Nitrogen	69
17	Sulphur	70
18	Strontium	71
19	Isotopic fractionation	71
20	Determination of equilibrium isotopic fractionation	73
21	Oxygen isotope fractionation in carbonates	74
22	Preparation of carbonates	82
23	Carbonate purification processes	83
24	Extraction of carbon dioxide	87
25	Environmental isotopes as palaeoclimatic indicators	97
26	Natural waters in the hydrosphere	99
27	Temperature, altitude and latitude effects	104
28	Carbon isotope disequilibrium in carbonate precipitation and vital effects	109
29	Oxygen isotope palaeoclimatology in palaeo-oceans: ice volume versus palaeotemperatures	113
30	Carbon distribution on Earth	120
31	Oxygen and carbon isotopes in freshwater shells, terrestrial plant organic carbon and marine plankton	122
32	Deuterium in organic matter	132
33	Forward to the past	133

### Chapter 3 ISOTOPES AND THE GLOBAL CARBON CYCLE NOW AND IN THE QUATERNARY

1	The NOAA/GMCC measurement programme	145
2	Simulating atmospheric carbon dioxide distribution	146
3	Past atmospheric carbon dioxide from ice cores	148
4	Ancient carbon cycle changes from tree-ring carbon-13 and carbon-14	152
5	Northern Hemisphere $^{13}\text{C}/^{12}\text{C}$ trends of atmospheric carbon dioxide in tree rings	157
6	Carbon in terrestrial ecosystems	159
7	Modelling the global carbon cycle	161
8	Modelling the oceans	167

### Chapter 4 ISOTOPES AND ICE AGE IMPACTS

1	The glacial theory	175
2	Cause(s) of the ice age(s)	178
3	Oxygen, carbon and hydrogen isotopes in seas and trees	183

4	Ice age geography	190
5	Simulating the ice age	196
6	Ice cores	200
7	Ocean sediment cores	204
8	Orbital-frequency rhythms in the $\delta^{18}\text{O}$ record	208
9	Constructing models of climatic response for the Pleistocene	209
10	Spectral and cross-spectral models	212
11	Gain-and-phase models	212
12	Dynamic models	217
13	Climatic variations in other frequency bands	217
14	Orbital variations as the cause of Pleistocene ice ages	218
15	North American cryospheric fluctuations	219
16	Pre-Pleistocene glacial episodes	220
17	Modelling arrays in the space, time and frequency domains	222
18	Transformations	224
19	Multivariate procedures	225
20	Climate forcing	227
21	Pleistocene-Holocene climatic changes	230
22	Changes in oceanic water deuterium content with time	232
23	From the Eocene-Oligocene Boundary to today	233
24	Extending the isotope stages back to the latest Pliocene	235
25	Comparing Late Pleistocene extinctions and those at the Cretaceous-Tertiary Boundary	239
26	Using quantitative techniques in isotope chronostratigraphy	243
27	A TYPE record for the Pleistocene $\delta^{18}\text{O}$ signal with time as a template for comparison with other Plio-Pleistocene oxygen isotope records	247
28	Formulation of a TYPE record	252

### Chapter 5 ISOTOPES AND TERTIARY CRISES. THE CRETACEOUS-TERTIARY (K/T) AND OTHER BOUNDARIES. MASS EXTINCTIONS THROUGH TIME

1	Pliocene palaeoclimates and their relevance to that of Earth in the twenty-first century	269
2	Strontium isotopes in the Late Neogene ocean. Palaeoceanographic changes in the late Oligocene and Early Miocene	272
3	The climate of the Eocene ocean	277
4	The Cretaceous-Tertiary (K/T) Boundary and mass extinctions	282
5	Astronomical driving mechanisms, periodic impacts and mass extinctions	292
6	Oxygen and carbon isotope variations in foraminiferal carbonates across the K/T Boundary	297
7	Further observations on K/T-related mass extinctions	306
8	Analysing periodicity	313
9	Judgement on the K/T mass extinction event	317



<b>Chapter 6 MESOZOIC CLIMATES AND ISOTOPES</b>	<b>336</b>
1 Terrestrial plants and animals, sedimentary criteria and oxygen isotope data as palaeoclimatic indicators in the Mesozoic Era	336
2 Oxygen isotope analyses of benthonic foraminifera from deep Pacific cores, belemnite rostrae and Mesozoic palaeoclimatology	345
3 The Cretaceous Period and its temperature variations	349
4 Patterns of continental precipitation	351
5 Fluctuating Jurassic palaeotemperatures	353
6 The problem of equability and the dramatic Permian–Triassic mass extinction	355
7 Limit of predictability in a chaotic solar system and the palaeoclimates of the Mesozoic and earlier time intervals	366
<b>Chapter 7 THE ISOTOPES OF OXYGEN AND CARBON IN PALAEOZOIC OCEANS AND ORGANISMS</b>	<b>376</b>
1 Climatic modelling for the earlier Phanerozoic Aeon	376
2 The oxygen and carbon isotopic record	377
3 Secular variations and their causes	382
4 Isotopic composition of seawater	384
5 Chemical diagenesis and Palaeozoic fossils from North America	385
6 $^{87}\text{Sr}/^{86}\text{Sr}$ Ratios in Permo–Carboniferous seawater from	
<b>Chapter 8 'THROUGH A GLASS DARKLY': THE PRECAMBRIAN AEONS</b>	<b>396</b>
1 A chronological behemoth	396
2 Palaeoclimates of the Eoproterozoic	398
3 The Vendian Ice Age	399
4 Carbon and sulphur isotopes in the Precambrian of the Canadian Shield	401
5 Precambrian palaeobiology	404
6 The Archaean–Proterozoic Transition	408
<b>GLOSSARY</b>	<b>413</b>
<i>Author Index</i>	<b>453</b>
<i>Subject Index</i>	<b>465</b>