

Isotopes in the Earth Sciences

Robert Bowen



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ISOTOPES IN THE EARTH SCIENCES

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ISOTOPES IN THE EARTH SCIENCES

Preface

'The most incomprehensible thing about the world is that it is comprehensible.'

ALBERT EINSTEIN, 1950

The tremendous progress of recent years in the field of isotopes in the earth sciences has proved invaluable in attempting to solve a varied spectrum of geological and geochemical problems. The lunar exploration programmes provided rocks for analysis, stimulating refinements in mass spectrometry which were later used for terrestrial samples too. Among significant advances was the development of electrostatic tandem accelerator mass spectrometers allowing the precise measurement of abundances of cosmic radionuclides. Also, new geochronometers were devised, for instance those dependent upon the radioactive decay of samarium-147 to neodymium-143, lutetium-176 to hafnium-176, rhenium-187 to osmium-187 and potassium-40 to calcium-40, these supplementing prior dating methods. Their impact as regards the origin of igneous rocks was considerable. Isotopic compositions of neodymium, strontium, lead and hafnium in these rocks showed that magmas from the mantle are often crustally contaminated. In addition, isotopic compositions of carbon, oxygen and sulphur aided the elucidation of aspects of petrogenesis. These and many other facets of the subject are discussed in this book.

Since the matter is of encyclopaedic scope, a state-of-the-art treatment in detail is impractical; therefore basic data are included in a tripartite approach. The first two chapters cover isotopes in general and mass spectrometry. The Finnigan MAT 251, 261, delta and delta-E instruments are described because the author is familiar with them. He is indebted to the company in Bremen and its Dr E. Weber and Herr

Holger Mannier for their kind permission to adapt and reproduce technical drawings from their literature. The remaining chapters are grouped into Part II, dating methods, and Part III, environmental isotopes now and in earth history. The latter surveys atmosphere, hydrosphere, biosphere and lithosphere as well as palaeoclimatology and the question of radioactive wastes, their disposal and its hazards. Finally, there is a glossary, appendices and indices of authors and main themes.

The book is intended as a not-too-voluminous source for earth scientists, chemists, physicists, biologists, environmental scientists, civic and land planners and sociologists. Its philosophy embodies the injunction of Job (12:8): 'Speak to the earth and it shall teach thee'.

ROBERT BOWEN
Münster

AEON	ERA	SUB - ERA	PERIOD	EPOCH	AGE	Ma	Chronometrically calibrated		
PHANEROZOIC	CENOZOIC	QUAT +		HOLOCENE		0.012			
				PLEISTOCENE					
		TERTIARY	NEOGENE	Pliocene	Piacenzian	3.1			
					Zanclean				
				MIOCENE	3	Messinian		11.3	
					2	Tortonian			
					1	Serravallian		14.4	
			Late Langhian						
			Early Langhian			24.6			
			Burdigalian						
			Aquitanian						
			PALAEOGENE	Oligocene		Chattian		38.0	
					Rupelian				
		3			Priabonian	50.5			
		2			Bartonian				
		1			Lutetian				
		Eocene			Ypresian	60.2			
					Thanetian				
					Danian				
				CRETACEOUS	K ₂	Senonian		Maastrichtian	73
								Campanian	
		Santonian	87.5						
		Coniacian							
		K ₁	Neocomian					Turonian	91
					Cenomanian				
					Albian	113			
					Aptian				
					JURASSIC	J ₃		Malm	Barremian
	Hauterivian								
	Valanginian	138							
	Berriasian								
	J ₂	Dogger	Tithonian	150					
			Kimmeridgian						
			Oxfordian	163					
			Callovian						
			J ₁	Lias		Bathonian		179	
	Bajocian								
	Aalenian	188							
	Toarcian								
	TRIASSIC	Tr ₃				Pliensbachian		200	
			Sinemurian						
			Hettangian	213					
			Rhaetian						
			Tr ₂			Norian		225	
		Camian							
		Ladinian			238				
		Anisian							
		Tr ₁				Olenekian		248	
			Spathian						
	Smithian		258						
	Dieherian								
	Griesbachian								
	PALAEO - ZOIC	PERMIAN	P ₂	Tatarian	258				
				Kazanian					
				Ufimian	268				
			Kungurian						
			Artinskian	286					
			Sakmarian						
Asselian									
*Quaternary (Pleistogene)									

Chronometrically calibrated

Chronostratic Scale (Holocene to Permian).

AEON	ERA	SUB - ERA PERIOD	EPOCH	AGE		Ma
PHANEROZOIC	PALAEOZOIC	O CARBONIFEROUS	PERMIAN P1	Asselian	Westphalian	286
			Gzelian	Noginskian		
			Kasimovian	Krevyakinsk	Stephanian	296
			Moscovian	Myachkov		
			Bashkirian	Yeadonian	Namurian	315
			Seroukhovian			
			Visean	Holkerian		333
			Tournaisian	Ivorian		352
				Hastarian		360
				Famennian		367
		DEVONIAN	D3	Frasnian		374
			D2	Givetian		394
			D1	Eifelian		408
				Emsian		
		SILURIAN		Siegenian		
				Gedinnian		
			Pridoli			
			Ludlow			
			Wenlock	Sheinwoodian		
		ORDOVICIAN	Llandovery			
			Ashgill			
			Caradoc	Costonian		
			Llandeilo			
			Llanymyr			
			Arenig			
			Tremadoc			
			Merioneth	Dolgellian		
			St David's	Maentwrogian		
			Caerfai	Menevian		
		CAMBRIAN		Solvan		
				Lenian		
				Ardabanian		
				Tommotian		
PROTEROZOIC	SINIAN	VEND- IAN	Ediraran			
			Varangian			
		STURTIAN		Mortensnes		
				Smaifjord		
PROTEROZOIC	Riph- ean	YURMATIN				
		BURZ- YAN				
PROTEROZOIC	SWAZIAN					
HADEAN	LUNAR SEQUENCE					
E	M					
AGE OF EARTH						4550
ACCRETION OF EARTH AND MOON						4600

Chronometrically calibrated

Chronostratic Scale (Permian to Earth Origin).

Source: HARLAND, W. B., COX, A. V., LLEWELLYN, P. G., PICKTON, C. A. G., SMITH, A. G. and WALTERS, R., 1982. *A Geologic Time Scale*, Cambridge University Press, 131 pp.

IA	IIA	IIIB	IVB	VB	VIB	VIIb	VIII	IB	IIb	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0079	KEY TO CHART Atomic Number → 50 Symbol → Sn Atomic Weight → 118.69														2 He 4.00260
3 Li 6.94	4 Be 9.01218	Transition Elements Group VIII Transition Elements													
11 Na 22.98977	12 Mg 24.305														
19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.90	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.546	30 Zn 65.38	31 Ga 69.735	32 Ge 72.59	33 As 74.9216	34 Se 78.96
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc 98.9062	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.4	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60
55 Cs 132.9054	56 Ba 137.33	57* La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.9665	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.9804	84 Po (209)
87 Fr (223)	88 Ra (226)	89** Ac (227)	104 Rf (260)	105 Ha (260)	106 Db (263)										

*Lanthanides	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967 + 0.003
	90 Th 232.0381	91 Pa 231.0359	92 U 238.029	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Numbers in parentheses are mass numbers of most stable isotope of that element

Periodic Table of the Elements.

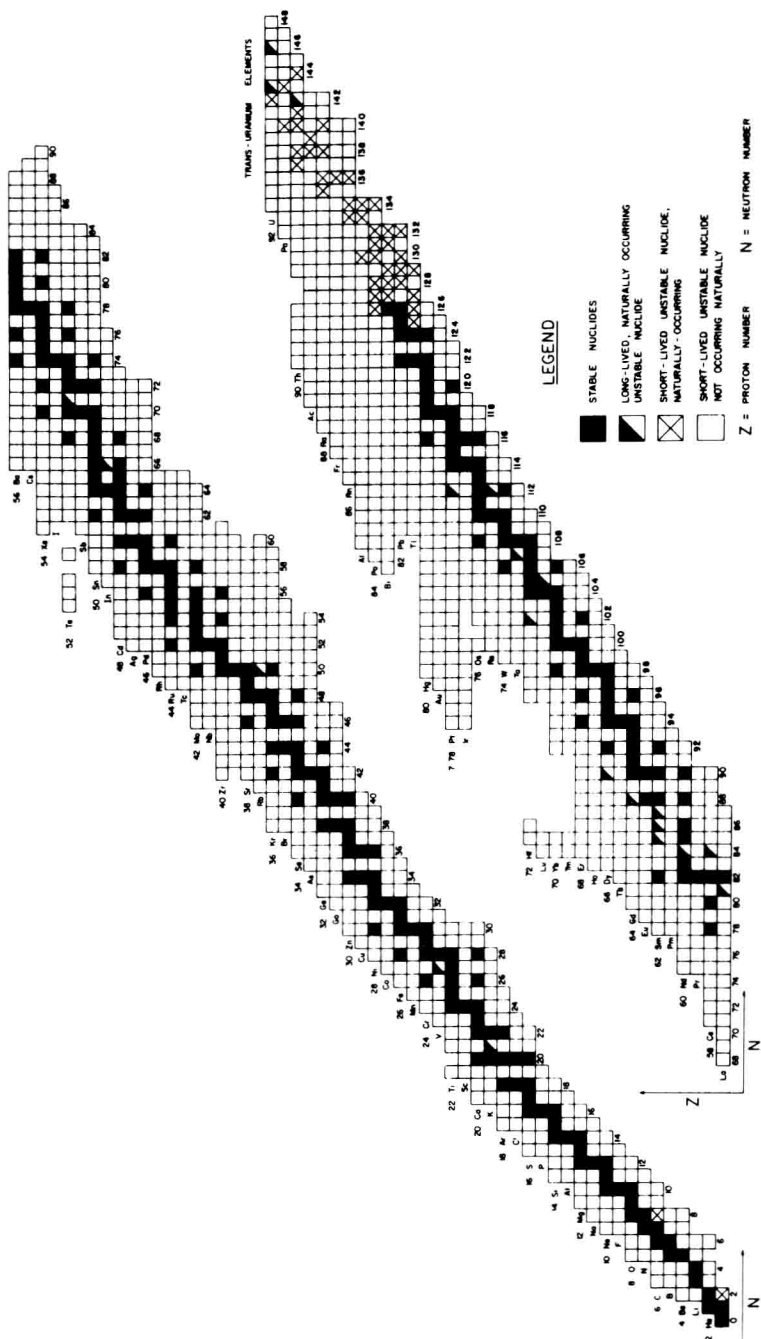


Chart of the Nuclides.

Contents

<i>Preface</i>	v
<i>Chronostratic Scale</i>	xiii
<i>Periodic Table of the Elements</i>	xv
<i>Chart of the Nuclides</i>	xvi

Part I: Introductory Chapters

Chapter 1. INTRODUCTION

1.1. The Big Bang: Forces, Particles and Isotopes	3
1.2. Supernovae, the Solar System and Isotopes	7
1.2.1. The Allende meteorite	8
1.2.2. Excess oxygen-16	9
1.2.3. Other anomalies	10
1.3. Elementary Particles	12
1.4. Elements	16
1.5. Radioactivity	24
1.6. Fractionation	30
1.7. Palaeothermometry	33
1.8. Unstable Atomic Nuclei	34
1.9. Beta Particles	36
1.10. Positron Decay	40
1.11. Electron Capture	42
1.12. Branched Decay	43
1.13. Alpha Decay	44
1.14. Nuclear Fission	47
1.15. Radioactive Decay	49
1.16. Decay Series	53
1.17. Radioactivity Units	57

1.18. Neutron Activation	61
1.19. Isotopic Translocation	65

Chapter 2. MASS SPECTROMETRY

2.1. Background	69
2.2. The Mass Spectrometer	70
2.3. Sample Preparation for Gas Isotope Mass Spectrometers	70
2.4. The Inlet System	75
2.5. The Ion Source	79
2.6. The Mass Analyser	80
2.7. Ionic Motions	83
2.8. Collector Systems and Ion Current Measurements	84
2.9. System Configuration Delta	89
2.10. Automatic Thermal Ionization Isotope Mass Spectrometer	91
2.11. Accelerator-Based Mass Spectrometry	100
2.12. Laser Mass Spectrometry	104
2.13. Ion Microprobes	107
2.14. Isotope Dilution	108

Part II: Dating Methods

Chapter 3. URANIUM, THORIUM, LEAD DATING

3.1. Background	115
3.2. Geochemistry	116
3.3. Decay Series	117
3.4. Lead	120
3.5. U-Pb Concordia Diagrams	125
3.6. Concordia Models	129
3.7. U-Pb, Th-Pb, Pb-Pb Isochrons	131
3.8. Common-Lead Dating	131
3.9. Anomalous Leads	136
3.10. Multistage Leads	140
3.11. Whole-Rock Dating	144
3.12. Lead in Feldspars	145
3.13. Recent Advances	146

Chapter 4. RUBIDIUM-STRONTIUM DATING

4.1. Background	162
4.2. Geochemistry	162
4.3. Dating Methodology	165
4.4. Isochrons	175
4.5. Mixtures	176
4.6. Fictitious Isochrons	179
4.7. Strontium Through Geological Time	180
4.7.1. Chondrites and achondrites	181
4.7.2. The Moon	186
4.7.3. The isotope evolution of terrestrial strontium	187

4.7.4. The origin of granites	193
4.8. Strontium in Sedimentary Deposits	196

Chapter 5. POTASSIUM-ARGON AND ARGON-40/ARGON-39 DATING

5.1. Background	201
5.2. Theory and Assumptions in Potassium-Argon Dating	203
5.3. Thermal Loss of Argon During Metamorphism	207
5.4. Isochrons	211
5.5. Sedimentary Rocks	213
5.6. Mantle-Derived Argon	215
5.7. Geomagnetic Polarity Reversals	217
5.8. The Metamorphic Veil of R. L. Armstrong	219
5.9. Precambrian Time Scale	221
5.10. Argon-40/Argon-39 Dating	223
5.11. Theory	224
5.12. Incremental Heating	228
5.13. Correlation of Argon Isotopes	233
5.14. Caveats	235
5.15. Developments	237

Chapter 6. CARBON-14 DATING

6.1. Background	247
6.2. Discovery	248
6.3. Carbon-14 Dating	249
6.4. Isotope Fractionation	254
6.5. Analytical Methods	256
6.6. Carbonate Samples	260

Chapter 7. TRITIUM DATING

7.1. Background	264
7.2. Tritium Dating	266

Chapter 8. OTHER DATING METHODS

8.1. Samarium-Neodymium Dating	270
8.1.1. Geochemistry	270
8.1.2. Assessment of ages	272
8.1.3. Neodymium through geological time	274
8.1.4. Recent advances	278
8.2. Rhenium-Osmium Dating	283
8.2.1. Geochemistry	283
8.2.2. Assessment of ages	284
8.2.3. Osmium through geological time	287
8.2.4. Common-osmium dating	289
8.2.5. The C-T iridium anomaly	289
8.3. Potassium-Calcium Dating	291
8.3.1. Calcium isotopes fractionation	292

8.3.2.	Potassium-calcium dating approach	294
8.4.	Calcium Diffusion Dating	296
8.4.1.	Theory	296
8.4.2.	Calculation of D'	297
8.5.	Lutetium-Hafnium Dating	298
8.5.1.	Geochemistry	299
8.5.2.	Assessment of ages	301
8.5.3.	Hafnium through geological time	303
8.6.	Uranium Series Disequilibrium Dating	309
8.6.1.	Ionium dating of deep sea sediments	311
8.6.2.	The uranium-234-uranium-238 geochronometer	315
8.6.3.	Thorium-230-uranium-238, thorium-230-uranium-234 dating	318
8.6.4.	Ionium-protactinium dating	320
8.6.5.	Lead-210 dating	322
8.7.	Radiation-Damage Methods	330
8.7.1.	Electron spin resonance	330
8.7.2.	Thermoluminescence	336
8.7.3.	Pleochroic haloes	340
8.7.4.	Fission track dating	342

Part III: Environmental Isotopes

Chapter 9. ENVIRONMENTAL ISOTOPES IN THE ATMOSPHERE AND HYDROSPHERE

9.1.	Background	371
9.2.	Stable Isotopes of Oxygen and Hydrogen in the Hydrosphere	375
9.3.	Stratigraphy of Ice and Snow	382
9.4.	Sea Water Isotopic Composition	384
9.5.	Oceanic Palaeothermometry	386
9.6.	Variation of $\delta^{18}\text{O}$ in Sea Water	391
9.6.1.	Biogenic silica	391
9.6.2.	Biogenic phosphate	392
9.7.	Geothermal Waters	395
9.8.	Cosmogenic Radionuclides in the Hydrologic Cycle	398
9.9.	Sediment Dating with Cosmogenic Radionuclides	403
9.9.1.	Manganese nodules	405
9.9.2.	Beryllium-10 in volcanics	407
9.10.	Dating Ice Sheets and Groundwaters	408
9.10.1.	Beryllium-10 and aluminium-26	408
9.10.2.	Chlorine-36	408
9.10.3.	Silicon-32	415
9.10.4.	Argon-39	418
9.10.5.	Krypton-81 and krypton-85	419
9.11.	Exposure Ages of Terrestrial Rocks and Meteorites	420
9.12.	Nitrogen	425
9.13.	Sulphur	429

9.14. Strontium	434
9.14.1. Fresh-water carbonates	434
9.14.2. Oceans	437
9.15. Neodymium	439
9.16. Artificial Isotope Hydrology	440
Chapter 10. ISOTOPES IN THE BIOSPHERE	
10.1. A Basis for Terrestrial Life	452
10.2. Biospheric Carbon	454
10.3. Total Dissolved Inorganic Carbon (TDC) in Natural Fresh Waters	458
10.4. $\delta^{13}\text{C}$ of Marine Planktonic and Particulate Organic Carbon	459
10.5. Kerogen and Proto-Kerogen $\delta^{13}\text{C}$ in Marine Sediments	460
10.6. $\delta^{13}\text{C}$ of Ocean Total Dissolved Carbon	460
10.7. Organic Material Degradation in Anoxic Porewaters	463
10.8. Carbonate Minerals and Carbon-Rich Sediments	464
10.9. Fossil Fuels	464
10.9.1. Coal and lead	466
10.9.2. Coal and sulphur	467
Chapter 11. ISOTOPES IN THE LITHOSPHERE	
11.1. Oxygen in Rocks	470
11.2. Stony Meteorites and Lunar Rocks	477
11.3. Hydrothermal Ore Deposits	478
11.4. Volcanic Rocks and Batholiths	479
11.5. Oxygen and Hydrogen Isotope Compositions in Sedimentary Rocks	481
11.6. Oxygen in Metamorphosed Rocks	484
11.7. Nitrogen in Igneous Rocks	487
11.8. Sulphur in Igneous Rocks	488
11.9. Sulphide Ores	491
11.10. Native Sulphur	494
11.11. Precambrian Sedimentary Rocks	495
11.12. Carbon: Carbonatites, Diamonds	497
11.13. Carbon: Marble, Graphite, Calcite-Graphite Isotope Geothermometer	499
11.13.1. Calcite-graphite isotope geothermometer	500
Chapter 12. ISOTOPES IN PALAEOCLIMATOLOGY	
12.1. Background	508
12.2. Oxygen Isotope Composition in the Past	509
12.3. Cretaceous Extinctions	510
12.4. Campanian-to-Palaeocene Palaeotemperature and Carbon Isotope Sequence	511
12.4.1. Surface temperatures	511
12.4.2. Bottom temperatures	512
12.4.3. Surface carbon isotopic values	513

12.4.4.	Surface-to-bottom carbon isotope differences	513
12.5.	Oxygen Isotopes in Neogene Molluscan Fossils and Quaternary Foraminifera	515
12.6.	Comparison of Isotopes and Plankton in a Late Quaternary Core	516
12.7.	Stratigraphical Uncertainty Arising from Bioturbation	517
12.8.	Further Foraminiferal Work	518
12.9.	Ostracods	519
12.10.	Some Carbon-13/Carbon-12 Data	519
12.10.1.	Changes in the oceanic carbon-13/carbon-12 ratio during the last 140 000 years	524
12.10.2.	The carbon-13/carbon-12 ratio now	524
12.11.	$\delta^{13}\text{C}$ and Animal Diets	526
 Chapter 13. RADIOACTIVE WASTE		
13.1.	Background	531
13.2.	Nuclear Power	536
13.3.	Chernobyl, USSR	540
13.4.	Sizewell, England	544
13.5.	Probability of Nuclear Reactor Accidents	547
13.6.	Nuclear Waste Disposal	549
13.7.	Selection of Nuclear Waste Sites	551
13.8.	Appropriate Geological Environments for Deep Underground Repositories for Nuclear Wastes in the UK	561
13.8.1.	Inland basins	562
13.8.2.	Seawardly dipping and off-shore sediments	562
13.8.3.	Lower permeability basement under a sedimentary cover	563
13.8.4.	Hard rocks in low-relief terrane	563
13.8.5.	Small islands	563
13.9.	Fast-Breeder Reactors	566
13.10.	The Problem of $^{239}_{94}\text{Pu}$	570
13.11.	A Matter of Balance	571
GLOSSARY		575
APPENDIXES		598
1.	The Exchange of Oxygen Isotopes in Carbon Dioxide-Phosphoric Acid Systems	598
2.	Concentration and Purification of Zircon	611
3.	A Palaeotemperature Equation for Planktonic Foraminifera	615
<i>Author Index</i>		619
<i>Subject Index</i>		633

PART I

Introductory Chapters

‘What canst thou see elsewhere which thou canst not see here? Behold the heaven and the earth and all the elements; for of these are all things created.’

THOMAS À KEMPIS, *Imitation of Christ*, (1:20).