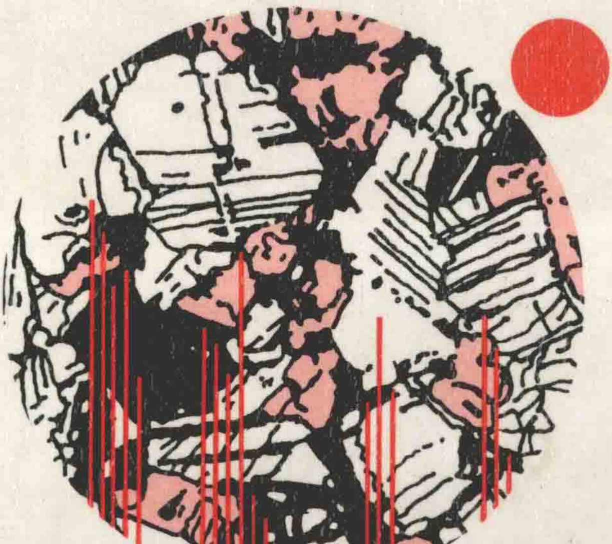
Isotopes in the Earth Sciences

Robert Bowen



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ISOTOPES IN THE EARTH SCIENCES

ROBERT BOWEN

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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'.

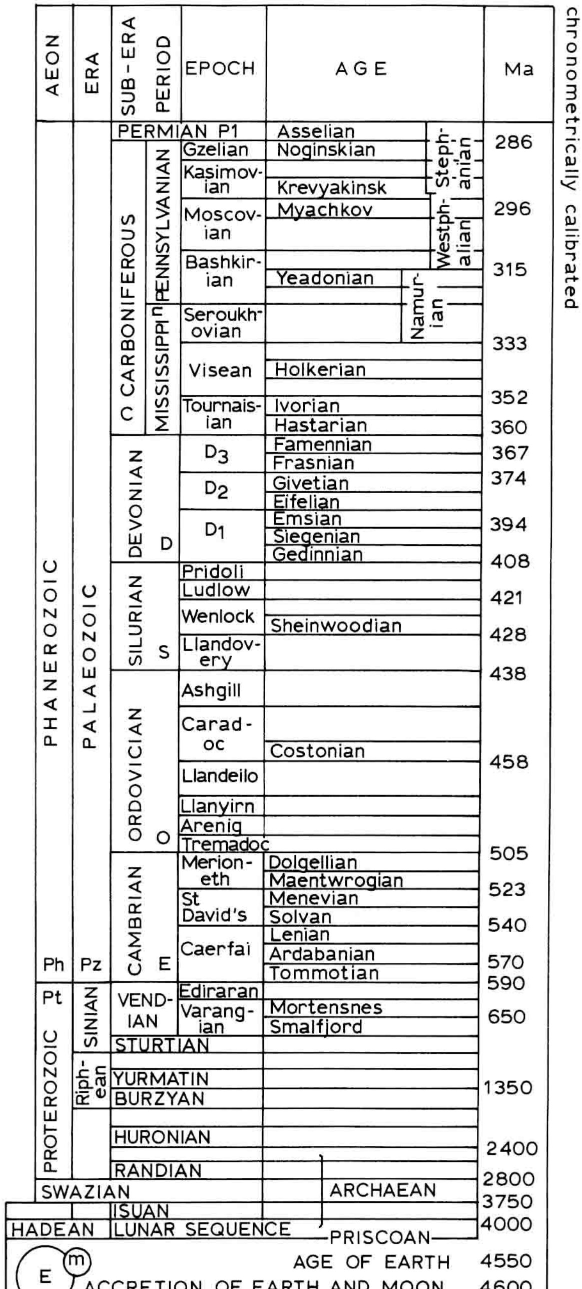
ROBERT BOWEN
Münster

AEON	ERA	SUB-ERA	PERIOD	EPOCH		AGE		Ma
PHANEROZOIC	CENOZOIC	QUAT*		HOLOCENE				0·01
				PLEISTOCENE				2
		TERTIARY	NEOGENE	Pliocene		Piacenzian		
						Zanclian		3·1
				MIOCENE	3	Messinian		
						Tortonian		11·3
					2	Serravallian		
						Late Langhian		14·4
					1	Early Langhian		
						Burdigalian		
						Aquitanian		24·6
			PALAEOGENE	Oligo-cene		Chattian		
						Rupelian		38·0
				EOCENE	3	Priabonian		
					2	Bartonian		
						Lutetian		50·5
					1	Ypresian		
				Palae-ocene		Thanetian		60·2
						Danian		
	MESOZOIC		CRETACEOUS K	K_2	Senon-ian	Maastrichtian		73
						Campanian		
						Santonian		87·5
						Coniacian		
						Turonian		91
						Cenomanian		
				K_1		Albian		113
						Aptian		
						Barremian		125
					Neoco-mian	Hauterivian		
						Valanginian		138
						Berriasian		
			JURRASSIC J	J_3	Malm	Tithonian		150
						Kimmeridgian		
						Oxfordian		163
				J_2	Dogger	Callovian		
						Bathonian		179
						Bajocian		
						Aalenian		188
				J_1	Lias	Toarcian		
						Pliensbachian		200
						Sinemurian		
						Hettangian		213
			TRIASSIC Tr	Tr_3		Rhaetian		
						Norian		225
						Carnian		
				Tr_2		Ladinian		238
						Anisian		
				Tr_1		Olenekian	Spathian	
							Smithian	
						Induan	Dienerian	
							Griesbachian	
	PALAEO-ZOIC		PERMIAN P	P_2		Tatarian		248
						Kazanian		
						Ufimian		
				P_1		Kungurian		258
						Artinskian		268
						Sakmarian		
						Asselian		286

*Quaternary (Pleistogene)

chronometrically calibrated

Chronostratic Scale (Holocene to Permian).



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.

KEY TO CHART

Atomic Number → 50
Symbol → **Sn**
Atomic Weight → 118·69

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 **H** 1·0079																	2 **He** 4·00260
3 **Li** 6·94	4 **Be** 9·01218											5 **B** 10·81	6 **C** 12·011	7 **N** 14·0067	8 **O** 15·9994	9 **F** 18·998403	10 **Ne** 20·17$_9$
11 **Na** 22·98977	12 **Mg** 24·305	Transition Elements					Group VIII			Transition Elements		13 **Al** 26·98154	14 **Si** 28·0855	15 **P** 30·97376	16 **S** 32·06	17 **Cl** 35·453	18 **Ar** 39·948
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	35 **Br** 79·904	36 **Kr** 83·80
37 **Rb** 85·467$_8$	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	53 **I** 126·9045	54 **Xe** 131·30
55 **Cs** 132·9054	56 **Ba** 137·33	57* **La** 138·9055	72 **Hf** 178·49	73 **Ta** 180·947$_9$	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)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226·0254	89** **Ac** (227)	104 **Rf** (260)	105 **Ha** (260)	106 (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
**Actinides	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.

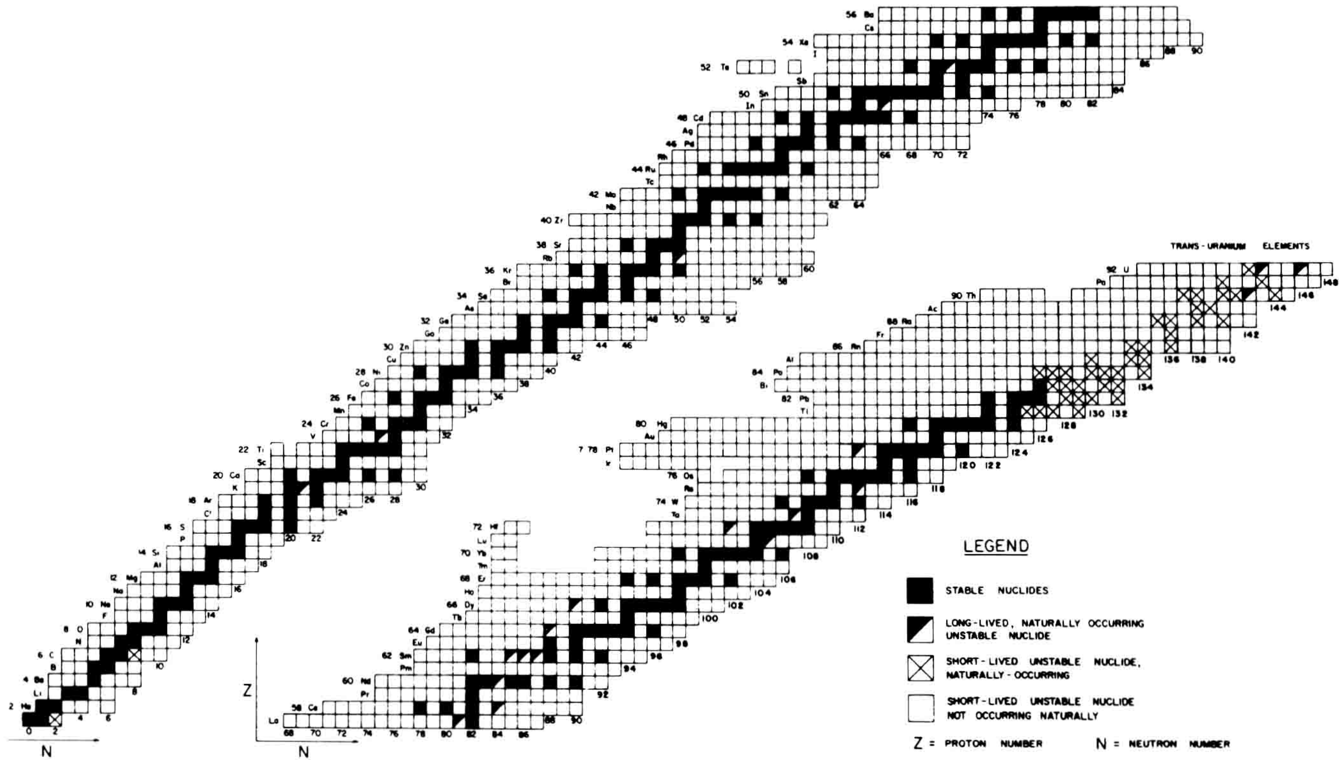


Chart of the Nuclides.

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Chapter 9. ENVIRONMENTAL ISOTOPES IN THE ATMOSPHERE AND HYDROSPHERE

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).