

Contents

Preface	xiii
Authors	xv

SECTION I Notation and Units

1 Physical Units and Constants	3
1.1 SI Units (Système International D'unités)	3
1.2 Unit Conversions: SI Equivalents of Other Units	5
1.3 Fundamental Constants	8
2 Some Shorthand Conventions	11
2.1 Selected Acronyms and Abbreviations	11
2.2 The Greek Alphabet	15

SECTION II The Building Blocks: Elements to Planets

3 Elements, Isotopes and Radioactivity	19
3.1 Periodic Table of Elements: A Geochemical Classification	20
3.2 Periodic Table of Elements: A Biological Classification	21
3.3 Isotopes of the Naturally Occurring Elements	22
3.4 Naturally Occurring Long-Lived Radioactive Isotopes	27
3.5 Some Extinct Isotopes	28
3.6 Short-Lived Isotopes	29
3.7 Fission Products	30
3.8 Radiogenic Heat	31
4 The Solar System	33
4.1 Physics	34
4.2 Chemistry	36

SECTION III Global Geophysics

5	Whole Earth Properties	41
5.1	Planetary Parameters	41
5.2	Global Energy	43
5.3	Precession, Wobble and the Milankovitch Cycles	44
5.4	Gravity	45
5.4.1	Algebraic Forms of Spherical Harmonics	46
5.4.2	Harmonic Coefficients of the Earth's Gravitational Potential	46
5.4.3	Gravity Anomalies	48
5.5	The Geomagnetic Field	51
5.5.1	The Main Field	51
5.5.2	Spherical Harmonic Representation	52
5.5.3	Geomagnetic Reference Field	54
5.5.4	Secular Variation	55
5.5.5	Geomagnetic Reversals	57
5.6	The Magnetosphere and Rapid Magnetic Variations	60

SECTION IV Major Subdivisions of the Earth: Structures and Properties

6	The Core	69
6.1	Core Details from the Preliminary Reference Earth Model	69
6.2	Core Properties	69
6.3	Core Energetics	69
7	The Mantle	75
7.1	Reference Earth Model from Seismology	75
7.2	General Mantle Properties	76
7.3	Mantle Minerals and Phase Transitions	82
7.4	Energy Balance of the Mantle	84
8	The Crust	87
8.1	A Veneer Displaying the History of the Earth	87
8.2	Average Crustal Structure and Isostasy	90
8.3	Heat Balance of the Crust	90
8.4	Elemental Composition of the Crust	91

9	The Oceans	97
9.1	Global Ocean Properties	97
9.1.1	Sea Level Rise	97
9.2	Sea Water Properties	97
9.3	Tides and Tidal Friction	103
9.3.1	The Gravitational Forces	103
9.3.2	Energy Dissipation (Tidal Friction)	105
10	Inland Salt Lakes	107
11	Freshwater and Ice	111
11.1	Freshwater Lakes	111
11.2	Man-Made Reservoirs	112
11.3	Rivers, Streams and Land Drainage	114
11.3.1	Drainage Patterns	116
11.4	Suspended Solids	119
11.4.1	Global Range	119
11.4.2	Turbidity	119
11.5	Ice	121
11.6	Global Water Exchanges	122
12	The Atmosphere	123
12.1	General Physical Properties of Air and the Atmosphere	123
12.2	Atmospheric Structure and Composition	124
12.3	Water Vapour Pressure and Latent Heat	127
12.4	Refractive Index of Air	129
12.5	Atmospheric Electricity	129
12.6	Energetics of the Atmosphere	130
12.6.1	Kinetics	130
12.6.2	Thermal Balance	130

SECTION V Geological Activity: The Restless Earth

13	Tectonics	135
13.1	The Surface Plates and Geometry	135
13.2	Tectonic Energy and Mantle Viscosity	138

13.3	Fault Stresses and Orientations and Seismic First Motions	139
13.3.1	Faults as Responses to Stress	139
13.3.2	Seismic First Motions	139
14	Earthquakes	143
14.1	Measures of Size: Magnitudes, Moments, Energies, Fault Dimensions and Frequency of Occurrence	143
14.2	Historically Significant Events	146
14.2.1	Earthquakes of Particular Scientific Interest	146
14.3	Seismic Waves	148
14.4	Slow Earthquakes and Non-Volcanic Tremor	148
14.5	Seismic Tomography	150
15	Volcanism	153
15.1	Spreading Centres	153
15.2	Subduction Zones	153
15.2.1	Notable Subduction Zone Eruptions	155
15.3	Flood Basalts, Hot Spots and Mass Extinctions	157
15.4	Environmental Effects of Volcanism	158
15.4.1	Volcanic Ash and Aircraft	161
16	Tsunamis	163
16.1	Wave Propagation	163
16.2	Earthquake-Triggered Tsunamis	164
16.3	Volcanically Generated Tsunamis	164
16.4	Landslide/Slump-Generated Tsunamis	165
17	Weathering, Erosion, Crustal Recycling and Regeneration	167
17.1	Some Definitions and Specialist Jargon	167
17.2	A Global Perspective	168
17.3	Erosive Effect of Rainfall	169
17.4	River and Stream Transport of Sediment	169
17.5	Mass Wasting	171
17.6	Igneous Regeneration of the Crust	174
17.6.1	Continental Crust	174
17.6.2	Oceanic Crust	174
18	Geological Time and the Fossil Record	175
18.1	Definitions	175
18.2	Geologic Record	177

21.2.2	Specific Heat and Expansion Coefficient	254
21.2.3	Melting	255
21.2.4	Thermal Conduction	257
21.3	Electrical Properties	260
21.3.1	Dielectric Constants and Molecular Polarity	260
21.3.2	Electrical Conduction in Minerals, Rocks and the Mantle	262
21.3.3	Electrical Conductivities of Iron and the Core	263
21.4	Magnetic Properties	264
21.4.1	Spontaneous Magnetisation	264
21.4.2	Susceptibility and Remanent Magnetism	265
21.4.3	Self-reversing Remanence	267
21.5	Optical Properties	268
21.5.1	Thin Sections	270

SECTION VII Resources

22	Elements as Resources	275
22.1	A Survey of the Elements: Their Occurrence, Properties and Uses	275
22.2	Production of Selected Metals	315
23	Rocks and Minerals as Resources	321
23.1	The Irreversibility of Resource Use	321
23.2	Mineralisation Associated with Tectonic Settings	325
23.2.1	Crust–Mantle Separation	325
23.2.2	Tectonic Situations Identified with Mineralisation	325
24	Fossil Fuels	335
24.1	Fuel Types and Basic Chemistry	335
24.2	Coal	336
24.2.1	Coal Grade and Non-Carbonaceous Constituents	338
24.2.2	Variations in Coal Formation with Time, Latitude and Environmental Conditions	342
24.3	Oil	344
24.3.1	Generation, Migration and Trapping	344
24.3.2	Variations in Oil Formation with Time and Latitude	345
24.3.3	Unconventional Oil	346
24.4	Gas	347
24.4.1	Sources	347
24.4.2	Methane Clathrate	348

24.7	Uses of the Fossil Fuels and CO ₂ Emission	354
24.8	A Note on Terminology and Units Used in Oil/Gas Reservoir Engineering and Hydrogeology	357
24.8.1	Darcy's Law of Fluid Flow in Porous Media	357
24.8.2	Some Technical Jargon	358
25	Energy Sources Alternative to Fossil Fuels	359
25.1	Energies of Some Natural Phenomena	359
25.1.1	Solar Energy	359
25.1.2	Wind Power	360
25.1.3	Tides	361
25.1.4	Geothermal Power	361
25.1.5	Tectonics	362
25.1.6	River Flow	362
25.1.7	Waves	363
25.1.8	Atmospheric Electricity	363
25.2	Generation of Non-fossil Fuel Power	363
25.2.1	Major Contributions: Nuclear and Hydropower	363
25.2.2	Hydroelectric Installations	365
25.2.3	Rapidly Expanding Sources: Solar and Wind	368
25.2.4	Geographically Restricted Sources: Geothermal, Tides and Waves	368
25.2.5	Ethanol and Biodiesel	370
26	Land Degradation, Waste Disposal and Recycling	373
26.1	A Historical Perspective	373
26.2	Land Use and Usability	374
26.3	Material Recycling	375
26.3.1	High-Volume Recyclables	375
26.3.2	Rarer Elements	376
26.3.3	Precious Metals	377
26.3.4	Rare Earths and Other Elements with Special Uses	377
26.4	A Watch List of Elements with Supply Insecurity	378
26.5	Some Problems	378
	References	381
	Index	385