

Contents

<i>Preface to the Third Edition</i>	<i>page xi</i>
1 Plate Tectonics	1
In this Chapter	1
1.1 Introduction	2
1.2 The Lithosphere	7
1.3 Accreting Plate Boundaries	7
1.4 Subduction	11
1.5 Transform Faults	16
1.6 Hotspots and Mantle Plumes	17
1.7 Continents	21
1.8 Paleomagnetism and the Motion of the Plates	24
1.9 Triple Junctions	40
1.10 The Wilson Cycle	43
1.11 Continental Collisions	46
1.12 Volcanism and Heat Flow	52
1.13 Seismicity and the State of Stress in the Lithosphere	56
1.14 The Driving Mechanism	60
1.15 Comparative Planetology	61
1.16 The Moon	62
1.17 Mercury	68
1.18 Mars	71
1.19 Phobos and Deimos	77
1.20 Vesta	79
1.21 Venus	80
1.22 The Galilean Satellites	83
1.23 Saturnian Satellites	87
Summary	90
Further Reading	91
2 Stress and Strain in Solids	92
In this Chapter	92
2.1 Introduction	92
2.2 Body Forces and Surface Forces	93
2.3 Stress in Two Dimensions	100
2.4 Stress in Three Dimensions	104
2.5 Pressures in the Deep Interiors of Planets	105

vi Contents

2.6	Stress Measurement	106
2.7	Basic Ideas about Strain	108
2.8	Strain Measurements	115
	Summary	128
	Further Reading	128
3	Elasticity and Flexure	130
	In this Chapter	130
3.1	Introduction	130
3.2	Linear Elasticity	131
3.3	Uniaxial Stress	132
3.4	Uniaxial Strain	134
3.5	Plane Stress	135
3.6	Plane Strain	136
3.7	Pure Shear and Simple Shear	137
3.8	Isotropic Stress	138
3.9	Two-Dimensional Bending or Flexure of Plates	138
3.10	Bending of Plates under Applied Moments and Vertical Loads	142
3.11	Buckling of a Plate under a Horizontal Load	144
3.12	Deformation of Strata Overlying an Igneous Intrusion	146
3.13	Application to the Earth's Lithosphere	147
3.14	Periodic Loading	148
3.15	Stability of the Earth's Lithosphere under an End Load	150
3.16	Bending of the Elastic Lithosphere under the Loads of Island Chains	151
3.17	Bending of the Elastic Lithosphere at an Ocean Trench	153
3.18	Flexure and the Structure of Sedimentary Basins	155
	Summary	158
	Further Reading	158
4	Heat Transfer	160
	In this Chapter	160
4.1	Introduction	160
4.2	Fourier's Law of Heat Conduction	161
4.3	Measuring the Earth's Surface Heat Flux	162
4.4	The Earth's Surface Heat Flow	164
4.5	Heat Generation by the Decay of Radioactive Elements	164
4.6	One-Dimensional Steady Heat Conduction with Volumetric Heat Production	167
4.7	A Conduction Temperature Profile for the Mantle	169
4.8	Continental Geotherms	170
4.9	Radial Heat Conduction in a Sphere or Spherical Shell	173
4.10	Temperatures in the Moon	175
4.11	Steady Two- and Three-Dimensional Heat Conduction	176
4.12	Subsurface Temperature Due to Periodic Surface Temperature and Topography	177
4.13	One-Dimensional, Time-Dependent Heat Conduction	179

4.14	Periodic Heating of a Semi-Infinite Half-Space: Diurnal and Seasonal Changes in Subsurface Temperature	180
4.15	Instantaneous Heating or Cooling of a Semi-Infinite Half-Space	183
4.16	Cooling of the Oceanic Lithosphere	188
4.17	Plate Cooling Model of the Lithosphere	192
4.18	The Stefan Problem	193
4.19	Solidification of a Dike or Sill	196
4.20	The Heat Conduction Equation in a Moving Medium: Thermal Effects of Erosion and Sedimentation	200
4.21	One-Dimensional, Unsteady Heat Conduction in an Infinite Region	201
4.22	Thermal Stresses	204
4.23	Ocean Floor Topography	207
4.24	Changes in Sea Level	210
4.25	Thermal and Subsidence History of Sedimentary Basins	212
4.26	Heating or Cooling a Semi-Infinite Half-Space by a Constant Surface Heat Flux	216
4.27	Frictional Heating on Faults: Island Arc Volcanism and Melting on the Surface of the Descending Slab	217
4.28	Mantle Geotherms and Adiabats	219
4.29	Thermal Structure of the Subducted Lithosphere	223
4.30	Culling Model for the Erosion and Deposition of Sediments	225
	Summary	228
	Further Reading	228
5	Gravity	230
	In this Chapter	230
5.1	Introduction	230
5.2	Gravitational Acceleration External to the Rotationally Distorted Earth	231
5.3	Centrifugal Acceleration and the Acceleration of Gravity	236
5.4	The Gravitational Potential and the Geoid	237
5.5	Moments of Inertia	241
5.6	Surface Gravity Anomalies	244
5.7	Bouguer Gravity Formula	246
5.8	Reductions of Gravity Data	248
5.9	Compensation	249
5.10	The Gravity Field of a Periodic Mass Distribution on a Surface	250
5.11	Compensation Due to Lithospheric Flexure	251
5.12	Isostatic Geoid Anomalies	253
5.13	Compensation Models and Observed Geoid Anomalies	254
5.14	Forces Required to Maintain Topography and the Geoid	259
	Summary	260
	Further Reading	261

viii Contents

6 Fluid Mechanics	263
In this Chapter	263
6.1 Introduction	264
6.2 One-Dimensional Channel Flows	265
6.3 Asthenospheric Counterflow	268
6.4 Pipe Flow	270
6.5 Artesian Aquifer Flows	272
6.6 Flow Through Volcanic Pipes	273
6.7 Conservation of Fluid in Two Dimensions	273
6.8 Elemental Force Balance in Two Dimensions	274
6.9 The Stream Function	276
6.10 Postglacial Rebound	277
6.11 Angle of Subduction	282
6.12 Diapirism	284
6.13 Folding	289
6.14 Stokes Flow	295
6.15 Plume Heads and Tails	300
6.16 Pipe Flow with Heat Addition	303
6.17 Aquifer Model for Hot Springs	305
6.18 Thermal Convection	307
6.19 Linear Stability Analysis for the Onset of Thermal Convection in a Layer of Fluid Heated from Below	309
6.20 A Transient Boundary-Layer Theory for Finite-Amplitude Thermal Convection	313
6.21 A Steady-State Boundary-Layer Theory for Finite-Amplitude Thermal Convection	316
6.22 The Forces that Drive Plate Tectonics	323
6.23 Heating by Viscous Dissipation	326
6.24 Mantle Recycling and Mixing	328
Summary	333
Further Reading	334
7 Rock Rheology	336
In this Chapter	336
7.1 Introduction	336
7.2 Elasticity	338
7.3 Diffusion Creep	345
7.4 Dislocation Creep	352
7.5 Shear Flows of Fluids with Temperature- and Stress-Dependent Rheologies	356
7.6 Mantle Rheology	364
7.7 Rheological Effects on Mantle Convection	369
7.8 Mantle Convection and the Cooling of the Earth	371
7.9 Crustal Rheology	373
7.10 Viscoelasticity	376

7.11 Elastic–Perfectly Plastic Behavior	379
Summary	383
Further Reading	384
8 Faulting	386
In this Chapter	386
8.1 Introduction	386
8.2 Classification of Faults	387
8.3 Friction on Faults	389
8.4 Anderson Theory of Faulting	391
8.5 Strength Envelope	395
8.6 Thrust Sheets and Gravity Sliding	396
8.7 Earthquakes	398
8.8 San Andreas Fault	404
8.9 North Anatolian Fault	408
8.10 Some Elastic Solutions for Strike–Slip Faulting	410
8.11 Stress Diffusion	417
8.12 Thermally Activated Creep on Faults	419
Summary	422
Further Reading	423
9 Flows in Porous Media	425
In this Chapter	425
9.1 Introduction	425
9.2 Darcy’s Law	426
9.3 Permeability Models	427
9.4 Flow in Confined Aquifers	428
9.5 Flow in Unconfined Aquifers	430
9.6 Geometrical Form of Volcanoes	440
9.7 Equations of Conservation of Mass, Momentum, and Energy for Flow in Porous Media	443
9.8 One-Dimensional Advection of Heat in a Porous Medium	444
9.9 Thermal Convection in a Porous Layer	446
9.10 Thermal Plumes in Fluid-Saturated Porous Media	450
9.11 Porous Flow Model for Magma Migration	456
9.12 Two-Phase Convection	459
Summary	462
Further Reading	463
10 Chemical Geodynamics	465
In this Chapter	465
10.1 Introduction	465
10.2 Radioactivity and Geochronology	466
10.3 Geochemical Reservoirs	471

x	Contents	
10.4	A Two-Reservoir Model with Instantaneous Crustal Differentiation	473
10.5	Noble Gas Systems	479
10.6	Isotope Systematics of OIB	480
	Summary	484
	Further Reading	484
11	Numerical Tools	486
	In this Chapter	486
11.1	Introduction	486
11.2	Getting Started with MATLAB	487
11.3	Integration of Fourier's Law of Heat Conduction, an Initial Value Problem	493
11.4	Integration of the Equation for One-Dimensional Steady Heat Conduction with Volumetric Heat Production, a Boundary Value Problem	495
11.5	Integration of the Equation for Two-Dimensional Steady Heat Conduction	502
11.6	Integration of the Equation for One-Dimensional Time-Dependent Heat Conduction	508
	Summary	513
12	Geophysical Applications of Computational Modeling	514
	In this Chapter	514
12.1	Bending of the Lithosphere under a Triangular Load	514
12.2	Bending of the Elastic Lithosphere under Axisymmetric Loads	518
12.3	MATLAB Evaluation of Temperature and Surface Heat Flow for the Plate Model of the Cooling Oceanic Lithosphere	521
12.4	MATLAB Evaluation of Seafloor Depth for the Plate Model of the Cooling Oceanic Lithosphere	522
12.5	Cooling of a Solidified Dike	524
12.6	Gravity Anomaly above a Rectangular Prism	527
12.7	Free-air Gravity Anomaly of Arbitrary Topography	531
12.8	Postglacial Rebound and Crater Relaxation: Axisymmetric Geometry	536
12.9	A Numerical Solution for Steady, Two-Dimensional, Finite-Amplitude Thermal Convection	545
12.10	Surface Velocity for Strike–Slip Faulting	552
12.11	Additional Solutions for Strike–Slip Faulting	552
12.12	Faulting on Cracks of Arbitrary Size and Orientation	560
	Summary	565
	Appendix A Symbols and Units	567
	Appendix B Physical Constants and Properties	572
	Appendix C Answers to Selected Problems	578
	<i>References</i>	607
	<i>Index</i>	612

Color plate section is between pages 338 and 339.