Contents

Preface	*page* xi
Preface to the Second Edition	xiii
ONE. Plate Tectonics	1
1–1 Introduction	1
1–2 The Lithosphere	5
1–3 Accreting Plate Boundaries	6
1–4 Subduction	9
1–5 Transform Faults	13
1–6 Hotspots and Mantle Plumes	14
1–7 Continents	17
1–8 Paleomagnetism and the Motion of the Plates	22
1–9 Triple Junctions	35
1–10 The Wilson Cycle	38
1–11 Continental Collisions	41
1–12 Volcanism and Heat Flow	46
1–13 Seismicity and the State of Stress in the Lithosphere	49
1–14 The Driving Mechanism	54
1–15 Comparative Planetology	55
1–16 The Moon	56
1–17 Mercury	58
1–18 Mars	59
1–19 Phobos and Deimos	64
1–20 Venus	65
1–21 The Galilean Satellites	67
TWO. Stress and Strain in Solids	73
2–1 Introduction	73
2–2 Body Forces and Surface Forces	73
2–3 Stress in Two Dimensions	80
2–4 Stress in Three Dimensions	83
2–5 Pressures in the Deep Interiors of Planets	84

2–6 Stress Measurement 85
2–7 Basic Ideas about Strain 87
2–8 Strain Measurements 94

THREE. Elasticity and Flexure 105

3–1 Introduction 105
3–2 Linear Elasticity 106
3–3 Uniaxial Stress 106
3–4 Uniaxial Strain 108
3–5 Plane Stress 109
3–6 Plane Strain 111
3–7 Pure Shear and Simple Shear 111
3–8 Isotropic Stress 112
3–9 Two-Dimensional Bending or Flexure of Plates 112
3–10 Bending of Plates under Applied Moments and Vertical Loads 116
3–11 Buckling of a Plate under a Horizontal Load 118
3–12 Deformation of Strata Overlying an Igneous Intrusion 119
3–13 Application to the Earth's Lithosphere 121
3–14 Periodic Loading 122
3–15 Stability of the Earth's Lithosphere under an End Load 123
3–16 Bending of the Elastic Lithosphere under the Loads of Island Chains 124
3–17 Bending of the Elastic Lithosphere at an Ocean Trench 127
3–18 Flexure and the Structure of Sedimentary Basins 129

FOUR. Heat Transfer 132

4–1 Introduction 132
4–2 Fourier's Law of Heat Conduction 132
4–3 Measuring the Earth's Surface Heat Flux 133
4–4 The Earth's Surface Heat Flow 135
4–5 Heat Generation by the Decay of Radioactive Elements 136
4–6 One-Dimensional Steady Heat Conduction with Volumetric Heat Production 138
4–7 A Conduction Temperature Profile for the Mantle 140
4–8 Continental Geotherms 141
4–9 Radial Heat Conduction in a Sphere or Spherical Shell 144
4–10 Temperatures in the Moon 145
4–11 Steady Two- and Three-Dimensional Heat Conduction 146
4–12 Subsurface Temperature Due to Periodic Surface Temperature and Topography 147
4–13 One-Dimensional, Time-Dependent Heat Conduction 149
4–14 Periodic Heating of a Semi-Infinite Half-Space: Diurnal and Seasonal Changes in Subsurface Temperature 150
4–15 Instantaneous Heating or Cooling of a Semi-Infinite Half-Space 153
4–16 Cooling of the Oceanic Lithosphere 157
4–17 Plate Cooling Model of the Lithosphere 161
4–18 The Stefan Problem 162

4–19 Solidification of a Dike or Sill 166
4–20 The Heat Conduction Equation in a Moving Medium: Thermal Effects of Erosion and Sedimentation 168
4–21 One-Dimensional, Unsteady Heat Conduction in an Infinite Region 169
4–22 Thermal Stresses 171
4–23 Ocean Floor Topography 174
4–24 Changes in Sea Level 178
4–25 Thermal and Subsidence History of Sedimentary Basins 179
4–26 Heating or Cooling a Semi-Infinite Half-Space by a Constant Surface Heat Flux 183
4–27 Frictional Heating on Faults: Island Arc Volcanism and Melting on the Surface of the Descending Slab 184
4–28 Mantle Geotherms and Adiabats 185
4–29 Thermal Structure of the Subducted Lithosphere 190
4–30 Culling Model for the Erosion and Deposition of Sediments 191

FIVE. Gravity 195

5–1 Introduction 195
5–2 Gravitational Acceleration External to the Rotationally Distorted Earth 195
5–3 Centrifugal Acceleration and the Acceleration of Gravity 200
5–4 The Gravitational Potential and the Geoid 201
5–5 Moments of Inertia 205
5–6 Surface Gravity Anomalies 207
5–7 Bouguer Gravity Formula 210
5–8 Reductions of Gravity Data 212
5–9 Compensation 213
5–10 The Gravity Field of a Periodic Mass Distribution on a Surface 213
5–11 Compensation Due to Lithospheric Flexure 214
5–12 Isostatic Geoid Anomalies 216
5–13 Compensation Models and Observed Geoid Anomalies 219
5–14 Forces Required to Maintain Topography and the Geoid 223

SIX. Fluid Mechanics 226

6–1 Introduction 226
6–2 One-Dimensional Channel Flows 226
6–3 Asthenospheric Counterflow 230
6–4 Pipe Flow 231
6–5 Artesian Aquifer Flows 233
6–6 Flow Through Volcanic Pipes 234
6–7 Conservation of Fluid in Two Dimensions 234
6–8 Elemental Force Balance in Two Dimensions 235
6–9 The Stream Function 237
6–10 Postglacial Rebound 238
6–11 Angle of Subduction 242
6–12 Diapirism 244
6–13 Folding 249

6–14 Stokes Flow 254
6–15 Plume Heads and Tails 259
6–16 Pipe Flow with Heat Addition 262
6–17 Aquifer Model for Hot Springs 264
6–18 Thermal Convection 266
6–19 Linear Stability Analysis for the Onset of Thermal Convection in a Layer of Fluid Heated from Below 267
6–20 A Transient Boundary-Layer Theory for Finite-Amplitude Thermal Convection 272
6–21 A Steady-State Boundary-Layer Theory for Finite-Amplitude Thermal Convection 274
6–22 The Forces that Drive Plate Tectonics 280
6–23 Heating by Viscous Dissipation 283
6–24 Mantle Recycling and Mixing 285

SEVEN. Rock Rheology 292

7–1 Introduction 292
7–2 Elasticity 293
7–3 Diffusion Creep 300
7–4 Dislocation Creep 307
7–5 Shear Flows of Fluids with Temperature- and Stress-Dependent Rheologies 311
7–6 Mantle Rheology 318
7–7 Rheological Effects on Mantle Convection 323
7–8 Mantle Convection and the Cooling of the Earth 325
7–9 Crustal Rheology 327
7–10 Viscoelasticity 329
7–11 Elastic-Perfectly Plastic Behavior 333

EIGHT. Faulting 339

8–1 Introduction 339
8–2 Classification of Faults 339
8–3 Friction on Faults 341
8–4 Anderson Theory of Faulting 343
8–5 Strength Envelope 347
8–6 Thrust Sheets and Gravity Sliding 347
8–7 Earthquakes 350
8–8 San Andreas Fault 355
8–9 North Anatolian Fault 359
8–10 Some Elastic Solutions for Strike–Slip Faulting 361
8–11 Stress Diffusion 367
8–12 Thermally Activated Creep on Faults 368

NINE. Flows in Porous Media 374

9–1 Introduction 374
9–2 Darcy's Law 374
9–3 Permeability Models 375

9–4 Flow in Confined Aquifers 376
9–5 Flow in Unconfined Aquifers 378
9–6 Geometrical Form of Volcanoes 387
9–7 Equations of Conservation of Mass, Momentum, and Energy for Flow in Porous Media 390
9–8 One-Dimensional Advection of Heat in a Porous Medium 391
9–9 Thermal Convection in a Porous Layer 393
9–10 Thermal Plumes in Fluid-Saturated Porous Media 396
9–11 Porous Flow Model for Magma Migration 402
9–12 Two-Phase Convection 405

TEN. Chemical Geodynamics **410**

10–1 Introduction 410
10–2 Radioactivity and Geochronology 411
10–3 Geochemical Reservoirs 415
10–4 A Two-Reservoir Model with Instantaneous Crustal Differentiation 417
10–5 Noble Gas Systems 423
10–6 Isotope Systematics of OIB 424

APPENDIX ONE. Symbols and Units **429**

APPENDIX TWO. Physical Constants and Properties **433**

Answers to Selected Problems 437
Index 441