

Contents

| | | | |
|--|-----------|---|-----|
| <i>Preface</i> | <i>xi</i> | | |
| CHAPTER 1 Introduction | 1 | CHAPTER 3 Introduction to Faults | 61 |
| 1.1 What Are Structural Geology and Tectonics? | 1 | 3.1 Types of Faults | 61 |
| 1.2 Structural Geology, Tectonics, and the Use of Models | 2 | 3.2 Recognition of Faults | 63 |
| 1.3 The Interior of the Earth and of Other Terrestrial Bodies | 7 | 3.3 Determination of Fault Displacement | 70 |
| 1.4 The Earth's Crust and Plate Tectonics: Introduction | 9 | 3.4 Fault Geometry | 81 |
| 1.5 Ocean Basins | 14 | 3.5 Balanced Cross Sections | 88 |
| 1.6 The Structure of Continental Crust | 17 | 3.6 Summary and Preview | 88 |
| 1.7 Precambrian Shields | 19 | CHAPTER 4 Normal Faults | 91 |
| 1.8 Phanerozoic Regions | 25 | 4.1 Characteristics of Normal Faulting | 91 |
| 1.9 Summary and Preview | 30 | 4.2 Shape and Displacement of Normal Faults | 93 |
| Box 1-1 <i>The Scientific Method</i> | 4 | 4.3 Structural Associations of Normal Faults | 95 |
| | | 4.4 Kinematic Models of Normal Fault Systems | 107 |
| PART I BRITTLE DEFORMATION | 35 | 4.5 Determination of Extension associated with Normal Faults | 111 |
| CHAPTER 2 Fractures and Joints | 37 | CHAPTER 5 Thrust or Reverse Faults | 115 |
| 2.1 Classification of Extension Fractures | 38 | 5.1 Recognition of Thrust Faults | 115 |
| 2.2 Geometry of Fracture Systems in Three Dimensions | 43 | 5.2 Shape and Displacement of Thrust Faults | 117 |
| 2.3 Features of Fracture Surfaces | 52 | 5.3 Structural Environments of Thrust Faults | 119 |
| 2.4 Timing of Fracture Formation | 54 | 5.4 Kinematic Models of Thrust Fault Systems | 127 |
| 2.5 Relationships of Fractures to Other Structures | 57 | 5.5 Geometry and Kinematics of Thrust Systems in the Hinterland | 128 |
| Box 2-1 <i>Fractals and the Description of Joint Patterns</i> | 46 | 5.6 Analysis of Displacement on Thrust Faults | 131 |
| | | CHAPTER 6 Strike-Slip Faults | 135 |
| | | 6.1 Characteristics of Strike-Slip Faults | 136 |

| | | | | | |
|--|--|-----|-----|--|--|
| 6.2 | Shape, Displacement, and Related Structures | 139 | | | |
| 6.3 | Structural Associations of Strike-Slip Faults | 141 | | | |
| 6.4 | Kinematic Models of Strike-Slip Fault Systems | 146 | | | |
| 6.5 | Analysis of Displacement | 148 | | | |
| 6.6 | Balancing Strike-Slip Faults | 149 | | | |
| CHAPTER 7 Stress | | | 151 | | |
| 7.1 | Force, Traction, and Stress | 151 | | | |
| 7.2 | The Mohr Diagram for Two-Dimensional Stress | 168 | | | |
| 7.3 | Terminology for States of Stress | 173 | | | |
| 7.4 | A Closer Look at the Mohr Circle for Two-Dimensional Stress | 175 | | | |
| 7.5 | The Stress Tensor | 180 | | | |
| | Box 7-1 <i>What Is a Vector: A Brief Review</i> | 154 | | | |
| | Box 7-2 <i>The Mohr Diagram for Three-Dimensional Stress</i> | 178 | | | |
| | Box 7-3 <i>What Is a Tensor?</i> | 184 | | | |
| | Box 7-4 <i>Sign Conventions Galore: A Cautionary Note</i> | 187 | | | |
| | Box 7-5 <i>Derivation of Principal Stresses in Two Dimensions</i> | 189 | | | |
| | Appendix 7-A <i>Illustrative Problem 1</i> | 193 | | | |
| | Appendix 7-B <i>Illustrative Problem 2</i> | 201 | | | |
| CHAPTER 8 Mechanics of Fracturing and Faulting: Experiment and Theory | | | 209 | | |
| 8.1 | Experimental Fracturing of Rocks | 209 | | | |
| 8.2 | A Fracture Criterion for Tension Fractures | 210 | | | |
| 8.3 | The Coulomb Fracture Criterion for Confined Compression | 212 | | | |
| 8.4 | Effects of Confining Pressure on Fracturing and Frictional Sliding | 216 | | | |
| 8.5 | Effects of Pore Fluid Pressure on Fracturing and Frictional Sliding | 220 | | | |
| 8.6 | Effects on Fracturing of Anisotropy, the Intermediate Principal Stress, Temperature, and Scale | 221 | | | |
| 8.7 | Limitations of the Coulomb Fracture Criterion | 225 | | | |
| 8.8 | The Griffith Theory of Fracture | 226 | | | |
| | Box 8-1 <i>The Coulomb Fracture Criterion in Terms of Principal Stresses</i> | 214 | | | |
| CHAPTER 9 Mechanics of Natural Fractures and Faults | | | 231 | | |
| 9.1 | Elastic Deformation | 231 | | | |
| 9.2 | Techniques for Determining Stress in the Earth | 233 | | | |
| 9.3 | Mechanisms of Stressing the Earth's Crust | 236 | | | |
| 9.4 | Stress in the Earth | 238 | | | |
| 9.5 | Stress Histories and the Origin of Joints | 241 | | | |
| 9.6 | The Spacing of Extension Fractures | 250 | | | |
| 9.7 | Distinguishing Extension Fractures from Shear Fractures | 251 | | | |
| 9.8 | Fractures Associated with Faults | 252 | | | |
| 9.9 | Fractures Associated with Folds | 253 | | | |
| 9.10 | Stress Distributions and Faulting | 254 | | | |
| 9.11 | The Mechanics of Large Overthrusts | 258 | | | |
| 9.12 | Cause and Effect: A Word of Caution | 267 | | | |
| | Box 9-1 <i>The Effect of Burial and Uplift on Stress in the Crust</i> | 244 | | | |
| | Box 9-2 <i>Simplified Model of a Thrust Sheet</i> | 264 | | | |
| PART II DUCTILE DEFORMATION | | | 271 | | |
| CHAPTER 10 The Description of Folds | | | 273 | | |
| 10.1 | Geometric Parts of Folds | 274 | | | |
| 10.2 | Fold Scale and Attitude | 280 | | | |
| 10.3 | The Elements of Fold Style | 282 | | | |
| 10.4 | The Order of Folds | 290 | | | |
| 10.5 | Common Styles and Structural Associations of Folding | 292 | | | |
| CHAPTER 11 Foliations and Lineations in Deformed Rocks | | | 297 | | |
| 11.1 | Tectonites | 297 | | | |
| 11.2 | Compositional Foliations | 298 | | | |
| 11.3 | Disjunctive Foliations | 299 | | | |
| 11.4 | Crenulation Foliations | 302 | | | |
| 11.5 | Continuous Foliations | 302 | | | |
| 11.6 | The Relationship of Foliations to Other Structures | 303 | | | |
| 11.7 | Special Types of Foliation and Nomenclature | 309 | | | |
| 11.8 | Structural Lineations | 309 | | | |
| 11.9 | Mineral Lineations | 313 | | | |
| 11.10 | Associations of Lineations with Other Structures | 316 | | | |

| | | | | | |
|-------------------|--|------------|----------------------|--|------------|
| CHAPTER 12 | Geometry of Homogenous Strain | 319 | CHAPTER 15 | Observations of Strain in Deformed Rocks | 423 |
| 12.1 | Measures of Strain | 321 | 15.1 | Measuring Strain in Rocks | 423 |
| 12.2 | The State of Strain | 324 | 15.2 | Relationship of Strain to Foliations and Lineations | 426 |
| 12.3 | Special States of Strain | 328 | 15.3 | Measurement of Strain in Folds | 427 |
| 12.4 | Progressive Deformation | 333 | 15.4 | Strain in Shear Zones | 432 |
| 12.5 | Progressive Stretch of Material Lines | 336 | 15.5 | Deformation History | 446 |
| 12.6 | Homogeneous and Inhomogeneous Deformation | 339 | Box 15-1 | <i>Brittle Strain Inferred from Fault Systematics</i> | 439 |
| 12.7 | The Representation of Three-Dimensional Strain States and Progressive Strains | 339 | Appendix 15-A | <i>Common Techniques for Measuring Strain</i> | 449 |
| 12.8 | Tensor Representations of Strain | 350 | | | |
| 12.9 | Finite Strain of an Arbitrary Line Segment and the Mohr Circle | 355 | | | |
| 12.10 | Applications of Strain Analysis | 361 | PART III | RHEOLOGY | 457 |
| | Box 12-1 <i>Other Measures of Linear Strain</i> | 322 | | | |
| | Box 12-2 <i>Terminology of Strain Compared with Stress: Beware!</i> | 346 | CHAPTER 16 | Macroscopic Aspects of Rock Deformation: Rheology and Experiment | 459 |
| | Box 12-3 <i>A More Quantitative View of Strain</i> | 352 | 16.1 | Continuum Models of Material Behavior | 460 |
| CHAPTER 13 | Kinematic Analysis of Folds | 363 | 16.2 | Experiments on Friction and Cataclastic Flow: Implications for Faulting | 466 |
| 13.1 | Flexural Folding of a Layer | 364 | 16.3 | Experimental Investigation of Ductile Flow | 475 |
| 13.2 | Passive Shear Folding of a Layer | 369 | 16.4 | Steady-State Creep | 477 |
| 13.3 | Volume-Loss Folding of a Layer | 371 | 16.5 | The Effects of Pressure, Grain Size, Chemical Environment, and Partial Melt on Steady-State Creep | 481 |
| 13.4 | Homogeneous Flattening of Folds in a Layer | 374 | 16.6 | Application of Experimental Rheology to Natural Deformation | 487 |
| 13.5 | Folding of Multilayers | 376 | Box 16-1 | <i>Measures of Strain Rate</i> | 465 |
| 13.6 | Formation of Kink and Chevron Folds | 379 | Box 16-2 | <i>The Rate- and State-Dependent Friction Law</i> | 471 |
| 13.7 | Fault-Bend and Fault-Propagation Folding of a Multilayer | 383 | Box 16-3 | <i>Experimental Determination of the Material Constants in the High-Temperature Creep Equation</i> | 485 |
| 13.8 | Drag Folds and Hansen's Method for Slip-Line Determination | 390 | Box 16-4 | <i>Constitutive Equations in Three Dimensions</i> | 491 |
| 13.9 | Superposed Folding | 390 | | | |
| 13.10 | Diapiric Flow | 395 | CHAPTER 17 | Microscopic Aspects of Ductile Deformation: Mechanisms and Fabrics | 495 |
| CHAPTER 14 | Analysis of Foliations and Lineations | 399 | 17.1 | Mechanisms of Low-Temperature Deformation | 497 |
| 14.1 | Material and Nonmaterial Foliations and Lineations | 399 | 17.2 | Twin Gliding | 499 |
| 14.2 | Mechanisms of Formation of Foliations and Lineations and their Relationships to Strain | 400 | 17.3 | Diffusion and Solution Creep | 500 |
| 14.3 | Interpretation of the Morphological Types of Foliation | 405 | 17.4 | Linear Crystal Defects: The Geometry and Motion of Dislocations | 503 |
| 14.4 | Steady-State Foliations | 412 | | | |
| 14.5 | Foliations and Shear Planes | 413 | | | |
| 14.6 | Interpretation of Morphological Types of Lineation | 415 | | | |
| 14.7 | Lineations on Folds | 421 | | | |

| | | | | | |
|--|--|-----|-----|--|--|
| 17.5 | Mechanisms of Dislocation Creep | 513 | | | |
| 17.6 | Microstructural Fabrics associated with Dislocation Creep | 518 | | | |
| 17.7 | Preferred Orientation Fabrics of Dislocation Creep | 524 | | | |
| 17.8 | Symmetry Principles in the Interpretation of Deformed Rocks | 535 | | | |
| | Box 17-1 <i>Rheologies Inferred from Mechanisms of Ductile Deformation</i> | 517 | | | |
| | Box 17-2 <i>Inferring the Orientation and Magnitude of Paleostresses in Deformed Rocks</i> | 520 | | | |
| CHAPTER 18 Scale Models and Quantitative Models of Rock Deformation | | | 543 | | |
| 18.1 | Constraints on Physical Models | 544 | | | |
| 18.2 | The Theory of Scale Models | 546 | | | |
| 18.3 | Scale Models of Folding | 548 | | | |
| 18.4 | Scale Models of Gravity-Driven Deformation | 551 | | | |
| 18.5 | Plastic Slip-Line Field Theory and Faulting | 553 | | | |
| 18.6 | Analytic Solution for the Viscous Buckling of a Competent Layer in an Incompetent Matrix | 561 | | | |
| 18.7 | Numerical Models of Buckling and the Effects of Different Rheologies | 563 | | | |
| | Box 18-1 <i>Formulation of a Mathematical Model with Application to the Problem of Viscous Deformation</i> | 573 | | | |
| PART IV REGIONAL ASSOCIATIONS OF STRUCTURES | | | 579 | | |
| CHAPTER 19 Development of Structures at Active Plate Margins | | | 581 | | |
| 19.1 | Divergent Margins on the Continents: Continental Rifting | 581 | | | |
| 19.2 | Divergent Margins in Ocean Basins | 590 | | | |
| 19.3 | Major Strike-Slip Faults: Transform Faults and Megashears | 601 | | | |
| 19.4 | Convergent Margins | 615 | | | |
| 19.5 | Active Collisions | 626 | | | |
| | Box 19-1 <i>Structures of Convergent and Divergent Strike-Slip along the Boundaries of the Sierran Microplate</i> | 611 | | | |
| CHAPTER 20 Anatomy and Tectonics of Orogenic Belts | | | 639 | | |
| 20.1 | Introduction | 639 | | | |
| 20.2 | The Foredeep or Foreland Basin | 640 | | | |
| 20.3 | The External Thrust Complex: Foreland Fold and Thrust Belt, Slate Belt, Ophiolites, and Sutures | 644 | | | |
| 20.4 | The Crystalline Core Zone: Metamorphism | 648 | | | |
| 20.5 | The Crystalline Core Zone: Structure and Lithology | 653 | | | |
| 20.6 | Extensional Deformation and Low-Angle Detachments | 660 | | | |
| 20.7 | High-Angle Fault Zones | 665 | | | |
| 20.8 | Minor Structures and Strain in the Interpretation of Orogenic Zones | 666 | | | |
| 20.9 | Tectonics, Topography, and Erosion | 670 | | | |
| 20.10 | Tectonics and Metamorphism | 671 | | | |
| 20.11 | Simple Models of Orogenic Deformation | 673 | | | |
| 20.12 | A Two-Dimensional Plate Tectonic Model of Orogeny | 677 | | | |
| 20.13 | The "Wilson Cycle" and Plate Tectonics | 685 | | | |
| 20.14 | Terrane Analysis | 688 | | | |
| APPENDIX 1 The Orientation and Representation of Structures | | | 693 | | |
| A1.1 | The Attitude of Planes and Lines | 693 | | | |
| A1.2 | Graphical Presentation of Orientation Data | 695 | | | |
| A1.3 | Geologic Maps | 697 | | | |
| A1.4 | Cross Sections: Portrayal of Structures in Three Dimensions | 698 | | | |
| APPENDIX 2 Geophysical Techniques | | | 701 | | |
| A2.1 | Seismic Studies | 701 | | | |
| A2.2 | Analysis of Gravity Anomalies | 708 | | | |
| A2.3 | Geomagnetic Studies | 709 | | | |
| APPENDIX 3 Units and Constants | | | | | |
| | Basic SI (Système Internationale; mks) Units | 713 | | | |
| | Table of SI Multiples | 713 | | | |
| | Other Systems of Units | 713 | | | |
| | Units and Constants Used in the Book and Some Common Equivalents | 714 | | | |
| INDEX | | | 717 | | |

TABLES

| | | | | | |
|-------------|---|-----|--------------|--|-----|
| Table 3.1 | Fault Rock Terminology | 64 | Table 9-2.1 | Relationships among Fracture Angle, Coefficient of Internal Friction, and K | 265 |
| Table 7.1 | Development of the Concept of Stress | 152 | Table 10.1 | Elements of Fold Style | 283 |
| Table 7.2 | Components for the Two-Dimensional Stress σ in the Mohr Circle Sign Convention | 165 | Table 10.2 | Aspect Ratio | 285 |
| Table 7.3 | Components for the Three-Dimensional Stress σ in the Mohr Circle Sign Convention | 168 | Table 10.3 | Tightness of Folding | 286 |
| Table 7.4 | Notation for Stress | 191 | Table 10.4 | Bluntness of Folds | 287 |
| Table 7-4.1 | Sign Conventions for Stress Components | 187 | Table 10.5 | Style of a Folded Layer | 289 |
| Table 9.1 | Stress Interpretation of Fractures in Folds | 254 | Table 12.1 | Extensional Strain of a Material Line | 322 |
| Table 9-1.1 | Mechanical Properties of Sediment during Burial and Uplift | 244 | Table 12-2.1 | Strain versus Stress Terminology | 347 |
| | | | Table 12-2.2 | Antonym Pairs: Strain versus Stress Terminology | 348 |
| | | | Table 16.1 | Examples of Material Constants for Steady-State Power-Law Flow of Selected Rocks in the Moderate-Stress Regime | 488 |
| | | | Table 17.1 | Dominant Slip Systems of Some Common Minerals | 510 |
| | | | Table 18.1 | Scale Factors for Selected Variables in Mechanics | 547 |