## CONTENTS

List of Contributors  
Preface

### 1 INTRODUCTION TO FRACTURE MECHANICS AND ITS GEOPHYSICAL APPLICATIONS

Barry Kean Atkinson

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Concepts, Definitions and Theory</td>
<td>4</td>
</tr>
<tr>
<td>1.3</td>
<td>Overview of Geophysical Applications</td>
<td>18</td>
</tr>
<tr>
<td>1.4</td>
<td>Future Perspectives</td>
<td>20</td>
</tr>
<tr>
<td>1.5</td>
<td>Plan of this Volume</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>23</td>
</tr>
</tbody>
</table>

### 2 JOINTS AND SHEAR FRACTURES IN ROCK

Terry Engelder

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Introduction</td>
<td>27</td>
</tr>
<tr>
<td>2.2</td>
<td>Historical Background</td>
<td>27</td>
</tr>
<tr>
<td>2.3</td>
<td>The Isolated Crack</td>
<td>29</td>
</tr>
<tr>
<td>2.4</td>
<td>Microcracks</td>
<td>31</td>
</tr>
<tr>
<td>2.5</td>
<td>Joints: Record of a Rupture</td>
<td>33</td>
</tr>
<tr>
<td>2.6</td>
<td>Recracking</td>
<td>41</td>
</tr>
<tr>
<td>2.7</td>
<td>Shear Fracturing</td>
<td>44</td>
</tr>
<tr>
<td>2.8</td>
<td>Patterns of Multiple Fractures and Joints</td>
<td>51</td>
</tr>
<tr>
<td>2.9</td>
<td>Loading Conditions Leading to Propagation of Joints</td>
<td>59</td>
</tr>
<tr>
<td>2.10</td>
<td>Conclusions</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>65</td>
</tr>
</tbody>
</table>

### 3 THEORY OF CRACK INITIATION AND PROPAGATION IN ROCK

Anthony R. Ingraffea

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>71</td>
</tr>
<tr>
<td>3.2</td>
<td>Crack Initiation</td>
<td>74</td>
</tr>
<tr>
<td>3.3</td>
<td>Crack Propagation</td>
<td>90</td>
</tr>
<tr>
<td>3.4</td>
<td>Notes on Implementation of Crack Initiation and Propagation Theories</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>108</td>
</tr>
</tbody>
</table>
CONTENTS

4 THE THEORY OF SUBCRITICAL CRACK GROWTH WITH APPLICATIONS TO MINERALS AND ROCKS 111
Barry Kean Atkinson and Philip George Meredith

4.1 Introduction 111
4.2 Micromechanisms of Fracture 114
4.3 Mechanisms of Subcritical Crack Growth 117
4.4 Constitutive Modelling of Subcritical Crack Growth 125
4.5 Overview of Experimental Data 136
4.6 Extrapolation of Subcritical Crack Growth Data to the Crustal Environment 149
4.7 Requirements for Further Studies 161
References 162

5 TIME-DEPENDENT DEFORMATION AND FAILURE 167
Laurence S. Costin

5.1 Introduction 167
5.2 Microcrack Growth 169
5.3 Prediction of Rate-dependent Properties 181
5.4 Closure 210
References 211

6 FRAC TURE MECHANICS APPROACH TO HYDRAULIC FR acturing STRESS MEASUREMENTS 217
F. Rummel

6.1 Introduction 217
6.2 Experimental Observations 218
6.3 Fracture Mechanics Approach to Hydraulic Fracturing 228
6.4 Application of Fracture Mechanics to Experimental Results 237
6.5 Concluding Comments 238
References 239

7 FRAC TURE MECHANICS APPLIED TO HOT, DRY ROCK GEOTHERMAL ENERGY 241
Hideaki Takahashi and Hiroyuki Abe

7.1 Introduction 241
7.2 Theoretical Consideration of the Behaviour of Artificial Cracks 242
7.3 Fracture Behaviour of Crustal Rock Mass 249
7.4 Concluding Remarks 272
References 275

8 THEORETICAL DISPLACEMENTS AND STRESSES NEAR FRACTURES IN ROCK: WITH APPLICATIONS TO FAULTS, JOINTS, VEINS, DYES, AND SOLUTION SURFACES 277
David D. Pollard and Paul Segall

8.1 Introduction 277
8.2 Elementary Elastic Crack Theory 281
8.3 The Displacement Field 294
8.4 The Stress Field 305
8.5 Approximate Fields in Special Regions 321
8.6 Applications to Selected Problems in Structural Geology and Tectonics 329
References 347

9 MECHANICS OF SHEAR RUPTURE APPLIED TO EARTHQUAKE ZONES 351
Victor C. Li

9.1 Introduction 351
9.2 Shear Fracture Mechanics 354
9.3 Slip-Weakening Model of Shear Rupture 366
9.4 Slip Distributions and Interactions 398
9.5 Summary and Conclusion 424
References 425

10 DYNAMIC ROCK FRAGMENTATION 429
D. E. Grady and M. E. Kipp

10.1 Dynamic Fracture Strength 431
10.2 Dynamic Fracture and Fragmentation 468
References 472

11 EXPERIMENTAL FRACTURE MECHANICS DATA FOR ROCKS AND MINERALS 477
Barry Kean Atkinson and Philip George Meredith

11.1 Introduction 477
11.2 Experimental Constraints and Limitations 478
11.3 Experimental Methods 483
11.4 Experimental Data 517
References 519

x

xi