CONTENTS

List of Contributors v
Foreword vii

Current Deformations of the Earth's Crust

P. Melchior

1. Introduction 2
2. Expression of the Deformations Produced by an External Potential on a Point at the Earth's Surface 5
3. Form of the Luni-Solar Potential 14
4. Expansion of the Potential in Its Principal Waves 23
5. Deformations of an Elastic Semi-Infinite Body Limited by a Plane Surface 28
6. Study of an Elastic Sphere Subjected to Deformation 35
7. Measuring Instruments 43
8. Some Results of Recent Observations 60

References 76

On The Upper Mantle

P. Caloi

1. Introduction 80
2. The Earth's Crust 87
3. Asthenosphere and Pa, Sa Waves 142
4. The "20° Discontinuity" 167
5. Attenuation and Mixed Zones 175
6. Free Oscillations of the Earth and Its Outer Shell 181
7. Earth's Internal Movements and Volterra's Theory 189

References 203

Wind Stress along the Sea Surface

E. B. Kraus

1. Introduction: The Transfer of Kinetic Energy 213
2. The Atmospheric Boundary Layer 215
3. Waves at the Interface 224

4. The Transfer of Momentum from Waves to Currents 241
5. Conclusions and Questions 245
Appendix 247
List of Symbols 251
References 253

Severe Convective Storms

CHESTER W. NEWTON

1. Introduction 257
2. General Thunderstorm Structure 259
3. Modes of Convection 262
4. The Severe Thunderstorm Environment and Its Modification 270
5. Thunderstorms in a Sheared Environment 273
6. Storm Movement 287
7. Squall Lines 291
8. Severe Weather Manifestations 296
9. Conclusion 301
List of Symbols 303
References 303

The Rise of Oxygen in the Earth's Atmosphere with Notes on the Martian Atmosphere

L. V. BERKNER and L. C. MARSHALL

1. Underlying Principles 309
2. Oxygenic Concentration in the Primitive Atmosphere of the Earth 310
3. Surface Oxidation in the Primitive Atmosphere 315
4. Ecology for Photosynthetic Oxygen Production in a Primitive Terrestrial Atmosphere 317
5. The First Critical Level—$O_2 \rightarrow 0.01$ P.A.L. 319
6. Identification of First Critical Level with Opening of Paleozoic Era 320
7. The Second Critical Level—$O_2 \rightarrow 0.1$ P.A.L.—the Late Silurian .. 321
8. Oxygenic Levels in the Late Paleozoie and Ensuing Eras 321
9. Further Refinement of the Model 323
10. Estimates of the Composition of the Martian Atmosphere and Surface 324
11. Life on Mars 328
12. A General Theory of Origin and Planetary Atmospheres 329
References 330

The Theory of Available Potential Energy and a Variational Approach to Atmospheric Energetics

JOHN A. DUTTON AND DONALD R. JOHNSON

1. Introduction 334
2. An Exact Theory of the Concept of Available Potential Energy 341
3. Applications to Observational Data 373
4. Variational Methods in Available Energy Theory 389
5. Contributions to the Amount of Available Potential Energy and Its Relationship to Other Quantities 398
6. The Dynamics of the General Circulation 412
7. Conclusion 430
List of Symbols 431
References 434

AUTHOR INDEX 437
SUBJECT INDEX 443

CURRENT DEFORMATIONS OF THE EARTH'S CRUST

P. Melchior

Royal Observatory of Belgium, University of Louvain, Brussels, Belgium

Page

1. Introduction 2
   1.1. Measurement Units Selected 4
2. Expression of the Deformations Produced by an External Potential on a Point at the Earth's Surface 5
   2.1. Basic Data 5
   2.2. Elastic Deformations of the Earth 7
   2.3. Components of the Deformation Tensor 8
   2.4. Deviations of the Vertical with Respect to the Earth's Crust 10
   2.5. Variations of Gravity 11
   2.6. Cubic Dilatations 12
   2.7. The Case of a Homogeneous Incompressible Earth 13
3. Form of the Luni-Solar Potential 14
   3.1. Amplitude of the Perturbations as a Function of Latitude 14
   3.2. Characteristics of the Three Kinds of Tide in the Various Components 20
   3.3. The Precession and Nutations Deduced from Tidal Forces 21
4. Expansion of the Potential in Its Principal Waves 23
   4.1. Analysis and Prediction of Earth Tides 23
   4.2. Distribution of Deformations around a Given Point of the Earth's Globe 25
   4.3. Deformations Relating to the Semidiurnal Sectorial Forces 26
5. Deformations of an Elastic Semi-infinite Body Limited by a Plane Surface 28
   5.1. Evaluation of the Effects of Deformation 28
   5.2. Terazawa's Problem 30
6. Study of an Elastic Sphere Subjected to Deformation 35
   6.1. The Two Deformations 35
   6.2. Application to a Plane Surface Bearing an Alternating Series of Parallel Mountain Chains and Valleys 38
7. Measuring Instruments 43
   7.1. Clinometers 43
   7.2. Gravimeters 50
   7.3. Difficulties Encountered in Interpretation of Gravimeter Results—Comparison With the Results of Horizontal Pendulums 54
   7.4. High-Precision Equipment Needed for First-Order Stations 57
8. Some Results of Recent Observations 60
   8.1. Indirect Effects of Tides 60
   8.2. Direct Observations of Current Deformations of the Earth's Crust 60
   8.3. Hydrological Effects: Deformations of the Ground due to Variations of the Level of the Meuse at Sclaigneaux 62
   8.4. Atmospheric and Hydrological Effects in Leveling 67
   8.5. Atmospheric Effects 69
   8.6. Frequency Dependence of Flexure 74
   8.7. Particle Accelerators in Nuclear Physics 74

References 76

ON THE UPPER MANTLE

P. Caloi

Istituto Nazionale di Geofisica, University of Rome

	Page
1. Introduction	80
1.1. The Upper Mantle	80
1.2. Problems of the Upper Mantle	80
1.3. Composition of the Upper Mantle	80
2. The Earth's Crust	87
2.1. General	87
2.2. Use of the Body Waves	87
2.3. Determination of Structural Features of the Earth's Crust by Studying Surface Waves	112
3. Asthenosphere and Pa, Sa waves	142
3.1. General	142
3.2. The Asthenosphere as Channel Guide of Seismic Energy	143
3.3. Dynamic Features of the Asthenosphere Channel	145
3.4. Real Velocities of Pa, Sa Waves	145
3.5. Channeling as a Phenomenon Concerning the Upper Mantle and the Crust	149
3.6. Channeling in Case of Deep Earthquakes	150
3.7. Discussion of Pa, Sa Waves	152
3.8. The Problem of Viscosity	154
3.9. Explanation of the Shadow Zone, Apart from Channeling	159
3.10. Shadow Zone and Channeling Zone	163
4. The "20° Discontinuity"	167
4.1. Discussion of the "20° Discontinuity"	167
4.2. The Asthenosphere and the 20° Discontinuity	168
4.3. Consequences of the Existence of the 20° Discontinuity	171
5. Attenuation and Mixed Zones	175
5.1. Introduction	175
5.2. Attenuation and Internal Friction	176
5.3. Attenuation and Mixed Zones	178
6. Free Oscillations of the Earth and Its Outer Shell	181
6.1. Free Oscillations of the Earth	181
6.2. Distribution of Earthquake Energy	182
6.3. Distribution of Seismic Energy between Body Waves and Surface Waves	182
6.4. Possibility of Free Oscillations of the Outer Shell of the Earth	183
6.5. Periods of Outer Shell of the Earth	183
6.6. Observation of Periods of Same Order as Those of Section 6.5.	185
7. Earth's Internal Movements and Volterra's Theory	189
7.1. Polar Movements, Continental Shifts, and Subcrustal Currents	189
7.2. Volterra's Theory of the Earth's Internal Movements	192
References	203

WIND STRESS ALONG THE SEA SURFACE*

E. B. Kraus

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Page

1. Introduction: The Transfer of Kinetic Energy 213
2. The Atmospheric Boundary Layer 215
   2.1. The Region of Constant Stress over a Fluid Interface 215
   2.2. The Effect of Density Variation 219
   2.3. The Role of Bubbles and Spray in Momentum Transfer 222
3. Waves at the Interface 224
   3.1. General Aspects of Wave Processes 225
   3.2. Surface Waves on Deep Water 226
   3.3. Motion within the Interface 230
   3.4. The Generation of Wind Waves 232
   3.5. The Effect of Waves on Wind Profiles 237
4. The Transfer of Momentum from Waves to Currents 241
   4.1. The Problem of Wave Decay 241
   4.2. Slicks and Three-Dimensional Perturbations of the Boundary Layer 242
5. Conclusions and Questions 245

Appendix 247

List of Symbols 251

References 253

SEVERE CONVECTIVE STORMS

Chester W. Newton

National Center for Atmospheric Research, Boulder, Colorado

Page

1. Introduction 257
2. General Thunderstorm Structure 259
3. Modes of Convection 262
   - 3.1. Parcel Convection 262
   - 3.2. Modified Concepts of Convection 264
   - 3.3. "Bubble" Convection 266
   - 3.4. Continuous Draft Convection 268
   - 3.5. Remarks on the Different Viewpoints 269
4. The Severe Thunderstorm Environment and Its Modification 270
5. Thunderstorms in a Sheared Environment 273
   - 5.1. Dynamical Interaction between Storm and Environment 274
   - 5.2. Organized Convective Circulations 277
   - 5.3. "Steady State" Severe Storms 281
   - 5.4. Size Sorting and Recirculation of Precipitation Particles 284
6. Storm Movement 287
   - 6.1. Single-Celled Storms 287
   - 6.2. Influence of Propagation on Movement of Large Storms 287
   - 6.3. Size Discrimination in Relation to Water Budget 288
7. Squall Lines 291
   - 7.1. General Structure 291
   - 7.2. Migration of Storms within Lines and Regeneration Pattern 293
   - 7.3. Over-all Aspects of a Mature Squall-Line System 294
8. Severe Weather Manifestations 296
   - 8.1. Hail 296
   - 8.2. Lightning 297
   - 8.3. Surface Winds 297
   - 8.4. Tornadoes 298
   - 8.5. Heavy Rains 300
   - 8.6. Hazards to Aircraft 300
9. Conclusion 301

List of Symbols 303

References 303

THE RISE OF OXYGEN IN THE EARTH'S ATMOSPHERE WITH NOTES ON THE MARTIAN ATMOSPHERE*†

L. V. Berkner and L. C. Marshall

Southwest Center for Advanced Studies, Dallas, Texas

Page

1. Underlying Premises 309
2. Oxygenic Concentration in the Primitive Atmosphere of the Earth 310
3. Surface Oxidation in the Primitive Atmosphere 315
4. Ecology for Photosynthetic Oxygen Production in a Primitive Terrestrial Atmosphere 317
5. The First Critical Level—$O_2 \rightarrow 0.01$ P.A.L. 319
6. Identification of First Critical Level with Opening of Paleozoic Era 320
7. The Second Critical Level—$O_2 \rightarrow 0.1$ P.A.L.—the Late Silurian 321
8. Oxygenic Levels in the Late Paleozoic and Ensuing Eras 321
9. Further Refinement of the Model 323
10. Estimates of the Composition of the Martian Atmosphere and Surface 324
11. Life on Mars 328
12. A General Theory of Origin of Planetary Atmospheres 329

References 330

THE THEORY OF AVAILABLE POTENTIAL ENERGY AND A VARIATIONAL APPROACH TO ATMOSPHERIC ENERGETICS

John A. Dutton*

Department of Meteorology, The Pennsylvania State University
University Park, Pennsylvania

and

Donald R. Johnson

Department of Meteorology, The University of Wisconsin, Madison, Wisconsin

Page

1. Introduction 334
   1.1. History of the Concept of Available Potential Energy 335
   1.2. The Concept of Available Potential Energy 335
   1.3. Generalization of Reference States 336
   1.4. Present Expressions for the Amount of Available Potential Energy 338
   1.5. Available Potential Energy and General Circulation Theories 339
   1.6. Purpose of This Article 341
2. An Exact Theory of the Concept of Available Potential Energy 341
   2.1. The Basis of the Concept 342
   2.2. Assumptions and Fundamental Relations 346
   2.3. Properties of the Reference State 347
   2.4. The Amount of Available Potential Energy 351
   2.5. The Rate of Change of $\bar{A}$ 355
   2.6. Available Potential Energy in Atmospheres with Static Instabilities 358
   2.7. Generation and Destruction of Available Potential Energy by Diabatic Processes 361
   2.8. Total Diabatic Generation and Frictional Dissipation 370
3. Applications to Observational Data 373
   3.1. The Amount of Available Potential Energy 374
   3.2. The Region of Maximum Contribution to $\bar{A}$ 378
   3.3. The Structure of the Reference State 379
   3.4. Average and Transient Components 380
   3.5. Comparison of Numerical Results from Exact and Approximate Expressions 381
   3.6. The Energy Budget of the Atmosphere 387
4. Variational Methods in Available Energy Theory 389
   4.1. Introduction to Variational Methods 389
   4.2. Necessary Conditions for Minima of the Total Potential Energy 390
   4.3. Comment on Sufficient Conditions 395
   4.4. Variational Approach to the Energy Available for Meridional Flow 396

* Formerly with the Environmental Technical Applications Center, U.S. Air Force (previously, Climatic Center, U.S. Air Force), Washington, D.C.

Page

5. Contributions to the Amount of Available Potential Energy and its Relationship to Other Quantities 398
   5.1. Contributions from Hydrostatic Defects 398
   5.2. Barotropic Atmospheres and Available Energy 401
   5.3. Relationships to Other Quantities 405
   5.4. The Importance of Variable Static Stability 409
   5.5. Energy Available to Perturbations 410
6. The Dynamics of the General Circulation 412
   6.1. Extrema of the Total Potential Energy 412
   6.2. Least Action Principles and the General Circulation 413
   6.3. Applications to Rotating Convection Experiments 416
   6.4. The Role of Available Potential Energy 424
   6.5. Use of the Least Action Principle 429
7. Conclusion 430

List of Symbols 431

References 434