

# Contents

Foreword xi

## PART I

### Geomorphology and Its Tools 3

## 1 Earth's Dynamic Surface 5

### Introduction 5

#### Geosphere 6

Isostasy 6

Tectonics 11

Lithology and Structure 13

#### Hydrosphere 14

Climate and Climate Zones 14

Hydrologic Cycle 16

#### Biosphere 16

Geographical Distribution of

Ecosystems 18

Humans 20

#### Landscapes 20

Process and Form 22

Spatial Scales 22

Temporal Scales 23

#### Unifying Concepts 24

Conservation of Mass 24

Conservation of Energy 24

Material Routing 24

Force Balances and Thresholds 25

Equilibrium and Steady State 27

Recurrence Intervals and Magnitude-Frequency Relationships 28

Applications 28

Selected References and Further Reading 30

Digging Deeper: Why Is Earth Habitable? 31

Worked Problem 34

Knowledge Assessment 34

#### A Brief History of Geomorphology 36

## 2 Geomorphologist's Tool Kit 43

### Introduction 43

#### Characterizing Earth's Surface 44

Field Surveys 44

Active Remote Sensing 46

Passive Remote Sensing 47

Digital Topographic and Landscape Analysis 47

#### Relative Dating Methods 48

Landform Degradation 48

Rock Weathering and Soil Development 50

Rock Varnish 50

Calibrated Relative Dates 50

#### Numerical Dating Methods 52

Dendrochronology 52

Radiocarbon Dating 53

K/Ar Dating 54

U/Th Dating 56

Luminescence Dating 56

In-Situ Cosmogenic Nuclide Analysis 58

#### Measuring Rates of Geomorphic Processes 59

Sediment Generation Versus Sediment Yield 59

Landscape Change at Outcrop and

Hillslope Scales 61

Landscape Change at Basin Scales 63

Erosion Rates over  $10^6$  to  $10^8$  Year

Timescales 63

#### Experiments 63

Field Experiments 63

Laboratory Experiments 65

Numerical Models 66

#### Proxy Records 66

Applications 67

Selected References and Further Reading 68

Digging Deeper: How Does a Dating

Method Develop? 69

Worked Problem 72

Knowledge Assessment 72

## PART II

### Source to Sink 75

## 3 Weathering and Soils 77

### Introduction 77

#### Physical Weathering 80

Exfoliation 80

Freeze-Thaw 82

Thermal Expansion 82

Wetting and Drying 83

**Chemical Weathering 83**

- Mineral Stability 84
- Oxidation and Reduction 85
- Solution 85
- Hydrolysis 86
- Clay Formation 87
- Hydration 88
- Chelation 89
- Cation Exchange 89

**Soils 89**

- Soil-Development Processes 89
- Factors Affecting Soil Development 90
- Processes and Rates of Soil Production 91
- Soil Profiles 91
- Soil Classification 95

**Soils and Landscapes 99**

- Soil Development over Time 99
- Soil Catenas 99
- Paleosols 100

**Weathering-Dominated Landforms 101**

- Inselbergs and Tors 102
- Duricrusts 103
- Applications 104
- Selected References and Further Reading 105
- Digging Deeper: How Fast Do Soils Form? 106
- Worked Problem 109
- Knowledge Assessment 110

**4 Geomorphic Hydrology 111****Introduction 111****Precipitation 112**

- Duration and Intensity 113
- Recurrence Intervals 113
- Precipitation Delivery 114
- Climate Effects on Hydrology and Geomorphology 115

**Evapotranspiration 116**

- Evapotranspiration Rates 116
- Actual Versus Potential Evapotranspiration 116
- Geomorphic Importance of Evapotranspiration 116

**Groundwater Hydrology 118**

- Infiltration: Moving Water into the Ground 119
- Moving Water Through Earth Materials 120
- Hydrologic Flowpaths 122

**Surface Water Hydrology 126**

- Hydrographs 126
- Interactions Between Groundwater and Surface Flow 129
- Flood Frequency 130
- Water Budgets 132

**Hydrologic Landforms 133**

- Applications 137
- Selected References and Further Reading 137
- Digging Deeper: Humans, Hydrology, and Landscape Change—What's the Connection? 138
- Worked Problem 141
- Knowledge Assessment 142

**5 Hillslopes 145****Introduction 145****Slope-Forming Materials 146**

- Strength of Rock and Soil 147
- Effects of Weathering on Rock Strength 149

**Diffusive Processes 150**

- Rainsplash 150
- Sheetwash 151
- Soil Creep 151

**Mass Movements 153**

- Slides 154
- Flows 156
- Falls 158

**Slope Stability 159**

- Driving and Resisting Stresses 159
- Infinite-Slope Model 160
- Environmental and Time-Dependent Effects 161

**Slope Morphology 163**

- Weathering-Limited (Bedrock) Slopes 163
- Transport-Limited (Soil-Mantled) Slopes 165
- Threshold Slopes 166
- Hillslope Evolution 166
- Drainage Density 166
- Box 5.1 Derivation of the Form of Convex Hillslope Profiles 167
- Channel Initiation 170
- Applications 172
- Selected References and Further Reading 173
- Digging Deeper: How Much Do Roots Contribute to Slope Stability? 174
- Worked Problem 177
- Knowledge Assessment 178

**6 Channels 179****Introduction 179****External Controls on Fluvial Processes and Form 180**

- Discharge 181
- Sediment Supply 181

- Bed and Bank Material 181
- Vegetation 184

### Fluvial Processes 185

- Flow Velocity 185
- Discharge Variability 187
- Stream Power 189
- Box 6.1 Derivation of Stream Power 189
- Bedrock Incision 189
- Channel Migration 191

### Sediment Transport 194

- Initiation of Transport 194
- Sediment Loads 197
- Bedforms 198

### Channel Patterns 199

- Straight and Sinuous Channels 200
- Meandering Channels 201
- Braided Channels 201
- Anastomosing Channels 201

### Channel-Reach Morphology 202

- Colluvial Reaches 202
- Bedrock Reaches 202
- Alluvial Reaches 202
- Large Organic Debris 204

### Floodplains 205

### Channel Response 207

- Applications 208
- Selected References and Further Reading 209
- Digging Deeper: What Controls Rates of Bedrock River Incision? 211
- Worked Problem 214
- Knowledge Assessment 214

## 7 Drainage Basins 217

### Introduction 217

### Basin-Scale Processes 219

- Sediment Budgets 219
- Sediment Routing and Storage 222

### Channel Networks and Basin Morphology 223

- Drainage Patterns 223
- Channel Ordering 225
- Downstream Trends 225

### Uplands to Lowlands 227

- Process Domains and Valley Segments 228
- Longitudinal Profiles 230
- Channel Confinement and Floodplain Connectivity 231

- Box 7.1 River Longitudinal Profiles 232
- Downstream Trends 232

### Drainage Basin Landforms 233

- Knickpoints 233
- Gorges 234
- Terraces 235
- Fans 237
- Lakes 239

### Applications 240

- Selected References and Further Reading 244
- Digging Deeper: When Erosion Happens, Where Does the Sediment Go? 245
- Worked Problem 250
- Knowledge Assessment 251

## 8 Coastal and Submarine Geomorphology 253

### Introduction 253

### Coastal Settings and Drivers 254

- Tectonic Setting 254
- Sea-Level Change 254
- Salinity 256
- Substrate and Sediment Supply 256
- Tides 257
- Waves 259

### Coastal Processes and Landforms 264

- Rocky Coasts 264
- Beaches and Bars 266
- Spits, Tidal Deltas, and Barrier Islands 268
- Lagoons, Tidal Flats, and Marshes 270
- Estuaries 271
- Deltas 272
- Coastal Rivers 274

### Marine Settings and Drivers 274

- Currents 275
- Marine Sedimentation 276
- Dissolved Load 276

### Marine Landforms and Processes 276

- Continental Margins 277
- Abyssal Basins 278
- Mid-Ocean Ridges 278
- Trenches 279
- Coral Reefs 279

### Applications 281

- Selected References and Further Reading 281
- Digging Deeper: What Is Happening to the World's Deltas? 283
- Worked Problem 286
- Knowledge Assessment 287

## PART III

**Ice, Wind, and Fire 289****9 Glacial and Periglacial Geomorphology 291****Introduction 291****Glaciers 294**

- Glacier Mass Balance 294
- Glacier Energy Balance 296
- Accumulation and Ablation of Glacial Ice 297
- Glacier Movement 299
- Thermal Character of Glaciers 302
- Glacial Hydrology 303

**Subglacial Processes and Glacial Erosion 305****Glacial Sediment Transport and Deposition 309**

- Subglacial Sediments and Landforms 309
- Ice-Marginal Sediments and Landforms 310
- Glacially Related Sediments and Landforms 311

**Glacial Landscapes, Landforms, and Deposits 313**

- Landforms of Alpine Glaciers 313
- Landforms of Ice Sheets 314
- Geomorphic Effects of Glaciation and Paraglacial Processes 315

**Periglacial Environments and Landforms 316**

- Permafrost 317
- Characteristic Periglacial Landforms and Processes 318
- Applications 322
- Selected References and Further Reading 323
- Digging Deeper: How Much and Where Do Glaciers Erode? 324
- Worked Problem 327
- Knowledge Assessment 328

**10 Wind as a Geomorphic Agent 329****Introduction 329****Air as a Fluid 331**

- Wind Patterns and Speeds 332
- Vertical Distribution of Wind Speed 333
- Settling Speed of Particles in Air 333

**Spatial Distribution of Wind-Driven Geomorphic Processes 334****Aeolian Processes 335**

- Disturbance 335
- Erosion 335
- Sediment Transport 337
- Deposition 341

**Aeolian Features, Landforms, and Deposits 342**

- Aeolian Erosional Features and Landforms 342
- Aeolian Transport Features and Landforms 343
- Aeolian Dust Deposits and Loess 347

## Applications 350

## Selected References and Further Reading 351

## Digging Deeper: Desert Pavements—The Wind Connection 352

## Worked Problem 354

## Knowledge Assessment 354

**11 Volcanic Geomorphology 355****Introduction 355****Distribution and Styles of Volcanism 356**

- Magma Chemistry and Volcano Morphology 359
- Tectonic Forcing and Volcanic Provinces 361

**Eruptive Mechanisms and Products 363**

- Lava Flows 363
- Pyroclastic Flows and Falls 365
- Volcanic Gases 366

**Eruption Sizes and Types 368****Volcanic Landscapes 368**

- Landscapes of Basaltic Volcanism 368
- Landscapes of Silicic Volcanism 371

**Processes of Volcanic Landform Evolution 372**

- Geomorphic Effects of Magma Intrusion 372
- Biologic Colonization 373
- Denudation and Aging 374
- Mass Movements 374
- Lahars 375
- Volcano-River Interaction 377
- Hydrologic Considerations 377
- Erosional Landforms 380

## Applications 381

## Selected References and Further Reading 382

## Digging Deeper: Geomorphic Effects of Volcano Sector Collapse 383

## Worked Problem 386

## Knowledge Assessment 387

## PART IV

**The Bigger Picture 389****12 Tectonic Geomorphology 391****Introduction 391****Tectonic Processes 392**

- Uplift and Isostasy 393
- Thermal and Density Contrasts 397

**Tectonic Settings 397**

- Extensional Margins and Landforms 399
- Compressional Margins and Landforms 401
- Transform Margins and Landforms 404
- Continental Interiors 404
- Structural Landforms 408

**Landscape Response to Tectonics 411**

- Coastal Uplift and Subsidence 412
- Rivers and Streams 413
- Hillslopes 413
- Box 12.1 Drainage Area-Slope Analysis 414
- Erosional Feedbacks 415
- Applications 417
- Selected References and Further Reading 417
- Digging Deeper: When and Where Did that Fault Last Move? 419
- Worked Problem 422
- Knowledge Assessment 423

**13 Geomorphology and Climate 425****Introduction 425****Records of a Changing Climate 427**

- Landform Records of Climate Change 427
- Lake and Marine Sediment 429
- Ice Cores 432
- Windblown Terrestrial Sediment 433

**Climate Cycles 434**

- Glacial Cycles 434
- Orbital Forcing 436
- Local Events—Global Effects 436
- Climate Variability Within a Climate State 438
- Short-Term Climate Changes 439

**Geomorphic Boundary Conditions 439**

- Precipitation and Temperature 440
- Vegetation, Fire, and Geomorphic Response 440
- Base Level 442

**Climatic Geomorphology 444**

- Köppen Climate Classification 445
- Climate-Related Landforms and Processes 445
- Relict Landforms 446

**Landscape Response to Climate 447**

- Glacial-Interglacial Changes 447
- Isostatic Responses 448
- Climatic Control of Mountain Topography 449
- Climate Change Effects 449

**Landscape Controls on Climate 452**

- Regional Climate 452
- Earth's Energy Balance 452
- Hydrologic Cycling 452
- The Atmosphere 454
- Applications 454
- Selected References and Further Reading 455
- Digging Deeper: Do Climate-Driven Giant Floods Do Significant Geomorphic Work? 457
- Worked Problem 459
- Knowledge Assessment 460

**14 Landscape Evolution 461****Introduction 461****Factors of Landscape Evolution 462**

- Tectonics 462
- Climate 463
- Topography 464
- Geology 465
- Biology 465

**Models of Landscape Evolution 467**

- Conceptual Models 467
- Physical Models 469
- Mathematical Models 469

**Landscape Types 471**

- Steady-State Landscapes 471
- Transient Landscapes 474
- Relict and Ancient Landscapes 478
- Basin Hypsometry and Landscape Form 479

**Rates of Landscape Processes 480**

- Uplift Rates 481
- Erosion Rates 481
- Spatial and Temporal Variability 483
- Applications 487
- Selected References and Further Reading 487
- Digging Deeper: Is This Landscape in Steady State? 490
- Worked Problem 493
- Knowledge Assessment 494

**Table of Variables T-1****Index I-1**