

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**