

The Periglacial Environment

Third Edition

Hugh M. French

The University of Ottawa



John Wiley & Sons, Ltd

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Contents

Preface to First Edition	xiii
Preface to Second Edition	xv
Preface to Third Edition	xvii
Acknowledgments	xix
Part I The Periglacial Domain	1
1 Introduction	3
1.1 The Periglacial Concept	3
1.2 Disciplinary Considerations	7
1.2.1 The Growth of Geocryology	7
1.2.2 The Changing Nature of Quaternary Science	8
1.2.3 Modern Periglacial Geomorphology	8
1.3 The Growth of Periglacial Knowledge	9
1.4 The Periglacial Domain	11
1.5 The Scope of Periglacial Geomorphology	13
1.5.1 Permafrost-Related Processes and Landforms	13
1.5.2 Azonal Processes and Landforms	14
1.5.3 Paleo-Environmental Reconstruction	14
1.5.4 Applied Periglacial Geomorphology	14
Advanced Reading	15
Discussion Topics	15
2 Periglacial Landscapes?	16
2.1 Introduction	16
2.2 Proglacial, Paraglacial or Periglacial?	16
2.3 Unglaciaded Periglacial Terrain	18
2.3.1 Beaufort Plain, Northwest Banks Island, Arctic Canada	18
2.3.2 Barn Mountains, Northern Interior Yukon Territory, Canada	22
2.4 Relict Periglacial Landscapes	25
2.4.1 Chalk Uplands, Southern England and Northern France	25
2.4.2 Pine Barrens, Southern New Jersey, Eastern USA	26
2.5 Conclusions	28
Advanced Reading	28
Discussion Topics	30
3 Periglacial Climates	31
3.1 Boundary Conditions	31
3.2 Periglacial Climates	32

3.2.1 High Arctic Climates	34
3.2.2 Continental Climates	38
3.2.3 Qinghai-Xizang (Tibet) Plateau	38
3.2.4 Alpine Climates	39
3.2.5 Climates of Low Annual Temperature Range	39
3.2.6 Antarctica: A Special Case	40
3.3 Ground Climates	40
3.3.1 The n-Factor	41
3.3.2 The Thermal Offset	42
3.4 Periglacial Climates and the Cryosphere	44
Advanced Reading	45
Discussion Topics	46
Part II Present-Day Periglacial Environments	47
4 Cold-Climate Weathering	49
4.1 Introduction	49
4.2 Ground Freezing	49
4.2.1 The Freezing Process	50
4.2.2 Ice Segregation	52
4.2.3 The Frozen Fringe	53
4.2.4 Frost Heave	54
4.3 Freezing and Thawing	55
4.4 The Ground-Temperature Regime	57
4.4.1 The Seasonal Regime	57
4.4.2 Short-Term Fluctuations	60
4.5 Rock (Frost?) Shattering	60
4.5.1 Frost Action and Ice Segregation	61
4.5.2 Frost Weathering Models	63
4.5.3 Insolation Weathering and Thermal Shock	64
4.5.4 Discussion and Perspective	67
4.6 Chemical Weathering	68
4.6.1 General	68
4.6.2 Solution and Karstification	69
4.6.3 Salt Weathering	72
4.7 Cryogenic Weathering	75
4.8 Cryobiological Weathering	79
4.9 Cryopedology	79
4.9.1 Cryosols	80
4.9.2 Soil Micromorphology	81
Advanced Reading	82
Discussion Topics	82
5 Permafrost	83
5.1 Introduction	83
5.1.1 Definition	83
5.1.2 Moisture and Ice within Permafrost	85
5.2 Thermal and Physical Properties	85
5.2.1 The Geothermal Regime	86
5.2.2 Physical Properties	89

5.2.3 Thermal Properties	90
5.3 How Does Permafrost Aggrade?	90
5.3.1 General Principles	91
5.3.2 The Illisarvik Drained-Lake Experiment	92
5.4 Distribution of Permafrost	94
5.4.1 Latitudinal Permafrost	95
5.4.2 Alpine (Mountain) Permafrost	98
5.4.3 Montane Permafrost of Central Asia and China	101
5.5 Relict Permafrost	103
5.5.1 Sub-Sea Permafrost	103
5.5.2 Relict (Terrestrial) Permafrost	103
5.6 Permafrost Hydrology	104
5.6.1 Aquifers	105
5.6.2 Hydrochemistry	106
5.6.3 Groundwater Icings	106
5.7 Permafrost and Terrain Conditions	107
5.7.1 Relief and Aspect	107
5.7.2 Rock Type	108
5.7.3 Vegetation	108
5.7.4 Snow Cover	109
5.7.5 Fire	110
5.7.6 Lakes and Surface Water Bodies	111
5.8 The Active Layer	111
5.8.1 The Transient Layer	112
5.8.2 The Stefan Equation	114
5.8.3 Active-Layer Thermal Regime	114
Advanced Reading	115
Discussion Topics	115
6 Surface Features of Permafrost	116
6.1 Introduction	116
6.2 Thermal-Contraction-Crack Polygons	116
6.2.1 Coefficients of Thermal Expansion and Contraction	116
6.2.2 Ice, Sand, and Soil Wedges	117
6.2.3 Development of the Polygon Net	119
6.2.4 Polygon Morphology	121
6.2.5 Controls Over Cracking	123
6.2.6 Climatic Significance	124
6.3 Organic Terrain	127
6.3.1 Palsas	128
6.3.2 Peat Plateaus	129
6.4 Rock Glaciers	129
6.4.1 Creeping Permafrost	130
6.4.2 Types and Distribution	131
6.4.3 Origin	131
6.5 Frost Mounds	134
6.5.1 Perennial-Frost Mounds	134
6.5.2 Hydraulic (Open) System Pingos	136
6.5.3 Hydrostatic (Closed) System Pingos	137
6.5.4 Other Perennial-Frost Mounds	140

6.5.5	Seasonal-Frost Mounds	140
6.5.6	Hydrolaccoliths and Other Frost-Induced Mounds	142
6.6	Active-Layer Phenomena	142
6.6.1	Bedrock Heave	143
6.6.2	Needle Ice	144
6.6.3	Cryoturbation and Frost Heave	144
6.6.4	Frost Sorting	146
6.6.5	Patterned Ground	148
	Advanced Reading	152
	Discussion Topics	152
7	Ground Ice	153
7.1	Introduction	153
7.2	Classification	154
7.2.1	Pore Ice	156
7.2.2	Segregated Ice	157
7.2.3	Intrusive Ice	158
7.2.4	Vein Ice	159
7.2.5	Other Types of Ice	159
7.3	Ice Distribution	159
7.3.1	Amounts	159
7.3.2	Distribution with Depth	161
7.3.3	Ice in Bedrock	162
7.3.4	Ice in Unconsolidated Sediments	162
7.4	Cryostratigraphy and Cryolithology	164
7.4.1	Cryostructures, Cryotextures, and Cryofacies	165
7.4.2	Epigenetic and Syngenetic Cryostructures	167
7.4.3	Thaw Unconformities	171
7.4.4	Ice Crystallography	173
7.4.5	Ice Geochemistry	173
7.4.6	Cryostratigraphy and Past Environments	175
7.5	Ice Wedges	176
7.5.1	Epigenetic Wedges	177
7.5.2	Syngenetic Wedges	179
7.5.3	Anti-Syngenetic Wedges	180
7.6	Massive Ice and Massive-Icy Bodies	181
7.6.1	Nature and Extent	181
7.6.2	Intra-Sedimental Ice	183
7.6.3	Buried Glacier Ice	184
7.6.4	Other Mechanisms	184
	Advanced Reading	184
	Discussion Topics	185
8	Thermokarst	186
8.1	Introduction	186
8.2	Causes of Thermokarst	187
8.2.1	General	187
8.2.2	Specific	189

8.3	Thaw-Related Processes	191
8.3.1	Thermokarst Subsidence	191
8.3.2	Thermal Erosion	191
8.3.3	Other Processes	193
8.4	Thermokarst Sediments and Structures	193
8.4.1	Involuted Sediments	193
8.4.2	Retrogressive-Thaw-Slumps and Debris-Flow Deposits	194
8.4.3	Ice-Wedge Pseudomorphs and Composite-Wedge Casts	195
8.4.4	Ice, Silt, Sand, and Gravel Pseudomorphs	198
8.5	Ice-Wedge Thermokarst Relief	198
8.5.1	Low-Centered Polygons	198
8.5.2	High-Centered Polygons	200
8.5.3	Badland Thermokarst Relief	201
8.6	Thaw Lakes and Depressions	201
8.6.1	Morphology	203
8.6.2	Growth and Drainage	203
8.6.3	Oriented Thaw Lakes	205
8.7	Thermokarst-Affected Terrain	206
8.7.1	The Lowlands of Central and Northern Siberia	207
8.7.2	The Western North American Arctic	209
8.8	Human-Induced Thermokarst	210
8.8.1	Causes	210
8.8.2	Case Studies	213
	Advanced Reading	215
	Discussion Topics	215
9	Hillslope Processes and Slope Evolution	216
9.1	Introduction	216
9.2	Slope Morphology	216
9.2.1	The Free-Face Model	217
9.2.2	Rectilinear Debris-Mantled Slopes	218
9.2.3	Convexo-Concavo Debris-Mantled Slopes	219
9.2.4	Pediment-Like Slopes	221
9.2.5	Stepped Profiles	223
9.3	Mass Wasting	224
9.4	Slow Mass-Wasting Processes	225
9.4.1	Solifluction	225
9.4.2	Frost Creep	227
9.4.3	Gelifluction	228
9.4.4	Solifluction Deposits and Phenomena	229
9.5	Rapid Mass Wasting	232
9.5.1	Active-Layer-Detachment Slides	232
9.5.2	Debris Flows, Slushflows, and Avalanches	233
9.5.3	Rockfall	235
9.6	Slopewash	237
9.6.1	Snow-Bank Hydrology	238
9.6.2	Surface and Subsurface Wash	239

9.7	Frozen and Thawing Slopes	241
9.7.1	Permafrost Creep	241
9.7.2	Thermokarst and Thaw Consolidation	242
9.7.3	Stability of Thawing Slopes	243
9.8	Cold-Climate Slope Evolution	244
9.8.1	Cryoplanation	244
9.8.2	Slope Replacement and Richter Denudation Slopes	246
9.8.3	Rapidity of Profile Change	246
9.8.4	Summary	247
	Advanced Reading	247
	Discussion Topics	247
10	Azonal Processes and Landforms	248
10.1	Introduction	248
10.2	Fluvial Processes and Landforms	248
10.2.1	Major Rivers	249
10.2.2	Freeze-Up and Break-Up	251
10.2.3	Basin Hydrology	254
10.2.4	Sediment Flow, Surface Transport, and Denudation	257
10.2.5	Fluvio-Thermal Erosion	260
10.2.6	Channel Morphology	260
10.2.7	Valley Asymmetry	263
10.3	Eolian Processes and Sediments	264
10.3.1	Wind Abrasion	265
10.3.2	Wind Deflation	268
10.3.3	Niveo-Eolian Sediments	268
10.3.4	Loess-Like Silt	269
10.3.5	Sand Dunes and Sand Sheets	270
10.4	Coastal Processes and Landforms	272
10.4.1	The Coastal–Sea-Ice Interface	272
10.4.2	Sea Ice, Wave Generation, and Sediment Transport	273
10.4.3	Ice on the Beach	275
10.4.4	The Influence of Permafrost and Ground Ice	276
10.4.5	Cold-Climate Deltas	277
	Advanced Reading	279
	Discussion Topics	279
Part III	Quaternary and Late-Pleistocene Periglacial Environments	281
11	Quaternary Periglacial Conditions	283
11.1	Introduction	283
11.2	The Time Scale and Climatic Fluctuations	283
11.3	Global (Eustatic) Considerations	287
11.3.1	Sea-Level Changes	287
11.3.2	Uplift of Qinghai-Xizang (Tibet) Plateau	290
11.4	Pleistocene Periglacial Environments of High Latitudes	291
11.4.1	Extent of Past Glaciations	291
11.4.2	Relict Permafrost	293
11.4.3	Syngenetic Permafrost Growth	294

11.4.4	Loess Deposition	295
11.4.5	Mass-Wasting and “Muck” Deposits	296
11.5	Pleistocene Periglacial Environments of Mid-Latitudes	298
11.5.1	General Considerations	298
11.5.2	Mammals and Ecosystems	300
11.5.3	Perennial or Seasonal Frost?	300
11.5.4	Problems of Paleo-Environmental Reconstruction	302
11.5.5	Extent in the Northern Hemisphere	302
11.5.6	Extent in the Southern Hemisphere	306
11.6	Conclusions	306
	Advanced Reading	307
	Discussion Topics	307
12	Evidence for Past Permafrost	308
12.1	Introduction	308
12.2	Past Permafrost Aggradation	308
12.2.1	The Paleo-Permafrost Table	308
12.2.2	Frost-Fissure Pseudomorphs and Casts	310
12.2.3	Frost-Mound Remnants	315
12.3	Past Permafrost Degradation	317
12.3.1	Thermokarst Depressions	317
12.3.2	Paleo-Thaw Layers	318
12.3.3	Thermokarst Involutions and Sediment-Filled Pots	318
12.3.4	Large-Scale Soft-Sediment Deformations	320
12.3.5	Non-Diastrophic Structures in Bedrock	322
12.3.6	Discussion	323
12.4	Summary	323
	Advanced Reading	325
	Discussion Topics	325
13	Periglacial Landscape Modification	326
13.1	Introduction	326
13.2	Intense Frost Action	327
13.2.1	Soil Wedges	327
13.2.2	Frost-Disturbed Bedrock	327
13.2.3	Stratified Slope Deposits	330
13.2.4	Head and Solifluction Deposits	331
13.2.5	Frost-Disturbed Soils and Structures (Involutions)	332
13.3	Intense Wind Action	334
13.3.1	Wind-Abraded Rocks	334
13.3.2	Eolian Silt (Loess)	335
13.3.3	Cold-Climate Eolian Sand	336
13.4	Fluvial Activity	337
13.4.1	Major Rivers	339
13.4.2	Asymmetrical Valleys	340
13.4.3	Dells and Periglacial Valleys	342
13.5	Slope Modification	343
13.5.1	Mass Wasting on Slopes	343
13.5.2	Valley-Bottom Aggradation	343
13.5.3	Smoothing of Slopes	346

Advanced Reading	348
Discussion Topics	348
Part IV Applied Periglacial Geomorphology	349
14 Geotechnical and Engineering Aspects	351
14.1 Introduction	351
14.2 Cold-Regions Engineering	352
14.2.1 General Principles	352
14.2.2 General Solutions	353
14.3 Provision of Municipal Services and Urban Infrastructure	358
14.4 Construction of Buildings and Houses	359
14.5 Water-Supply Problems	361
14.6 Roads, Bridges, Railways, and Airstrips	364
14.7 Oil and Gas Development	367
14.7.1 Exploration Problems	367
14.7.2 Waste-Drilling-Fluid Disposal Problems	368
14.7.3 Pipelines and Permafrost	369
14.8 Mining Activities	371
Advanced Reading	372
Discussion Topics	372
15 Climate Change and Periglacial Environments	373
15.1 Global Change and Cold Regions	373
15.2 Climate Change and Permafrost	375
15.2.1 Ground-Thermal Regimes	376
15.2.2 Thickness of the Active Layer	376
15.2.3 Extent of Permafrost	377
15.2.4 Changes in Cryogenic Processes	378
15.3 Other Responses	381
15.3.1 Seasonal-Snow Cover	381
15.3.2 Sea Ice and Sea Level	382
15.3.3 Gas Hydrates and Methane	382
15.3.4 Seasonally-Frozen Ground	383
15.3.5 Boreal Forest, Tundra, and Polar Desert Ecosystems	383
15.4 The Urban Infrastructure	384
15.5 Conclusions	386
Advanced Reading	386
Discussion Topics	387
References	388
Index	449

Preface to First Edition

This book is intended for use by second- and third-year level geography students in universities or colleges of higher education in the United Kingdom. It is also suitable as a text for an undergraduate course on periglacial geomorphology at the honors level in Canada and the United States. On a more general level, the book may prove useful to high school teachers and other individuals interested or specializing in the physical geography of cold regions. I have assumed, however, that the reader will already possess some understanding of the physical environment, such as might be provided by a first-year physical geography or elementary geomorphology course.

In writing this book I had two aims in mind. The first was to give a realistic appraisal of the nature of the geomorphic processes and landforms in high-latitude periglacial environments. The second was to provide some guide to the recognition and interpretation of periglacial features in the now temperate regions of North America and Europe. The regional emphasis is oriented towards areas of which I have personal field experience, notably the western Canadian Arctic, central Siberia, southern England, and central Poland. Thus, the overall focus is more towards lowland, rather than alpine, periglacial conditions. Notwithstanding this comment, I have attempted to give a balanced world picture; important literature pertaining to other areas has been incorporated.

The reasons for writing this book are also twofold. First, the majority of students will never have the opportunity to experience, at first hand, high-latitude periglacial environments. However, since cold conditions prevailed over large areas of middle latitudes at several times during the last one million years, the appreciation of such conditions is essential for a balanced interpretation of these landscapes. Second, the vast northern regions of North America and Siberia are assuming an ever-increasing importance in man's quest for natural resources. Their development will be possible only if we understand the terrain and climatic conditions of these regions. For both these reasons, I hope this book will serve a useful purpose.

I have divided the book into three parts. Part 1 is a general introduction to periglacial conditions in which the extent of the periglacial domain and the variety of periglacial climates are briefly considered. Part 2 presents a systematic treatment of the various geomorphic processes operating in present-day periglacial environments. Wherever possible, I have attempted to show the relationship between process and form and to stress the multivariate nature of many landforms. The sequence of chapters is important since they are planned to be read successively. Part 3 serves only as an introduction to Pleistocene periglacial phenomena. Emphasis in this part is upon forms rather than processes and their interpretation in the light of our understanding of similar phenomena in present-day periglacial environments.

I have not attempted to be comprehensive in my treatment of the literature. By selecting information, I have attempted to give a viewpoint. Inevitably, this viewpoint is biased to

reflect my own prejudices and field experience. For example, if I had worked extensively in alpine rather than high-latitude lowland environments, probably I would not have given the same emphasis to permafrost, ground ice and thermokarst as I do. However, I believe a viewpoint is necessary since my experience with students is that they require some guidance in coping with the increasing volume of literature which appears each year.

I would like to acknowledge the help and encouragement given me by a number of individuals and organizations, without which this book would not have been written. The late Professor Jan Dylik of the University of Łódź, Poland, provided me with much inspiration and encouragement in the early stages, as well as friendship and hospitality. He was instrumental in planning the organization of many of the chapters and it is to be regretted that his untimely death in 1973 did not permit him to see the final product. Professors Ron Waters and Stan Gregory of the University of Sheffield, England, were also extremely helpful in encouraging me to write this book and identifying its basic thrust. In Canada, the opportunity to work in the Arctic since 1968 has been made possible by the active support of the Geological Survey of Canada and the Polar Continental Shelf Project. Numerous individuals both in Canada and the United Kingdom have helped in many ways, by discussion, providing material, and reading some of the early draft chapters; they include R. J. E. Brown, M. J. Clark, J. G. Fyles, P. G. Johnson, D. Mottershead, A. Pissart, D. A. St-Onge, R. J. Small, and P. Worsley. To all, I extend my thanks.

Last, and most important of all, the unfailing encouragement and support of my wife, Sharon, is acknowledged with deep gratitude and affection.

Hugh M. French
Ottawa, 1976

Preface to Second Edition

When I drafted the first edition of *The Periglacial Environment* over twenty years ago, I had worked in the cold, non-glacial regions of the world for only six years, mostly in the Canadian Arctic. Having previously completed my graduate studies upon the Pleistocene periglacial phenomena found on the Chalklands of Southern England, I looked to the polar region of North America as a natural analogue for the cold-climate conditions which had largely fashioned the Chalk landscape. Now, after nearly twenty more years of field work in many of the so-called periglacial regions of the world, I am not sure that a simple analogue exists. Instead, I am impressed by the complexity and diversity of periglacial environments, both today and in the past.

The last twenty years has also seen a dramatic expansion in our understanding of the geomorphic conditions, especially permafrost, which typify these environments. A distinct process-oriented geomorphology, termed *geocryology* or *permafrost science*, has developed in North America and elsewhere, building largely but not exclusively upon Russian concepts and principles. There has also been an integration into periglacial geomorphology of modern instrumentation and technology. At the same time, rapid advances in Quaternary dating techniques mean that our understanding of Pleistocene events is now more precise.

Underlying much of our interest in the cold non-glacial regions of the world is an appreciation of the natural resources known to occur in such regions. For example, the oil and gas resources of the Western Siberian Plain, some of the largest in the world, necessitate an understanding of the tundra and taiga environments. Modern environmental protection attitudes dictate that the exploitation of these resources is undertaken in a manner which minimizes harmful impacts upon the terrain, flora, fauna, and indigenous peoples of these regions. The same is true in North America, and in many of the alpine periglacial regions of the world. Finally, the significance of the cryosphere, of which the periglacial domain is an important component, is now being examined in the context of ongoing and predicted global changes. For various reasons, it is thought that global climate changes will be first apparent and most magnified in the high latitudes. Hence, there is an urgent need for the monitoring of change in the boreal forest, tundra, and polar desert environments.

For all these reasons, a second edition of my earlier work is justified. My aim has been to incorporate the results of these new developments while at the same time not altering the overall level, scope and organization of the book. I have tried to maintain the original flavor and style; however, many chapters are new and others have been entirely rewritten. The volume also looks different since I have deliberately tried to incorporate a large number of new or different diagrams and photos. As with the first edition, my selection of material is deliberately subjective; I have not attempted a comprehensive coverage of the literature, and the book is certainly not meant to be reference text. Rather, the second

edition continues to be my own personalized view of the cold non-glacial environments of the world. There is a heavy emphasis upon those areas with which I have familiarity, such as the North American and Eurasian polar and mid-latitude lowlands. The alpine, high-altitude periglacial environments of middle and low latitude are not neglected but, because there is a relative abundance of accurate up-to-date information available elsewhere, I feel justified in my lack of emphasis in this area. A second omission in the coverage of this book, also apparent in the first edition, is the relative lack of examples from the southern hemisphere, especially the ice-free areas of Antarctica. Here, I plead my partial ignorance. Finally, the extensive periglacial region of the Qinghai-Xizang (Tibet) Plateau has so far not been adequately described in the western literature, yet it is the same size as the North American or Eurasian periglacial regions. Thus, I have attempted to incorporate, wherever appropriate, data from this unusual environment.

Throughout my academic career I have taught in the Departments of Geography and Geology at the University of Ottawa. This has been a fruitful and productive milieu for pursuing my periglacial interests. I have been fortunate in supervising, over the years, a number of talented and energetic graduate students and employing undergraduate field assistants, all without whom my visits to the Arctic would have been much lonelier and certainly less productive. In this regard, special mention and warm appreciation must be given to the stimulus provided by Paul Egginton, Toni Lewkowicz, David Harry, Wayne Pollard, Dana Naldrett, Lorne Bennett, Julian Murton, and Baolai Wang. They have contributed much to my understanding of the geomorphology and Quaternary geology of the cold non-glacial regions of the world. At the same time numerous colleagues, both in Canada and elsewhere, have encouraged me, or collaborated with me; these include Mike Clark, Jan Gozdzik, Cheng Guodong, Charlie Harris, Stuart Harris, Alan Heginbottom, Alfred Jahn, Johannes Karte, Vyacheslav Konishchev, Eduard Koster, J. Ross Mackay, Derek Mottershead, Troy Péwé, Albert Pissart, Anders Rapp, Nikolai Romanovskii, Mike Smith, and Link Washburn. Several colleagues, sadly no longer alive, have also influenced me: the late Roger J. E. Brown was instrumental in encouraging me to become more involved in the geotechnical aspects of permafrost, and in the administration of permafrost science and engineering in Canada; the late Brian Rust, my longtime friend and colleague in Geology at the University of Ottawa, always provided critical support and fostered in me an appreciation of Pleistocene and Recent sedimentation. Finally, NSERC and PCSP have generously provided operating grants and Arctic logistics respectively over a twenty-five year period, and I have received close support and cooperation from many officers of the Geological Survey of Canada and from the Department of Indian and Northern Affairs, both agencies located in Ottawa.

My secretary, Pierrette Gouin, has provided outstanding service in the preparation of the text.

To all mentioned above, I owe a debt of gratitude since this second edition is as much their work as it is mine.

Hugh M. French
Ottawa, 1995

Preface to Third Edition

It is more than 30 years since I wrote the first edition of this text. In hindsight, that was a bold, possibly premature, venture that justified the *Second Edition* in 1996. Now, the last 10 years has witnessed continued advances in periglacial geomorphology, geocryology and Quaternary science. These have been combined with a growing awareness of the importance of high latitudes in the context of global climate warming. It is now widely accepted that high latitudes will be significantly impacted. Several positive feedback mechanisms will accentuate climate warming. These include progressive shrinkage of the snow and sea-ice covers and the thaw-degradation of permafrost. The latter will release increasing amounts of greenhouse gases (CO₂, CH₄) into the atmosphere. A different group of recent concerns relate to the nine million or more people, mostly in Russia and northern Eurasia, who live in the periglacial environments. Their future health and economic well being are issues that need to be addressed. Closely linked is the fact that high latitudes contain significant natural resources, notably hydrocarbons and minerals, the future exploitation and development of which is almost inevitable. For all these reasons, there is a continued need to understand the periglacial environment, and a third edition is required.

Although the overall plan of the book remains the same, all chapters have been rewritten or reorganized. However, the balance of the text remains unchanged. There is a deliberate emphasis upon cold-climate weathering, permafrost, ground ice, and thermokarst (Chapters 4–8). This is because I believe these topics lie at the heart of periglacial geomorphology and supply the solid scientific base upon which the discipline rests.

The third edition continues to be my personalized view of the landscapes of the cold, non-glacial regions of the world. As before, it does not attempt a comprehensive coverage of the literature. At the same time, I have attempted to give a balanced interpretation. The professional reader may find fault in my treatment of certain controversial topics, such as cold-climate weathering, the relative importance of azonal versus permafrost-related processes, and global climate change. The geotechnical reader will find my treatment of ground freezing, certain geomorphic processes, and the engineering aspects, to be descriptive and somewhat superficial. Likewise, techniques of investigation, either in the field, laboratory, remotely-sensed, or involving numerical simulation, are brief. On the other hand, I hope that my treatment is sufficiently provocative and in-depth as to stimulate further research.

There are some areas where I have deliberately not ventured far. As in earlier editions, I have continued to emphasize high latitude, at the expense of alpine, periglacial environments. This is because other colleagues have more in-depth experience of the latter, especially in the mid-latitudes of the world, and of mountains. Glaciers, and surface snow and ice in general, I also leave to others, yet an understanding of these topics is clearly relevant to modern periglacial geomorphology. I am also conscious of the vast amount of Quaternary knowledge now available and the sophistication of dating and other

techniques. Therefore, I view my treatment of Pleistocene periglacial environments in Part III as merely an introduction to a highly specialized field that deserves separate treatment. The same must be said for Part IV. I have always been aware of the need to apply periglacial knowledge and believe that periglacial geomorphology should not be a narrowly focused academic discipline. Part IV serves as an introduction to a field that deserve separate and much fuller treatment elsewhere.

For nearly forty years, I have conducted field work in the cold, non-glacial environments of the high latitudes. Since publication of the *Second Edition*, I have undertaken additional fieldwork in Antarctica and Svalbard. I am grateful to the Italian Antarctic Program (PNRA) for providing the opportunity to work in Southern Victoria Land in the late 1990s, and to GAP Adventures for allowing me to visit the Falkland Islands, South Georgia, and many localities in the Antarctic Peninsula in 2005–2006. As regards Svalbard, I thank UNIS and Professor Ole Humlum for inviting me each spring between 1999 and 2004. In recent years, I also commenced Pleistocene periglacial investigations in the mid-latitudes of eastern North America, notably the Gaspésie Mountains of Québec, Canada, and the Pine Barrens of Southern New Jersey, USA. I have attempted to incorporate all these recent experiences into the third edition.

The *Second Edition* owed much to the research of my Arctic graduate students at the University of Ottawa. A number continue to provide me with inspiration. Equally important, in my role as Editor-in-Chief of *Permafrost and Periglacial Processes* (PPP) between 1990 and 2005, my interaction with numerous authors, reviewers and Editorial Board members has broadened significantly my understanding of periglacial geomorphology, geocryology, and Quaternary science. Finally, I have received invaluable support, guidance and encouragement from numerous good friends and colleagues, several of more than thirty years standing. The latter include the late Alfred Jahn, J. Ross Mackay, the late Troy Péwé, Albert Pissart, and Link Washburn. To all the above, I express my sincere thanks because you have all contributed, in numerous ways that you cannot recognize, to the third edition.

Finally, I thank Jill, who patiently allowed me the time to read, write, and travel in the periglacial world.

Hugh French
Ottawa, 2006

Acknowledgments

A number of individuals have generously allowed use of their photographs and other material in this edition. These are: Professor L. Eissmann (Figure 12.2), Dr J. Gozdzik (Figure 13.6), Professor O. Humlum (Figures 6.9B, 6.12), Professor V. N. Konishchev (Figure 4.12), Professor A. G. Lewkowicz (Figure 9.13), Professor J. R. Mackay (Figures 5.4, 7.3, 7.17), Professor D. N. Mottershead (Figure 13.3B), D. Nasagaloak (Figure 10.2C), Professor T. L. Péwé (dec.) (Figure 6.2), Professor M. Seppälä (Figure 6.8), Professor H. Svensson (Figure 12.5), Dr S. C. Zoltai (dec.) (Figure 6.20B), Dr R. Zurawek (Figure 13.3A).

PART I

The Periglacial Domain

1 Introduction

This chapter outlines the periglacial concept and the historical growth of periglacial geomorphology, and its interaction with geocryology, geomorphology, and Quaternary science. The core of periglacial geomorphology concerns the study of freezing processes, the associated ground ice, and related landforms. Permafrost occupies a central, but not defining, position. Periglacial geomorphology is a component of cold-region geomorphology and incorporates a mix of glacial, periglacial, and azonal processes that assume distinct characteristics in the cold non-glacial regions of the world.

Approximately one quarter of the earth's land surface currently experiences periglacial conditions. During the Pleistocene an additional one fifth was affected to greater or lesser extent.

1.1. THE PERIGLACIAL CONCEPT

The term “periglacial” was first used by the Polish geologist Walery von Lozinski in the context of the mechanical disintegration of sandstones in the Gorgany Range of the southern Carpathian Mountains, now part of central Romania (Lozinski, 1909, 1912). Subsequently, at the XI Geological Congress in Stockholm in 1910, he introduced the concept of a “periglacial zone” to describe the climatic and geomorphic conditions of areas peripheral to the Pleistocene ice sheets and glaciers. Theoretically, this was a tundra zone that extended as far south as the treeline. In the mountains, it was a zone between timberline and snowline (Figure 1.1).

Almost certainly, Lozinski was influenced by the Swedish geologist J. G. Andersson, who, a few years earlier (1906, pp. 94–97), had summarized his observations on mass-wasting on Bear Island (latitude 74°N), a cold, wet, and windswept island in the North Atlantic. It was Andersson who introduced the term “solifluction” to the scientific literature. He also described the “stone runs,” or quartzite blockfields, that characterize the valley-side slopes of the equally cold and damp Falkland Islands, located in the South Atlantic (Andersson, 1906, pp. 97–101). On hearsay alone, these phenomena had already been compared to the “rubble-drift” and “head” deposits of southern England by James Geikie (1894, pp. 722–723), who attributed the latter to a cold climate “more severe than the present.”

Lozinski referred to his rock-rubble accumulations as *periglacial facies*. He observed that similar deposits occurred on many of the upland massifs of central Europe. In subsequent years, coarse angular rock-rubble accumulations on upland slopes and summits were widely reported in the scientific literature. Today, they are usually referred to as blockstreams, blockfields, felsenmeer, or kurums.

Two criteria are regarded as diagnostic of periglacial environments. First, there is ground freezing and thawing. According to J. Tricart, “the periglacial morphogenetic

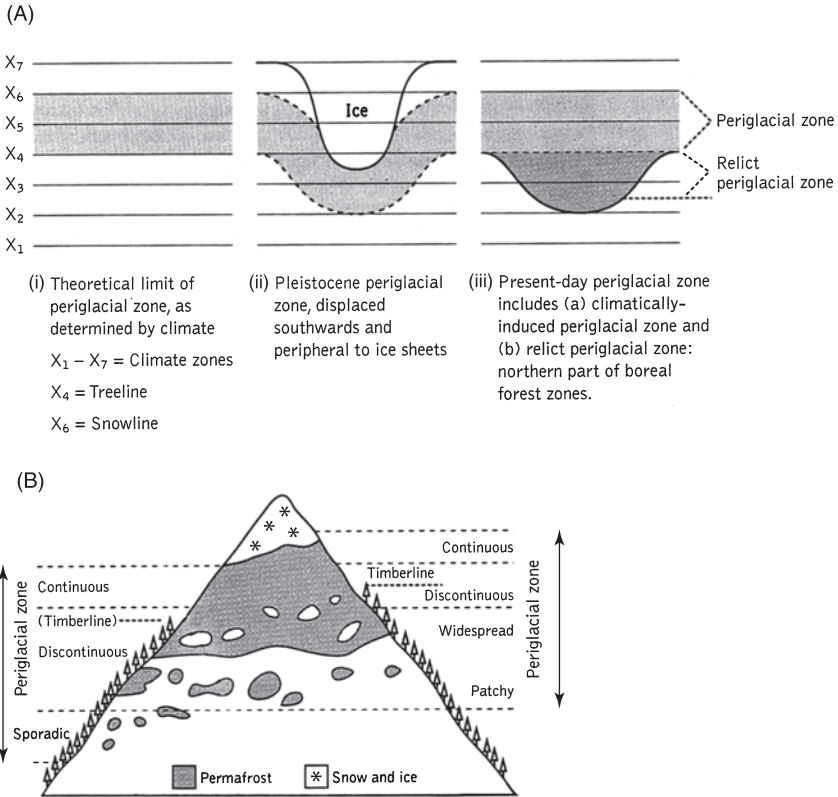


Figure 1.1. Schematic diagram illustrating limits of the periglacial zone: (A) high latitudes; (B) alpine areas.

milieu is that where the influence of freeze–thaw oscillations is dominant” (Tricart, 1968, p. 830). Second, there is the presence of perennially-frozen ground, or permafrost. According to T. L. Péwé, “permafrost is the common denominator of the periglacial environment, and is practically ubiquitous in the active periglacial zone” (Péwé, 1969, p. 4).

Periglacial geomorphology developed rapidly in the 1950–1970 period as a sub-discipline of a European-dominated climatic geomorphology (Büdel, 1963, 1977; Tricart, 1950, 1963; Tricart and Cailleux, 1967). During this period, the International Geographical Union (IGU) supported a Periglacial Commission under the leadership of Professor J. Dylík between 1952 and 1972. An international journal, *Biuletyn Peryglacjalny*, was started in Łódź, Poland, in 1954.

In hindsight, there were several weaknesses associated with the growth of periglacial geomorphology. First, there was a largely uncritical acceptance of mechanical (frost) weathering and of rapid cold-climate landscape modification. Second, the variability, duration, and severity of cold-climate conditions, both today and during the Quaternary, were not fully appreciated. Another concern was that insufficient consideration was given to the influence of lithology in controlling landforms. A final concern related to terminology. Although “cryo” terminology had been proposed earlier to reflect the cold-climate (cryogenic) processes involved (Bryan, 1946, 1949; Capello, 1959), the Pleistocene orientation of periglacial geomorphology led to acceptance of the term

“periglacial” (Dylik, 1964a; Dylikowa, 1962; Hamelin, 1964). This raised criticism because the term was used to refer to both processes and areas. The apparent misuse of the term led to the suggestion that it be replaced by more specific terms such as permafrost, ground-ice, or soil-ice environment (Linton, 1969). More recently, cryological terminology has been reintroduced (ACGR, 1988) in order to accommodate a major semantic problem posed by the thermal and physical states of water. The problem appears simple. Unfrozen water can exist in soil or rock at temperatures below 0°C due to the presence of mineral salts, pressure, or other causes. Because of this, “perennially-frozen ground” (i.e. ground at a temperature >0°C, or “cryotic” in nature) may not, in fact, be “frozen”. Thus, cryotic ground can be either “frozen” or “unfrozen” depending upon the amount of unfrozen water present. It follows that not all permafrost is necessarily frozen!

These terminological problems persist today. An obvious example is in the definition of the active layer proposed by the ACGR (1988). Traditionally, the active layer was defined as the near-surface layer above permafrost which thaws during summer (see Chapter 5). The ACGR definition would include the uppermost part of permafrost in those situations where either salinity or clay content allows permafrost to thaw and refreeze annually, even though the material remains cryotic (below 0°C). Under this definition, it is argued that the active layer cannot be determined consistently in time and space (Burn, 1998b) and the term is impossible to use effectively in the field. A partial solution has been to recognize a “transient layer” at the top of permafrost and at the base of the active layer (Shur et al., 2005). The active layer and the transient layer are discussed in detail in Chapter 5.

Today, the utility of the periglacial concept requires careful assessment. Lozinski referred to a specific and limiting environment that is not typical of the vast majority of periglacial environments today. In fact, few, if any, modern-day analogues can be identified (French, 2000). Lozinski also used the term to refer primarily to areas or regions. However, one may argue that typical “periglacial regions” do not exist, and, if they do, lack well-defined boundaries. Thus, André (1999) explicitly questions the effectiveness of freeze–thaw in fashioning the periglacial landscape and refers to the “smokescreen of the periglacial scenery.” In a similar vein, French and Thorn (2006) suggest that periglacial areas are cold-climate “zones” in which seasonal and perennial frost, snow, and normal azonal processes are present to greater or lesser degree. The reality is that many periglacial landscapes inherit the imprint, in varying degrees, of either glacial or non-cold-climate conditions.

A further complication is that so-called “periglacial” conditions often extend south of the latitudinal treeline and below the altitudinal timberline (Figure 1.2). This is because many areas of northern boreal forest are underlain by relict permafrost and, in alpine regions, glaciers may extend below timberline and into the forest zone. Finally, the treeline is a zone rather than a line and may extend over a latitudinal distance of ~100–150 km.

To summarize, therefore, modern usage of the term “periglacial” refers to a range of cold, non-glacial processes. We can define periglacial geomorphology as the sub-discipline of geomorphology concerned with cold non-glacial landforms. Because permafrost is a central, but not defining, element, much of the core of periglacial geomorphology is also a component of geocryology. However, periglacial geomorphology also includes the impact of seasonal freezing and the roles of seasonal snow, and of ice of a fluvial, lacustrine, and marine nature. Finally, periglacial geomorphology must embrace the azonal processes such as running water, wind, and waves that exhibit distinct characteristics in cold-climate environments.

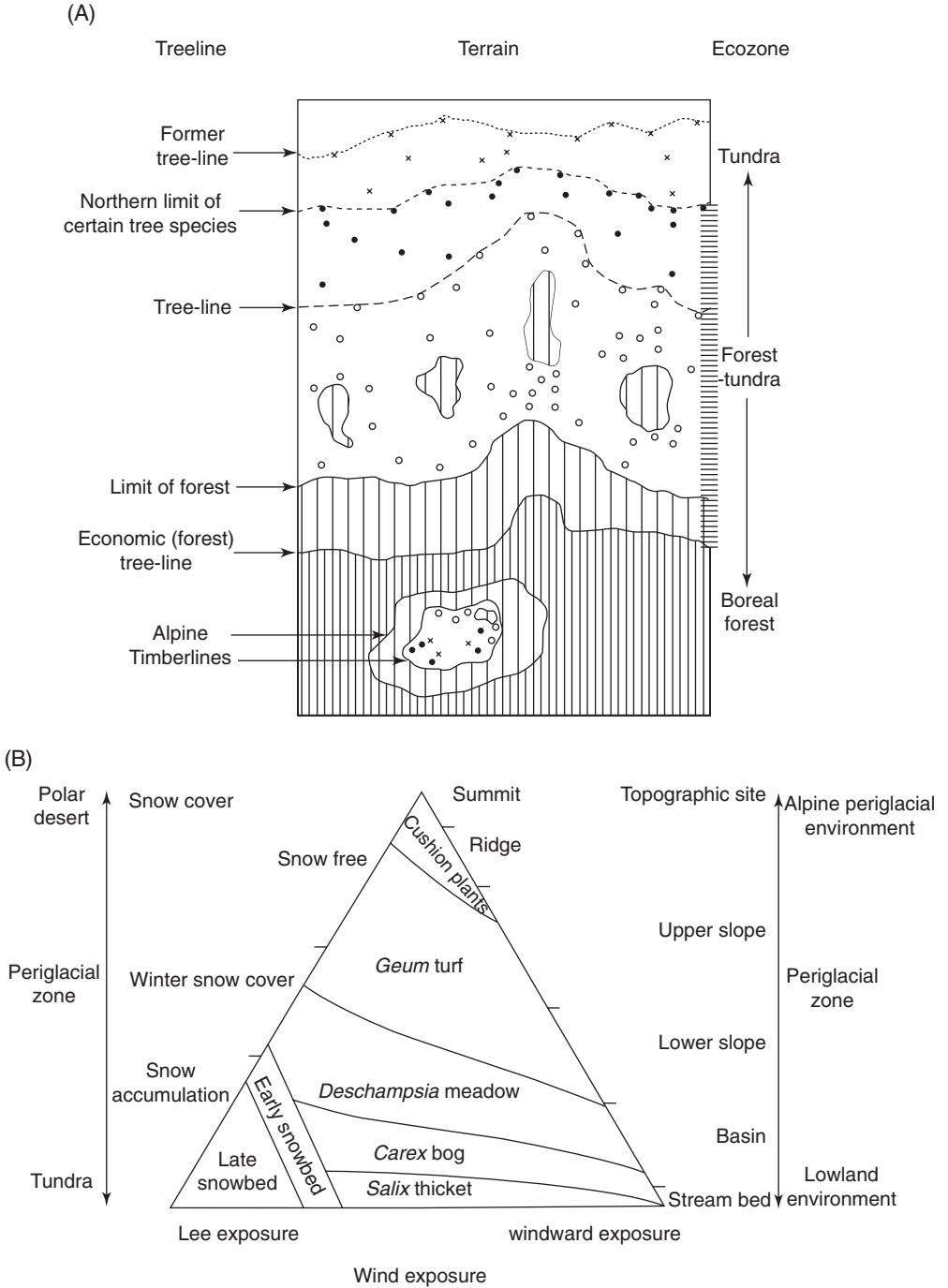


Figure 1.2. Relationship between the periglacial zone, the treeline and the timberline. (A) Forest limits and tree-lines according to Hustich (1966). (B) The plant type distribution, from tundra to polar desert, and from lowland to alpine (upland) environments, according to Billings and Mooney (1968).

1.2. DISCIPLINARY CONSIDERATIONS

Periglacial geomorphology currently maintains a bridging position between geomorphology, geocryology, and Quaternary science. Here, the disciplinary overlaps are considered. They are illustrated schematically in Figure 1.3.

1.2.1. The Growth of Geocryology

Geocryology, or permafrost science, is one of the cryospheric sciences. Clearly, the cryolithosphere (i.e. perennially and seasonally cryotic – that is, below 0°C , – ground) is central, and the cryohydrosphere (i.e. snow cover, glaciers, and river, lake, and sea ice) less central, to periglacial geomorphology.

For several reasons, the relations between geocryology and periglacial geomorphology are complex. First, for many years, permafrost studies were conducted in North America and the former Soviet Union (Russia) not only in relative isolation to each other but also in isolation from mainstream (geographical) geomorphology. Second, Russian and Chinese

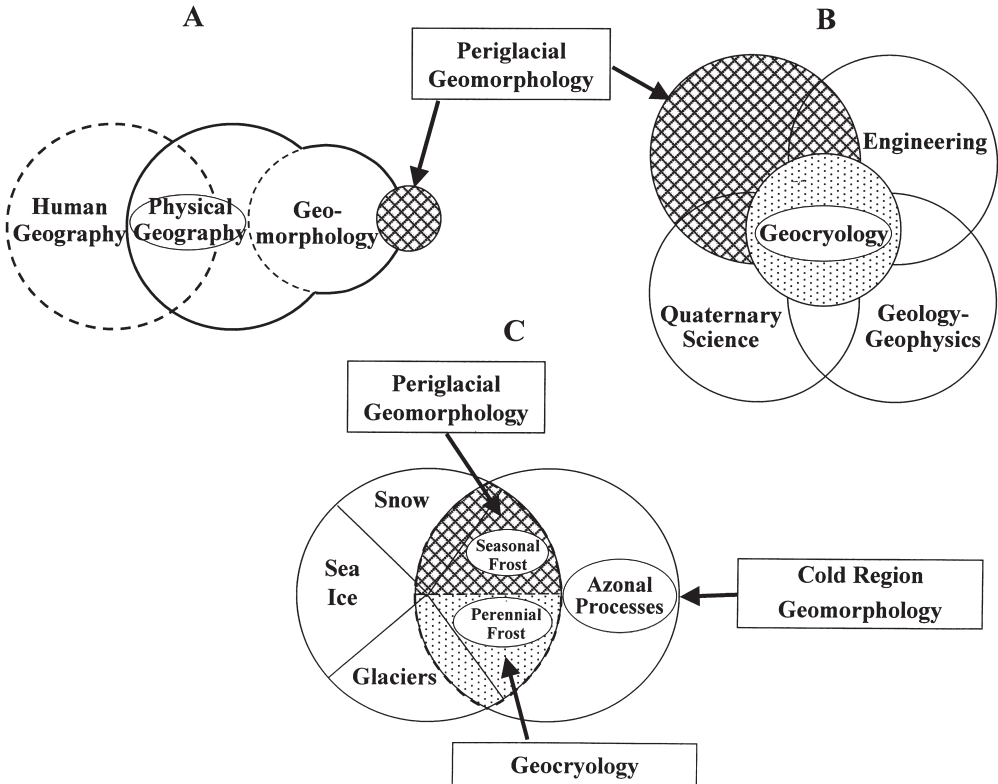


Figure 1.3. Diagram illustrating the disciplinary interactions and overlap of periglacial geomorphology. (A) The relations between physical geography, geomorphology, and periglacial geomorphology. (B) The relation between periglacial geomorphology and geocryology and the interactions of these disciplines with Quaternary science and other natural sciences. (C) Periglacial geomorphology and its overlap with the cryospheric sciences. Note: all the disciplinary boundaries are porous and those marked by broken lines are particularly so.

geocryology adopt holistic all-encompassing approaches whereas North American permafrost studies are characterized as being either “science” or “engineering” in nature. Thus, there is no North American text that equals the breadth and depth presented by the most recent Russian and Chinese texts, *General Geocryology* (Yershov, 1990) and *Geocryology in China* (Zhou Youwu et al., 2000). Third, permafrost studies sit awkwardly between the disciplines of geography and geology. For example, in North America and much of Europe, periglacial geomorphology is taught usually in geography departments while permafrost is within geology, geophysics, or earth science departments. Similar fractionation occurs in Russia and China.

The most obvious areas of overlap between periglacial geomorphology and geocryology lie in the problems associated with ground freezing and the occurrence of ground ice.

1.2.2. The Changing Nature of Quaternary Science

Advances in Quaternary science, and in particular the expansion and proliferation of sophisticated dating techniques, mean that studies involving paleo-environmental reconstruction no longer rely solely upon the morphological and stratigraphical evidence (Büdel, 1951, 1953; Poser 1948; Smith, 1949) that was typically used in traditional Pleistocene periglacial studies. Instead, a broader range of evidence now includes biological phenomena such as fauna and flora, arboreal and non-arboreal pollen, temperature-sensitive insects such as beetles (coleoptera sp.), and geochemical indicators such as isotopes. Stratigraphy is increasingly being supplemented by the study of ground ice, or cryostratigraphy. Thaw unconformities, truncated ice bodies, and cryostructures are now used to infer previous freezing and thawing events or early Holocene climate change (Burn, 1997; French, 1999; Melnikov and Spesivtsev, 2000). One must conclude that much of traditional Pleistocene periglacial geomorphology has been largely replaced by cryostratigraphy and cryolithology.

1.2.3. Modern Periglacial Geomorphology

As noted by M. Church (2005), geomorphology is no longer the preserve of geographers and geologists. However, periglacial geomorphology continues to be identified as a process sub-discipline of geomorphology that is distinct from both geocryology and Quaternary science. The key processes are those associated with seasonal and perennial frost.

While geocryologists concentrate upon the thermal implications of terrain and the presence of ice within the ground, periglacial geomorphologists emphasize the associated landforms, and their growth and modification through time. Obviously, there is considerable overlap between the two. For example, the recognition of anti-syngenetic wedges on hillslopes (Mackay, 1990a, 1995b) is an illustration of the overlap between landscape evolution (geomorphology) and permafrost-related processes (geocryology). Likewise, as discussed above, there is a complex overlap between periglacial geomorphology and Quaternary science via cryostratigraphy and cryolithology.

Permafrost cannot be the only diagnostic criterion for periglacial geomorphology. This is because permafrost is a thermal concept while geomorphology is concerned with landforms that are not controlled by ground temperature alone. On the other hand, permafrost and ground ice must be central to periglacial geomorphology in the same way that hillslopes and running water are central to geomorphology at large.

It is easy to forget that the broad features of cold-climate terrain are largely influenced by lithological variability, the nature and distribution of ice contained within bedrock or