## Contents

Foreword xix  
Acknowledgements xx  
Dedication xxii  

### Chapter 1  
Introduction to engineering geology and geomorphology of glaciated and periglaciated terrains  

1.1 Introduction 1  

1.2 A history of engineering difficulties in formerly glaciated and periglaciated terrain 3  
- Case History 1.1: A glacially over-deepened valley and a tunnel heading in Switzerland 5  
- Case History 1.2: The first identification of solifluction shear surfaces at low slope angles, Sevenoaks Bypass, Kent 7  
- Case History 1.3: Landslide in quick clay at Rissa, Norway, 1978 (Gregersen 1981) 10  
- Case History 1.4: Residential apartment blocks constructed on loess, Volgodonsk, Rostov Oblast, Russia 11  
- Case History 1.5: Reactivation of periglacial shear surfaces resulting in embankment dam failure 12  
- Case History 1.6: A51 Grenoble to Sisteron Autoroute through former glacial Lac de Trièves 13  
- Case History 1.7: Glaciotectonic raft of Chalk interpreted during an offshore ground investigation, southern North Sea, UK 16  

1.3 The Working Party 18  
- 1.3.1 Background 18  
- 1.3.2 Membership 18  
- 1.3.3 Objectives 20  

1.4 Scope of the report 20  

1.5 Structure of the book and its contents 22  

1.6 Using the Working Party book 25  

References 27  

### Chapter 2  
The Quaternary  

2.1 Introduction 31  
- 2.1.1 Terms and definitions 33  
- 2.1.2 Origins of, and mechanisms driving, Quaternary climate change 33  
- 2.1.3 Purpose and focus of this report 34  

2.2 Reconstructing Quaternary environmental change 34  
- 2.2.1 Archives recording Quaternary history 34  
- 2.2.1.1 Oxygen isotope stages 35  
- 2.2.1.2 Climate change in both archives and implications: a synthesis 36  
- 2.2.1.3 Glaciological implications of Heinrich events 36  
- 2.2.1.4 A scenario of ice-sheet–climate–ocean interaction 37  
- 2.2.1.5 Terrestrial archives 37  

- 2.2.2 Dating Quaternary sediments 37  

2.3 Resulting subdivision and timing of the Quaternary 40  
- 2.3.1 Terrestrial stratigraphy 41  
- 2.3.2 Quaternary cold-climate lithostratigraphy 41  
- 2.3.3 The Wolstonian ‘problem’ 42
## CONTENTS

2.4 The depositional record of sea-level changes in glaciated terrains 44
2.5 Terrestrial sedimentary response to Quaternary climatic fluctuations 45
2.6 Implications for engineering geology 52
References 52

### Chapter 3  Geomorphological framework: glacial and periglacial sediments, structures and landforms 59

3.1 Introduction 59
3.2 Terrain evaluation 60
3.3 Terrain classification 60
3.4 Engineering geological, glacial and periglacial ground models 62
  3.4.1 Engineering geological ground models 62
  3.4.2 Geomorphological landsystem models 65
    3.4.2.1 Glacial landsystems 65
    3.4.2.2 Periglacial landsystems 69
3.5 Glaciogenic sediment descriptors 78
   3.5.1.1 Subglacial traction till 83
   3.5.1.2 Glaciotectonite 86
   3.5.1.3 Supraglacial mass-flow diamicton/glaciogenic debris-flow deposit 89
   3.5.1.4 Melt-out till 91
   3.5.2.1 Rhythmites (non-genetic) 93
   3.5.2.2 Varves (seasonal rhythmites) 95
   3.5.2.3 Cycopels and cyclopsams (tidally influenced rhythmites) 97
   3.5.2.4 Turbidites 99
   3.5.2.5 Dropstone mud and plumites/silt and mud drapes (ice-rafter debris) 101
   3.5.2.6 Dropstone diamicton and glaciomarine varves (ice-rafter debris) 103
   3.5.2.7 Undermelt diamicton 105
   3.5.2.8 Iceberg-contact deposits (ice keel turbate, iceberg dump structures and mounds) 106
   3.5.2.9 Glaciogenic debris flow (debrites)/subaqueous slide and slump deposits (including cohesive and cohesionless) 108
   3.5.2.10 Subaqueous debris-fall deposits (including olistostromes) 111
   3.5.2.11 Palimpsest lags 113
   3.5.3.1 Hyperconcentrated flow deposits (jökulhlaup-type flood deposits) 114
   3.5.3.2 Gravel rhythmites (flood facies) 116
   3.5.3.3 Plane bed deposits 119
   3.5.3.4 Cross-bedded facies (dunes and antidunes) 120
   3.5.3.5 Ripple cross-laminations (including climbing ripple drift) 123
   3.5.3.6 Gravel sheets 126
3.6 Periglacial sediment descriptors 128
   3.6.1.1 Granular head deposits 129
   3.6.1.2 Clay-rich head deposits 131
   3.6.1.3 Slopewash deposits 133
   3.6.1.4 Fluviocolluvial deposits 135
   3.6.1.5 Talus deposits 137
   3.6.1.6 Avalanche deposits 140
   3.6.1.7 Blockslope deposits 143
   3.6.1.8 Debris-flow deposits 145
   3.6.2.1 Sorted sand and gravel 147
   3.6.2.2 Channel scours 148
CONTENTS

3.6.2.3 Fine-grained sediments and organic beds in channel fills and on floodplains 149
3.6.3.1 Fluvio-aeolian sand 150
3.6.4.1 Loess 151
3.6.4.2 Coversand (sand-sheet deposits) 152
3.6.4.3 Dune sand 154
3.6.4.4 Niveo-aeolian sand deposits 155
3.6.5.1 Blockfield deposits 158
3.6.5.2 Brecciated bedrock 161

3.7 Macrostructural, erosional and sediment architectural element descriptors 164

3.7.1.1 Clastic dykes, intrusions and hydrofracture fills 165
3.7.1.2 Soft sediment deformation and slump and loading structures 167
3.7.1.3 Dewatering structures 168
3.7.1.4 Microfluting 170
3.7.1.5 Boulder pavements 171
3.7.1.6 Canal fills 172
3.7.2.1 Glaciotectonic foliations 173
3.7.2.2 Glaciotectonic lineations 174
3.7.2.3 Glaciotectonic boudinage 175
3.7.2.4 Glaciotectonic shear zones 177
3.7.2.5 Glaciotectonic folds 178
3.7.2.6 Glaciotectonic faults and thrusts 180
3.7.2.7 Glaciotectonic grabens and half-grabens 183
3.7.3.1 P-forms 184
3.7.3.2 Lunate fractures 185
3.7.3.3 Crescentic gouges 186
3.7.3.4 Crescentic fractures 187
3.7.3.5 Chattermarks 188
3.7.3.6 Rat tails 189
3.7.3.7 Grooves, striations and polished surfaces 190
3.7.4.1 Channel elements 191
3.7.4.2 Downstream accretion elements 192
3.7.4.3 Lateral accretion elements 193
3.7.4.4 Gravel bar and bedform elements 194
3.7.4.5 Sediment gravity-flow elements 195
3.7.4.6 Sandy bedform elements 196
3.7.4.7 Laminated sand-sheet elements 197
3.7.4.8 Overbank fines elements 198
3.7.5.1 Periglacial involutions 199
3.7.5.2 Periglacial creep folds 200
3.7.5.3 Platy structures 201
3.7.5.4 Relict periglacial shears 202
3.7.5.5 Thermal contraction cracks 203
3.7.5.6 Ice-wedge pseudomorphs 204
3.7.5.7 Relict sand wedges 206
3.7.5.8 Composite-wedge pseudomorphs 207
3.7.5.9 Vertical to steeply dipping elongate clasts 208
3.7.5.10 Downslope-deflected strata 209
3.7.5.11 Gulls
3.7.5.12 Dip and fault structures
3.7.5.13 Superficial valley disturbances and valley bulges
3.7.5.14 Buried hollows
3.7.6 Superimposed or overprinted sedimentary and structural signatures
3.7.6.1 Interbedded diamictons and thin stratified lenses
3.7.6.2 Glaciotectonite
3.7.6.3 Ice-wedge pseudomorph developed in glaciolacustrine sediments
3.7.6.4 Ground ice developed in refrozen mass-flow deposits
3.7.6.5 Periglacial involutions within refrozen mass-flow deposits
3.7.6.6 Banded massive ground ice beneath glacial diamicton
3.8 Microstructures in glacial and periglacial sediments
3.8.1 Periglacial microstructures in engineering soils
3.8.1.1 Relict periglacial shear microstructure
3.8.1.2 Platy or lenticular microstructure
3.8.1.3 Banded microstructure or ‘banded fabric’
3.8.1.4 Granular microstructure
3.8.1.5 Silt cappings microstructure
3.8.1.6 Vesicular microstructure
3.8.2 Periglacial microstructures superimposed on glaciogenic sediments
3.8.2.1 Platy or lenticular microstructure
3.8.2.2 Granular microstructure
3.8.2.3 Silt cappings microstructure
3.8.2.4 Calcitans microstructure
3.8.2.5 Clay cutans or ferri-argillans microstructure
3.8.2.6 Oriented clay domains microstructure
3.8.2.7 Banded microstructure
3.8.3 Glaciogenic sediment microstructures
3.8.3.1 Base of subglacial traction till
3.8.3.2 Base of subglacial mass-flow diamicton
3.8.3.3 Bedrock-rich subglacial traction till
3.8.3.4 Faulted lake sediments
3.8.3.5 Hydrofracture
3.8.3.6 Massive till
3.8.3.7 Soft-sediment deformation
3.8.3.8 Pseudo-stratified diamicton
3.8.3.9 Glaciotectonite in lake sediments
3.8.3.10 Till over laminated lake sediments
3.8.3.11 Melt-out till
3.9 Terrain unit descriptors
3.10 Glacial landsystems
3.10.1.1 Areal scouring
3.10.1.2 Glaciated valleys and glacial troughs
3.10.1.3 Hanging valleys
3.10.1.4 Arêtes
3.10.1.5 Glacial watershed breaches
3.10.1.6 Whalebacks

CONTENTS

3.7.5.11 Gulls 210
3.7.5.12 Dip and fault structures 211
3.7.5.13 Superficial valley disturbances and valley bulges 212
3.7.5.14 Buried hollows 213
3.7.6 Superimposed or overprinted sedimentary and structural signatures 214
3.7.6.1 Interbedded diamictons and thin stratified lenses 214
3.7.6.2 Glaciotectonite 215
3.7.6.3 Ice-wedge pseudomorph developed in glaciolacustrine sediments 216
3.7.6.4 Ground ice developed in refrozen mass-flow deposits 217
3.7.6.5 Periglacial involutions within refrozen mass-flow deposits 218
3.7.6.6 Banded massive ground ice beneath glacial diamicton 219
3.8 Microstructures in glacial and periglacial sediments 220
3.8.1 Periglacial microstructures in engineering soils 220
3.8.1.1 Relict periglacial shear microstructure 221
3.8.1.2 Platy or lenticular microstructure 222
3.8.1.3 Banded microstructure or ‘banded fabric’ 223
3.8.1.4 Granular microstructure 224
3.8.1.5 Silt cappings microstructure 225
3.8.1.6 Vesicular microstructure 226
3.8.2 Periglacial microstructures superimposed on glaciogenic sediments 227
3.8.2.1 Platy or lenticular microstructure 228
3.8.2.2 Granular microstructure 229
3.8.2.3 Silt cappings microstructure 230
3.8.2.4 Calcitans microstructure 231
3.8.2.5 Clay cutans or ferri-argillans microstructure 232
3.8.2.6 Oriented clay domains microstructure 233
3.8.2.7 Banded microstructure 234
3.8.3 Glaciogenic sediment microstructures 235
3.8.3.1 Base of subglacial traction till 235
3.8.3.2 Base of subglacial mass-flow diamicton 236
3.8.3.3 Bedrock-rich subglacial traction till 237
3.8.3.4 Faulted lake sediments 238
3.8.3.5 Hydrofracture 239
3.8.3.6 Massive till 240
3.8.3.7 Soft-sediment deformation 242
3.8.3.8 Pseudo-stratified diamicton 243
3.8.3.9 Glaciotectonite in lake sediments 245
3.8.3.10 Till over laminated lake sediments 246
3.8.3.11 Melt-out till 247
3.9 Terrain unit descriptors 248
3.10 Glacial landsystems 248
3.10.1.1 Areal scouring 249
3.10.1.2 Glaciated valleys and glacial troughs 250
3.10.1.3 Hanging valleys 251
3.10.1.4 Arêtes 252
3.10.1.5 Glacial watershed breaches 253
3.10.1.6 Whalebacks 254
3.10.1.7 Trough heads 255
3.10.1.8 Rock basins 256
3.10.1.9 Rock steps 257
3.10.1.10 Cirques (corrie or cwm) 258
3.10.1.11 Cols 259
3.10.1.12 Horns 260
3.10.1.13 Nunataks 261
3.10.1.14 Roche moutonnées 262
3.10.1.15 Röthlisberger channels 263
3.10.1.16 Crag and tail ridges 264
3.10.1.17 Riegel 265
3.10.1.18 Push and squeeze moraines 266
3.10.1.19 Dump moraines and ice-marginal aprons 267
3.10.1.20 Latero-frontal fans and ramps 268
3.10.1.21 Medial moraines 269
3.10.1.22 Hummocky moraine and controlled moraines 270
3.10.1.23 Ribbed terrain 271
3.10.1.24 Glacial erratics 272
3.10.1.25 Crevasse-fill ridges (including crevasse-squeeze ridges) 273
3.10.1.26 Megascale glacial lineations, megaflutes and megagrooves 274
3.10.1.27 Flutes 275
3.10.1.28 Drumlins 276
3.10.1.29 Glacial trimlines 277
3.10.2.1 Composite ridges and thrust block moraines 278
3.10.2.2 Hill–hole pairs 279
3.10.2.3 Cupola hills 280
3.10.2.4 Megablocks and rafts 281
3.10.3.1 Tunnel valleys, tunnel channels, rinnentäler 282
3.10.3.2 Lateral meltwater channels 283
3.10.3.3 Ice-marginal channels 284
3.10.3.4 Subglacial gorges 285
3.10.3.5 Nye channels 286
3.10.3.6 Eskers 287
3.10.3.7 Kame mounds 288
3.10.3.8 Kame terraces 289
3.10.3.9 Valley trains 290
3.10.3.10 Sandar/outwash fans and plains 291
3.10.3.11 Pitted sandar (kettle outwash plain) 292
3.10.3.12 Kettle holes/ponds 293
3.10.3.13 Iceberg melt-out pits and scours 294
3.10.4.1 Morainal banks and coalescent subaqueous fans 295
3.10.4.2 De Geer (washboard) moraines 296
3.10.4.3 Ice-shelf moraines 297
3.10.4.4 Shorelines or strandlines 298
3.10.4.5 Fjords 299
3.10.4.6 Submarine troughs (cross-shelf troughs) 300
3.10.4.7 Grounding line or subaqueous outwash fans 301
3.10.4.8 Grounding-zone wedges 302
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.10.4.9</td>
<td>Trough-mouth fans</td>
<td>303</td>
</tr>
<tr>
<td>3.10.4.10</td>
<td>Ice-contact deltas</td>
<td>304</td>
</tr>
<tr>
<td>3.10.4.11</td>
<td>Gilbert-type deltas</td>
<td>305</td>
</tr>
<tr>
<td>3.10.4.12</td>
<td>Hjulström-type deltas</td>
<td>306</td>
</tr>
<tr>
<td>3.11</td>
<td>Periglacial landsystems</td>
<td></td>
</tr>
<tr>
<td>3.11.1.1</td>
<td>Blockfields/felsenmeer</td>
<td>307</td>
</tr>
<tr>
<td>3.11.1.2</td>
<td>Frost-patterned ground</td>
<td>308</td>
</tr>
<tr>
<td>3.11.1.3</td>
<td>Periglacial trimlines</td>
<td>309</td>
</tr>
<tr>
<td>3.11.1.4</td>
<td>Tors</td>
<td>310</td>
</tr>
<tr>
<td>3.11.1.5</td>
<td>Deflation scars</td>
<td>311</td>
</tr>
<tr>
<td>3.11.1.6</td>
<td>Deflation surfaces</td>
<td>312</td>
</tr>
<tr>
<td>3.11.1.7</td>
<td>Wind stripes</td>
<td>313</td>
</tr>
<tr>
<td>3.11.1.8</td>
<td>Wind crescents</td>
<td>314</td>
</tr>
<tr>
<td>3.11.2.1</td>
<td>Solifluction sheets and aprons</td>
<td>315</td>
</tr>
<tr>
<td>3.11.2.2</td>
<td>Solifluction lobes</td>
<td>316</td>
</tr>
<tr>
<td>3.11.2.3</td>
<td>Solifluction benches and terraces</td>
<td>317</td>
</tr>
<tr>
<td>3.11.2.4</td>
<td>Ploughing boulders</td>
<td>318</td>
</tr>
<tr>
<td>3.11.3.1</td>
<td>Talus accumulations and slopes</td>
<td>319</td>
</tr>
<tr>
<td>3.11.3.2</td>
<td>Rock glaciers</td>
<td>320</td>
</tr>
<tr>
<td>3.11.3.3</td>
<td>Protalus ramparts and pronival ramparts</td>
<td>321</td>
</tr>
<tr>
<td>3.11.3.4</td>
<td>Cryoplanation terraces</td>
<td>322</td>
</tr>
<tr>
<td>3.11.3.5</td>
<td>Nivation hollows</td>
<td>323</td>
</tr>
<tr>
<td>3.11.3.6</td>
<td>Cliffs</td>
<td>324</td>
</tr>
<tr>
<td>3.11.4.1</td>
<td>Periglacial debris flows</td>
<td>325</td>
</tr>
<tr>
<td>3.11.4.2</td>
<td>Periglacial debris cones</td>
<td>326</td>
</tr>
<tr>
<td>3.11.4.3</td>
<td>Boulder sheets and lobes</td>
<td>327</td>
</tr>
<tr>
<td>3.11.4.4</td>
<td>Alluvial fans</td>
<td>328</td>
</tr>
<tr>
<td>3.11.5.1</td>
<td>Periglacial river terraces</td>
<td>329</td>
</tr>
<tr>
<td>3.11.5.2</td>
<td>Dry valleys</td>
<td>330</td>
</tr>
<tr>
<td>3.11.5.3</td>
<td>Relict frost mounds/relict ramparted ground-ice depressions: pingos</td>
<td>331</td>
</tr>
<tr>
<td>3.11.5.4</td>
<td>Relict frost mounds/relict ramparted ground-ice depressions: palsas and lithalsas</td>
<td>332</td>
</tr>
<tr>
<td>3.11.5.5</td>
<td>Large relict thermokarst depressions</td>
<td>333</td>
</tr>
<tr>
<td>3.11.5.6</td>
<td>Cambered strata</td>
<td>334</td>
</tr>
<tr>
<td>3.11.6.1</td>
<td>Buried valleys</td>
<td>335</td>
</tr>
<tr>
<td>3.12</td>
<td>Slope failures in glaciated and periglaciated terrains</td>
<td></td>
</tr>
<tr>
<td>3.12.1</td>
<td>Active-layer slides (shallow translational slides)</td>
<td>336</td>
</tr>
<tr>
<td>3.12.2</td>
<td>Retrogressive thaw slumps</td>
<td>337</td>
</tr>
<tr>
<td>3.12.3</td>
<td>Deep-seated rotational slides</td>
<td>338</td>
</tr>
<tr>
<td>3.12.4</td>
<td>Translational rockslides</td>
<td>339</td>
</tr>
<tr>
<td>3.12.5</td>
<td>Rockfalls and rock avalanches</td>
<td>340</td>
</tr>
<tr>
<td>3.12.6</td>
<td>Mountain slope deformation (deep-seated gravitational failures)</td>
<td>341</td>
</tr>
<tr>
<td>3.12.7</td>
<td>Sensitive clay spreads and flowslides</td>
<td>342</td>
</tr>
</tbody>
</table>

Photo credits 343
References 344
Quaternary Research Association (London) Field Guides 345
Chapter 4  Conceptual glacial ground models: British and Irish case studies

4.1 Introduction and rationale
   4.1.1 The glacial debris cascade and till sedimentology
   4.1.2 The glacial landsystems approach
   4.1.3 British and Irish palaeoglaciology

4.2 Ice-sheet-related landsystems
   4.2.1 Sediment–landform associations
      4.2.1.1 Subglacial footprint
      4.2.1.2 Ice-marginal complexes
      4.2.1.3 Supraglacial debris complexes
   4.2.2 Typical British and Irish ground models
      4.2.2.1 Ice-sheet beds
      4.2.2.2 Ice-sheet marginal settings
      4.2.2.3 Supraglacial assemblages

4.3 Upland glacial landsystems (hard bedrock terrain)
   4.3.1 Sediment–landform associations
      4.3.1.1 Subglacial footprint
      4.3.1.2 Ice-marginal complexes
      4.3.1.3 Supraglacial debris complexes
   4.3.2 Typical British and Irish ground models
      4.3.2.1 Ice-sheet recessional settings/topographically constrained ice flow
      4.3.2.2 Mountain icefields
      4.3.2.3 Smaller mountain glaciers

4.4 Glaciofluvial sediment–landform associations
   4.4.1 Sediment–landform associations
      4.4.1.1 Ice-contact settings
      4.4.1.2 Proglacial settings
   4.4.2 Typical British and Irish ground models
      4.4.2.1 The Brampton kame belt and Pennine Escarpment meltwater channels
      4.4.2.2 Lleyn Peninsula
      4.4.2.3 Strathallan
      4.4.2.4 Carstairs

4.5 Subaqueous glacial depositional sequences
   4.5.1 Sediment–landform associations
      4.5.1.1 Ice-proximal depocentres
      4.5.1.2 Distal subaqueous sediment assemblages
   4.5.2 Typical British and Irish ground models
      4.5.2.1 Rhosesmor and Wrexham deltas
      4.5.2.2 Achnasheen
      4.5.2.3 NW Britain continental shelf
      4.5.2.4 Waterville, Ireland

4.6 Conclusions: reconciling landsystems and domains

References

Chapter 5  Periglacial and permafrost ground models for Great Britain

5.1 Introduction and rationale
   5.1.1 Conceptual framework
   5.1.2 Periglacial, permafrost and paraglacial environments
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.2.1</td>
<td>Periglacial environments</td>
<td>502</td>
</tr>
<tr>
<td>5.1.2.2</td>
<td>Permafrost</td>
<td>502</td>
</tr>
<tr>
<td>5.1.2.3</td>
<td>Paraglacial landscape modification</td>
<td>504</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Ground ice</td>
<td>505</td>
</tr>
<tr>
<td>5.1.3.1</td>
<td>Occurrence</td>
<td>505</td>
</tr>
<tr>
<td>5.1.3.2</td>
<td>Pore ice</td>
<td>506</td>
</tr>
<tr>
<td>5.1.3.3</td>
<td>Segregated ice</td>
<td>506</td>
</tr>
<tr>
<td>5.1.3.4</td>
<td>Intrusive ice</td>
<td>507</td>
</tr>
<tr>
<td>5.1.3.5</td>
<td>Wedge ice</td>
<td>508</td>
</tr>
<tr>
<td>5.1.4</td>
<td>Periglacial disturbance, periglacial debris system and frost susceptibility</td>
<td>508</td>
</tr>
<tr>
<td>5.1.4.1</td>
<td>Periglacial disturbance</td>
<td>508</td>
</tr>
<tr>
<td>5.1.4.2</td>
<td>Periglacial debris system</td>
<td>508</td>
</tr>
<tr>
<td>5.1.4.3</td>
<td>Frost susceptibility</td>
<td>509</td>
</tr>
<tr>
<td>5.1.5</td>
<td>Periglacial landsystems, terrains and regions</td>
<td>509</td>
</tr>
<tr>
<td>5.1.5.1</td>
<td>Periglacial landsystems</td>
<td>509</td>
</tr>
<tr>
<td>5.1.5.2</td>
<td>Periglacial regions</td>
<td>510</td>
</tr>
<tr>
<td>5.2</td>
<td>Lowland periglacial terrains</td>
<td>513</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Lowland periglacial landsystems</td>
<td>513</td>
</tr>
<tr>
<td>5.2.1.1</td>
<td>Chronology</td>
<td>513</td>
</tr>
<tr>
<td>5.2.1.2</td>
<td>Environmental conditions and permafrost extent</td>
<td>515</td>
</tr>
<tr>
<td>5.2.1.3</td>
<td>Permafrost thickness</td>
<td>516</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Lowland plateau landsystems</td>
<td>516</td>
</tr>
<tr>
<td>5.2.2.1</td>
<td>Weathering profiles (brecciated bedrock)</td>
<td>516</td>
</tr>
<tr>
<td>5.2.2.2</td>
<td>Cold-climate aeolian deposits and erosional features</td>
<td>521</td>
</tr>
<tr>
<td>5.2.2.3</td>
<td>Involution</td>
<td>523</td>
</tr>
<tr>
<td>5.2.2.4</td>
<td>Large-scale frost-patterned ground</td>
<td>523</td>
</tr>
<tr>
<td>5.2.2.5</td>
<td>Periglacial-karst features</td>
<td>525</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Sediment-mantled hillslope landsystems</td>
<td>528</td>
</tr>
<tr>
<td>5.2.3.1</td>
<td>Deformed weathered bedrock</td>
<td>528</td>
</tr>
<tr>
<td>5.2.3.2</td>
<td>Relict periglacial slope (head) deposits</td>
<td>530</td>
</tr>
<tr>
<td>5.2.3.3</td>
<td>Cambered strata and widened vertical joints (gulls)</td>
<td>533</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Rock-slope landsystems</td>
<td>537</td>
</tr>
<tr>
<td>5.2.5</td>
<td>Slope-foot landsystems</td>
<td>537</td>
</tr>
<tr>
<td>5.2.5.1</td>
<td>Sediment lobes</td>
<td>538</td>
</tr>
<tr>
<td>5.2.5.2</td>
<td>Alluvial fans</td>
<td>538</td>
</tr>
<tr>
<td>5.2.5.3</td>
<td>Aprons, sheets or remnant patches of head deposits</td>
<td>538</td>
</tr>
<tr>
<td>5.2.5.4</td>
<td>Deep-seated landslides</td>
<td>538</td>
</tr>
<tr>
<td>5.2.6</td>
<td>Valley landsystems</td>
<td>541</td>
</tr>
<tr>
<td>5.2.6.1</td>
<td>Superficial valley disturbances (bedrock)</td>
<td>541</td>
</tr>
<tr>
<td>5.2.6.2</td>
<td>Dry valleys, slopewash and fluvio-colluvial deposits</td>
<td>542</td>
</tr>
<tr>
<td>5.2.6.3</td>
<td>Periglacial fluvial deposits and river terraces</td>
<td>544</td>
</tr>
<tr>
<td>5.2.6.4</td>
<td>Thermal contraction crack structures</td>
<td>547</td>
</tr>
<tr>
<td>5.2.6.5</td>
<td>Relict frost mounds</td>
<td>549</td>
</tr>
<tr>
<td>5.2.6.6</td>
<td>Large relict thermokarst depressions</td>
<td>552</td>
</tr>
<tr>
<td>5.2.7</td>
<td>Buried landsystems</td>
<td>552</td>
</tr>
<tr>
<td>5.2.8</td>
<td>Submerged landsystems</td>
<td>553</td>
</tr>
<tr>
<td>5.2.8.1</td>
<td>Southern North Sea Basin</td>
<td>553</td>
</tr>
<tr>
<td>5.2.8.2</td>
<td>English Channel (La Manche)</td>
<td>553</td>
</tr>
</tbody>
</table>
5.2.9 Typical lowland ground models
  5.2.9.1 Limestone plateau-clay vale ground model
  5.2.9.2 Caprock plateau-mudstone valley ground model

5.3 Upland periglacial terrains
  5.3.1 Upland periglacial landsystems: chronology and environment
  5.3.2 Upland plateau landsystems
    5.3.2.1 Blockfields, trimlines and tors
    5.3.2.2 Frost-patterned ground
    5.3.2.3 Aeolian landforms and deposits on high plateaux
  5.3.3 Sediment-mantled hillslope landsystems
  5.3.4 Rock-slope landsystems
    5.3.4.1 Rock-slope failures
    5.3.4.2 Talus accumulations
    5.3.4.3 Rock glaciers and protalus ramparts
  5.3.5 Slope-foot landsystems
    5.3.5.1 Periglacial valley-fill deposits
    5.3.5.2 Snow avalanche deposits
    5.3.5.3 Debris flows and debris cones
    5.3.5.4 Alluvial fans
  5.3.6 Terrain models and typical upland ground models

5.4 Conclusions

Chapter 6 Material properties and geohazards

6.1 Introduction

6.2 Ice-related terrains: subglacial, supraglacial and glaciated valley
  6.2.1 Tills
    6.2.1.1 Introduction
    6.2.1.2 Glacial till stratigraphy
    6.2.1.3 Geotechnical properties
    6.2.1.4 Geotechnical properties
    6.2.1.5 Weathering of glacial tills
  6.2.2 Eskers, kames and kame terraces

6.3 Water-related domains (fluvial, lacustrine and marine): glaciofluvial, glaciolacustrine
  and glaciomarine
  6.3.1 Sands and gravels
  6.3.2 Glaciolacustrine deposits
    6.3.2.1 The glacial lake environment
    6.3.2.2 Glaciolacustrine deposits and depositional processes
    6.3.2.3 Geotechnical properties
    6.3.2.4 Geohazard behaviour
    6.3.2.5 UK lithostratigraphy
  6.3.3 Quick clay
  6.3.4 Ice-rafted debris (including dropstones) and iceberg-contact deposits

6.4 Ice-front-related terrains: glaciotectonic and ice marginal
  6.4.1 Deformed/shattered bedrock
  6.4.2 Subglacial deformation of soils

6.5 Upland periglacial terrains
6.5.1 Boulder fields and tongues 664
6.5.2 Scree and talus 664
6.6 Lowland periglacial terrains 664
  6.6.1 Solifluction deposits and colluvium 664
  6.6.2 Periglaciated rock surfaces 669
  6.6.3 Ice-wedge pseudomorphs and involutions 670
  6.6.4 Loessic deposits/brickearth 670
    6.6.4.1 Distribution and identification 670
    6.6.4.2 Composition 673
    6.6.4.3 Geotechnical properties 673
    6.6.4.4 Geohazards associated with loessic deposits 674
    6.6.4.5 Engineering treatment 678
6.7 Local geohazards 678
  6.7.1 Superficial valley disturbances: cambering, gulls and valley bulging 678
    6.7.1.1 Engineering aspects 680
  6.7.2 Solifluction shears 682
  6.7.3 Kettle holes 683
  6.7.4 Relict cryogenic mounds 683
    6.7.4.1 Characteristics of the relict forms 683
    6.7.4.2 Occurrence in the UK 684
    6.7.4.3 Processes of formation 684
    6.7.4.4 Engineering geological characteristics 685
    6.7.4.5 Mitigation measures 685
  6.7.5 Relict scour hollows 685
    6.7.5.1 Occurrence 687
    6.7.5.2 Formational processes 687
    6.7.5.3 Engineering geological characteristics 687
    6.7.5.4 Mitigation measures 687
6.8 Regional geohazards 689
  6.8.1 Neotectonics: differential crustal movements across SE England during the
    Holocene following deglaciation 689
    6.8.1.1 The eustatic record 691
    6.8.1.2 The isostatic record 691
    6.8.1.3 Case studies of two areas 691
    6.8.1.4 Summary of eustatic changes in SE England 697
  6.8.2 Quaternary palaeoseismicity 698
6.9 Summary and conclusions 701
Appendix 6.1 Summary description of British till formations and members
  A6.1.1 Caledonia Glacigenic Group (CALI) 702
  A6.1.2 Albion Glacigenic Group (ALBI) 710
Appendix 6.2 Additional Geotechnical Plots 713
Appendix 6.3 Particle Size Distribution and SPT ‘N’ Value Depth Plots by 100 km Grid Square
References 732

Chapter 7 Engineering investigation and assessment 741
7.1 Introduction 742
7.2 Preliminaries 742
  7.2.1 Desk studies and field reconnaissance 743
8.2.4.2 Excavatability
8.2.4.3 Pipeline foundations
8.2.4.4 Drainage, seepage and inundation
8.2.4.5 Reuse of materials
8.2.4.6 Corrosion (pipelines/cables) due to ground geochemistry
8.2.5 Aggregates and other materials
8.2.6 Conclusions

8.3 Tunnels and underground structures
8.3.1 Tunnelling considerations
8.3.2 Groundwater lowering
8.3.3 Common problems
8.3.4 Tunnelling techniques
8.3.5 Conclusions

8.4 Dams and reservoirs
8.4.1 Dam foundation problems
  8.4.1.1 Carsington Dam, Derbyshire, UK
  8.4.1.2 Zelazny Most Tailings Dam, Poland
  8.4.1.3 Empingham Dam, Rutland, UK
8.4.2 Embankment dams constructed on clay-rich tills
  8.4.2.1 Compaction of glacial clay fill
  8.4.2.2 Sliding failure due to high fill pore pressures
  8.4.2.3 Potential for overtopping wave due to landslides
8.4.3 Conclusions

8.5 Foundations
  8.5.1 Shallow foundations
  8.5.2 Pile foundations
  8.5.3 Retaining walls
  8.5.4 Specific problems
    8.5.4.1 Drift-filled hollows in London Clay
    8.5.4.2 Infilled periglacial valley
    8.5.4.3 Ice wedge and involutions
    8.5.4.4 Gulls in limestone
    8.5.4.5 Valley bulges
    8.5.4.6 Solution features
    8.5.4.7 Slopewash
  8.5.5 Summary
8.6 Offshore engineering and installation
  8.6.1 Introduction
  8.6.2 Central North Sea and German Bight: oil and gas, wind and tidal energy
  8.6.3 Norwegian Barents and Russian Kara seas: oil and gas
  8.6.4 Canadian Scotian Shelf: oil and gas and wind energy
  8.6.5 Gulf of Maine: wind and wave energy
  8.6.6 Driven–drilled and grouted piles
    8.6.6.1 Design issues
    8.6.6.2 Construction and installation issues
  8.6.7 Gravity-base structures
    8.6.7.1 Design issues