Contents

Preface		XV
Acknowledgements		xvi
Dedication	1	xvii
Chanter 1	Introduction to Geological Hazards in the UK: Their Occurrence,	
Monitorir	ng and Mitigation	1
1.1 Introd	uction	1
1.2 A hist	ory of significant geohazards in the UK	1
1.2.1	Gas hazards	2
	1.2.1.1 1986 Loscoe methane gas explosion, Derbyshire	2
	1.2.1.2 Radon hazard, Northamptonshire	2
1.2.2	Karst and dissolution hazard	2
	1.2.2.1 2012 Carsington Pasture, variable rockhead, Derbyshire	2
	1.2.2.2 Ripon dissolution subsidence, North Yorkshire	2
1.2.3	Landslides and slope failures	3
	1.2.3.1 Significant inland landslides	3
	1.2.3.2 1966 Aberfan tip failure, South Wales	3
	1.2.3.3 2000 M25 Flint Hall Farm landslide	3
	1.2.3.4 1979 Mam Tor landslide, Derbyshire	3
	1.2.3.5 Coastal landslides and coastal erosion	4
	1.2.3.6 1915 Folkestone Warren landslide, Kent	4
	1.2.3.7 1983 Holbeck Hall landslide, Scarborough, Yorkshire	4
1.2.4	Periglacial legacy	5
	1.2.4.1 1984 Carsington Dam embankment failure, Derbyshire	5
1.2.5	Central London, drift-filled hollows	5
	1.2.5.1 1965 A21 Sevenoaks Bypass slope failures, Kent	5
	1.2.5.2 1961 M6 Walton's Wood embankment failure	5
1.2.6	Seismic events	5
	1.2.6.1 1884 Colchester earthquake, Essex	5
	1.2.6.2 1931 Dogger Bank earthquake, North Sea	5
1.2.7	Tsunami events	5
	1.2.7.1 1755 Lisbon earthquake-generated tsunami	5
	1.2.7.2 c. 8150 BP Storegga submarine landslide and tsunami	6
1.2.8	Volcanic events	6
	1.2.8.1 2010 Eyjafjallajökull ash fall disruption	6
	1.2.8.2 1783–1784 Laki fissure eruption, Iceland	6
1.2.9	Mining hazards	6
	1.2.9.1 2000 chalk mine collapse, Reading, Berkshire	6
1.2.10	Deep coal workings	7
	1.2.10.1 1945 Ludovic Berry and Dolly the train incident, Wigan	7
1.2.11	Geotechnical hazards	7
	1.2.11.1 1976 subsidence related to clay shrinkage	7
1.2.12	Poorly recognized geohazards	9

vi CONTENTS

1.3	Geological Society Engineering Group Working Party on Geohazards	9
	1.3.1 Background	9
	1.3.2 Membership	9
	1.3.3 Terms of reference of the Working Party	9
	1.3.4 Developing the report	9
	1.3.5 Contents and structure of the report	10
	1.3.6 Geological hazards: Working Party definitions and report limitations	10
1.4	Section A: tectonic hazards	12
	1.4.1 Chapter 2: seismic hazard in the UK	12
	1.4.2 Chapter 3: tsunami hazard with reference to the UK	14
1.5	Section B: slope stability hazards	16
	1.5.1 Chapter 4: landslide and slope stability hazard in the UK	16
	1.5.2 Chapter 5: debris flows	18
1.6	Section C: problematic ground and geotechnical hazards	19
	1.6.1 Chapter 6: collapsible soils in the UK	19
	1.6.2 Chapter 7: quick-clay behaviour in sensitive Quaternary marine clays:	
	UK perspective	21
	1.6.3 Chapter 8: swelling and shrinking soils	22
	1.6.4 Chapter 9: peat hazards: compression and failure	23
	1.6.5 Chapter 10: relict periglacial hazards	25
1.7	Section D: mining and subsidence hazards	26
	1.7.1 Chapter 11: subsidence resulting from coal mining	26
	1.7.2 Chapter 12: subsidence resulting from chalk and flint mining	26
	1.7.2.1 Flint mine workings	28
	1.7.2.2 Chalk mine workings	28
	1.7.3 Chapter 13: hazards associated with mining and mineral exploitation in Cornwall and Devon, SW England	28
	1.7.4 Chapter 14: geological hazards from salt mining and brine extraction	29
	1.7.5 Chapter 15: geological hazards from carbonate dissolution	30
	1.7.6 Chapter 16: geological hazards caused by gypsum and anhydrite in the UK: dissolution, subsidence, sinkholes and heave	32
	1.7.7 Chapter 17: mining-induced fault reactivation in the UK	34
1.8	Section E: gas hazards	35
	1.8.1 Chapter 18: radon gas hazard	35
	1.8.2 Chapter 19: methane gas hazard	35
Cor	nclusions	38
	erences	38
Cha	apter 2 Seismic hazard	43
2.1	Earthquakes as a geohazard	43
2.2	Distribution of earthquakes in the UK	44
2.3	Consequences of British earthquakes	47
2.4	Identifying earthquakes as a geohazard in the UK	48
2.5		50
2.6	•	51
2.7	Earthquake monitoring in the UK	53
2.8		55
2.9	Limits to earthquake hazard in the UK	55

CONTENTS	vii
2.10 Actions to take in an earthquake	56
Glossary	56
Data sources and further reading	58
References	58
References	30
Chapter 3 Tsunami hazard with reference to the UK	61
3.1 Introduction	61
3.2 Tsunami geohazard	61
3.3 Tsunami wave characteristics	62
3.4 Tsunami generation processes	63
3.4.1 Tsunamigenic earthquakes	63
3.4.2 Tsunamigenic landslides	63
3.4.3 Tsunamigenic volcanism	63
3.4.4 Meteotsunami	64
3.4.5 Other potential tsunami-generating mechanisms	65
3.5 UK tsunami threat	65
3.6 Notable tsunami events with a UK impact	66
3.6.1 c. 8150 BP Holocene Storegga submarine landslide and tsunami	66
3.6.2 c. 5500 BP Holocene Garth tsunami	67
3.6.3 AD 1755 Lisbon earthquake and tsunami	68
3.6.4 AD 1911 Abbot's Cliff failure, Folkestone	69
3.6.5 Other Dover Straits events	73
3.7 Tsunami management and mitigation	74
3.8 Concluding comments	77
References	77
	0.1
Chapter 4 Landslide and slope stability hazard in the UK 4.1 Introduction	81 81
4.2 Landslide types	84
4.3 The landslide inventory for Great Britain	91
4.4 The Irish landslide inventory	92
4.5 The landslide environment of the UK	94
4.5.1 Peat failures	101
4.5.2 Slope deformation: cambering and complex rock block spreads	102
4.5.3 Large rock slope failures in the Scottish Highlands	105
4.5.4 Flow slides in colliery spoil	106
4.5.5 Coastal landslides: cliff behaviour units	106
4.6 Causes of landslides	108
4.6.1 Landslides and rainfall	114
4.6.2 Anthropogenic effects	116
4.6.3 Landslide controls: the influence of geology	119
4.7 Phases of landslide activity	124
4.7.1 Repeated phases of glacial and periglacial conditions	126
4.7.2 Impact of drainage adjustments during deglaciation	127
4.7.2 Impact of dramage adjustments during degraciation 4.7.3 Postglacial slope responses	127
4.7.4 Changing climatic conditions during the Holocene	127
4.7.4 Changing chinate conditions during the Froncene 4.7.5 Climatic deterioration during the Little Ice Age	129
4.7.6 Anthropogenic land-use changes	132
1.7.0 7 Munopogeme rand-use changes	132

viii CONTENTS

4.7.7 Extreme events	134
4.8 Landslide risk	134
4.8.1 Sources of risk	134
4.8.2 Assessing risk	135
4.9 Landslide hazard	140
4.9.1 Landslide hazard assessment	142
4.9.2 Landslide investigation	142
4.10 Landslide risk management	144
4.10.1 Avoid the risk	144
4.10.2 Restrict or prevent access to the area at risk from landsliding	144
4.10.3 Accept the risk	144
4.10.4 Share the risk	144
4.10.5 Transfer the risk through litigation to recover the costs of landslide damage	144
4.10.6 Reduce the exposure	145
4.10.7 Provide forewarning of potentially damaging incidents	145
4.10.8 Incorporate specific ground movement tolerating measures into the building design	145
4.10.9 Control the area between a landslide event and the assets at risk	145
4.10.10 Reduce the probability of the hazard	145
4.11 The role of government in landslide management	146
4.11.1 Provision of publicly funded coast protection works4.11.2 Control development in high-risk areas	146
4.11.2 Control development in high-risk areas 4.11.3 Control building standards	147 147
4.11.4 Fund and co-ordinate the response to major events	147
4.11.5 Protect strategic infrastructure	148
4.12 In practice: acceptable or tolerable risks?	149
4.13 Concluding remarks	151
References	152
Chapter 5 Debris flows	163
5.1 Introduction	163
5.2 Types of landslide and flow mechanisms	164
5.3 Occurrence	166
5.3.1 A83 Glen Kinglas/Cairndow: 9 August 2004	168
5.3.2 A9 North of Dunkeld: 11 August 2004	168
5.3.3 A85 Glen Ogle: 18 August 2004	170
5.3.4 A83 Rest and be Thankful: 28 October 2007	171
5.4 Hazard and risk assessment	172
5.5 Risk reduction	173
5.6 Impacts	178 179
5.7 Climate change Conclusions	183
References	183
References	103
Chapter 6 Collapsible soils in the UK	187
6.1 What are collapsible soils?	187
6.2 Loess in the UK	188
6.3 How to recognize loessic brickearth	191
6.3.1 Description and mineralogy	191
6.3.2 Geotechnical properties	193

CONTENTS	ix
6.3.2.1 Particle size distribution	193
6.3.2.2 Density	193
6.3.2.3 Plasticity	193
6.3.2.4 Strength, consolidation and permeability of brickearth/loess	193
6.4 Non-engineered fills	196
6.5 Identifying collapsibility	196
6.5.1 Collapse potential	196
6.6 Strategies for engineering management: avoidance, prevention and mitigation	197
6.7 Example of damage caused by collapse	198
6.8 Conclusions	200
Glossary and definitions	200
Further reading	200
References	201
Chapter 7 Quick clay behaviour in sensitive Quaternary marine clays – a UK perspective	205
7.1 Introduction	205
7.2 Mode of formation	205
7.3 Geotechnical properties and behaviour	208
7.4 Failure mechanisms	208
7.5 The UK context	212
7.6 Geohazard management and mitigation	216
7.7 Conclusions	218
References	218
Chapter 8 Swelling and shrinking soils	223
8.1 Introduction	223
8.2 Properties of shrink–swell soils	223
8.3 Costs associated with shrink–swell clay damage	224
8.4 Formation processes	225
8.5 Distribution	225
8.6 Characterization of shrink–swell soils	226
8.7 Mechanisms of shrink–swell	230
8.8 Shrink–swell behaviour	230
8.9 Strategies for engineering management: avoidance, prevention and mitigation	233
8.10 Shrink–swell soils and trees	236
8.11 Conclusions	237
Appendix: Definitions and glossary	238
Recommended further reading	240
Useful web addresses	240
References	240
Chapter 9 Peat hazards: compression and failure	243
9.1 Introduction and scope	243
9.2 Engineering background: peat consolidation and compression	245
9.2.1 Compression of peat	246
9.3 UK peatlands: extent and occurrence	249
9.4 Geological hazards associated with peat compressibility	250
9.4.1 Subsidence of peat	250
9.4.2 Derrybrien landslide, wind farm construction, County Galway 2003	251

CONTENTS X 9.4.3 Direct loading by quarry waste, Harthope Quarry, North Pennines, UK 252 9.4.4 Failure during upland road construction, North Pennines, UK 252 9.5 Mitigation of the hazards posed by compressible peat soils 253 9.6 Conclusion 255 References 256 Chapter 10 Periglacial geohazards in the UK 259 259 10.1 Introduction 10.2 Relict periglacial geohazards 262 10.2.1 Deep weathering 262 10.2.2 Shallow-slope movements 265 10.2.3 Cambering and superficial valley disturbances 276 10.2.4 Rockhead anomalies 280 10.2.5 Cryogenic wedges (ice-wedge pseudomorphs) 283 10.3 Subsidiary relict periglacial geohazards 284 10.3.1 The influence of periglacial climates and processes on deep-seated landslide systems 284 10.3.2 Carbonate dissolution 284 10.3.3 Buried terrains 285 10.3.4 Submerged periglacial terrains 285 10.3.5 Loess and coversand 285 10.4 Conclusions 285 References 286 Chapter 11 Coal mining subsidence in the UK 291 11.1 Introduction 291 11.2 Subsidence characteristics 291 11.3 Overview of mining methods 291 11.3.1 Adits, drifts (inclines) and shafts 291 292 11.3.2 Bell pits 11.3.3 Room-and-pillar 292 11.3.4 Longwall mining 293 11.3.5 Subsidence associated with partial extraction of coal 293 11.3.5.1 Mine shafts and bell pits 293 11.3.5.2 Room-and-pillar workings 293 11.3.6 Subsidence associated with total extraction of coal 295 11.3.6.1 Tilt 295 11.3.6.2 Slope 296 11.3.6.3 Curvature 296 11.3.6.4 Strain 296 11.3.6.5 Horizontal displacements 296 11.3.6.6 Strain 296 11.3.6.7 Width-depth ratio 297 11.3.6.8 Angle-of-draw (limit angle) 297 11.3.6.9 Area-of-influence 297 11.3.6.10 Maximum subsidence 297 11.3.6.11 The subsidence factor 297 11.3.6.12 Dip of seam 297

297

11.3.6.13 Bulking

CONTENTS	xi
11.3.6.14 Time-dependent subsidence and residual subsidence	297
11.3.6.15 Multiple seams	298
11.3.7 Subsidence and the engineering properties of soils and rocks	298
11.3.7.1 Soils/superficial deposits	298
11.3.7.2 Rock	299
11.3.8 Subsidence prediction	299
11.3.8.1 Empirical methods	300
11.3.8.2 Analytical or theoretical	300
11.3.8.3 Semi-empirical methods	300
11.3.8.4 Void migration	300
11.4 Managing subsidence risks	301
11.4.1 Desk study	302
11.4.2 Reconnaissance (walk-over) survey	303
11.4.3 Ground investigations	303
11.5 Mitigation and remediation	304
11.6 Summary	306
References	306
Chapter 12 Subsidence – chalk mining	311
12.1 Introduction	311
12.2 Geographical occurrence	311
12.3 Characteristics of the mine workings	313
12.3.1 Flint mine workings	313
12.3.1.1 Neolithic flint mines	313
12.3.1.2 Modern flint mines	314
12.3.1.3 Chalk mine workings	314
12.3.1.4 Bellpits	314
12.3.1.5 Deneholes	314
12.3.1.6 Chalkwells	315
12.3.1.7 Chalkangles	316
12.3.1.8 Pillar-and-stall mines	316
12.4 Engineering management strategy	317
Appendix: Further reading	319
Websites	319
References	319
Chapter 13 Hazards associated with mining and mineral exploitation in Cornwall and Devon, SW England	321
13.1 Introduction	321
13.2 The geological model and the setting for mining-related hazards	322
13.2.1 Geological overview	322
13.2.2 Paleozoic rocks of the Variscan (Rhenohercynian) basement	322
13.2.2.1 Upper Paleozoic rift basins of the Rhenohercynian passive margin	322
13.2.2.2 Upper Paleozoic mafic and ultramafic rocks of the Lizard Complex	324
13.2.2.3 Upper Paleozoic allochthons	325
13.2.2.4 Lower Paleozoic (pre-rift) basement	325
13.2.3 Regional structure	325
13.2.4 Post-Variscan cover, magmatism, mineralization and alteration	326
13.2.5 Superficial deposits	328
13.3 History of mining	328

xii CONTENTS

13.4	Environmental legacy of mining	333
	13.4.1 Underground voids and shafts	333
	13.4.2 Opencast mines	336
	13.4.3 Waste tips and contaminated land	337
	13.4.4 Infilled or silted-up estuaries	338
	13.4.5 Slurry lakes or tailings ponds	338
	13.4.6 Pollution by contaminated mine water	338
	13.4.7 Flooding	343
13.5	Investigating and assessing the hazards	344
	13.5.1 Desk studies	344
	13.5.2 Remote sensing	344
	13.5.3 Geophysics	345
	13.5.4 Field mapping	346
	13.5.5 Ground investigations	346
	13.5.6 Developing the ground model	350
	13.5.7 Hazard and risk assessment	350
	13.5.8 Monitoring	351
13.6	Planning, preservation, treatment and remediation	352
	13.6.1 International and local planning	352
	13.6.2 Preservation	352
	13.6.3 Treatment and remediation through engineering works	353
	13.6.4 Derelict land reclamation	355
	13.6.5 Mine water contamination and remediation	355
	13.6.6 Case studies of mine site treatment and remediation	356
	13.6.6.1 Wheal Peevor, Redruth, Cornwall. Kerrier District Council (2003–07)	357
	13.6.6.2 The National Trust	357
13.7	Conclusions	360
Refe	rences	362
Cha	pter 14 Geological hazards from salt mining, brine extraction and natural salt dissolution in the UK	369
	Introduction	369
	Distribution of salt deposits in the Triassic and Permian rocks of the UK	370
	Salt karst and natural dissolution	371
	Mining and dissolution mining of salt	372
	14.4.1 Natural 'wild' brine extraction	372
	14.4.2 Shallow salt mining and 'bastard' brining	372
	14.4.3 Modern salt mining	373
14.5	Mining of Permian salt deposits	375
	14.5.1 Teesside	375
14.6	Mining of the Triassic salt deposits	377
	14.6.1 Cheshire	377
	14.6.2 Blackpool and Preesall	378
	14.6.3 Stafford	378
	14.6.4 Droitwich	379
	14.6.5 Northern Ireland	380
14.7	Mitigating salt subsidence problems	380
	14.7.1 Brine Subsidence Compensation Board	380
	14.7.2 Salt mine stabilization	382
	14.7.3 Monitoring and investigation	384

CONTENTS	XIII
14.7.4 Planning for soluble rock geohazards	384
References	385
Chapter 15 Dissolution – carbonates	389
15.1 Introduction	389
15.2 Geographical occurrence	389
15.3 Characteristics of natural cavities formed by dissolution	392
15.4 Engineering management strategy	395
Further reading	400
Websites P. 6	400
References	400
Chapter 16 Geohazards caused by gypsum and anhydrite in the UK: including	402
dissolution, subsidence, sinkholes and heave 16.1 Introduction	403 403
16.2 The gypsum–anhydrite transition, expansion and heave	403
16.3 The gypsum dissolution problem	404
16.4 Geology of the gypsiferous rocks	404
16.4.1 Triassic	404
16.4.2 Permian	404
16.5 Subsidence caused by gypsum dissolution	407
16.5.1 Subsidence geohazards around Ripon	407
16.5.2 Subsidence geohazards around Darlington	409
16.5.3 Subsidence geohazards between Ripon and Doncaster	410
16.5.4 Subsidence geohazards in the Vale of Eden	410
16.5.5 Subsidence over Triassic gypsum	411
16.6 Ground investigation: surveying, geophysics and boreholes in gypsum areas	411
16.7 Gypsum dissolution as a hazard to civil engineering	413
16.8 Problems related to water abstraction and injection in gypsum areas	416
16.9 Planning for subsidence	417
Conclusions	419
References	419
Chapter 17 Mining-induced fault reactivation in the UK	425
17.1 Background	425
17.2 Occurrence	425
17.3 Diagnostic characteristics	426
17.4 Mitigation	427
References	430
Chapter 18 Padan gos bazard	433
Chapter 18 Radon gas hazard 18.1 Introduction	433
18.2 Other natural sources of radiation	434
18.2.1 Gamma rays from the ground and buildings (terrestrial gamma rays)	434
18.2.2 Cosmic rays	435
18.3 Health effects of radiation and radon	435
18.4 Radon release and migration	436
18.5 Factors affecting radon in buildings	438
18.6 Geological associations	438
18.6.1 Granites	439
18.6.2 Black shales	439

xiv CONTENTS

18.6.3 Phosphatic rocks and ironstones	444
18.6.4 Limestones and associated shales and cherts	445
18.6.5 Sands and sandstones	446
18.6.6 Ordovician–Silurian greywackes and associated rocks	446
18.6.7 Miscellaneous bedrock units	446
18.6.8 Superficial deposits	446
18.7 Measurement of radon	446
18.7.1 Radon testing in the home	446
18.7.2 Measurement of radon in soil-gas and solid materials	447
18.8 Radon hazard mapping and site investigation	448
18.8.1 Radon hazard mapping based on geology and indoor radon measurements	448
18.8.2 Radon hazard mapping based on geology, gamma spectrometry and soil-gas radon data	449
18.8.3 Radon site investigation methods	450
18.9 Strategies for management: avoidance, prevention and mitigation	451
18.9.1 Introduction	451
18.9.2 Environmental health regulations	451
18.9.3 Radon and the building regulations: protecting new buildings	452
18.9.4 Radon and workplaces	453
18.9.5 Radon and the planning system	453
18.9.6 Remedial measures	453
18.10 Scenarios for future events	454
References	454
References	7.77
Chapter 19 Methane gas hazard	457
19.1 The source and chemical properties of methane	457
19.2 Guidance and best practice	462
19.2.1 Legislative background	462
19.3 Developing the conceptual site model	462
19.3.1 Sources of methane	462
19.3.2 Pathways for migration	464
19.3.3 Potential receptors to methane	466
19.4 Examples of methane impacts	466
19.5 Managing risk	468
19.5.1 Site investigation for methane	468
19.5.2 UK contamination practices	468
19.5.3 The planning process	468
19.5.4 The definition of contaminated land	469
19.6 The risk assessment process	469
19.6.1 Qualitative risk assessment	470
19.6.2 Semi-quantitative risk assessment	471
19.6.3 NHBC Traffic Lights	472
19.6.4 British Standard BS8485: 2015	472
19.6.5 Quantitative risk assessment	474
19.6.6 Acute situation	475
19.7 Mitigating methane risks	475
19.8 Summary and conclusions	477
References	477
	.,,
Index	479