
Contents

Preface	xi
Livio RUFFINE, Daniel BROSETA and Arnaud DESMEDT	
Part 1. Field study and laboratory experiments of hydrate-bearing sediments	1
Introduction to Part 1	3
Livio RUFFINE	
Chapter 1. Water Column Acoustics: Remote Detection of Gas Seeps	11
Carla SCALABRIN and Stéphanie DUPRÉ	
1.1. Introduction.	11
1.2. Principle of the measurement	14
1.2.1. Instrumentations	14
1.2.2. Qualitative and quantitative measurements.	14
1.3 Bibliography	18
Chapter 2. Geophysical Approach	21
Bruno MARSSET	
2.1. Introduction.	21
2.2. Overview	21
2.3. Seismic processing	23
2.3.1. Positioning phase	23
2.3.2. Preprocessing phase	24
2.3.3. Processing phase	25
2.4. Example of gas hydrate exploration: the SYSIF instrument	28
2.5. Bibliography	29

Chapter 3. Hydrate Seismic Detection	31
Stephan KER	
3.1. Wave velocities of hydrate-bearing sediments	32
3.1.1. Empirical equations	32
3.1.2. Effective medium theories	33
3.2. Bibliography	34
Chapter 4. Geomorphology of Gas Hydrate-Bearing Pockmark	37
Vincent RIBOULOT	
4.1. Introduction.	37
4.2. Generalities about pockmarks	38
4.3. Impact of gas hydrate on seafloor deformation	39
4.4. Morphological evolution of gas hydrate pockmarks	42
4.5. Distinction between gas hydrate-bearing and gas hydrate-free pockmarks	44
4.6. Bibliography	45
Chapter 5. Geotechnics	49
Sébastien GARZIGLIA	
5.1. Introduction.	49
5.2. The Penfeld system	50
5.2.1. Piezocone and acoustic soundings in gas hydrate-bearing sediments	52
5.3. Bibliography	54
Chapter 6. Geochemistry	57
Livio RUFFINE, Sandrine CHÉRON, Emmanuel PONZEVERA, Christophe BRANDILY, Patrice WOERTHER, Vivien GUYADER, Audrey BOISSIER, Jean-Pierre DONVAL and Germain BAYON	
6.1. Introduction.	57
6.2. Sampling geological materials from hydrate-bearing sediment	58
6.2.1. The Calypso corer	58
6.2.2. Sampling of sediments, carbonates and pore fluids from the Calypso corer	62
6.3. Analyses.	65
6.3.1. Sediment and carbonate	65
6.3.2. Gases	75
6.3.3. Pore water	78
6.4. Bibliography	82

Chapter 7. Benthic Ecosystem Study	85
Karine OLU, Laurent TOFFIN and Christophe BRANDILY	
7.1. Microbial ecology in hydrate-bearing sediments	85
7.1.1. Study sites containing hydrate-bearing sediments	85
7.1.2. Sampling strategy for microbiology study of hydrate-bearing sediments	86
7.1.3. Laboratory analyses	87
7.2. Macrobial ecology studies at cold seeps	91
7.2.1. Mapping biogenic habitats	93
7.2.2. Chemical characterization of biogenic habitats	97
7.2.3. Sampling in biogenic habitats	103
7.2.4. Fauna	106
7.2.5. Symbiosis studies	110
7.3. Bibliography	111
Chapter 8. Physicochemical Properties of Gas Hydrate-bearing Sediments	121
Ludovic LEGOIX, Elke KOSSEL, Christian DEUSNER, Livio RUFFINE and Matthias HAECKEL	
8.1. Introduction.	121
8.2. Gas hydrate formation and dissociation	124
8.3. Fluid transport in gas hydrate-bearing sediments.	128
8.4. Thermal and electrical properties of gas hydrate-bearing sediments	133
8.5. Distribution and occurrence of gas hydrates in sediments	137
8.6. Experimental investigation of dynamic processes in gas hydrate-bearing sediments.	139
8.7. Bibliography	149
Chapter 9. Small-scale Laboratory Studies of Key Geotechnical Properties which are Not Possible to Measure from <i>In Situ</i> Deployed Technologies	165
Sébastien GARZIGLIA	
9.1. Introduction.	165
9.2. Influence of gas hydrates on the stiffness and strength properties of sediments	166
9.2.1. Elastic or small-strain stiffness properties	166
9.2.2. Large-strain stiffness and strength properties	168
9.2.3. Geotechnical consequences of gas hydrate destabilization.	170
9.3. Bibliography	172

Part 2. Modeling of Gas Hydrate-bearing Sediments and Case Studies	177
Chapter 10. Geomechanical Aspects	179
Assaf KLAR and Shun UCHIDA	
10.1. Introduction	179
10.2. Geomechanical characteristics	179
10.3. Constitutive models for continuum mechanics frameworks.	181
10.3.1. Stress–strain formulation for hydrate-bearing sediments.	183
10.3.2. DEM representation.	191
10.4. Coupled formulation.	195
10.5. Numerical simulations of the Nankai 2013 gas production test	202
10.5.1. The Nankai gas production test overview.	202
10.5.2. Modeling procedure	203
10.5.3. History matching of the 2013 Nankai production test.	210
10.5.4. Thermo–hydro–mechanical studies during the 2013 Nankai gas production test	211
10.6. Concluding remarks	213
10.7. Bibliography	214
Chapter 11. Geochemical Aspects	219
Wei-Li HONG and Malgorzata PESZYNSKA	
11.1. Introduction	219
11.2. Basic principles.	220
11.2.1. Transport in the aqueous phase by advection and diffusion	220
11.2.2. Numerical scheme for the advection–diffusion problem	222
11.2.3. Transport of methane in aqueous phase in the presence of gas hydrate phase	223
11.2.4. Transport of methane and salt species, with hydrate presence.	225
11.3. Model framework	226
11.4. Model validation and sensitivity tests.	230
11.5. Model application	230
11.6. Concluding remarks	239
11.7. Acknowledgments	239
11.8. Bibliography	239

Part 3. Geoscience and Industrial Applications	243
Chapter 12. Biogeochemical Dynamics of the Giant Pockmark Regab	245
Alexis DE PRUNELÉ, Karine OLU, Livio RUFFINE, H����������, Jean-Claude CAPRAIS, Germain BAYON, Anne-Sophie ALIX, Julie Le BRUCHEC and Louis G����	
12.1. Introduction	245
12.2. Location of the pockmark.	246
12.2.1. The pockmark Regab: hydrocarbon emission and morphology	247
12.3. Megafauna distribution on Regab pockmark in relation to fluid chemistry	250
12.3.1. Megafauna distribution on the Regab pockmark.	250
12.3.2. Mytilid habitats	252
12.3.3. Bacterial mat habitat	255
12.3.4. Vesicomid habitats	258
12.4. General conclusion on the megafauna distribution on the Regab pockmark in relation to fluid chemistry	263
12.5. Bibliography	264
 Chapter 13. Roles of Gas Hydrates for CO₂ Geological Storage Purposes	267
Andr�� BURNOL	
13.1. Introduction	267
13.2. Hydrate trapping of CO ₂ in subsurfaces (onshore, offshore and deep offshore cases)	269
13.2.1. Case of migration of CO ₂ within the overburden	269
13.2.2. Case of natural gas hydrates exploitation using CO ₂ injection.	270
13.2.3. Role of mixed gas hydrates in the “deep offshore” CO ₂ storage option	272
13.3. CO ₂ deep offshore storage capacity in the French and Spanish EEZs.	276
13.4. Summary and prospects.	281
13.5. Bibliography	281
 Chapter 14. Hydrate-Based Removal of CO₂ from CH₄ + CO₂ Gas Streams	285
Daniel BROSETA, Christophe DICHARRY and Jean-Philippe TORR��	
14.1. Introduction	285
14.2. Laboratory experiments of gas capture and separation by means of gas hydrates	290

14.2.1. Batch experiments.	292
14.2.2. Semibatch experiments.	295
14.2.3. Continuous separation experiments	295
14.3. Metrics of CO ₂ separation	295
14.4. Results from experiments of CO ₂ removal from CO ₂ /CH ₄ gas mixtures	300
14.4.1. Pure water and water with surfactant additives.	300
14.4.2. THF and other sII hydrate-forming additives.	301
14.4.3. TBAB, TBPB and other semiclathrate-forming additives	303
14.5. Routes to enhance the removal of CO ₂ from CO ₂ /CH ₄ gas mixtures	307
14.6. Concluding remarks	309
14.7. Bibliography	309
Chapter 15. Use of Hydrates for Cold Storage and Distribution in Refrigeration and Air-Conditioning Applications	315
Anthony DELAHAYE, Laurence FOURNAISON and Didier DALMAZZONE	
15.1. Introduction	315
15.2. Hydrate systems for cool storage and distribution	317
15.2.1. Refrigerant gas hydrate applied to cool storage	317
15.2.2. CO ₂ hydrates applied to cool storage and distribution	318
15.2.3. Quaternary salt hydrates for cool storage and distribution	319
15.2.4. Other hydrates applied to cool storage and distribution.	320
15.3. Criteria for use of hydrates in refrigeration	321
15.3.1. Thermodynamic criterion	322
15.3.2. Flow criterion	325
15.3.3. Thermal criterion	331
15.3.4. Kinetic criterion	332
15.3.5. Energy criterion	334
15.4. Hydrate applications in refrigeration and air conditioning	335
15.4.1. Slurry generation methods.	335
15.4.2. Examples of hydrate-based refrigeration systems	336
15.5. Conclusion	341
15.6. Bibliography	342
List of Authors	359
Index	363