

Contents

Introduction: Why a Book on the “Geomechanics of Coal Seams”?	xi
Jean-Michel PEREIRA and Matthieu VANDAMME	
 Chapter 1. Coal, Its Genesis, Its Characteristics.	1
Didier BONJOLY	
1.1. Definition	1
1.2. Deposition conditions.	4
1.3. The major periods of coal deposition.	5
1.4. Coalification process	9
1.5. Coal classification	11
1.6. Coal gas	13
1.6.1. Overview	13
1.6.2. Gas–coal interactions.	16
1.6.3. Fracturing and mechanical effects	16
1.7. Coal availability, resources and reserves	18
1.7.1. Coal resources	19
1.7.2. Global coal resources and reserves.	22
1.7.3. Coal resources and reserves in France.	24
1.8. The uses of coal	26
1.8.1. Steam coal	26
1.8.2. Iron and steel industry	26
1.8.3. Cement industry.	27
1.8.4. Coal gasification	28

1.9. Coal gas exploitation	30
1.9.1. Different types of coal gas.	30
1.9.2. Coal gas: a hazard turned resource.	30
1.9.3. In situ coal gasification (UCG)	34
1.10. Coal and climate change	37
1.10.1. Various CO ₂ capture solutions for the coal-fired power plant sector	39
1.10.2. CCS for carbon-intensive industries	41
1.10.3. Enhanced coalbed methane recovery by CO ₂ injection (ECBM).	44
1.11. Acknowledgments	46
1.12. References.	47
 Chapter 2. Hydrogeology of Fractured Media – With Special Reference to Coalbeds	51
Derek ELSWORTH, Jishan LIU, Shimin LIU, Brandon SCHWARTZ and Shugang WANG	
2.1. Introduction.	51
2.2. Controls on groundwater flow.	52
2.2.1. Transmission of fluids – permeability	52
2.2.2. Storage of fluids – specific storage.	57
2.2.3. Governing equations	58
2.3. Characterization methods	59
2.3.1. Laboratory methods	59
2.3.2. In situ methods	64
2.4. Permeability evolution models	67
2.4.1. Strain-controlled models.	68
2.4.2. Stress-controlled models.	75
2.4.3. Supercritical fluids	78
2.5. Summary	80
2.6. References	81
 Chapter 3. Measurement of Coal Physical Properties: Poromechanical and Adsorption Testing	85
D. Nicolas ESPINOZA	
3.1. Introduction.	85
3.2. Pressure, stress and strains in geological formations	86
3.3. Total gas-in-place and adsorption measurement	90
3.3.1. Manometric method	92

3.3.2. Volumetric method	94
3.3.3. Gravimetric method	97
3.3.4. Sorption models and extension to total adsorption amount	99
3.4. Adsorption-induced strains.	99
3.4.1. Dilatometer tests – swelling isotherms	100
3.4.2. Adsorption-induced strains in triaxial testing	105
3.5. Adsorption-induced stresses	106
3.5.1. Isochoric tests	106
3.5.2. Uniaxial-strain test	108
3.6. Reservoir scale implications	109
3.6.1. Natural gas production: stress-dependent permeability.	110
3.6.2. Natural gas production: desorption-induced shear failure	110
3.6.3. Carbon geological storage: coal swelling, fracture closing and injectivity decrease	110
3.7. Conclusions.	111
3.8. References	112
 Chapter 4. Poromechanical Modeling of Coal Material	117
Matthieu VANDAMME, Jean-Michel PEREIRA and David GRÉGOIRE	
4.1. Relevant scale for material modeling.	119
4.2. Physics of the phenomena involved	121
4.2.1. Fluids	121
4.2.2. Coal in the absence of fluid	124
4.2.3. Interactions between coal and pore fluids.	127
4.2.4. Impact of temperature	131
4.3. Classical poromechanical modeling of a saturated material in the absence of sorption	132
4.3.1. System under consideration	132
4.3.2. Energy balances and state variables	133
4.3.3. Constitutive equations for an isotropic poroelastic material	134
4.4. Poromechanical modeling of microporous materials undergoing sorption	136
4.4.1. Approach based on the concept of apparent magnitudes (confinement coefficient)	137
4.4.2. Approach based on univocally defined state variables	142
4.5. Examples of possible model enhancements	145
4.5.1. Multi-scale porosity of coal	145
4.5.2. Anisotropy of the hydro-poromechanical behavior of coal.	151
4.5.3. Transient effects related to transfers between fractures and the matrix	153

4.5.4. Fluid mixture	156
4.6. Limitations and perspectives of the models	157
4.6.1. Experimental limitations: complexity in interpreting experiments in light of models	157
4.6.2. Model perspectives	158
4.7. References	160
 Chapter 5. Molecular Scale Modeling of Coal and Its Behavior . . .	165
Laurent BROCHARD, Christelle MIQUEU and David GRÉGOIRE	
5.1. Introduction.	165
5.2. Nature of coal at the molecular scale.	169
5.3. Atomic simulations of adsorption in coals.	173
5.4. Adsorption modeling using DFT	182
5.5. Mechanics-adsorption coupling	189
5.5.1. Thermodynamic analysis of coupling and extended poromechanics	189
5.5.2. Molecular simulation of model systems.	196
5.5.3. Simplified poro-mechanical model applied to coal	200
5.6. Conclusion	203
5.7. References	205
 Chapter 6. Reservoir-Scale Modeling	211
Patrick DANGLA	
6.1. Introduction.	211
6.2. Isothermal constitutive laws of coal in the presence of adsorbates	212
6.2.1. Gas behavior.	212
6.2.2. Adsorption in a deformable coal matrix.	215
6.2.3. Gas content in fractured coal	218
6.2.4. Poroelastic behavior	219
6.2.5. Mass transfer kinetics between coal matrix and fractures	221
6.2.6. Permeability of fractured coal.	224
6.3. Reservoir scale field equations	225
6.3.1. Mechanical equilibrium	225
6.3.2. Gas transport.	227
6.3.3. Synthesis of equations and unknowns for the problem: case of a single fluid	228
6.4. Numerical solution via the finite element method	229
6.4.1. Weak formulation of the field equations	229

6.4.2. Time stepping and spatial discretization	231
6.4.3. Iterative Newton method for solving	232
6.5. Application examples	234
6.5.1. Methane production	234
6.5.2. Carbon dioxide injection through a draining macroscopic fracture	238
6.6. Conclusion	239
6.7. References	241
Chapter 7. Multiscale Modeling.	243
François BERTRAND and Frédéric COLLIN	
7.1. Introduction.	243
7.1.1. Different scales	243
7.1.2. Multiscale approaches	244
7.2. Principles of the FE^2 method	245
7.2.1. Macro-to-micro transition (localization)	246
7.2.2. Solving the microscale problem	247
7.2.3. Micro-macro transition (homogenization)	248
7.2.4. Solving the macroscale problem	249
7.2.5. FE^2 method algorithm	249
7.3. Hydro-mechanical model.	249
7.3.1. Representative volume element.	250
7.3.2. Boundary conditions	251
7.3.3. Equilibrium equations	253
7.3.4. Microscopic constitutive laws	254
7.3.5. Microscopic numerical solution	258
7.3.6. Homogenized response.	259
7.4. Application	261
7.4.1. Case study	261
7.4.2. Results	263
7.4.3. Discussion	264
7.5. Conclusion	271
7.6. References	272
List of Authors	277
Index	279

