PhD Thesis Research

FE^2 approach for the modelling of coupled hydro-mechanical behaviour of partially saturated coalbeds

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Supervised by: Frédéric COLLIN

University of Liège

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Introduction

Coalbed methane

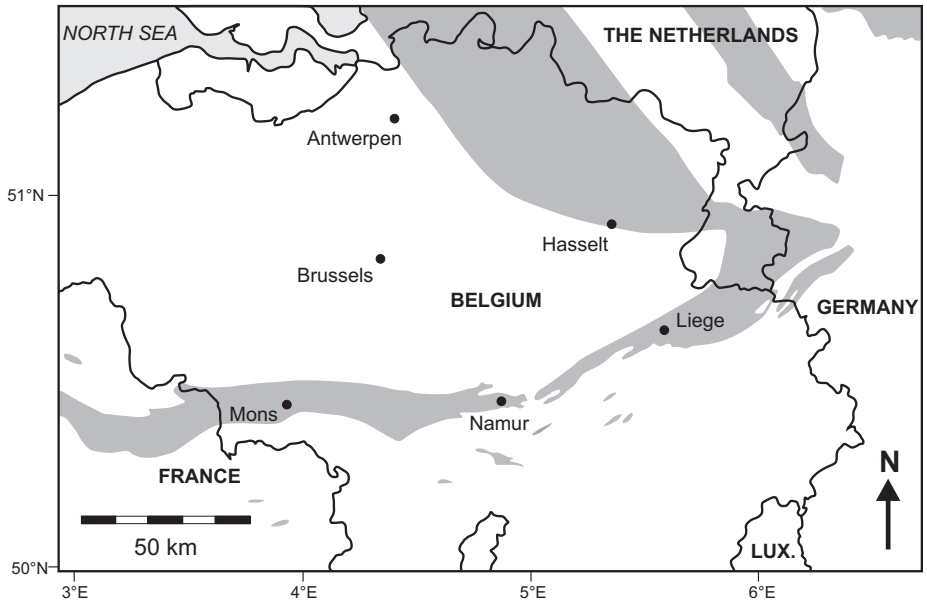


Figure: Map of the outcropping or shallow subsurface coal basins (shaded area) in and around Belgium. Modified after [Piessens and Dusar, 2006].

6 to 9 billions tons of coal

in the walloon basement

↓

100 to 300 billions m^3 of methane

? ↓ ?

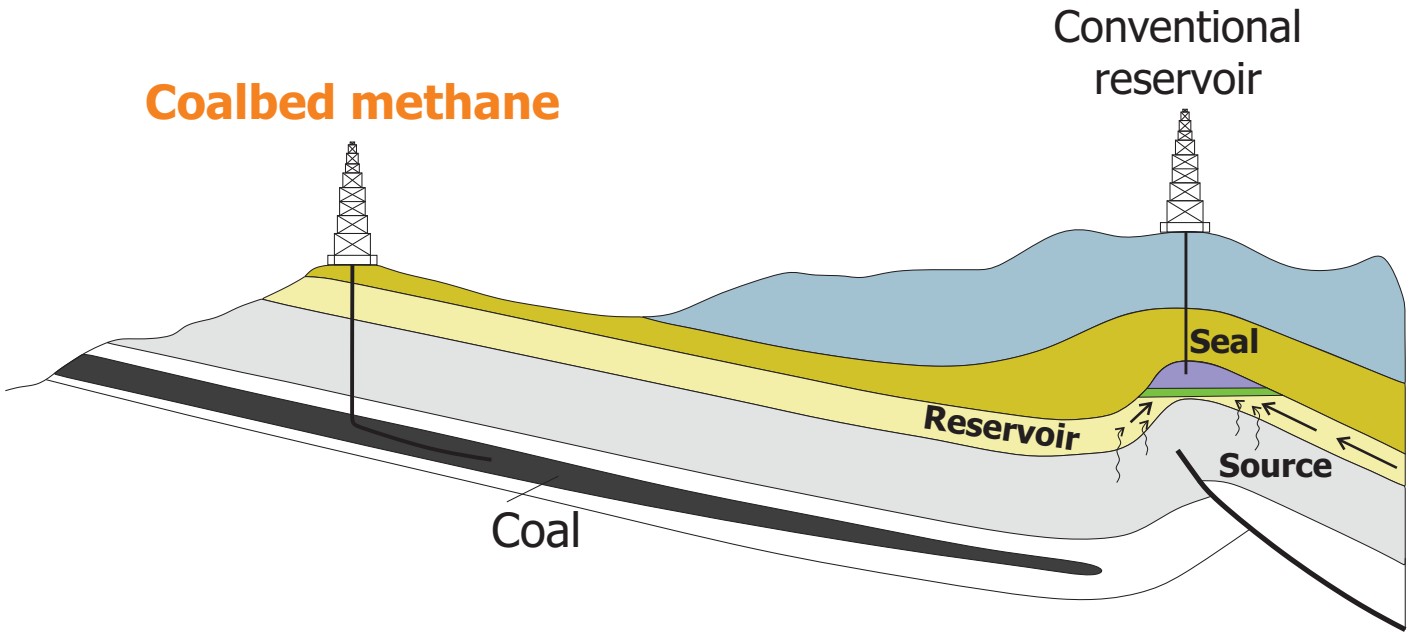
10 to 20 billions m^3 of recoverable methane?

↓

3 to 10 years of gas consumption in Belgium

Coalbed methane (CBM) = **unconventional resource**

Source rock (= coalbeds) is **also the reservoir** for the methane



Promising alternative to conventional gas

Introduction

Coal properties

Coalbeds = **dual porosity** systems

Micropores + Macropores $\Longleftrightarrow$ Matrix + Cleats

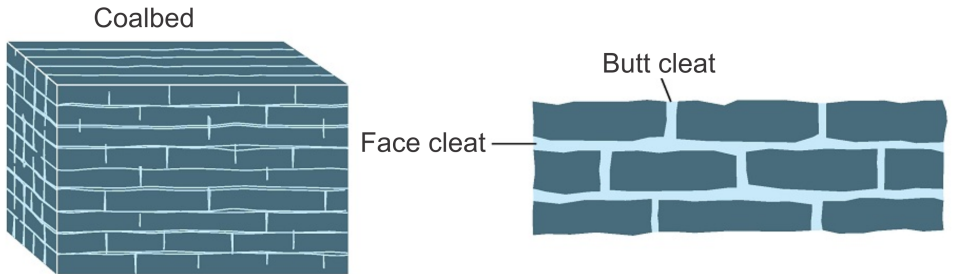
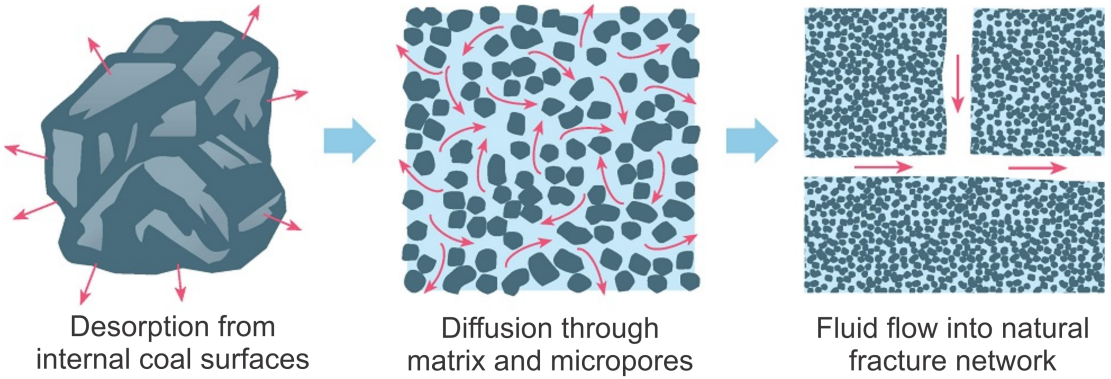


Figure: From Schlumberger Oilfield Glossary



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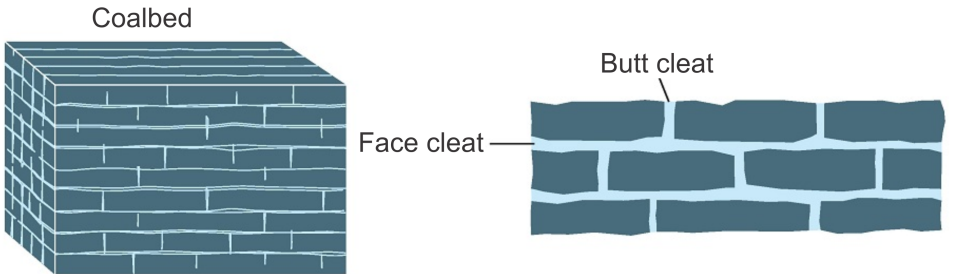

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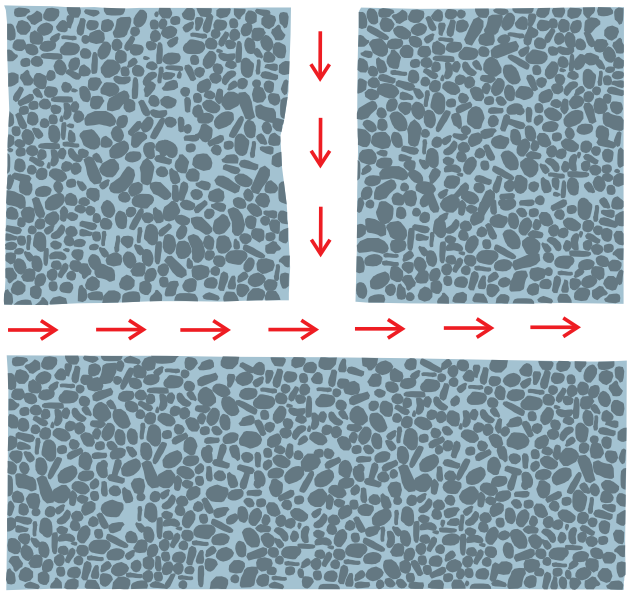

Cleat **permeability** is directly dependent on the **width of the cleats**.

Introduction

Challenge

"The influence of **geomechanical processes** is an **important issue for coalbed methane** recovery and **ignoring** geomechanical processes **may lead to errors** in the evaluation of coalbed methane production." [Gu et al., 2005]

But

Coupled hydro-mechanical behaviour of coalbeds

= **complex** + still **defeats a comprehensive description**

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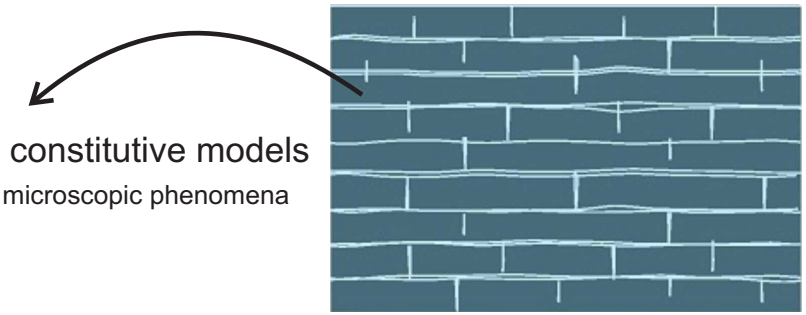
Current models



Phenomenological constitutive models

Laws at macroscale for microscopic phenomena

Macroscale FE computation

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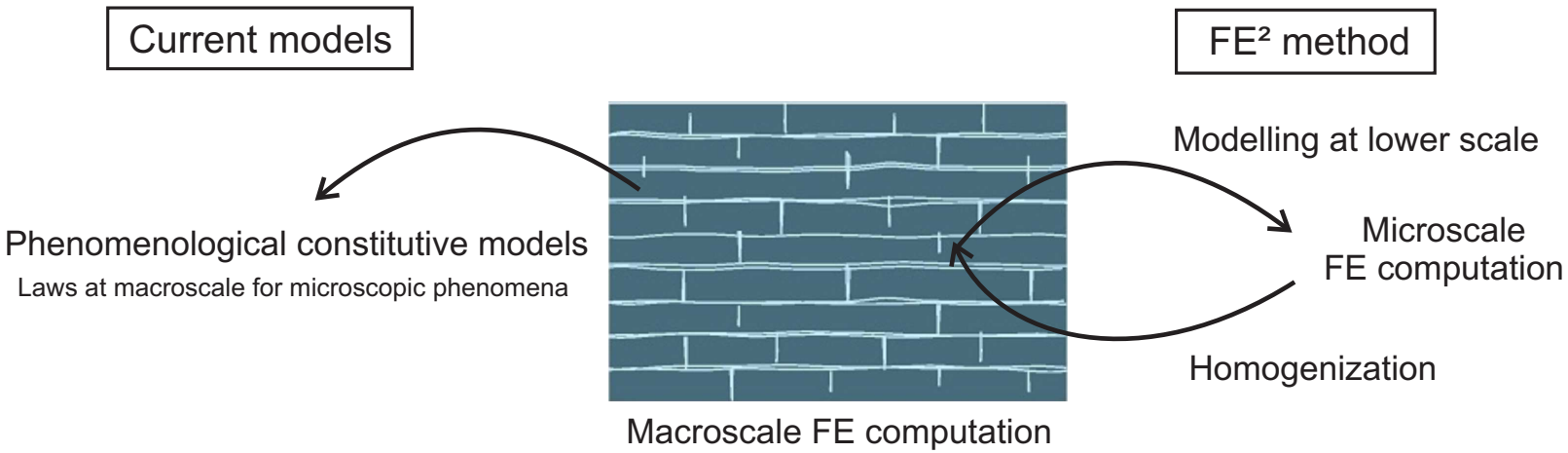


Apply a **multi-scale method** taking advantage of the **periodical structure of coal**.

Contents

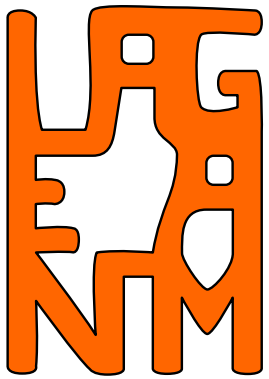
Work environment

Université de Liège

Geomechanics and Engineering research unit

Thesis supervised by F. Collin

Expertise in computational geomechanics
(FE code Lagamine)



Université Joseph Fourier
(France, Grenoble)

Laboratoire 3S-R

Thesis on FE²
by B. Van den Eijnden

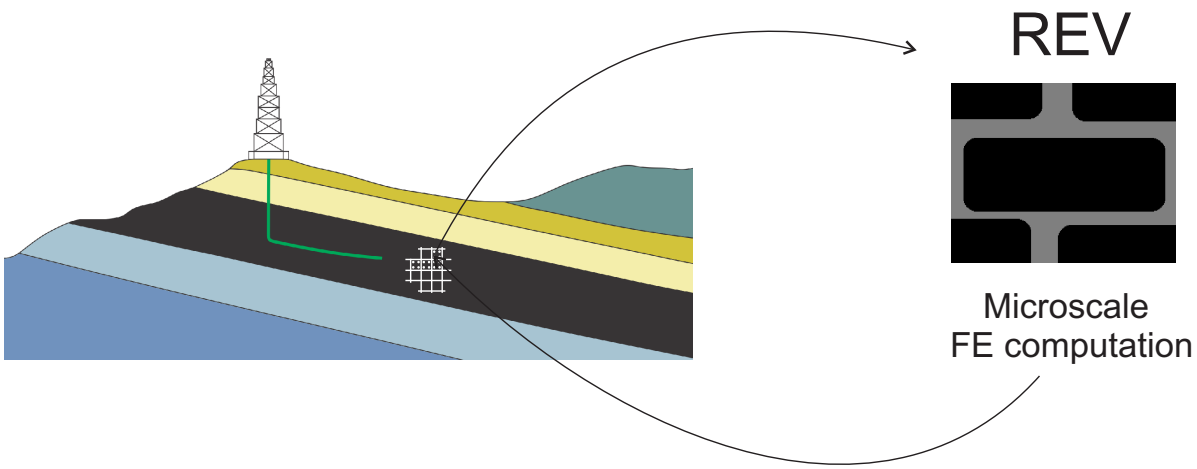
University of Newcastle
(Australia)

Team Pr O. Buzzi

Expertise on coal

Workpackage 1: Multiphase flow model

FE^2 method :



Constitutive equations (flow law, storage law) are applied only on the **microscopic scale**.

- Task 1.1: **Extension** of the FE^2 method **to unsaturated conditions**.
- Task 1.2: Extension **to multiphase flow conditions** (liquid and gas).
- Task 1.3: The developed **model** is **faced and compared** with others models found in the literature: [Pan and Connell, 2012], [Shi et al., 2014].

Workpackage 2: Development of a mechanical model

The **mechanical behaviour** of the coalbed **results from** the **geometry** and the **properties** of the components.

Triaxial experimental results $\Leftrightarrow$ REV responses

- Task 2.1: Evaluate numerically the **influence of the cleat density** in the REV on the macroscopic behaviour of the material.
- Task 2.2: Identification of the **material parameters** through a back-analysis of some experimental results.

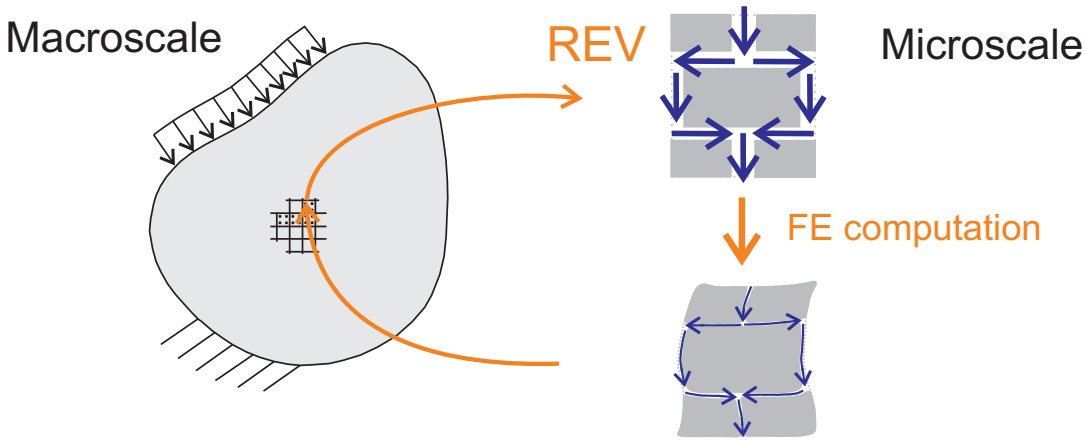
Workpackage 3: Coupled hydro-mechanical model

- Task 3.1: **Experimental campaign**

Hydro-mechanical tests on an **Australian coal**:

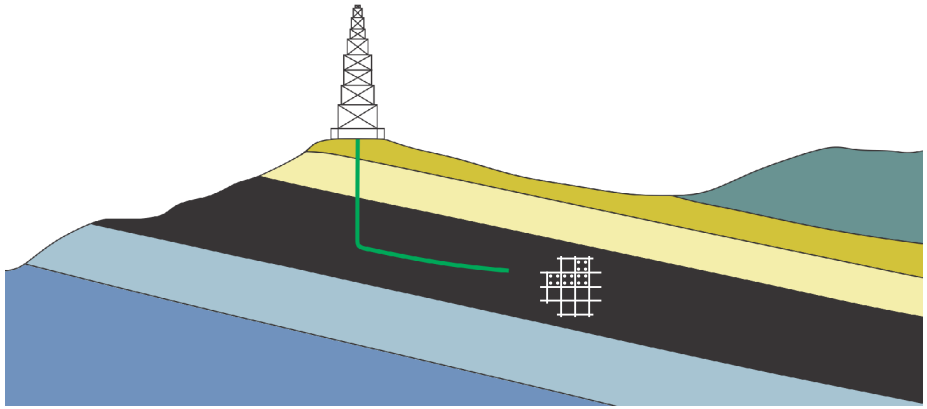
Shrinkage/swelling properties and permeability measurements

- Task 3.2: **Coupled model implemented** in the FE code LAGAMINE.



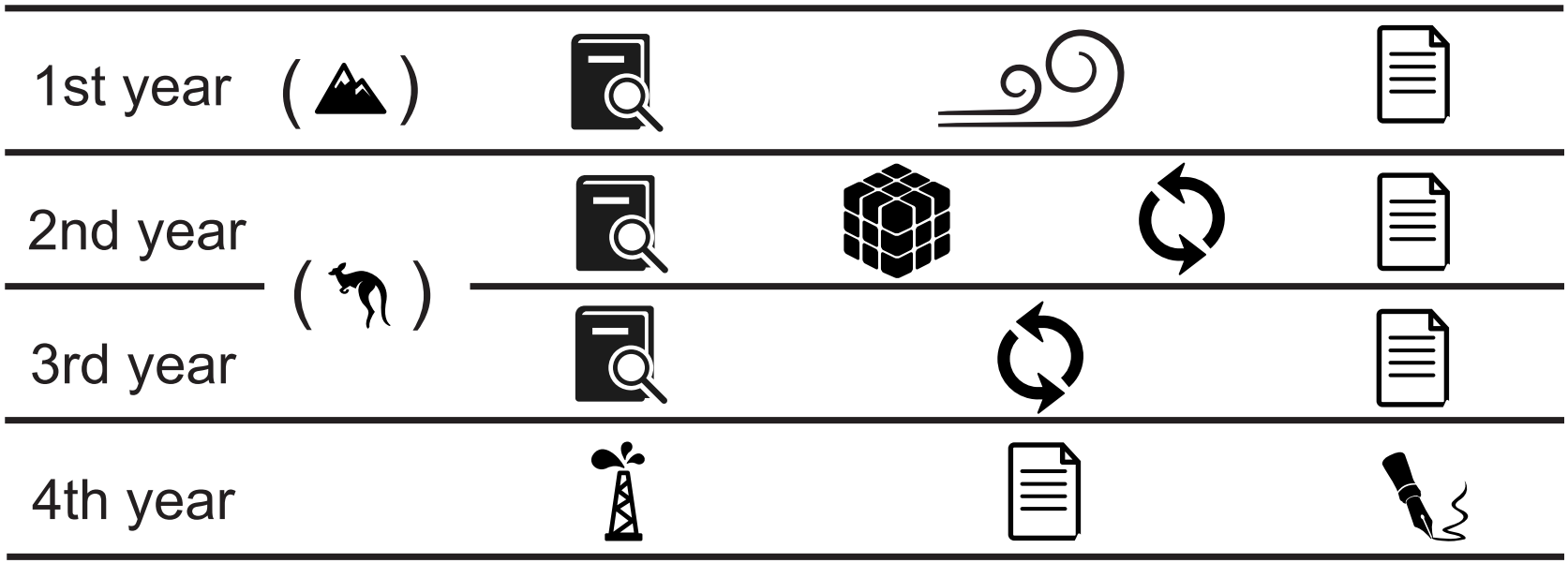
Workpackage 4: Reservoir modelling

A synthetic reservoir model with **one production well** is **simulated from the drilling** of the well **to the production** period.



The necessity or not of stimulation techniques is evaluated.

Work plan



: Multiphase flow model : Mechanical model : HM couplings : Reservoir modelling

: Literature review : Paper writing : Thesis writing

: Grenoble stay : Newcastle stay

Conclusion

High **potential for coalbed methane** in Wallonia

Challenge = better understand **methane migration** to optimize recovery.

Development of a coupled **hydro-mechanical model** for coalbed methane reservoirs in the framework of the finite element square method (FE^2).

Thank you for your attention!

FE^2 approach for the modelling of coupled hydro-mechanical behaviour of partially saturated coalbeds

Related work:

Efficiency of shaft sealing for CO_2 sequestration in coal mines, Presentation at the Workshop on Geomechanics & Energy EU 2015 (held from 13-10-2015 to 15-10-2015 in Celle, Germany).

References

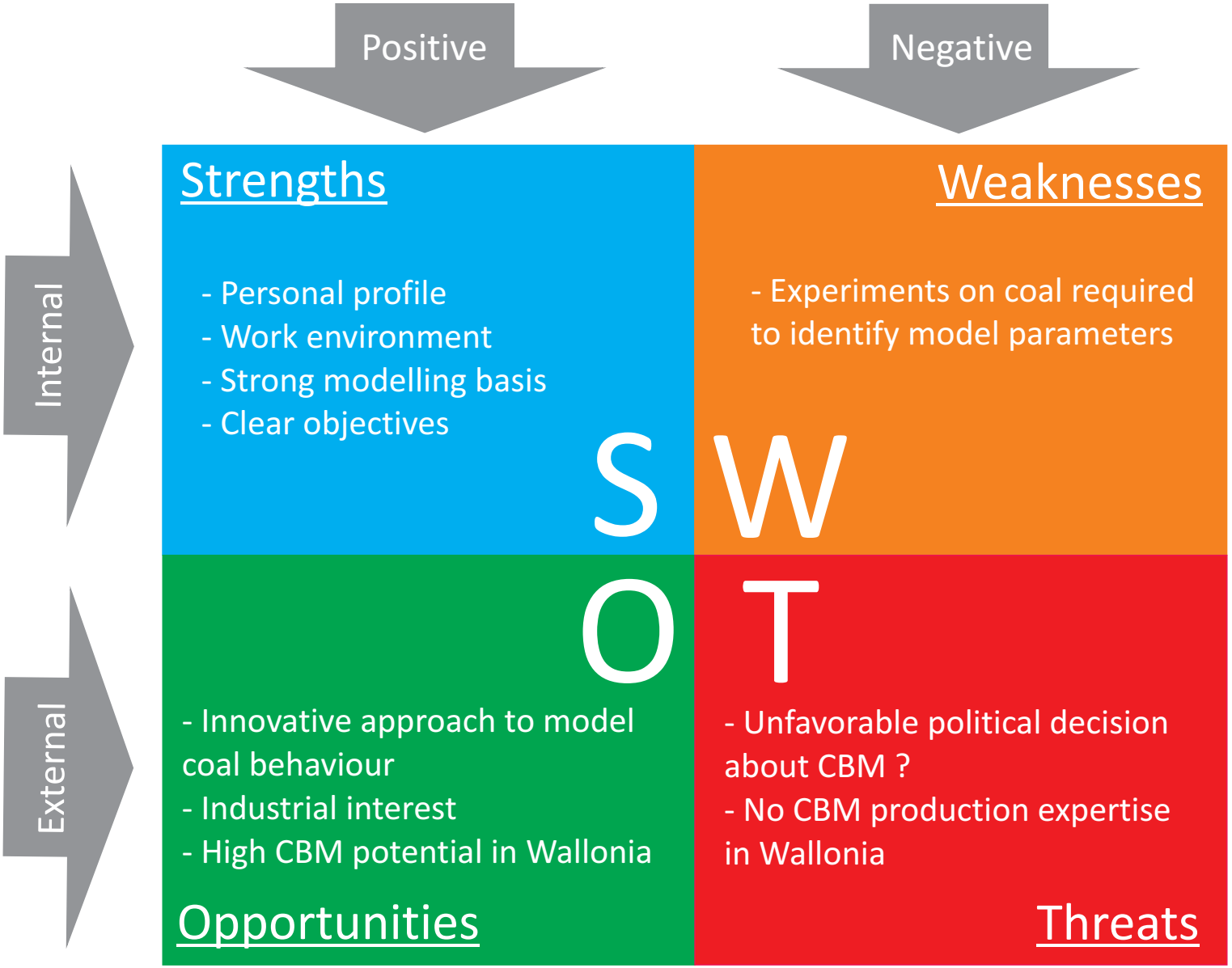
Gu, F., Chalaturnyk, J., et al. (2005).
Analysis of coalbed methane production by reservoir and geomechanical coupling simulation.
Journal of Canadian Petroleum Technology, 44(10).

Pan, Z. and Connell, L. D. (2012).
Modelling permeability for coal reservoirs: a review of analytical models and testing data.
International Journal of Coal Geology, 92:1–44.

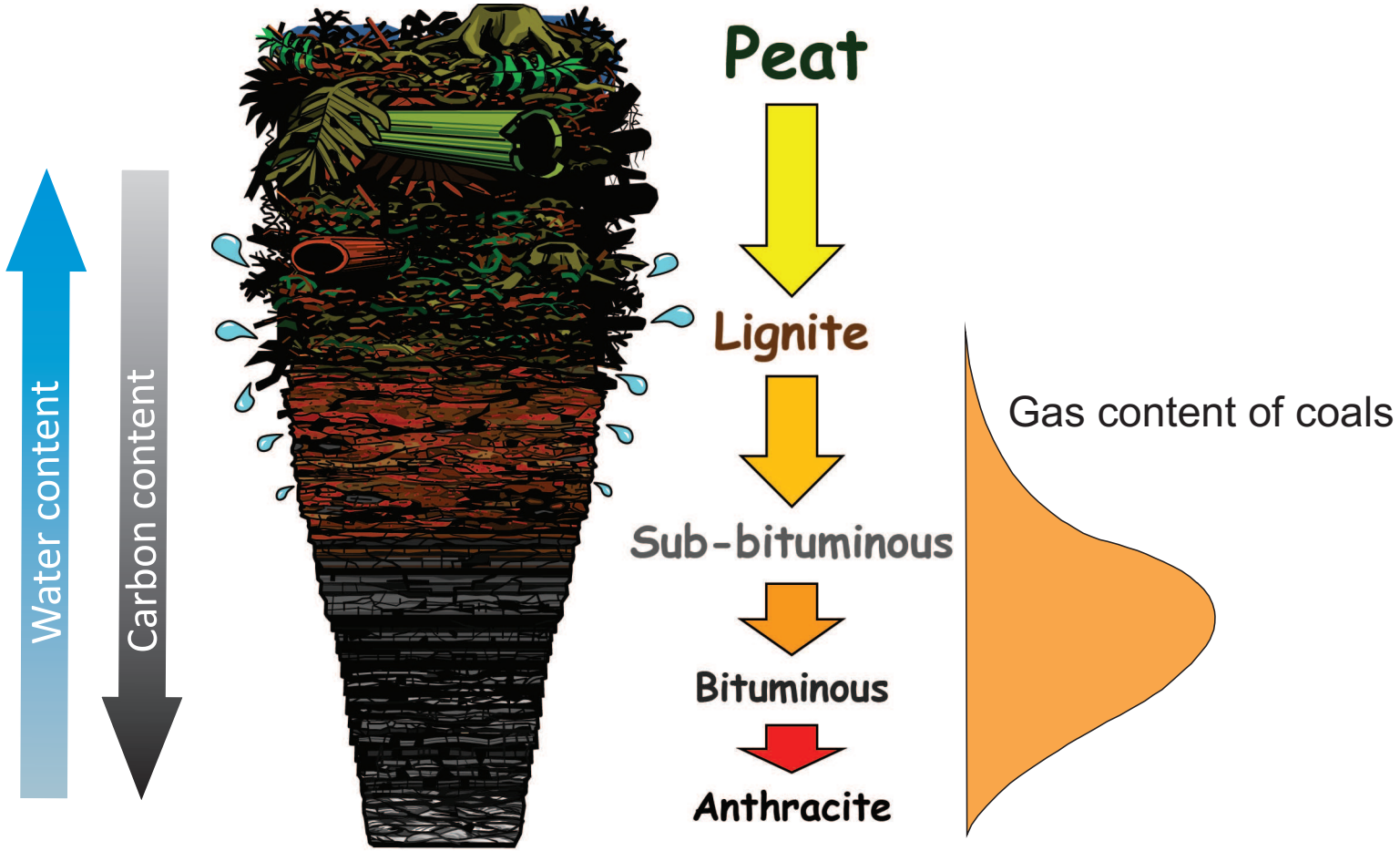
Piessens, K. and Dusar, M. (2006).
Feasibility of CO_2 sequestration in abandoned coal mines in belgium.
Geologica Belgica.

Shi, J.-Q., Pan, Z., and Durucan, S. (2014).
Analytical models for coal permeability changes during coalbed methane recovery: Model comparison and performance evaluation.
International Journal of Coal Geology, 136:17–24.

SWOT Analysis

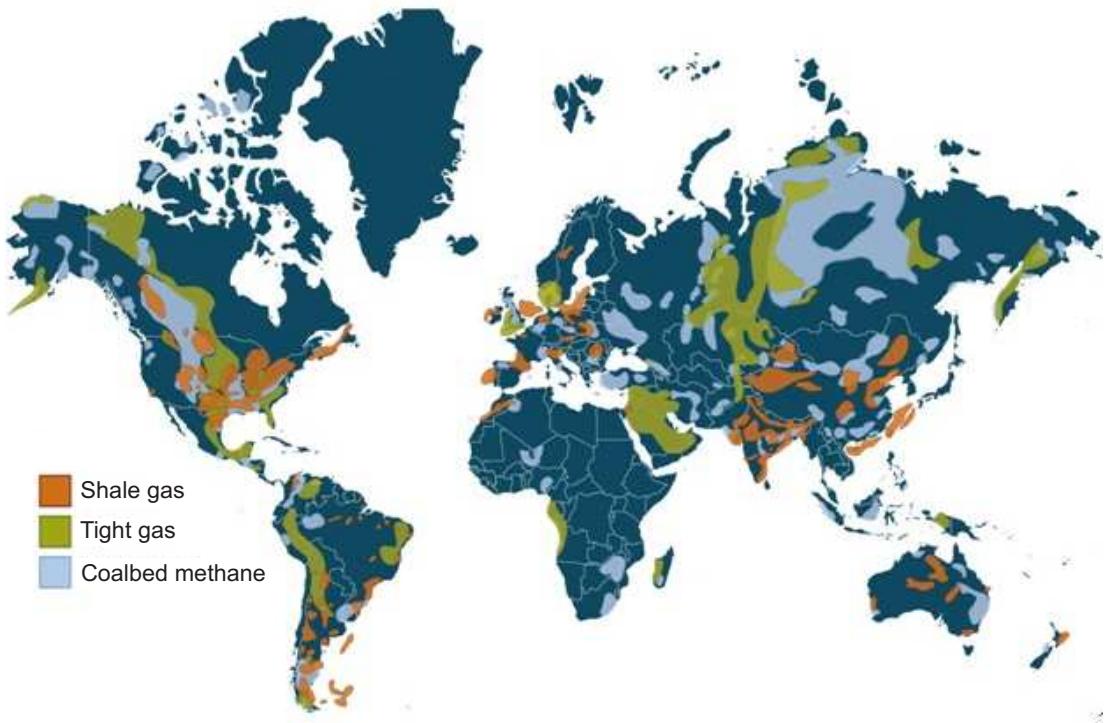


Coalification



Modified after Kentucky Geological Survey (University of Kentucky)

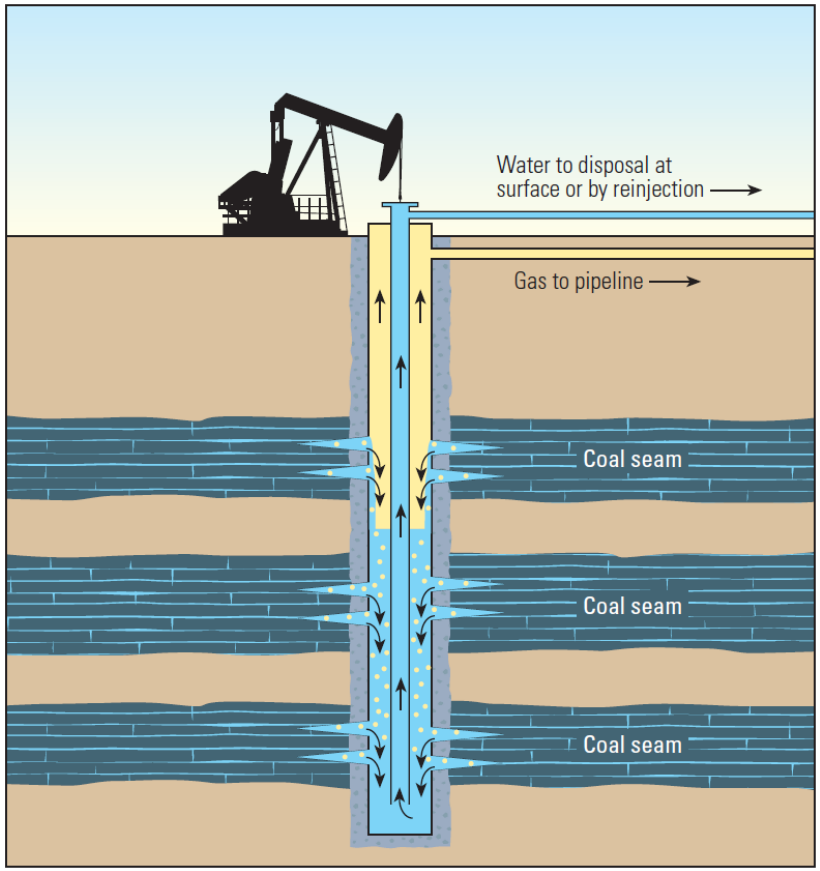
Global overview



Country	CBM resources [$10^{12} m^3$]	CBM annual production [$10^9 m^3$]
Russia	17.0 - 113.0	1
Canada	17.9 - 76.0	9
China	36.8	5
USA	21.5	52
Australia	8.0 - 14.0	4

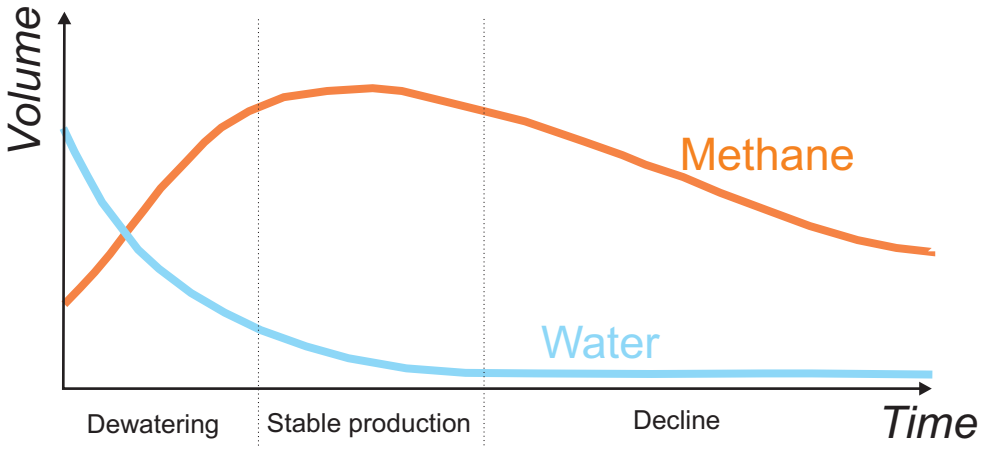
From IEA (2010)

Production

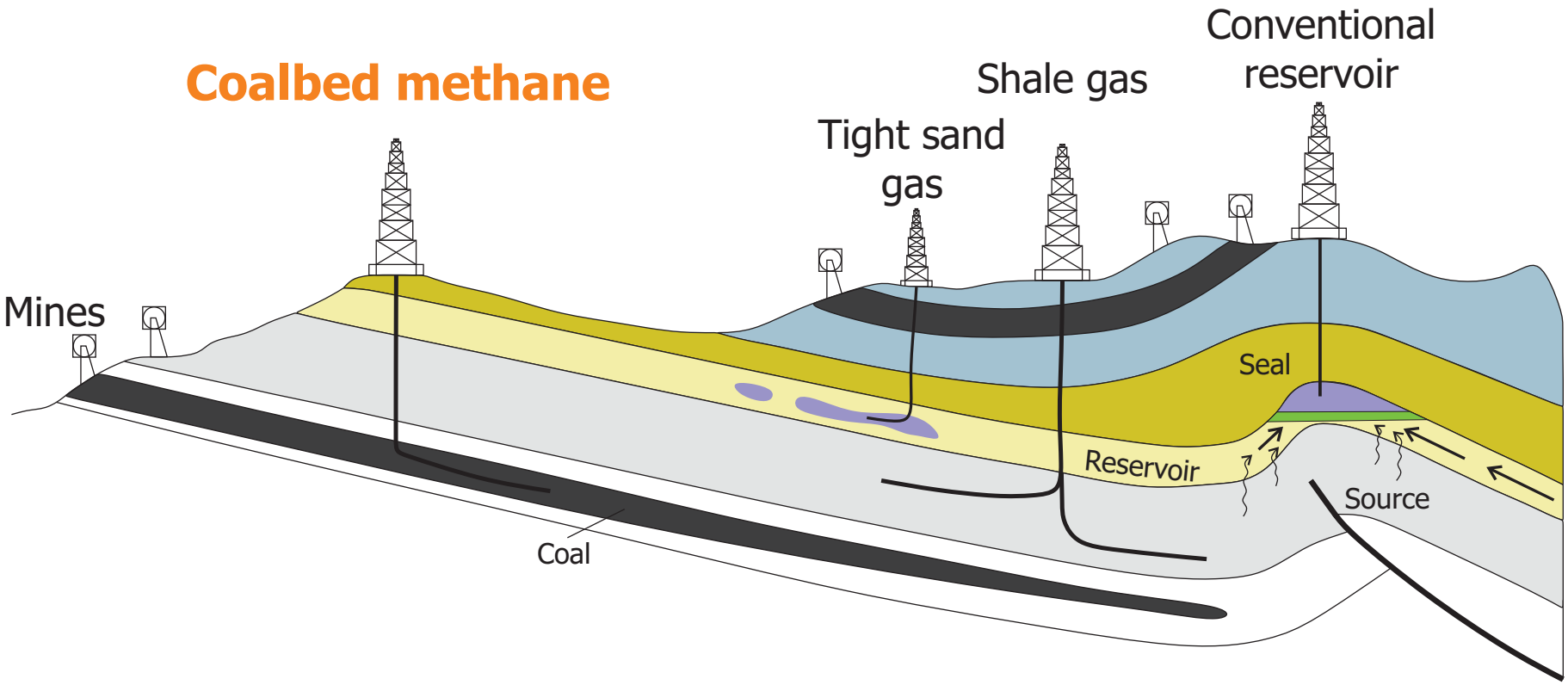


From Schlumberger (2009),

Coalbed Methane: Clean Energy for the World



CBM *versus* Shale gas

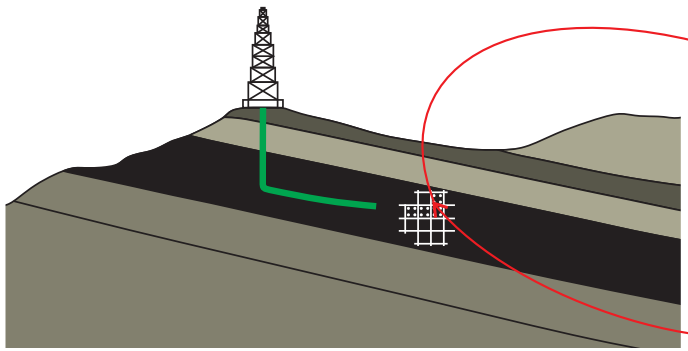


FE^2

1. **Macroscopic structure** discretised by finite elements

2. **Macroscopic deformation gradient tensor** computed for each IP from the estimation of the macroscopic nodal displacements relative to the external load

3. **REV** assigned at each macroscopic IP



4. **Localization**: apply appropriate **displacements to the REV** from the macroscopic deformation gradient tensor

5. **Microscale FE computation**: stress and deformation distributions in the REV

6. **Homogenization**: REV **averaged stress** returned to the macroscopic IP

7. Macroscopic **internal nodal forces**

8. **Macroscopic stiffness matrix**

9. **Balance** between external load and internal load?

\+ **Next time** increment evaluated

\- **Updated estimation** of the nodal **displacements** required (via macroscopic stiffness matrix)