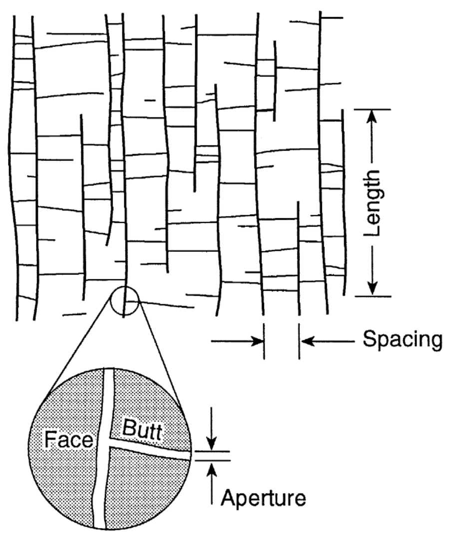
Geomechanical aspects of coalbed methane (CBM) production: Flow model formulation

François BERTRAND & Frédéric COLLIN

INTRODUCTION

Coalbed methane (CBM): miner's **curse** ⇒ **valuable fuel**.



From [1].

Coals = **naturally fracturated reservoirs**

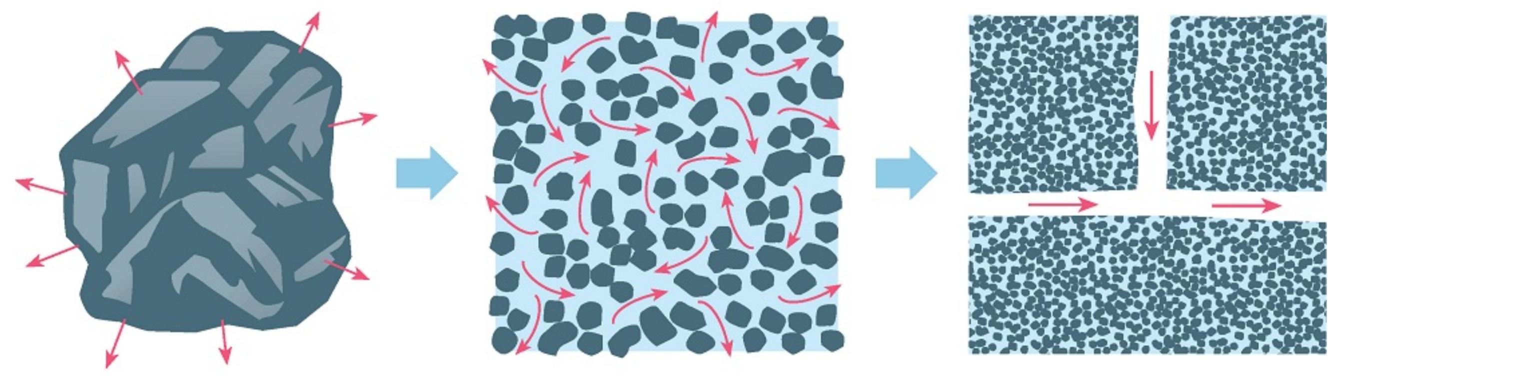
Blocks delimited by two sets of orthogonal fractures (fractures = **cleats**).

Coal deposits = (generally) **aquifers**

→ **methane maintained adsorbed** within the coal matrix **by** the **hydrostatic pressure**.

↓

CBM **production** = generate a pressure drop by **dewatering** the cleats.



→ Gas molecules diffuse in the matrix to reach the **cleats** which are **preferential pathways** (higher permeability). *From* [2].

Two distinct **phenomena affecting permeability**:

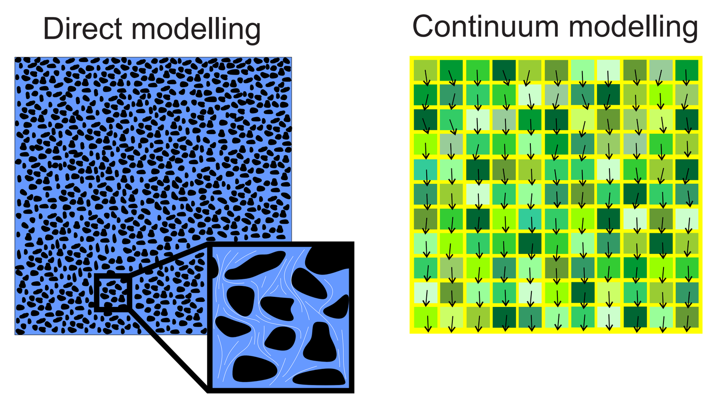
1. Pressure depletion → Reservoir **compaction** → Cleat permeability ↘
2. Gas desorption → Coal **matrix shrinkage** → Cleat permeability ↗

HYDRAULIC MODEL

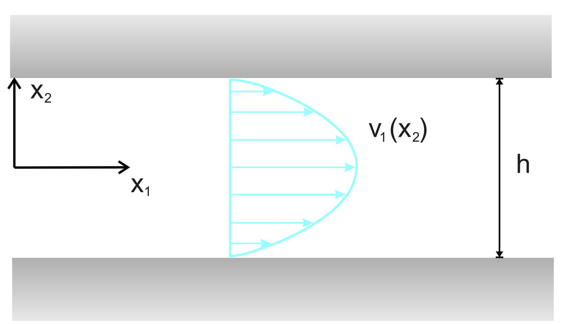
Flow model

- **Matrix**: **diffusive** gas flow → **Fick**'s law (Continuum modelling)

$$J_{g_i} = -D\frac{\partial C_g}{\partial x_i} \qquad (1)$$



- **Cleats**: **advective** flow
  - Macroscopic approach: **Darcy**'s law (Continuum modelling)
  - Microscopic approach: solve **Navier-Stokes** between two parallel plates (Direct modelling)



$$q = -\frac{h^2}{12}\cdot\frac{1}{\mu}\frac{\mathrm{d}p}{\mathrm{d}x_1} \qquad (2)$$

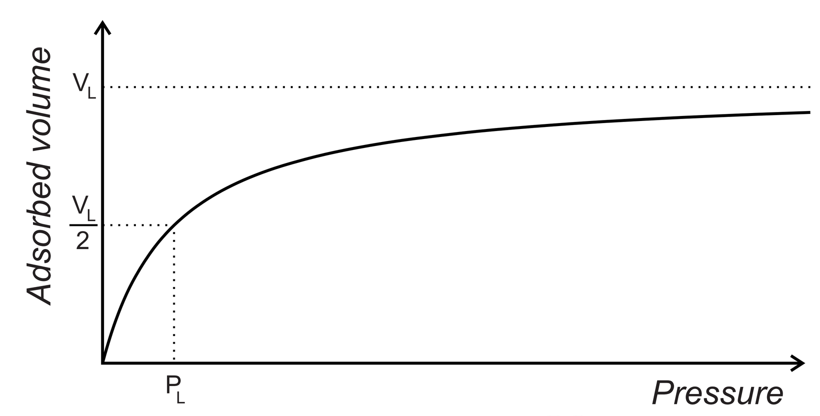
→ Equivalent to Darcy with $k = \frac{h^2}{12}$

For **unsaturated conditions**: $k_r(S_r)$ accounts for the **reduction in permeability**.

$$q_i = -\frac{k_r \cdot k_{ij}}{\mu}\cdot\frac{\partial p}{\partial x_j} \qquad (3)$$

Gas storage

→ in the **matrix**



$$V_{g,Ad}\ [m^3/kg] = \frac{V_L \cdot p}{P_L + p} \qquad (4)$$

P_L and V_L: **Langmuir**'s parameters [3]

→ Adsorbed gas density:

$$\rho_{g,Ad}\ [kg/m^3] = \rho_{coal}\cdot\rho_{g,std}\cdot V_{g,Ad} \qquad (5)$$

Mass balance equations

Microscopic approach

- Matrix (Continuum modelling)
  - *Gas*

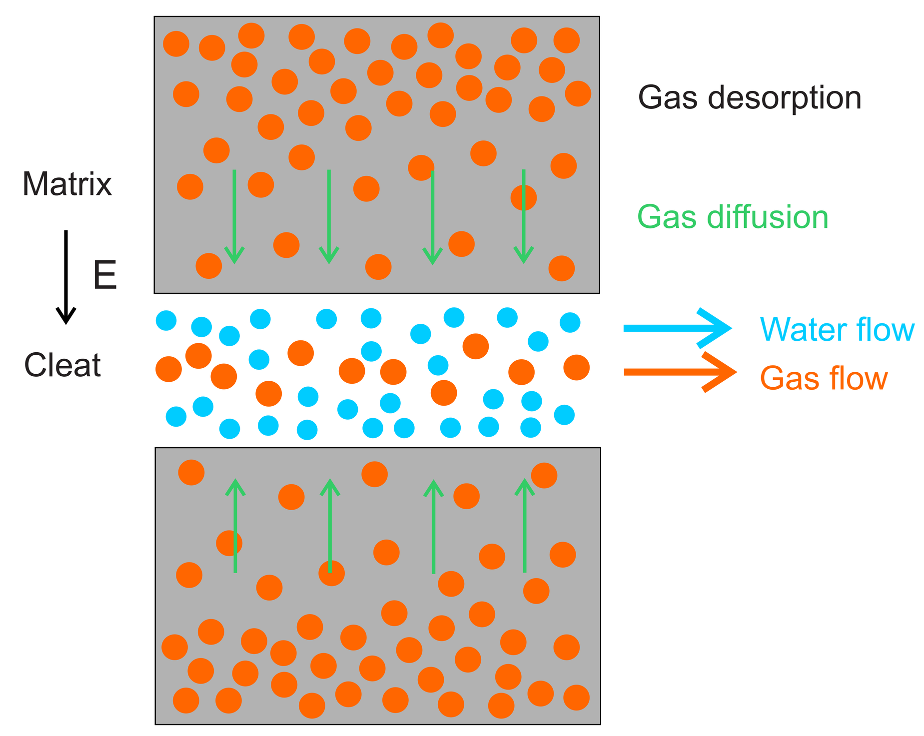
$$\frac{\partial}{\partial t}(\rho_{g,Ad}) + \frac{\partial}{\partial x_i}(J_{g_i}) = E_{Matrix\rightarrow Cleats} \qquad (6)$$

- Cleats (Direct modelling)
  - *Gas*

$$\underbrace{\frac{\partial}{\partial t}(\rho_{g,f}\,(1-S_{r,w})) + \frac{\partial}{\partial x_i}(\rho_{g,f}\; q_{g,f\,i})}_{\text{Gas phase}} + \underbrace{\frac{\partial}{\partial t}(H\rho_{g,f}\;S_{r,w}) + \frac{\partial}{\partial x_i}(H\rho_{g,f}\;q_{w\,i} + S_{r,w}\;J_{g_i})}_{\text{Dissolved gas in water phase}} = E_{Cleats\rightarrow Matrix} \qquad (7)$$

  - *Water*

$$\frac{\partial}{\partial t}(\rho_w S_{r,w}) + \frac{\partial}{\partial x_i}(\rho_w\; q_{w\,i}) = 0 \qquad (8)$$



CONCLUSION

Changes in reservoir **properties** = **crucial issue** for CBM recovery.

But sorption- and stress-induced coal **permeability alteration** are **improperly simplified** by classical macroscopic modelling approaches!

→ It is preferable to use a "**Microscopic**" approach because the discretization is made at the scale of the cleats and matrix.

However, the **computational cost** is too expensive at the scale of a reservoir.

→ The microscopic model will be the basis for a **multi-scale** approach.

REFERENCES

[1] S. Laubach, R. Marrett, J. Olson, and A. Scott, "Characteristics and origins of coal cleat: a review," *International Journal of Coal Geology*, vol. 35, no. 1, pp. 175–207, 1998.

[2] A. Al-Jubori, S. Johnston, C. Boyer, S. W. Lambert, O. A. Bustos, J. C. Pashin, and A. Wray, "Coalbed methane: clean energy for the world," *Oilfield Review*, vol. 21, no. 2, pp. 4–13, 2009.

[3] I. Langmuir, "The adsorption of gases on plane surfaces of glass, mica and platinum.," *Journal of the American Chemical society*, vol. 40, no. 9, pp. 1361–1403, 1918.

ACKNOWLEDGMENT

Ces recherches sont soutenues par le **FRIA** (Fonds pour la Recherche dans l'Industrie et l'Agriculture).

CONTACT INFORMATIONS

Francois.Bertrand@ulg.ac.be
F.Collin@ulg.ac.be