History Matching of the Allison Unit CO_2-ECBM Pilot and Alberta Flue Gas Injection Micro-Pilot Test: Application of a Dynamic Permeability Model

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Coalbed permeability has been shown to vary exponentially with changes in the effective horizontal stress acting across the cleats, through the cleat volume compressibility. A formulation for changes in the effective horizontal stress of coalbeds during enhanced as well primary methane recovery has recently been developed by the authors.

In this paper, validation of the permeability model against a recently published general pressure-dependent permeability multiplier curve representative of the San Juan Basin coalbeds at post-dewatering production stages is presented.

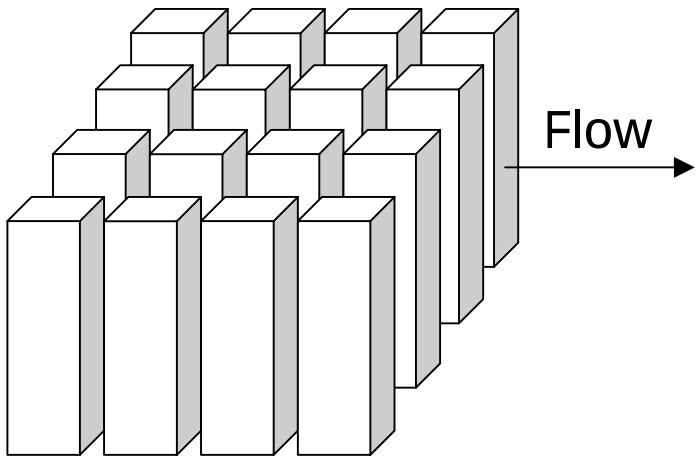
The permeability model has been successfully applied to history match two field trials:

- **the Allison CO_2-ECBM pilot, which consists of 16 producing wells, four CO_2 injecting welling and one pressure observation well;**
- **a micro-pilot test involving the injection of flue gas (roughly 13% CO_2 and 87% N_2) at the Fenn Big Valley, Alberta.**

The latter displayed an increase in the injectivity, as opposed to an estimated two order of reduction in the injection well permeability at the Allison project.

Stress-Dependent Permeability of Coalbed

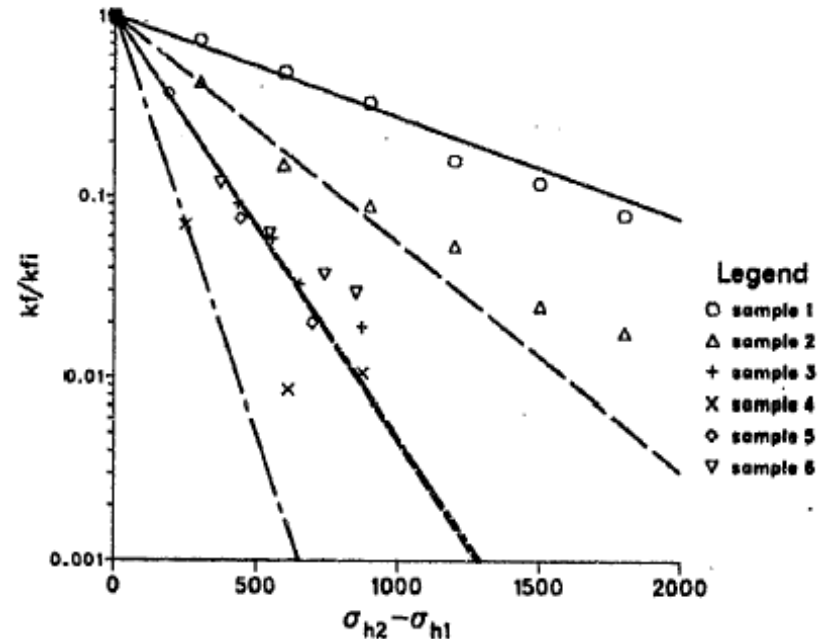
Bundled matchstick model

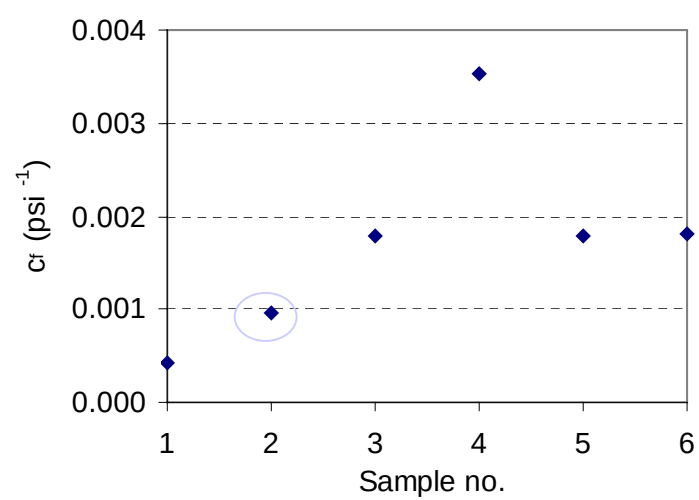


$$k = \frac{1}{12}\frac{b^3}{a} \rightarrow k = k_0 e^{-3c_f(\sigma - \sigma_0)}$$

c_f – cleat volume compressibility

San Juan Coal Samples





(after Seidle et al., 1992)

Formula for Changes in the Effective Horizontal stress

Primary recovery

$$\sigma - \sigma_0 = -\frac{\nu}{1-\nu}(p - p_0) + \frac{E\alpha_S (V - V_0)}{3(1-\nu)}$$

Shrinkage / swelling term

Enhanced recovery

$$\sigma - \sigma_0 = -\frac{\nu}{1-\nu}(p - p_0) + \frac{E}{3(1-\nu)}\left(\sum_{j=1}^{n} \alpha_{Sj} V_j - \sum_{j=1}^{n} \alpha_{Sj} V_{j0}\right)$$

α_S – shrinkage/swelling coefficient

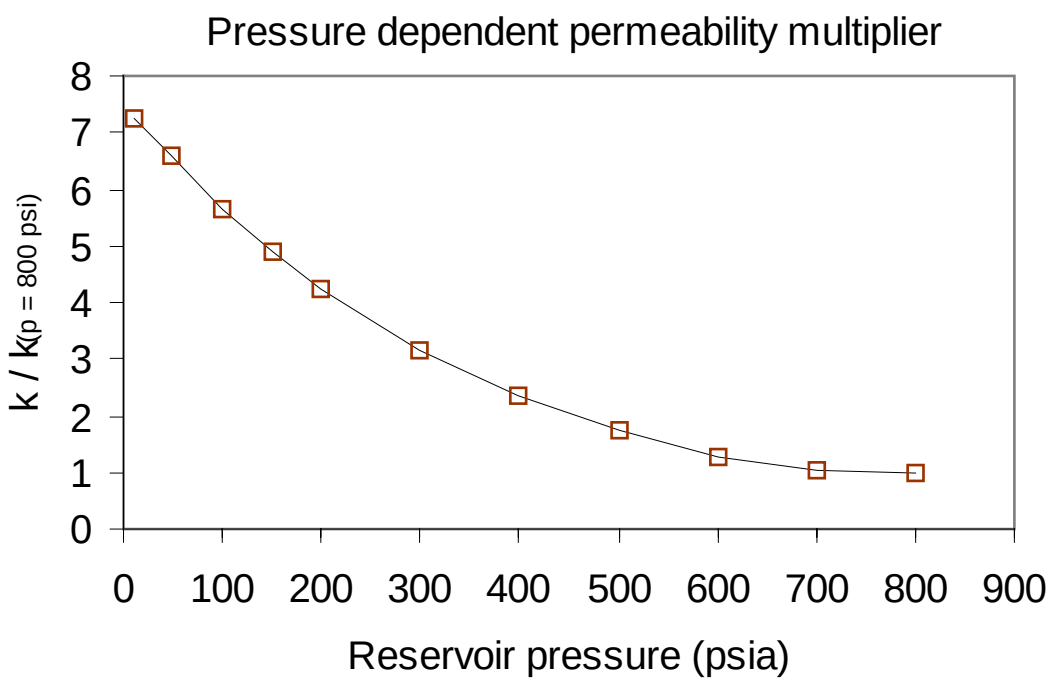
E – Young's modulus

V – adsorbed gas volume

ν – Poisson's ratio

San Juan Basin Field Permeability Multiplier Curve

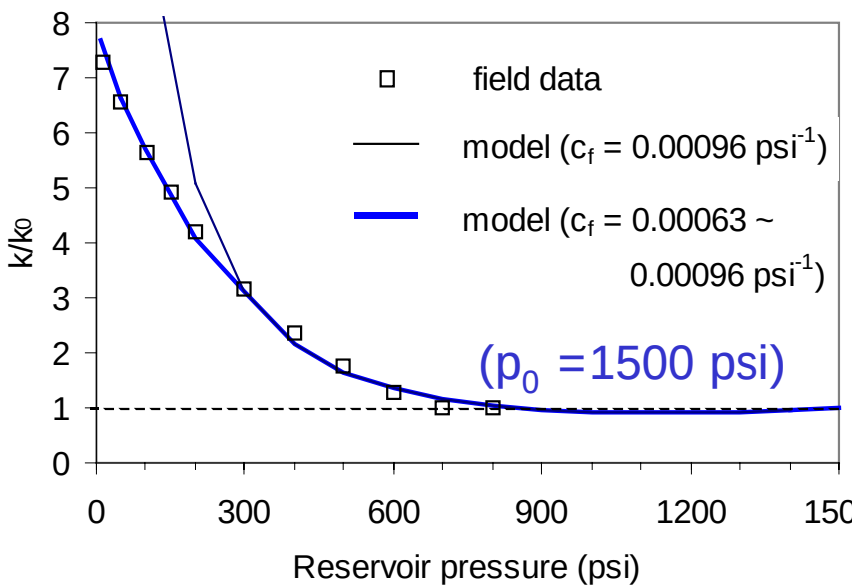
It has been estimated that the absolute permeability of the San Juan Basin coalbeds increases on average by up to a factor of 7 as the reservoir pressure is reduced from 800 psi to 10 psi.

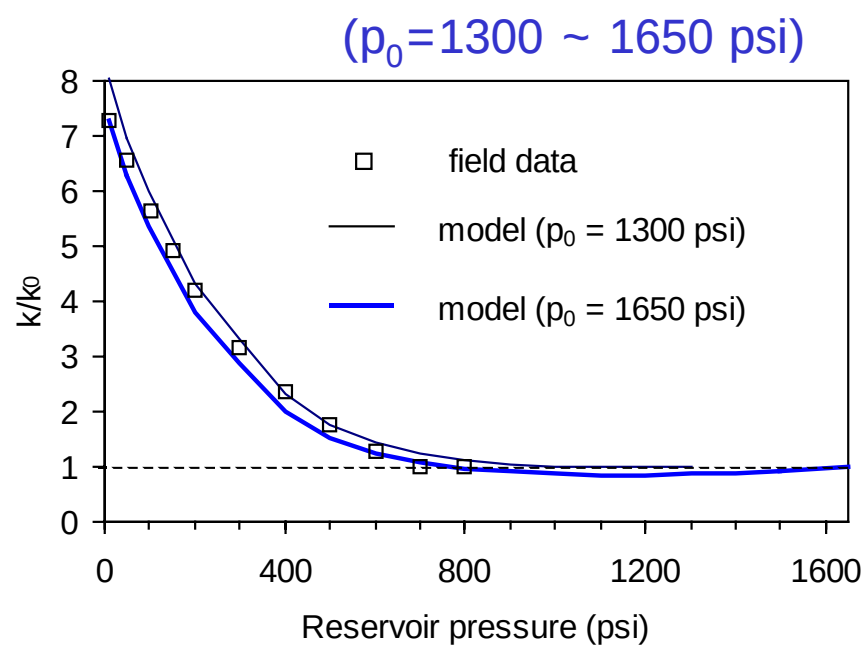


(after McGovern, 2004)

Model Match

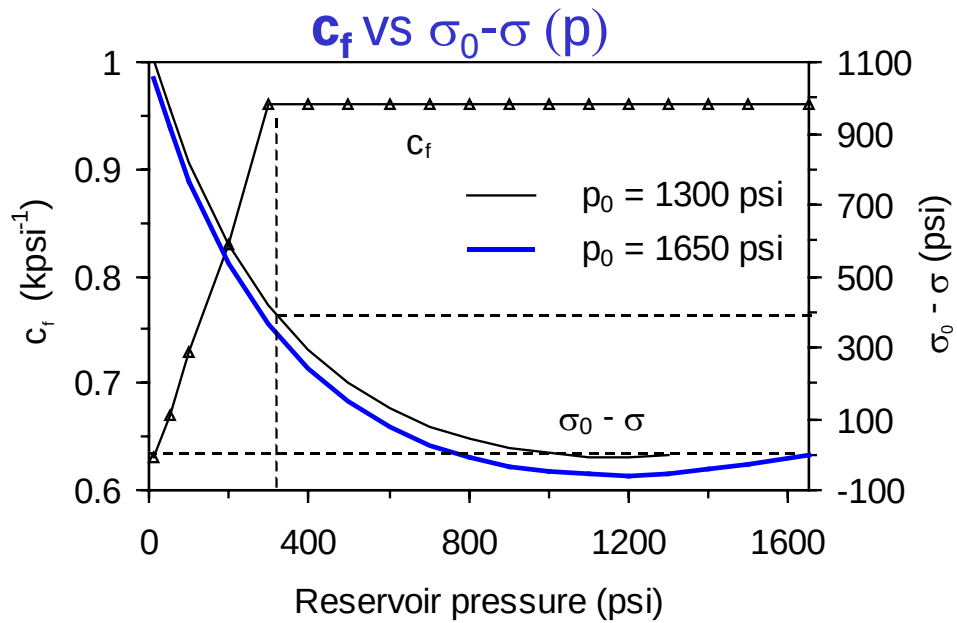
The permeability curve has been successfully matched for initial reservoir pressure (p_0) ranging from 1300 – 1650 psi. It was found that pressure-dependent cleat volume compressibility at low reservoir pressures was required to match the field permeability data.





Reservoir Parameters Representative of San Juan Basin Coalbeds

$\alpha_s V_L$	0.01266
ν	0.35
E (psi)	420,000
$1/b$ (psi)	625
c_f (psi^{-1})	0.00063 ~ 0.00096



$\sigma_0 - \sigma <= 400$ psi

$c_f = 0.00096$ psi^{-1}

$\sigma_0 - \sigma > 400$ psi

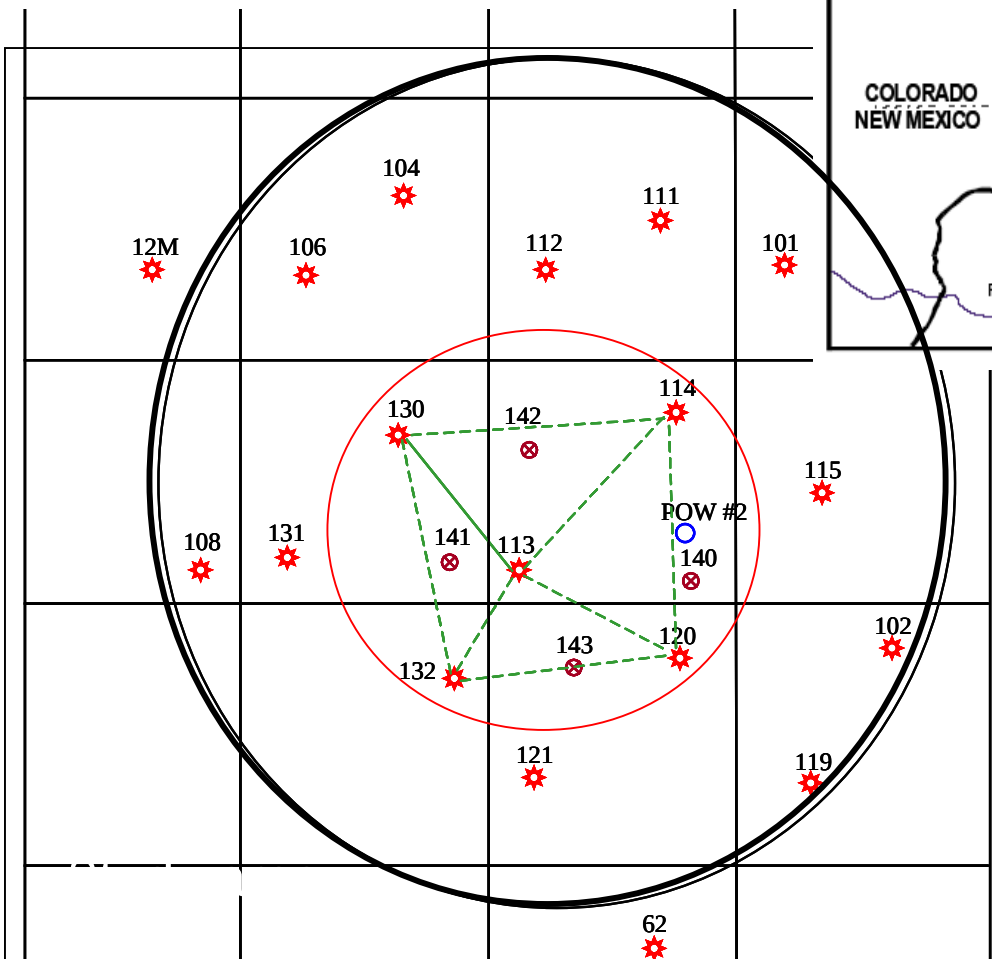
$c_f = A(\sigma_0-\sigma)^2 - B(\sigma_0-\sigma) + C$

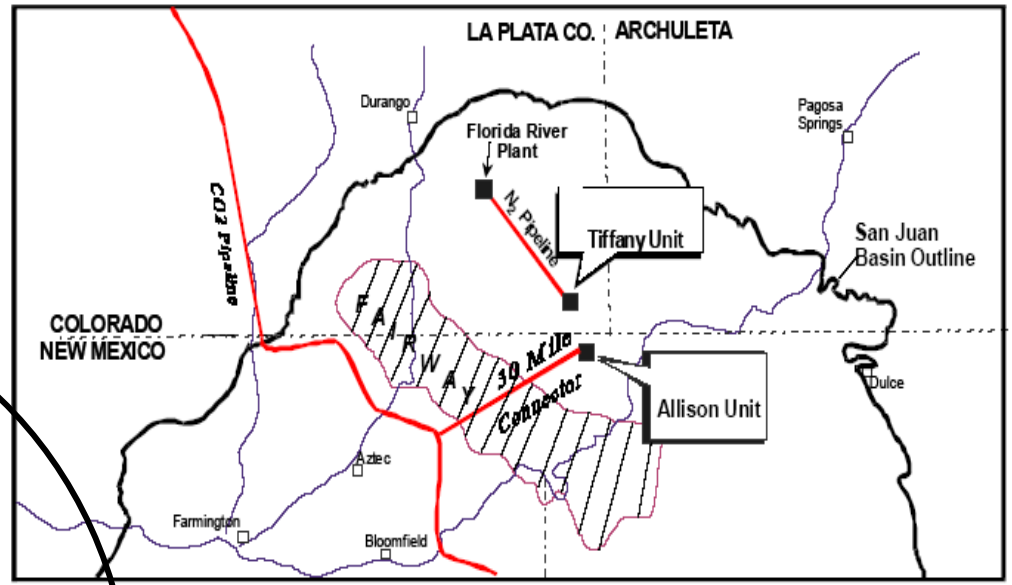
$A = 3.887 \times 10^{-10}$ psi^{-3}

$B = 1.043 \times 10^{-6}$ psi^{-2}

$C = 0.001306$ psi^{-1}

Allison Unit CO_2-ECBM Pilot





- CBM producer
- CO_2 injector
- Observation well

- **16 producers**
- **4 injectors**
- **1 observation well**

(after Reeves et al., 2003)

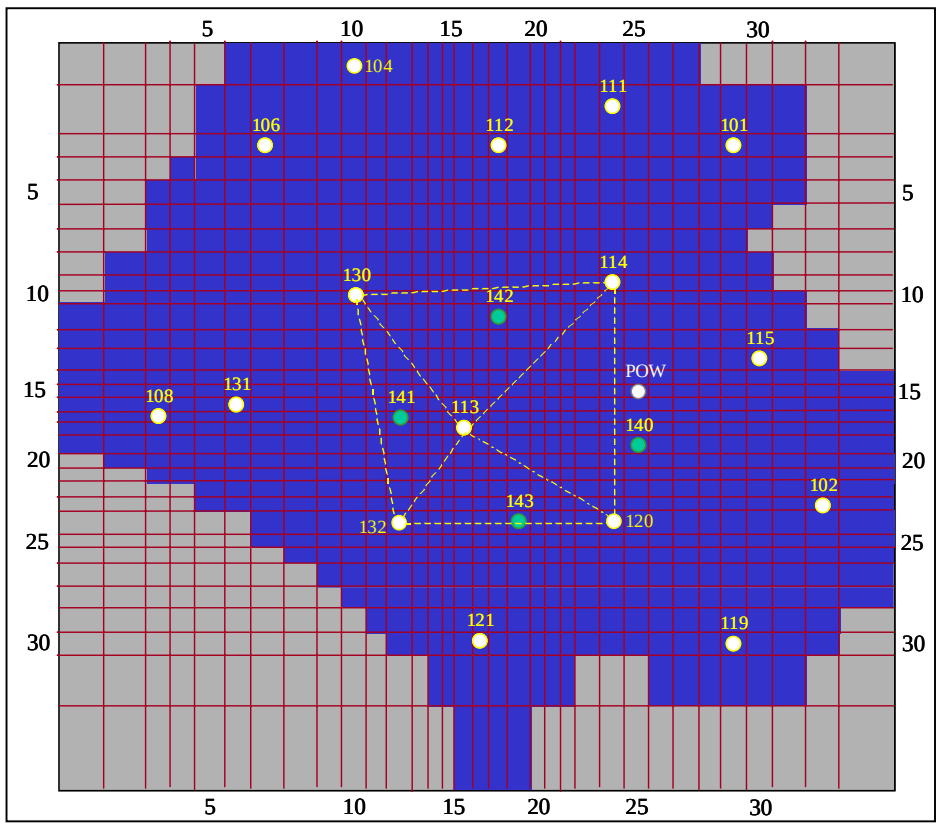
Reservoir Model and Grid Layout

Uniform layer thickness, assigned with the mean thickness of the three seams.

Homogenous reservoir-wide permeability of 100 md, chosen to be more representative of the central 5-spot pattern area of the reservoir.

A uniform porosity of 0.2% was used in an earlier study (GHGT-7). In the current effort, the reported porosity heterogeneity was honoured (with a cutoff of 0.1%).

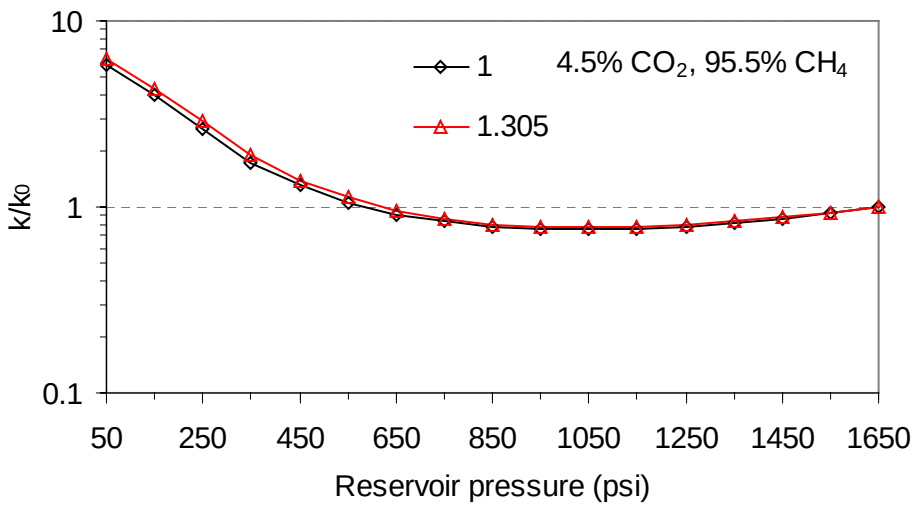
Covering an area of approximately 7,100 acres, divided into 33 x 32 = 1056 grid blocks (881 active).



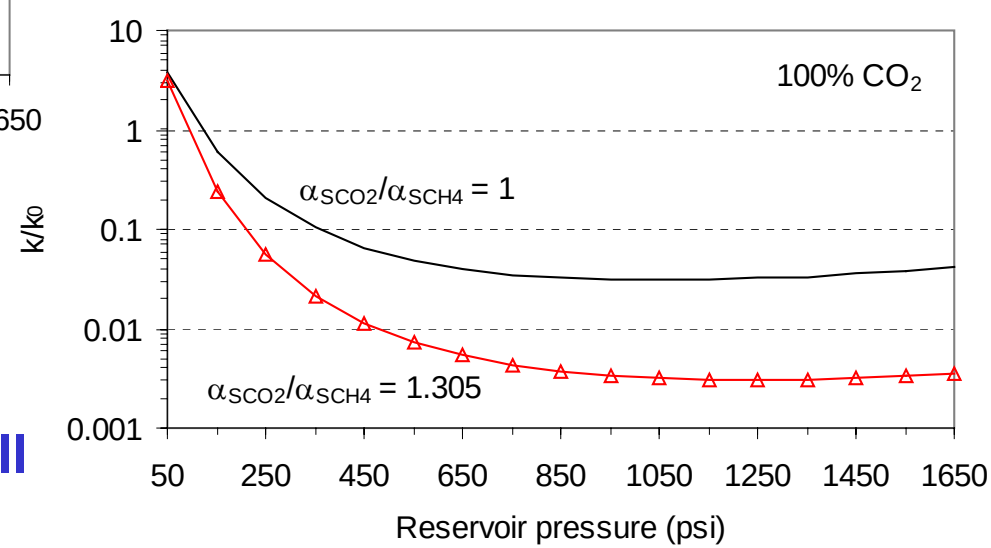
(adopted from Reeves et al., 2003)

Permeability Behaviour (Layer 1) around Production/CO_2 Injection Wells, and its Sensitivity to $\alpha_{SCO2}/\alpha_{SCH4}$

CH_4 production well



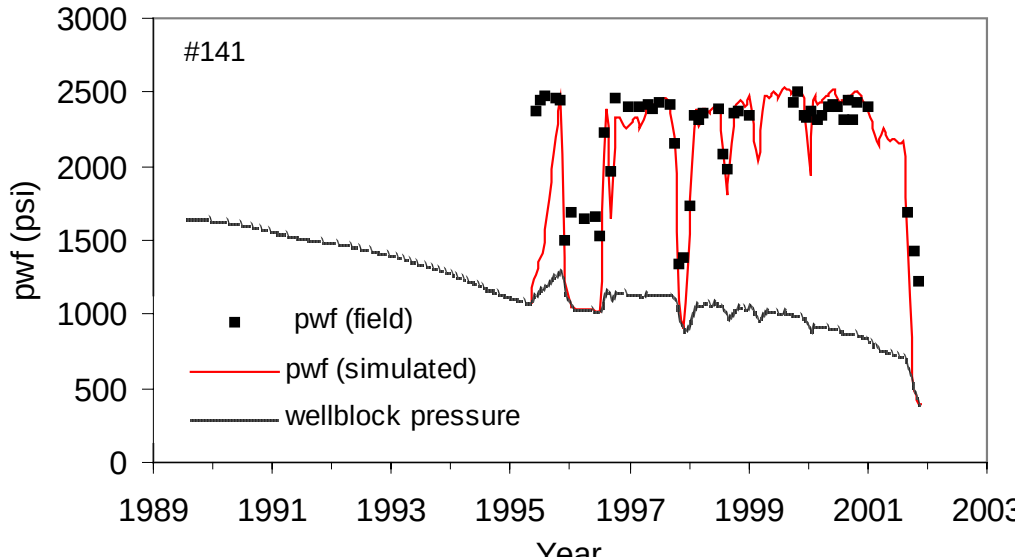
α_{SCH4} (ft³/SCF)	5.33×10^{-4}
ν	0.35
E (psi)	420,000
c_f (psi^{-1})	0.00063 ~ 0.00096

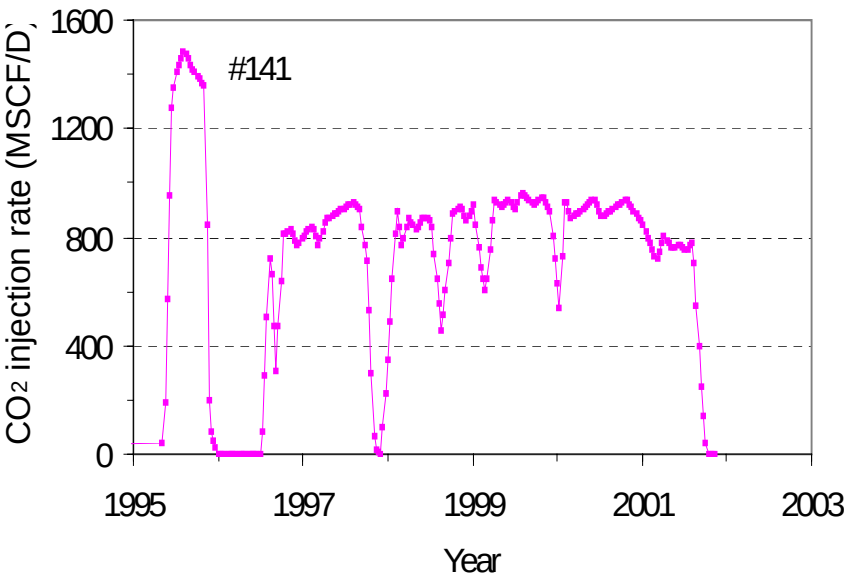


CO_2 injection well

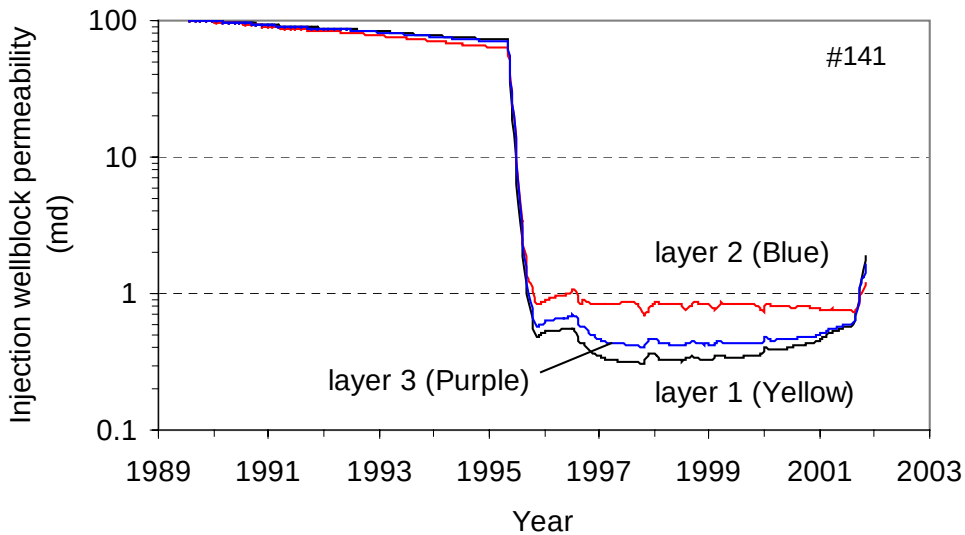
Match of Injection Well Bottomhole Pressure (#141)

Injection well BHP & wellblock pressure





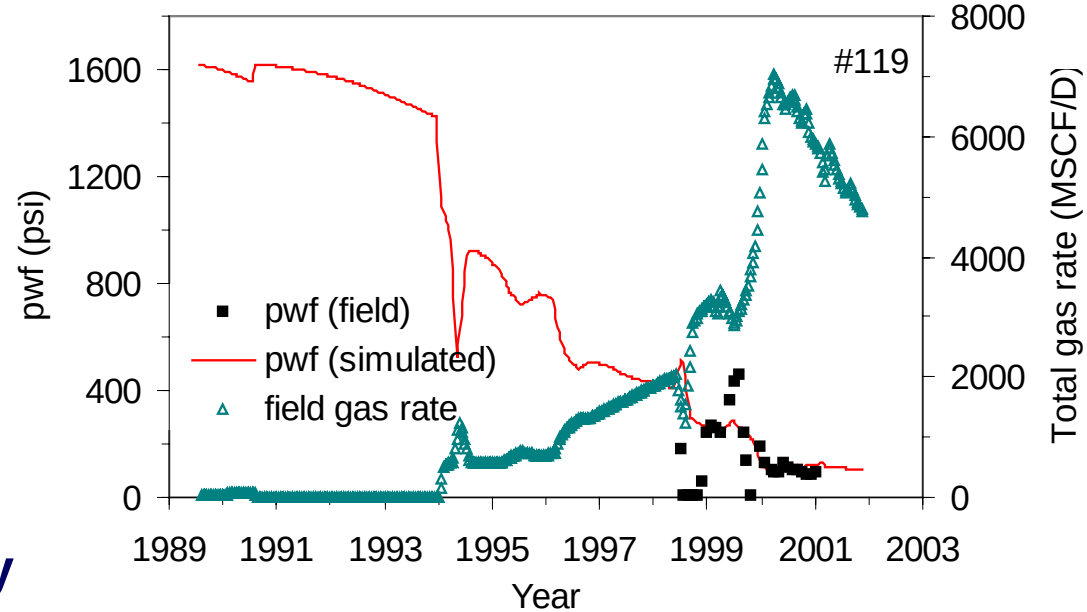
CO_2 injection rate



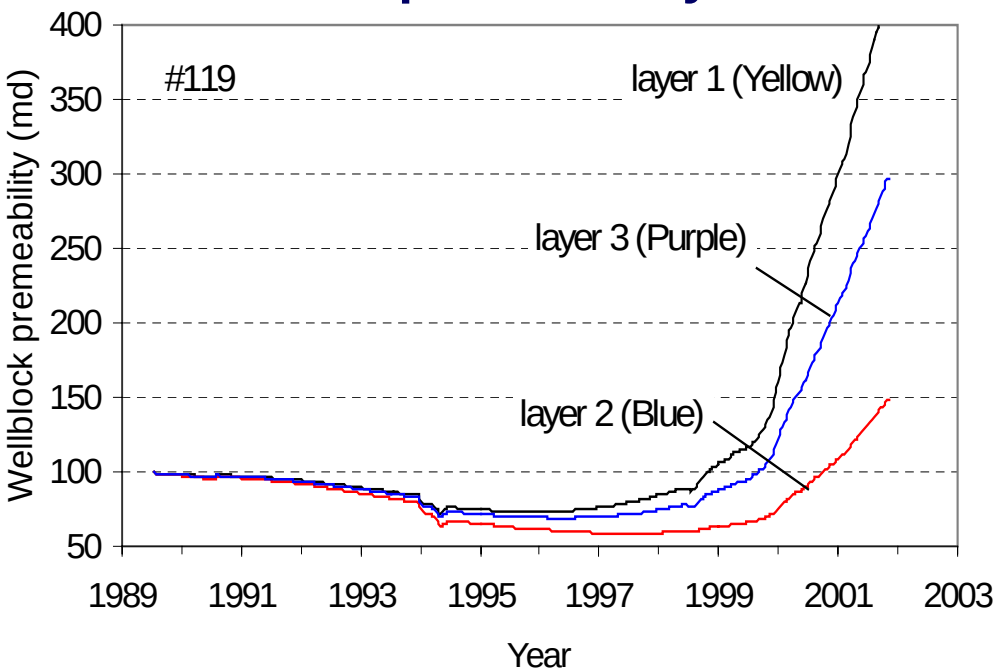
Wellblock permeability

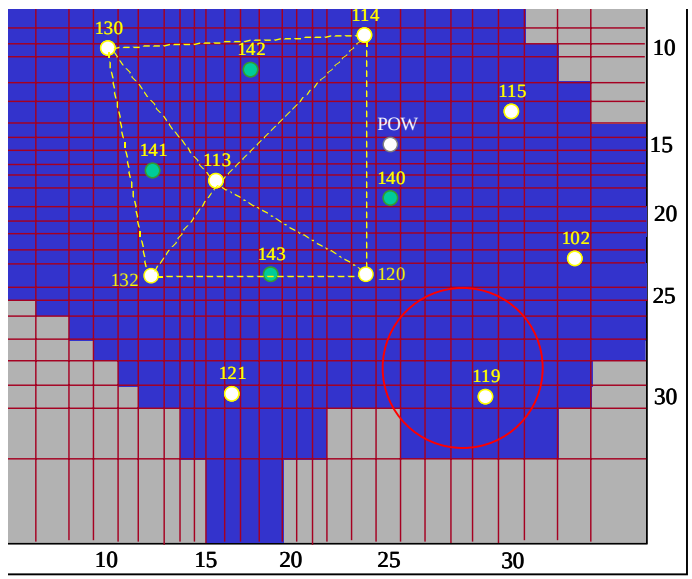
Simulation Results – Production Well Bottomhole Pressure (#119)

Gas rate & BHP

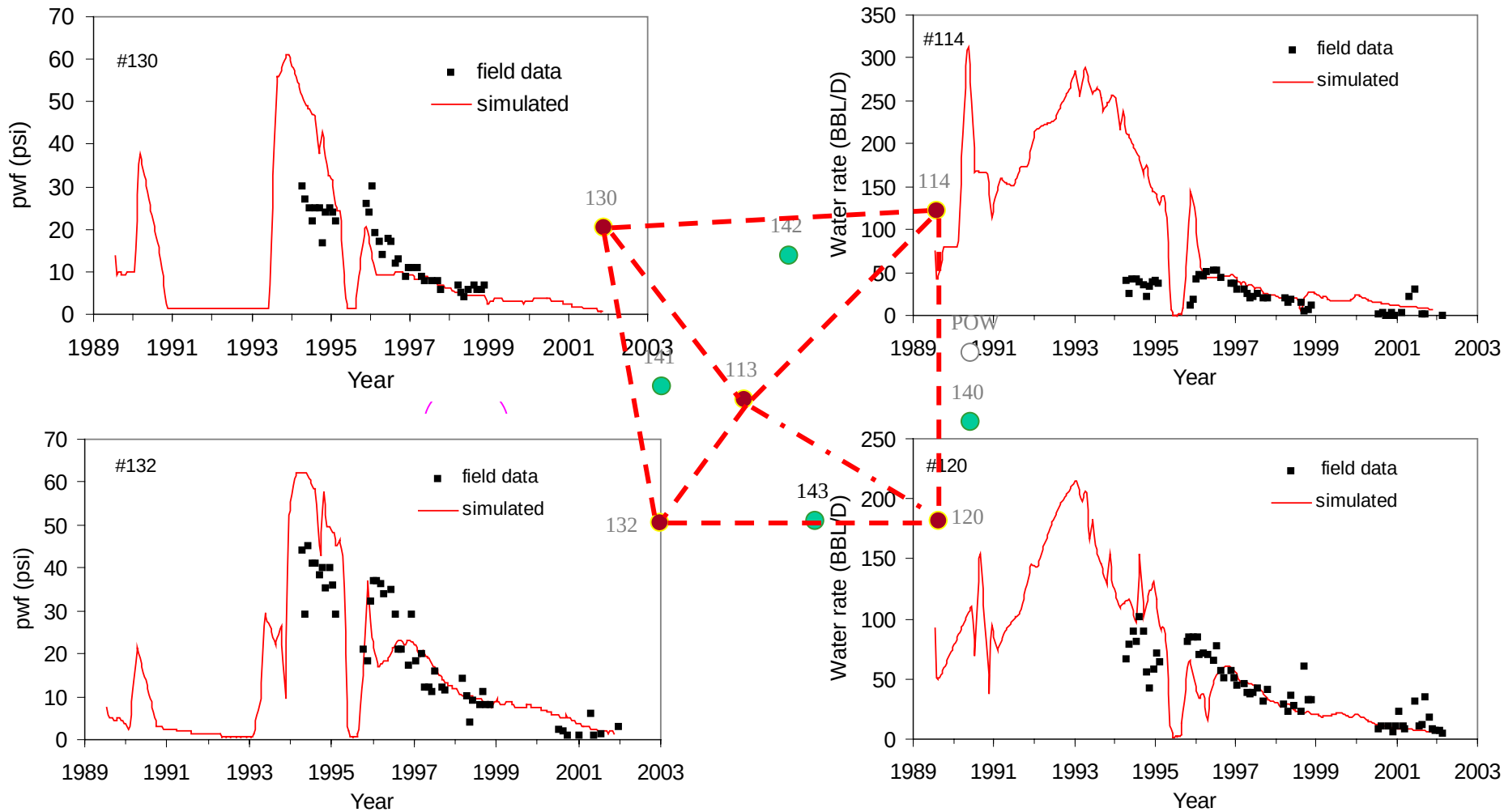


Wellblock permeability

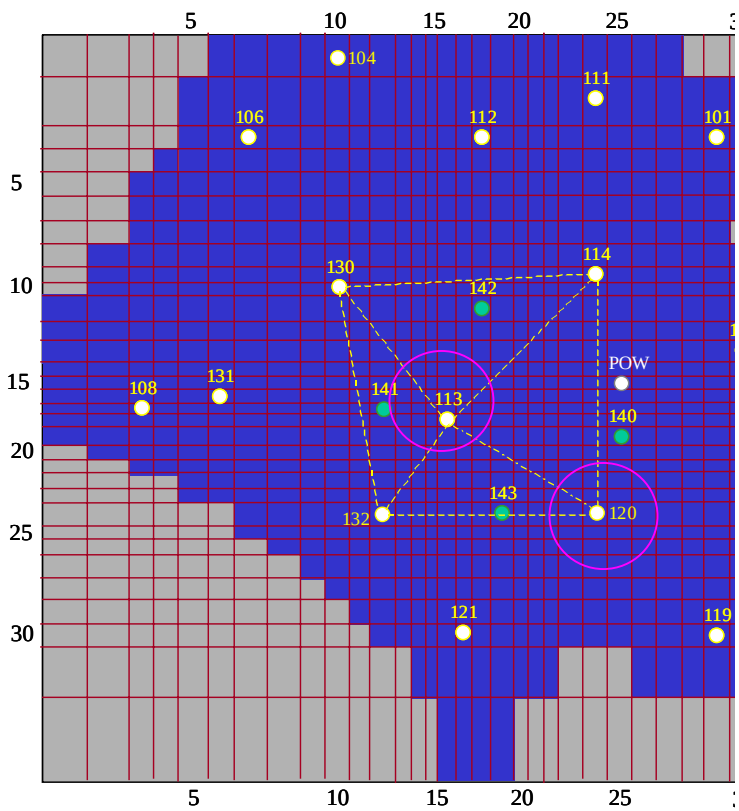


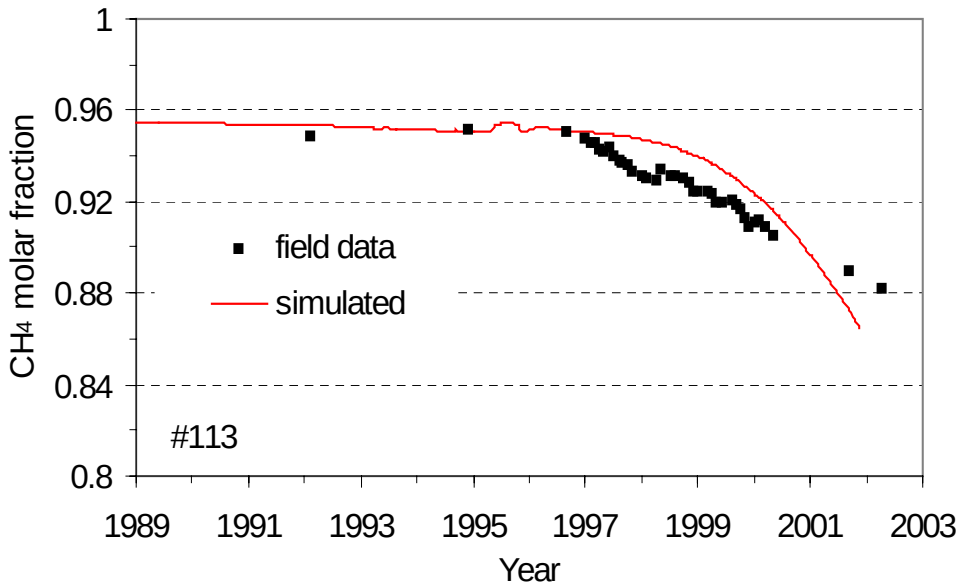


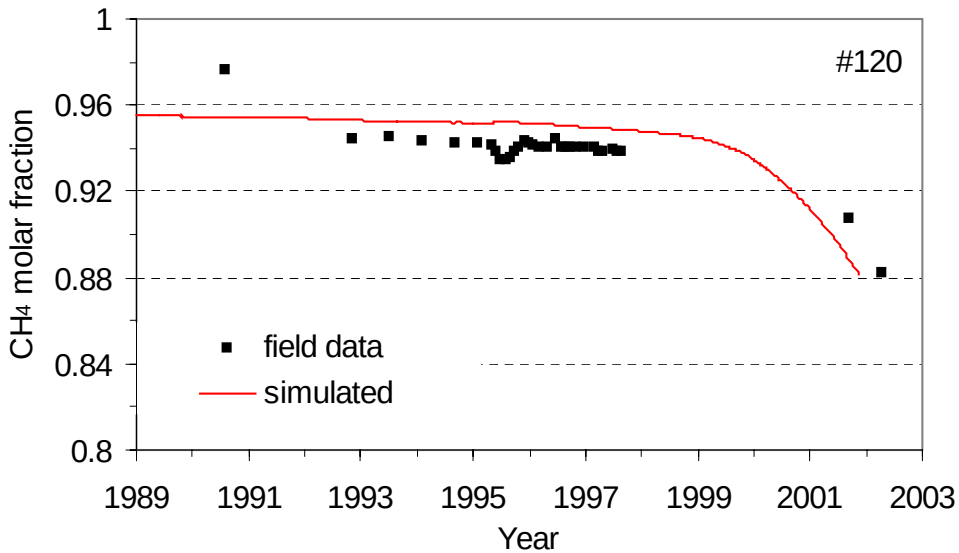
Simulation Results – Water Production Rates



Simulation Results – CO_2 Breakthrough

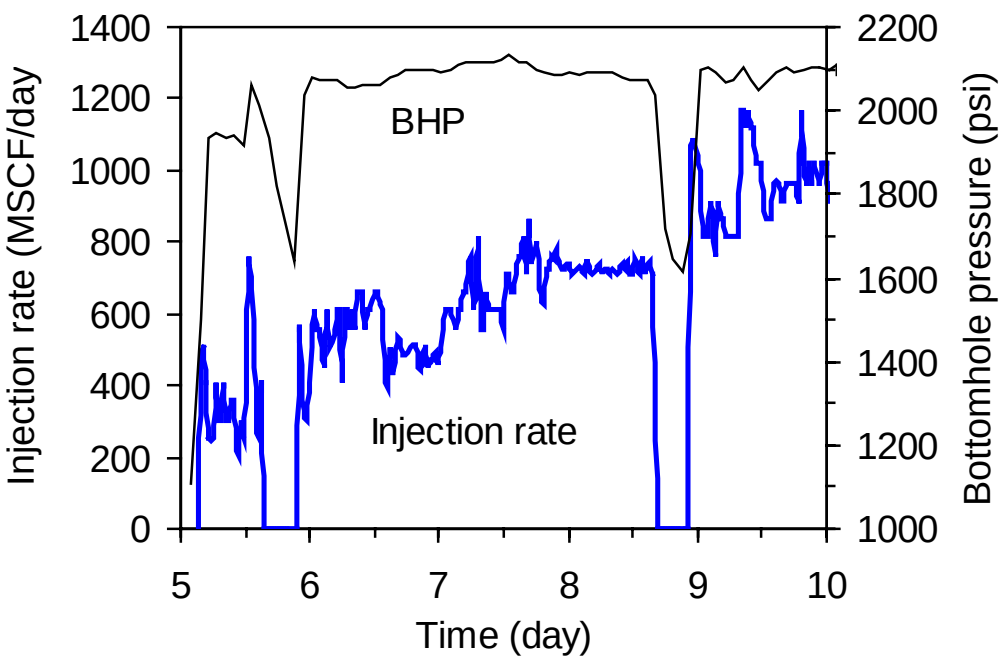






Alberta Fenn Big Valley Micro-Pilot Test – Flue Gas Injection at FBV–4A

The field pilot test was operated in three stages: 1) Flue gas injection (87.5% N_2 , 12.5% CO_2) ; 2) shut-in for pressure falloff; and 3) gas production.



Flue gas injection lasted 6 days

A total of 2946 MSCF flue gas injected

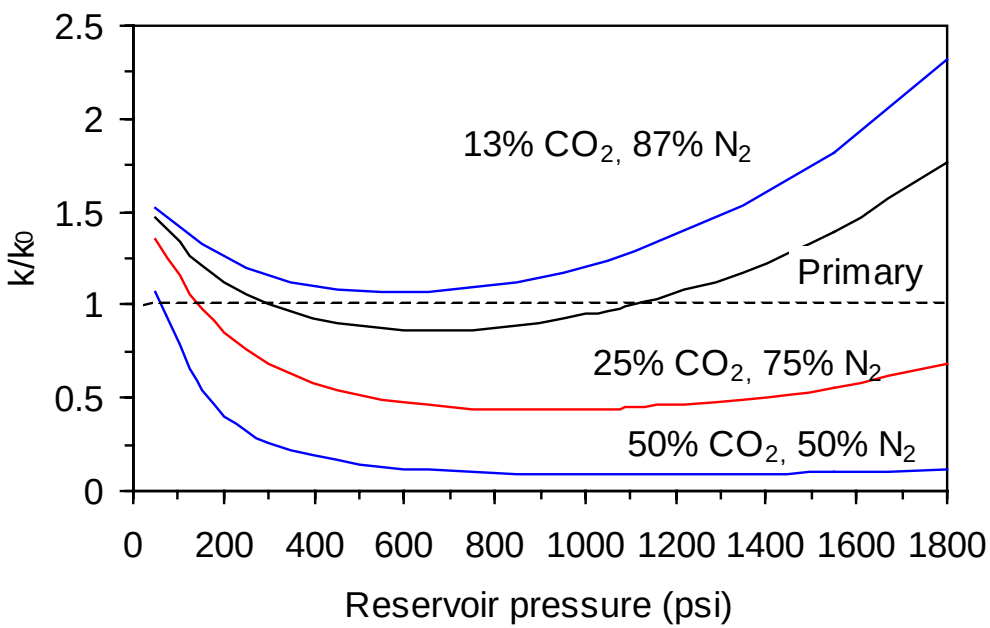
Rates increased from 300 to 1000 MSCF/day, at an injection pressure of 2100 psi

injection rate & bottomhle pressure

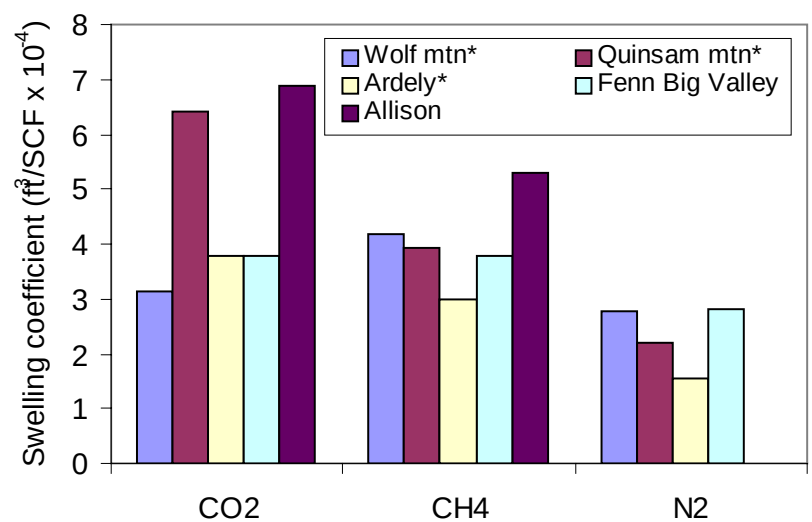
Permeability Response to Flue Gas Injection

E (psi)	420,000
ν	0.35
c_f (psi^{-1})	0.00096
α_{SCH4} (ft^3/SCF)	3.8×10^{-4}
α_{SCO2} (ft^3/SCF)	3.8×10^{-4}
α_{SCO2} (ft^3/SCF)	2.76×10^{-4}

Permeability response curves



Swelling coefficient

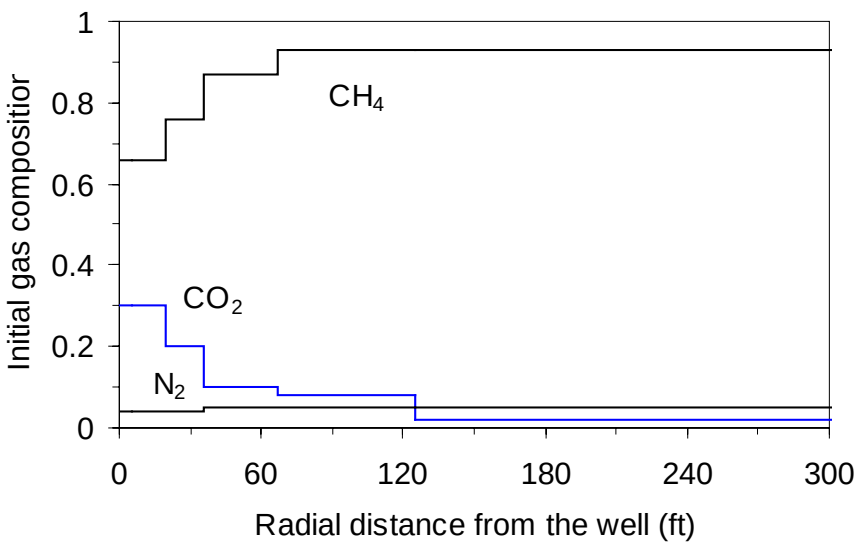


*(after Cui , 2003)

History Matching Results

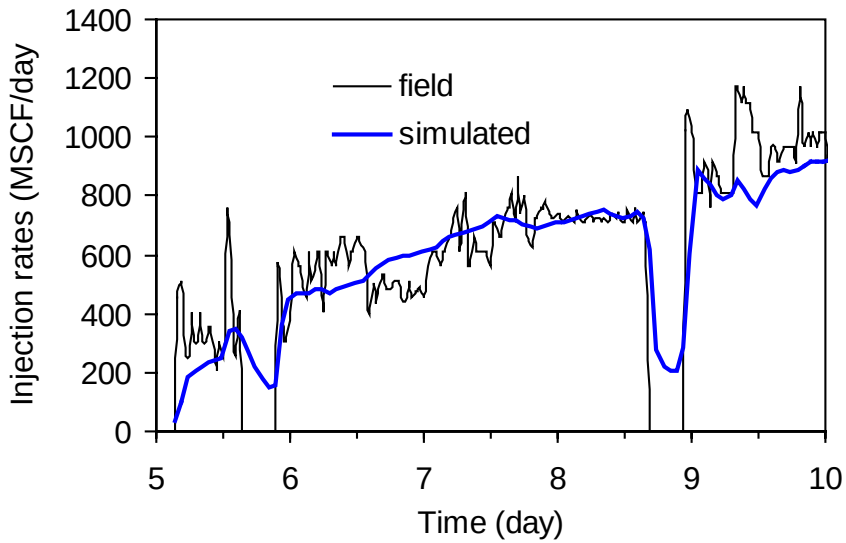
Initial dwonhole composition:

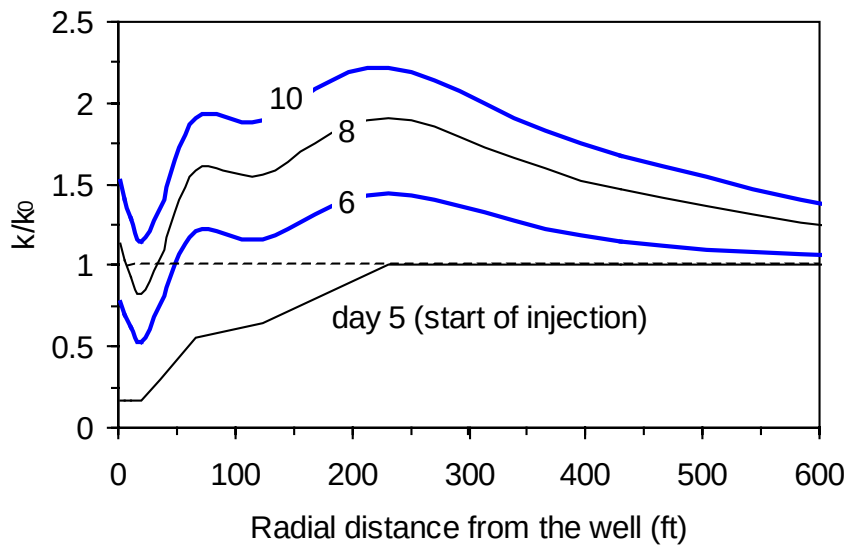
66.0% CH_4, 30.0% CO_2, 4.0% N_2

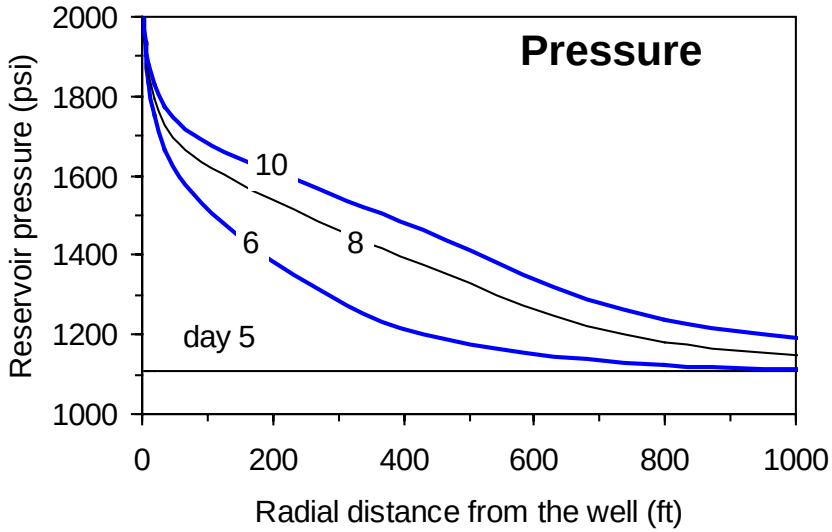
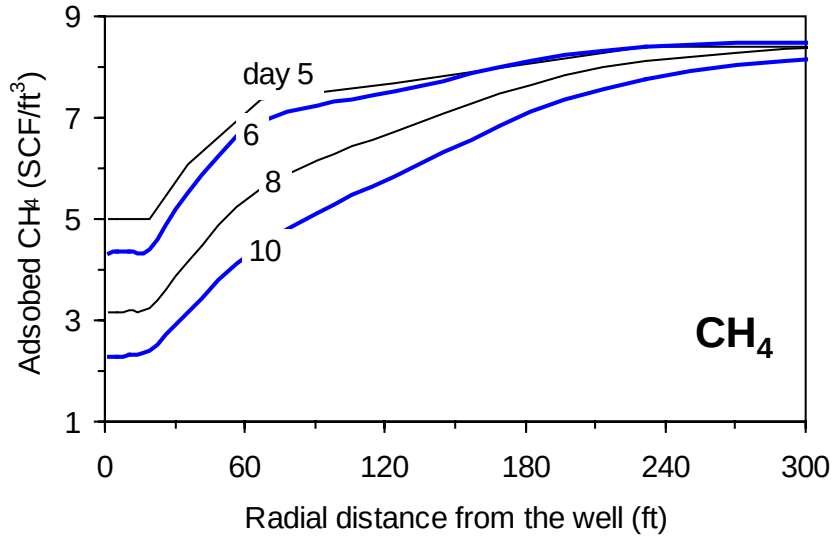
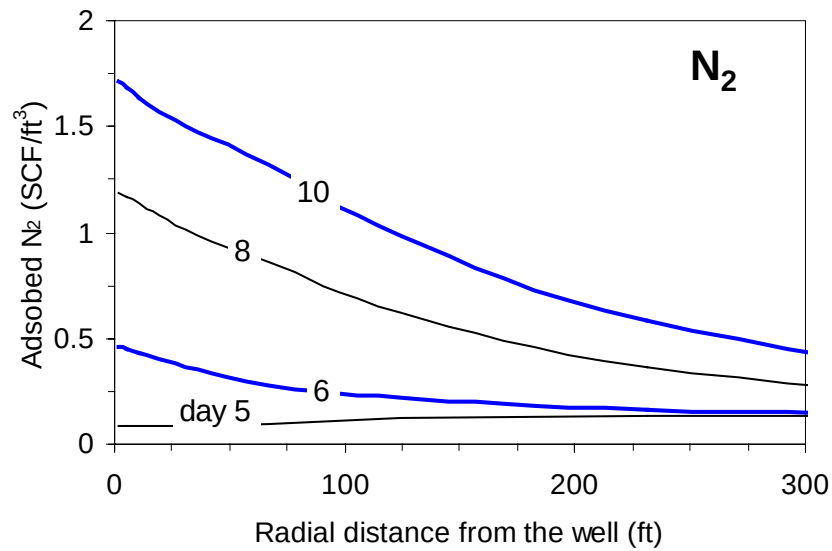
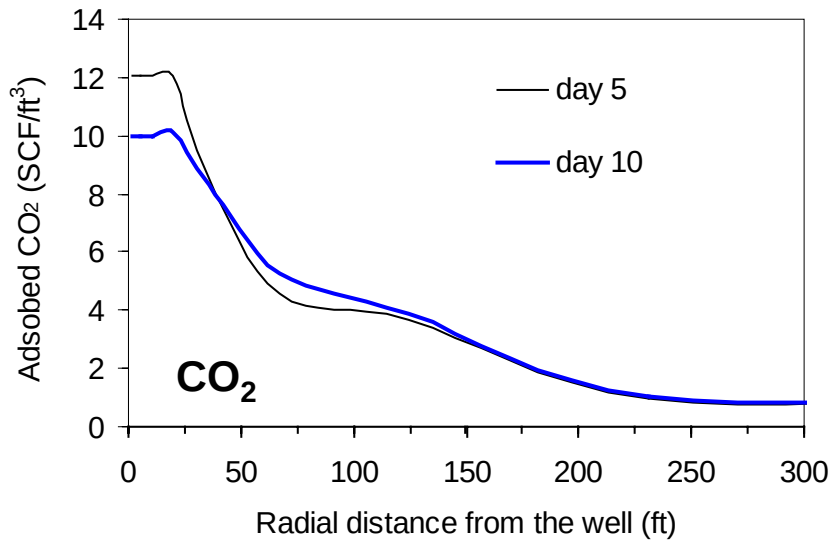


Initial gas composition profiles

Model match of injection rate





Simulated permeability profiles

Simulated Profiles of Pressure and Sorbed Gas Component Volume