

Reservoir Modeling and Simulation of the Devonian Gas Shale of Eastern Kentucky for Enhanced Gas Recovery and CO₂ Storage

2009 SPE International Conference on CO₂ Capture, Storage, and Utilization

Prepared by:

Karine Schepers, Advanced Resources International

Brandon Nuttall, Kentucky Geological Survey

Anne Oudinot, Advanced Resources International

Reinaldo Gonzalez

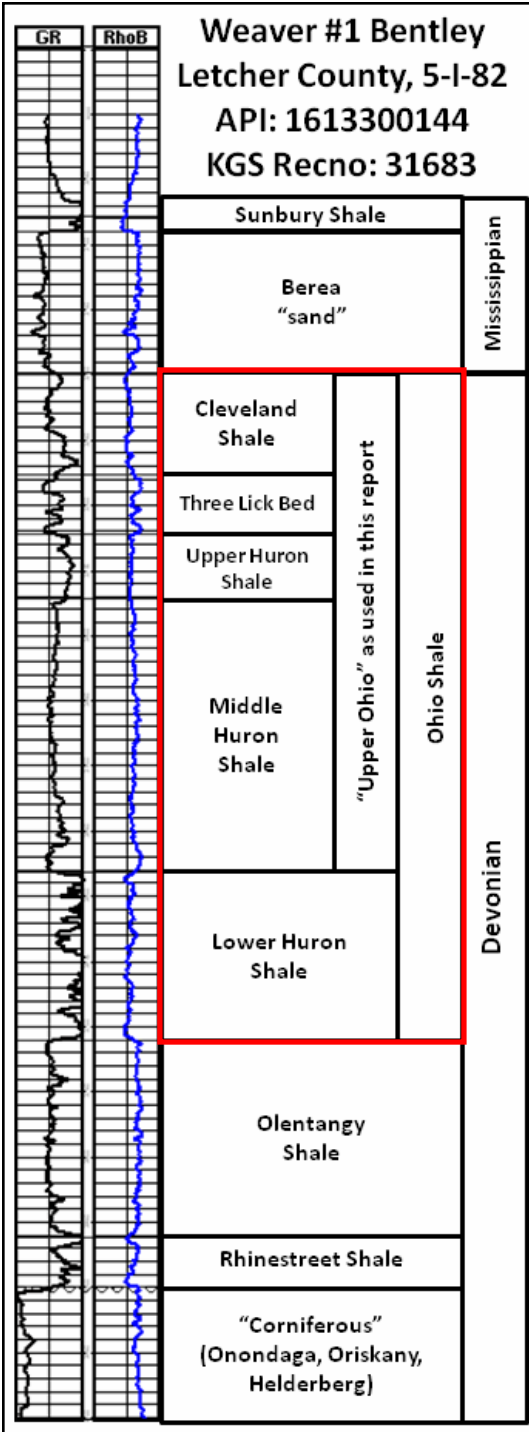
SPE 126620-PP

Presentation Outline

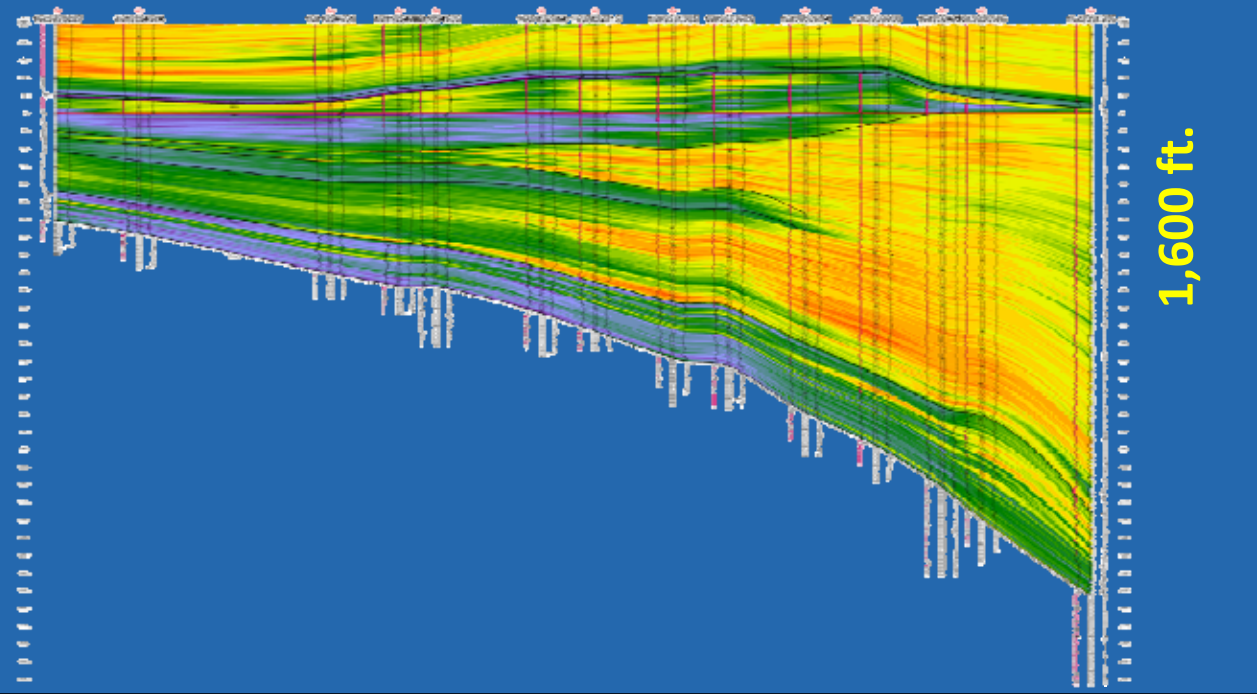
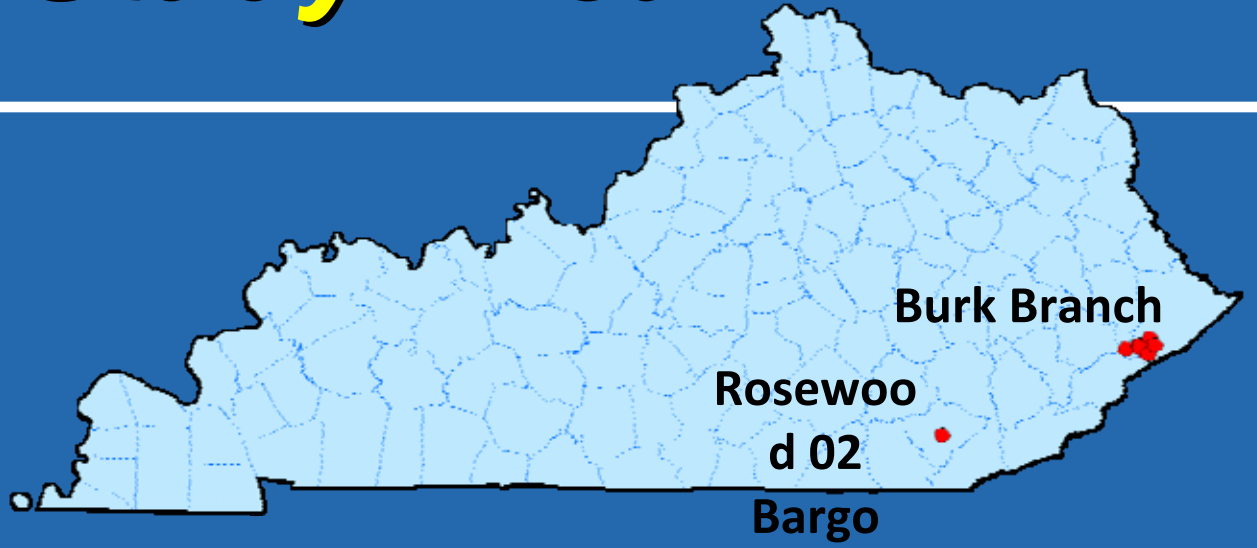
- Objectives and Methodology
- Reservoir Model
- History Matching
- Production Forecasts
- Results and Discussion

Objectives and Methodology

- Assess the potential of CO₂ injection into Upper Devonian Ohio Shale, Kentucky.
- History matching of gas production of offset wells to define reservoir parameters
- Then, several CO₂ injection scenarios designed to predict tertiary recovery

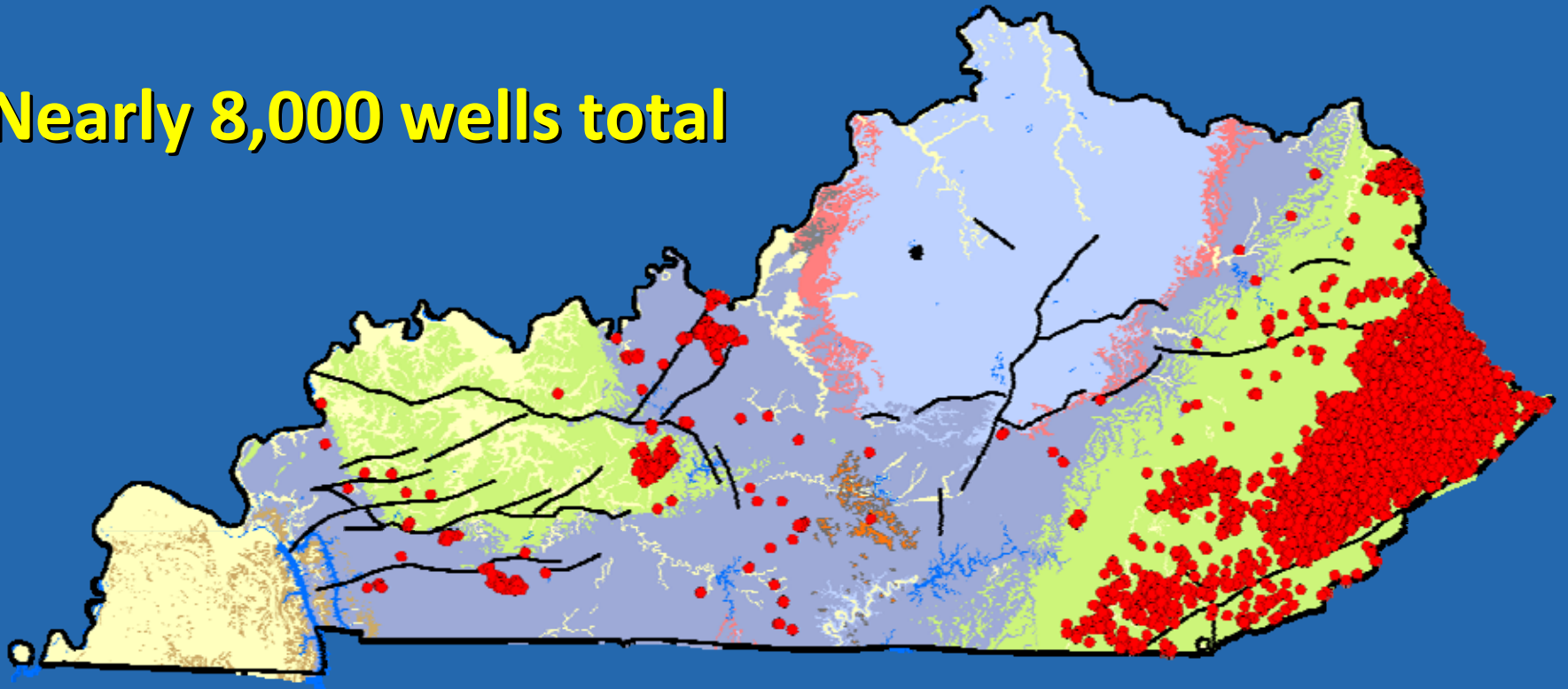


Study Area



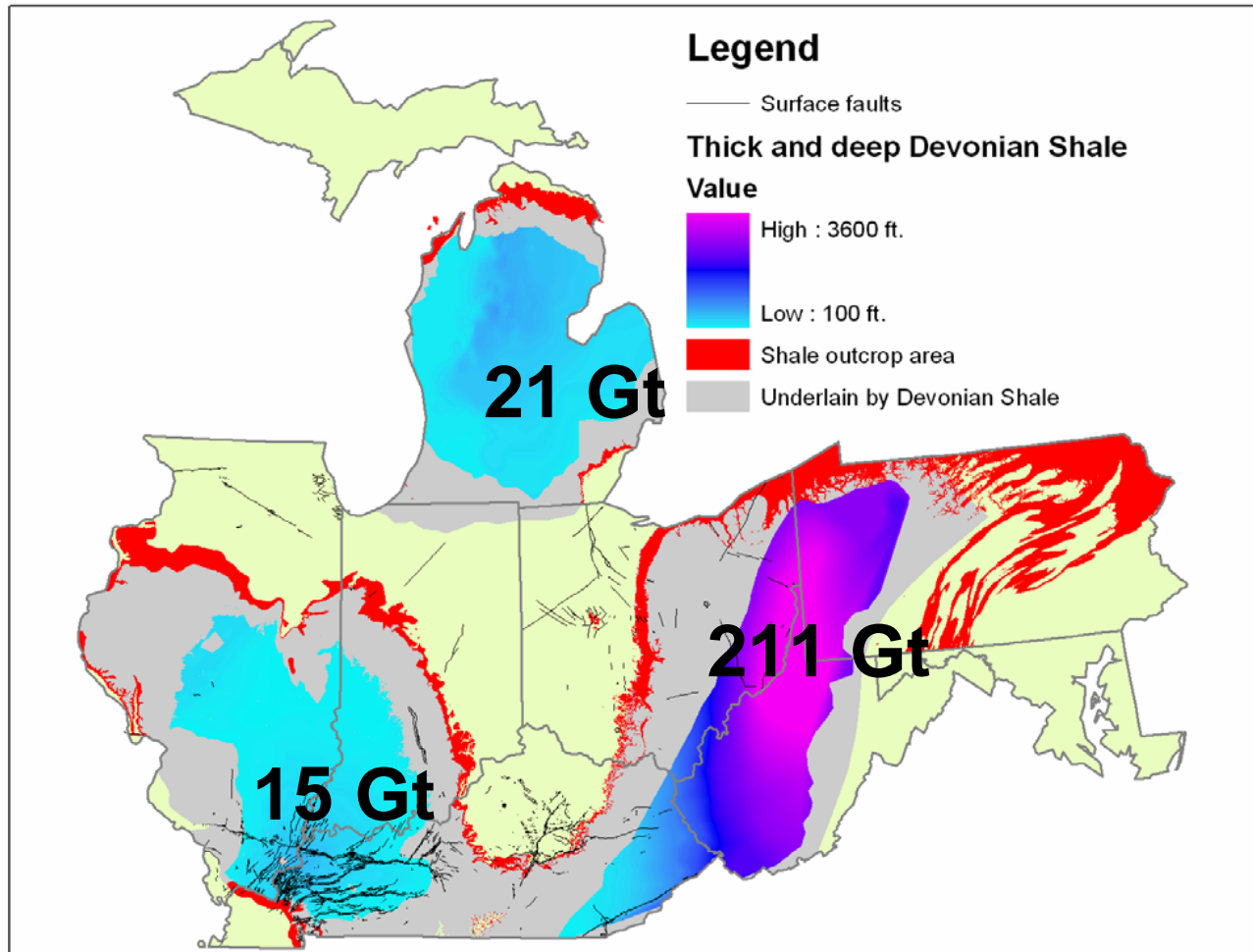
Area of Study - Shale Gas Wells in Kentucky

Nearly 8,000 wells total



*98% of gas production from all zones combined
is from eastern Kentucky*

PRCSP Phase I: Sequestration Capacity



247 Gt

The fine print

- Volumetric –
*based on
typical gas
adsorption*

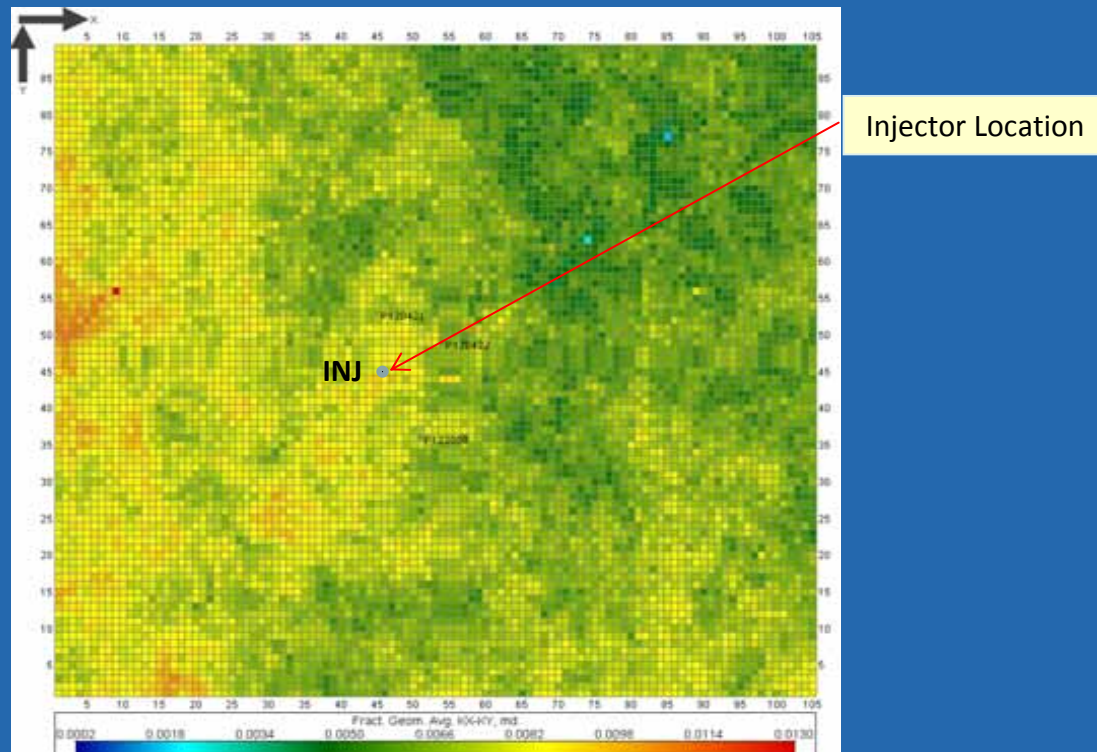
RESERVOIR MODEL

Reservoir Model

- Sector model containing three offset producers surrounding the potential injector
- Two layers to model Upper Devonian Ohio Shale Formation: Lower Huron Member individualized as main target for injection
- Dual porosity single permeability model

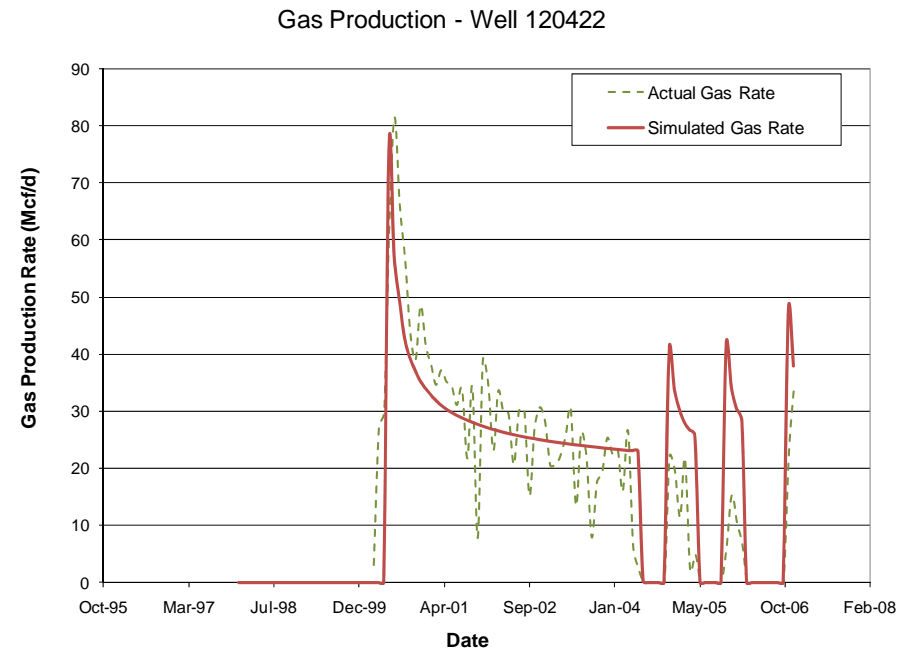
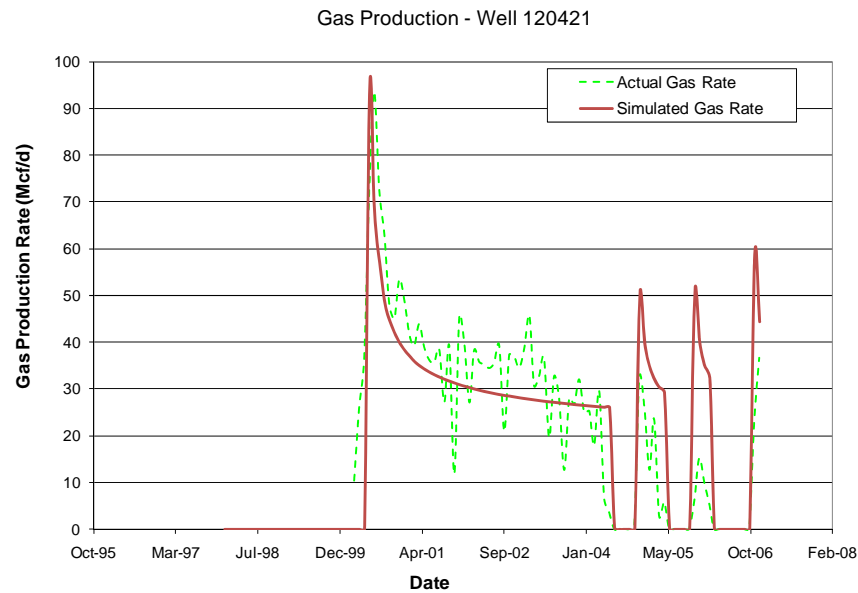
Reservoir Characterization

- Permeability is the main driver of gas production rate
 - heterogeneous gas production profiles often illustrate permeability heterogeneity
- Average gas production rate for each well used as a proxy to create geostatistical characterization of permeability



HISTORY MATCHING

History Matching – Two Closest Offset Producers



History Matching – Optimized Parameters

Parameters	Units	Minimum	Maximum	Optimized
Initial water saturation	%	0	10	2.3
Permeability Upper Ohio	mD	5.00E-05	0.5	1.30E-03
Permeability Lower Huron	mD	5.00E-04	5	1.30E-02
Permeability horizontal Anisotropy		0.1	10	4.6
Porosity Upper Ohio	%	0.1	3	0.8
Porosity Lower Huron	%	0.1	5	1.6
VL CH4	scf/t	17.3	50.4	38.9
PL CH4	psia	280	1960	1252
VL CO2	scf/t	30	320	131
PL CO2	psia	180	2790	1754
Skin well 120421	-	0	-5	-3.7
Skin well 120422	-	0	-5	-3.4
Skin well 122050	-	0	-5	-3.9

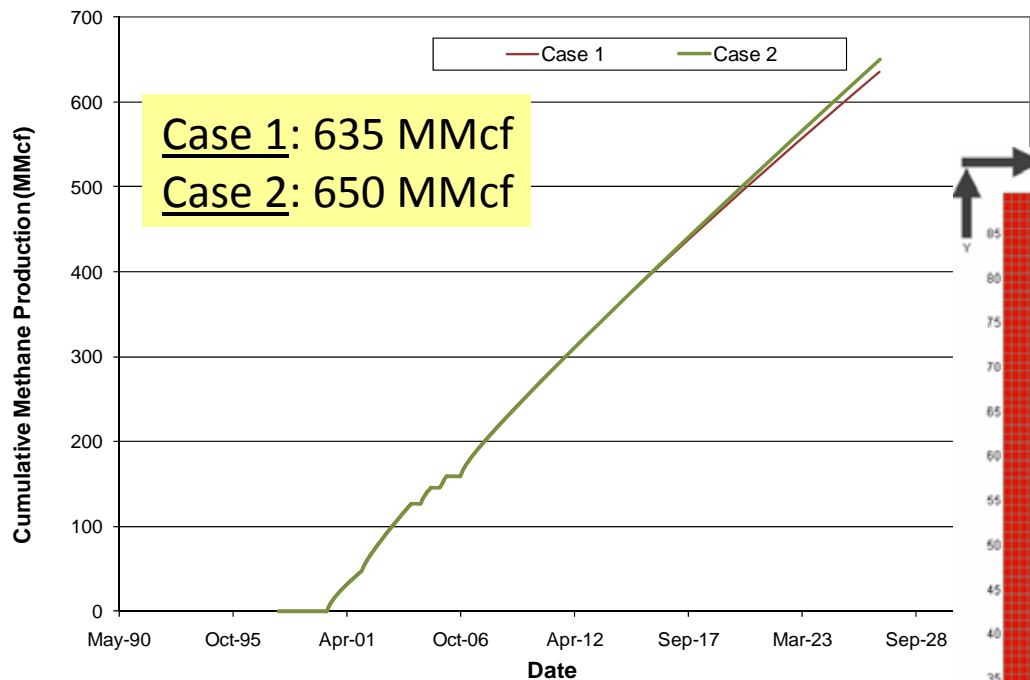
PRODUCTION FORECASTS

Continuous Injection Scenarios

- Case 1: Base case without any injection; production was forecasted for 30 yrs.
- Case 2: Production was forecasted for 30 yrs with CO₂ injection starting at the end of the history match period.

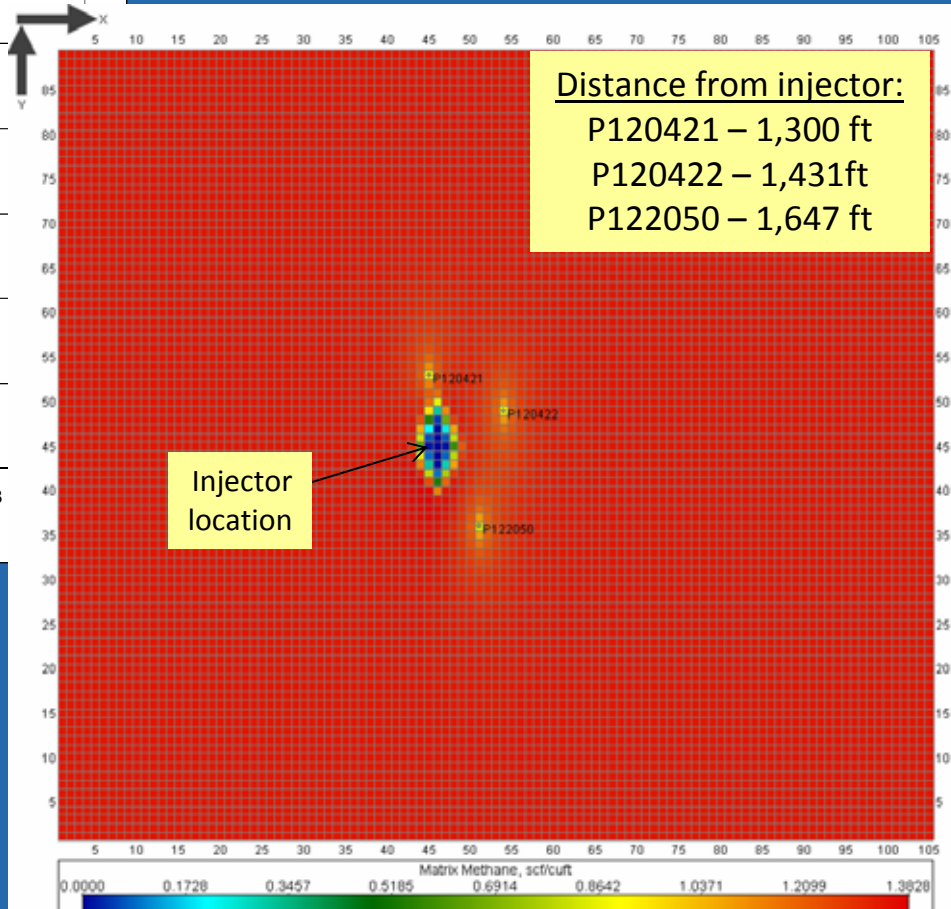
Field – 30 yrs Methane Recovery

Methane Production - Field



Case 1: 635 MMcf
Case 2: 650 MMcf

CO₂ Plume after 30 yrs: no breakthrough



CO₂ Injection Summary

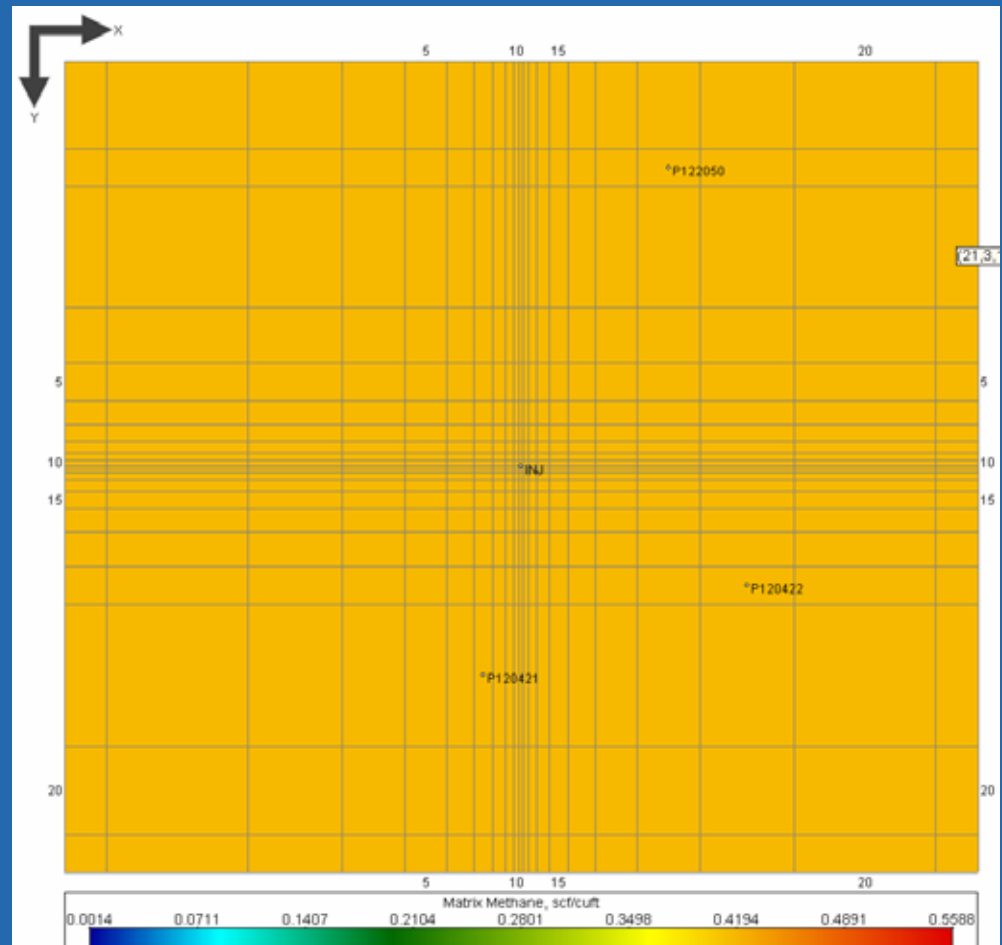
- When CO₂ injection starts:
 - little CH₄ has been desorbed
 - CO₂ adsorption is very limited
 - CO₂ mainly remains in fractures, limiting enhanced gas recovery.
- The completion (due to fracture stimulation) efficiency of these wells not well known. With 350ft thickness, model able to match data with a modest pressure drawdown.

CO₂ Injection Summary

- Should reservoir have less connectivity to the fracture stimulation, intervals contributing to gas production would be thinner and possibly more permeable.
 - sensitivity analyses performed under huff and puff and continuous injection cases
 - varying thickness but maintain the permeability-thickness product (“kh”).

Huff-and-Puff Scenario

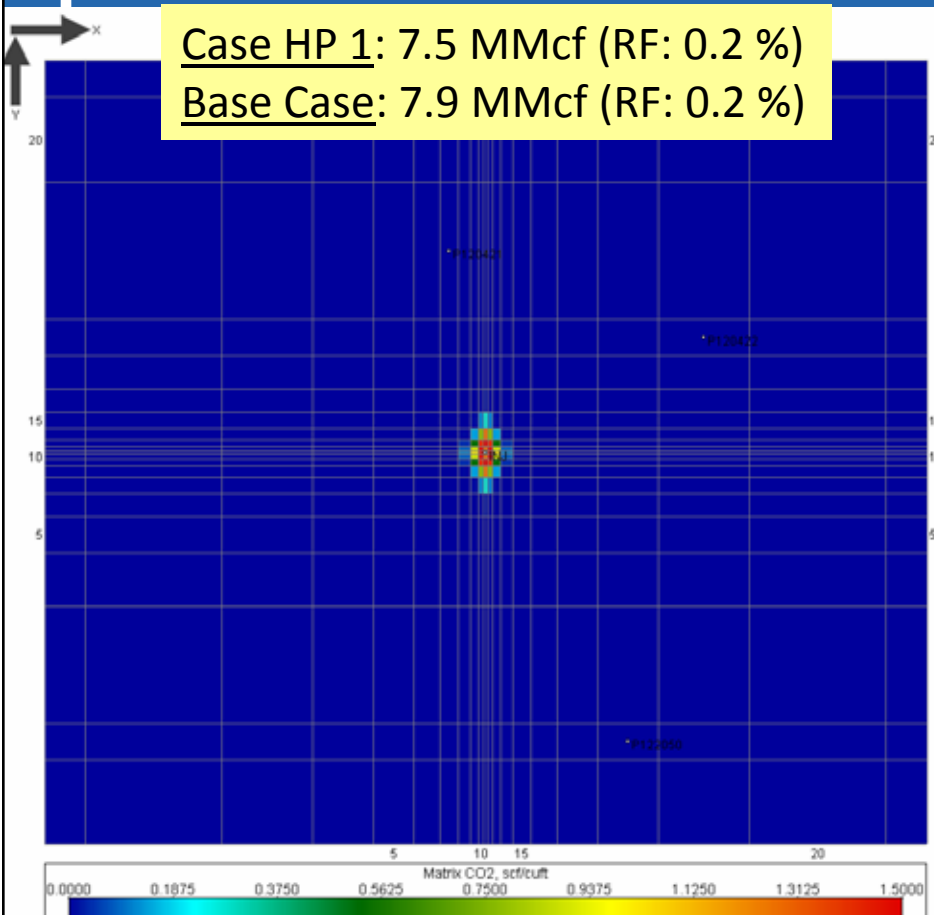
- Small volume injected during Huff-and-Puff; sub-model extracted from full-field model:
 - injection and three closest offset wells, 320 ac well spacing.
- Assumed reservoir pressure down to 250 psi in the Lower Huron
 - reservoir pressure at 400 psia in 1993 for Big Sandy field.



Huff-and-Puff Scenario 1

- For all cases, gas recovery given after 300 tons of CO₂ injected
 - minimum volume intended to be injected during the upcoming pilot injection test.
- Each case compared to a non-injection case
- The first case investigated injection of CO₂ into Lower Huron whole thickness (200 ft).

HP Scenario 1 Results



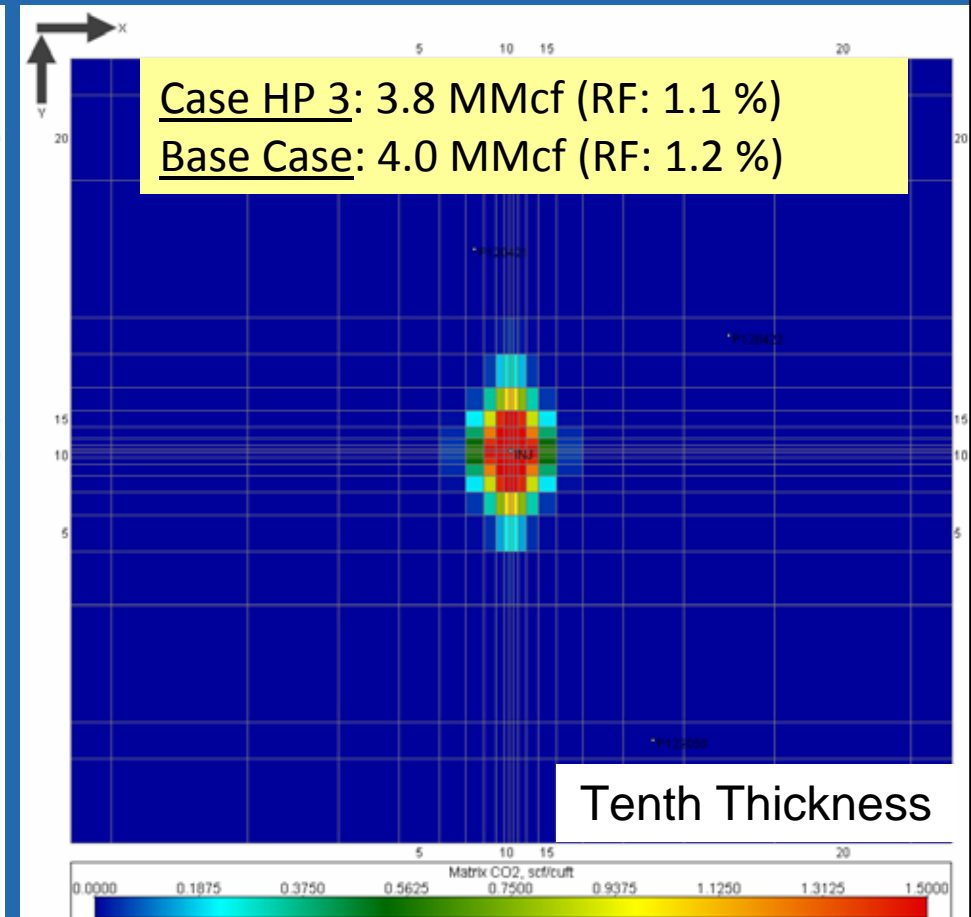
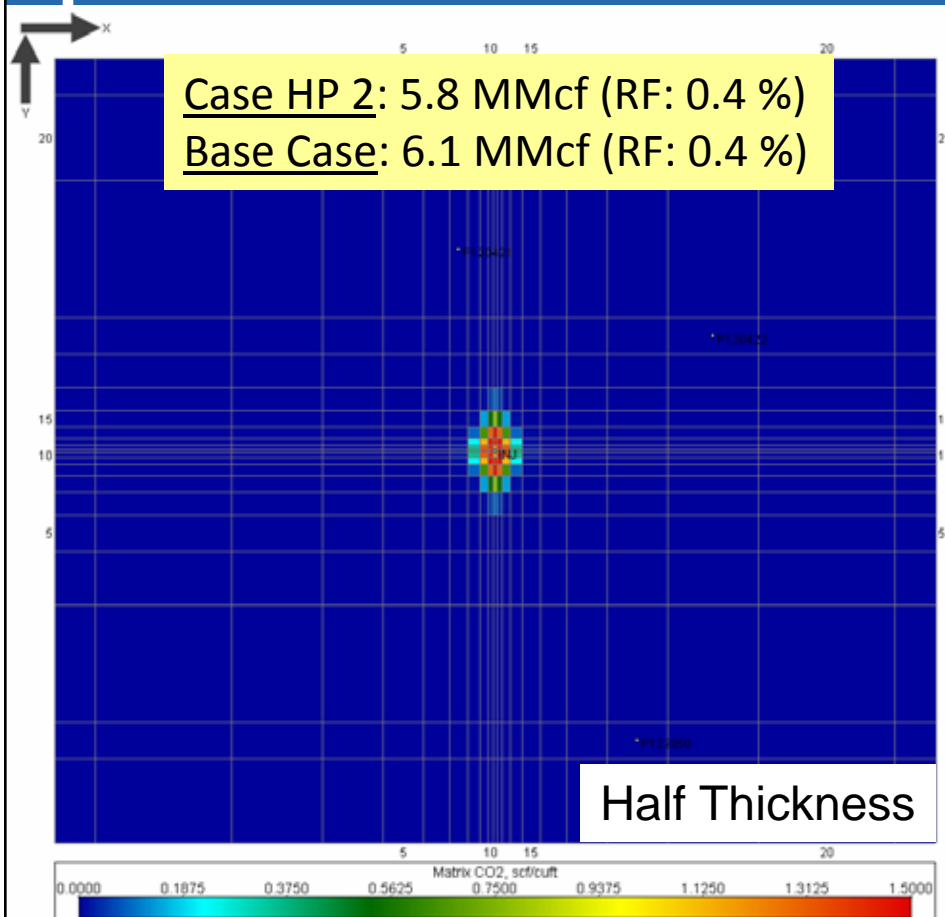
- No incremental methane recovery
- After soaking period, pressure decreases, some of sorbed CO₂ desorbs -> being reproduced at the injector.

Huff-and-Puff Scenarios 2 and 3

- Assuming a percentage of the thickness contributes to production:
 - Second case run with half of the thickness considered for each layer
- Finally, to better illustrate effect of thin layers, thickness reduced to ten percent of the original
- Correcting permeability and porosity accordingly.

HP Scenarios 2 and 3 Results

- Recovery significantly improved from full thickness case
- but no incremental methane production compared to base case.



Huff-and-Puff Scenarios Summary

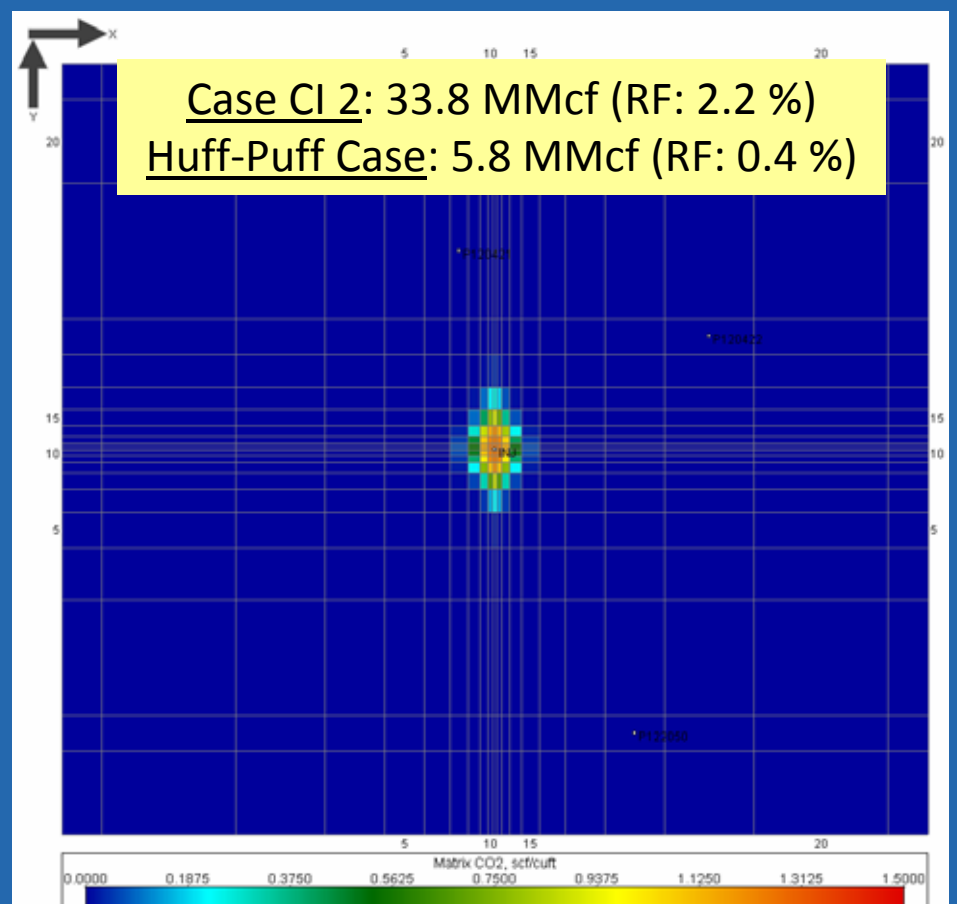
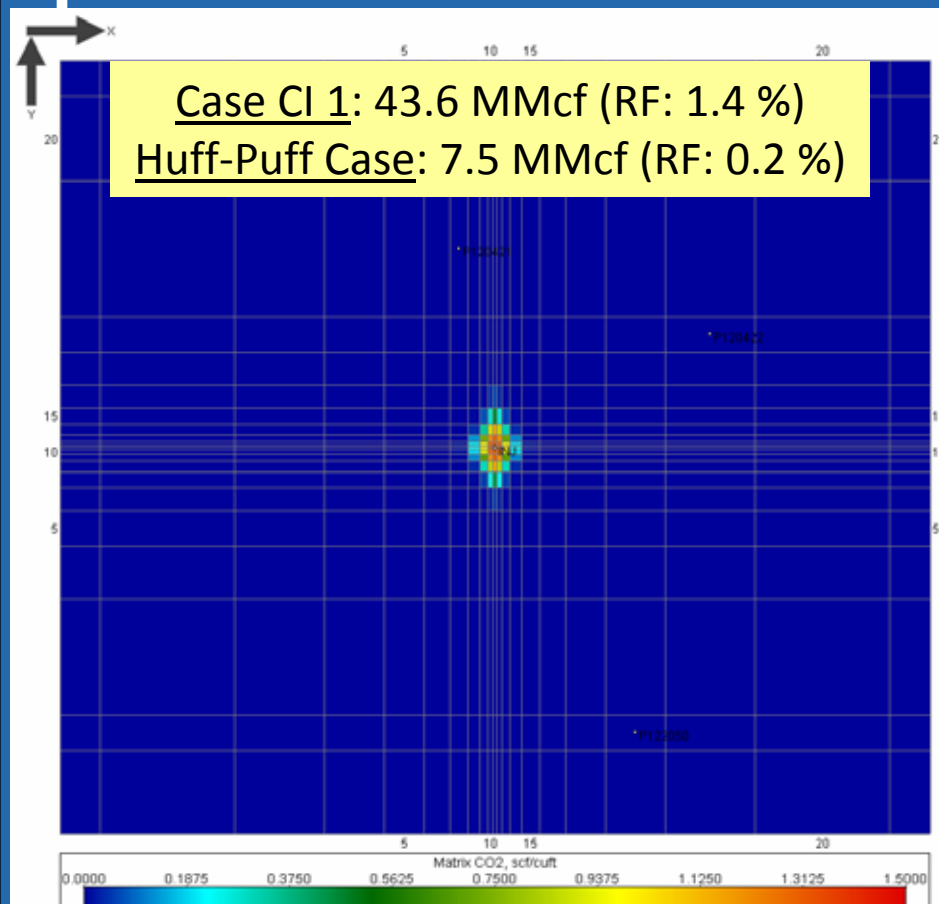
- Based on these results:
 - small volume huff and puff injection may not be applicable to shale production
 - Due to re-production of injected CO₂.

	CO ₂ Injected (tons)	Huff-and-Puff Scenario		Base Case
		Recovery (MMcf)	Recovery Factor (%)	Recovery Factor (%)
Full Thickness	300	7.5	0.2	0.2
Half Thickness	300	5.8	0.4	0.4
Tenth Thickness	300	3.8	1.1	1.2

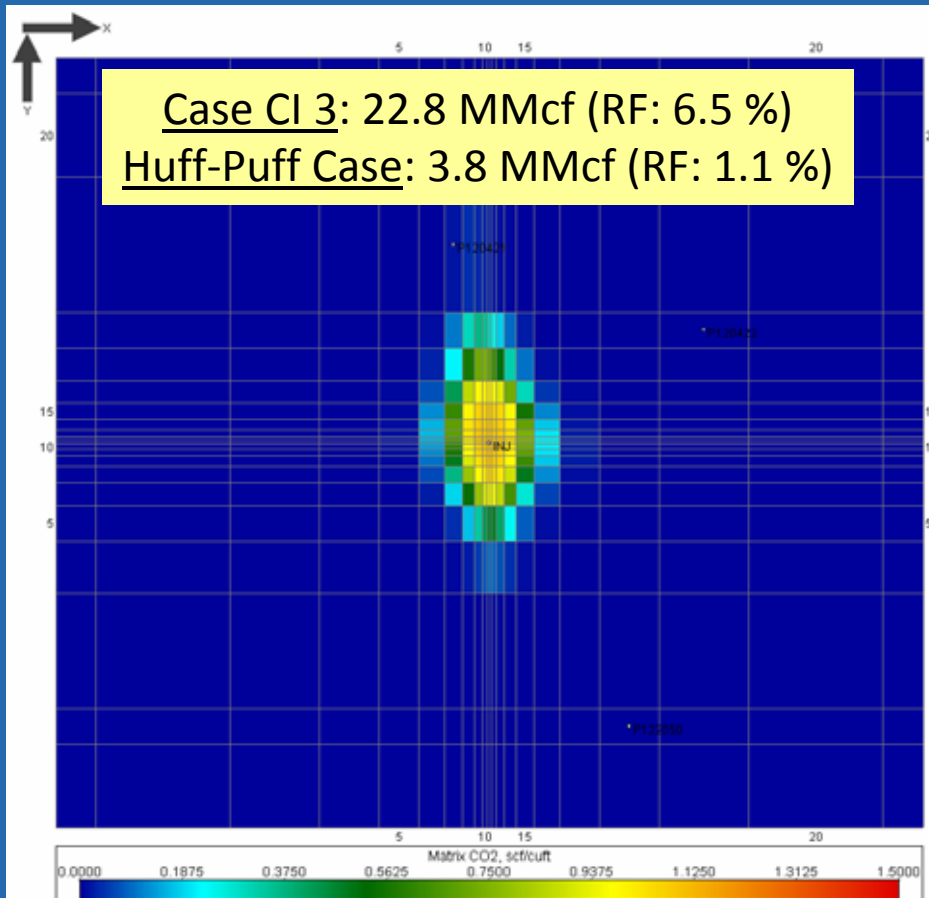
Continuous Injection Scenarios

- Similarly to huff and puff simulation cases, three thickness variation cases executed with a continuous injection of 300 tons of CO₂.
- Recoveries of each continuous scenario compared to equivalent Huff-and-Puff case

Continuous injection Scenarios 1 and 2: Recoveries



Continuous Injection Scenario 3: Recovery

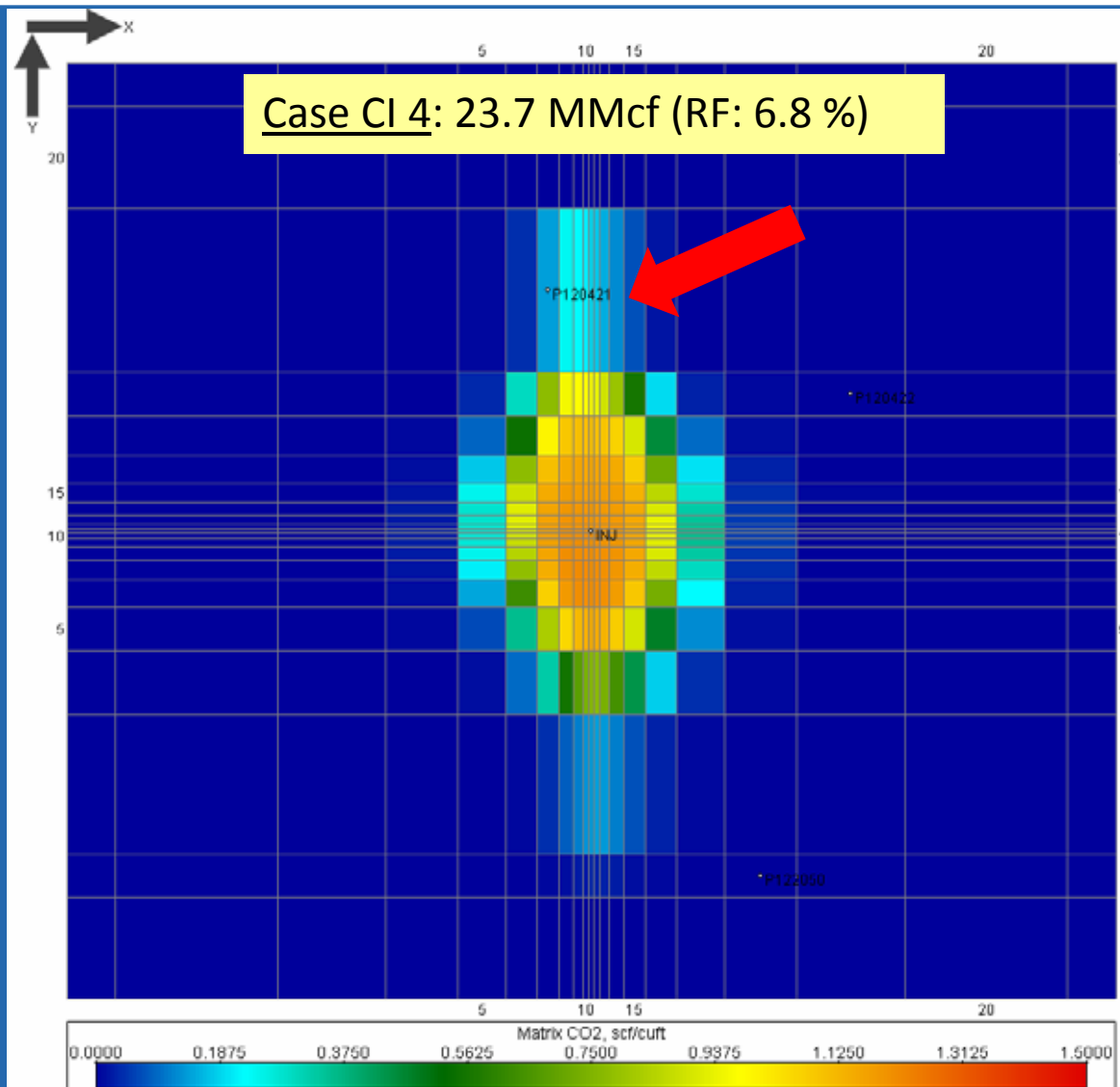


- In three scenarios, recovery significantly improved from huff-and-puff case
- Incremental recovery observed as well.

Continuous Injection Scenarios Summary

- Finally, assuming availability of larger CO₂ volume, one extra case run.
- Best performing case selected, tenth thickness:
 - injected CO₂ volume of 1,000 tons (maximum volume intended to be injected during upcoming pilot injection test).

Continuous Injection Scenario 4: CO₂ Plume Extent – 1,000 Tons



Continuous Injection Scenarios Summary

- Compared to base case, continuous injection cumulative recovery quadrupled: significant gain. From these results, continuous injection seems to be more adaptable to shale.

	Continuous Injection Scenario			Base Case
	CO ₂ Injected (tons)	CH ₄ Recovery (MMcf)	Recovery Factor (%)	Recovery Factor (%)
Full Thickness	300	43.6	1.4	1.4
Half Thickness	300	33.8	2.2	2.1
Tenth Thickness	300	22.8	6.5	6.3
Tenth Thickness	1,000	23.7	6.8	6.3

Results and Discussion

- Satisfactory match of gas rate optimized at a permeability of $1.3 \cdot 10^{-2}$ mD and porosity of 1.6 % for Lower Huron, $1.3 \cdot 10^{-3}$ mD and 0.8 % for Upper Ohio.
- Geostatistical characterization of fracture porosity and permeability based on productivity index used to capture geological heterogeneity
- Continuous CO₂ injection cases seem successful, allowing injection of 300 tons over a period of one month with a significant gain in recovery.

Results and Discussion cont.

- Huff-and-Puff scenario not good option for this specific reservoir: no enhanced gas recovery due to CO₂ reproduced during puff periods. Longer soaking periods did not seem to improve recovery.
- CO₂ injection should be focused on smaller thickness intervals to maximize CH₄ recovery per CO₂ injection volume.
- Finally, less than 10% to no CO₂ reproduced. Cases very successful from a sequestration standpoint.

Results and Discussion *cont.*

- For the thin layer case, even if larger volumes of CO₂ available, minor EGR
 - incremental of less than 1 % for 3 times more CO₂ injected
- As expected, flooding tenth thickness case with 300 tons of CO₂ best ECBM case, highest utilization ratio.

	Full Pattern Scenario			
	CO ₂ Injected (tons)	CH ₄ Recovery (MMcf)	Recovery Factor (%)	Utilization Ratio (Mcf/ton)*
Full Thickness	300	43.6	1.4	0.37
Half Thickness	300	33.8	2.2	0.67
Tenth Thickness	300	22.8	6.5	2.4
Tenth Thickness	1,000	23.7	6.8	1.62

*Utilization ratio is defined as incremental CH₄ recovery divided by volume of injected CO₂

Thank You!