HB-1: Testing CO_2 Enhanced Gas Recovery and Storage

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Kentucky Geological Survey

Pike County Fiscal Court

Sept. 1, 2010

Paradigm

If shale produces gas (CH_4), then in depleted wells:

GIGO

"Gas In (CO_2) = more Gas Out (CH_4)"

HB-1 (2007), Section 57

- Specifies: “At least one of the wells will test the Devonian shale for enhanced gas recovery and sequestration potential.”
- Encourages: the Survey to “…use these funds to match available federal and private funds to the extent possible.”

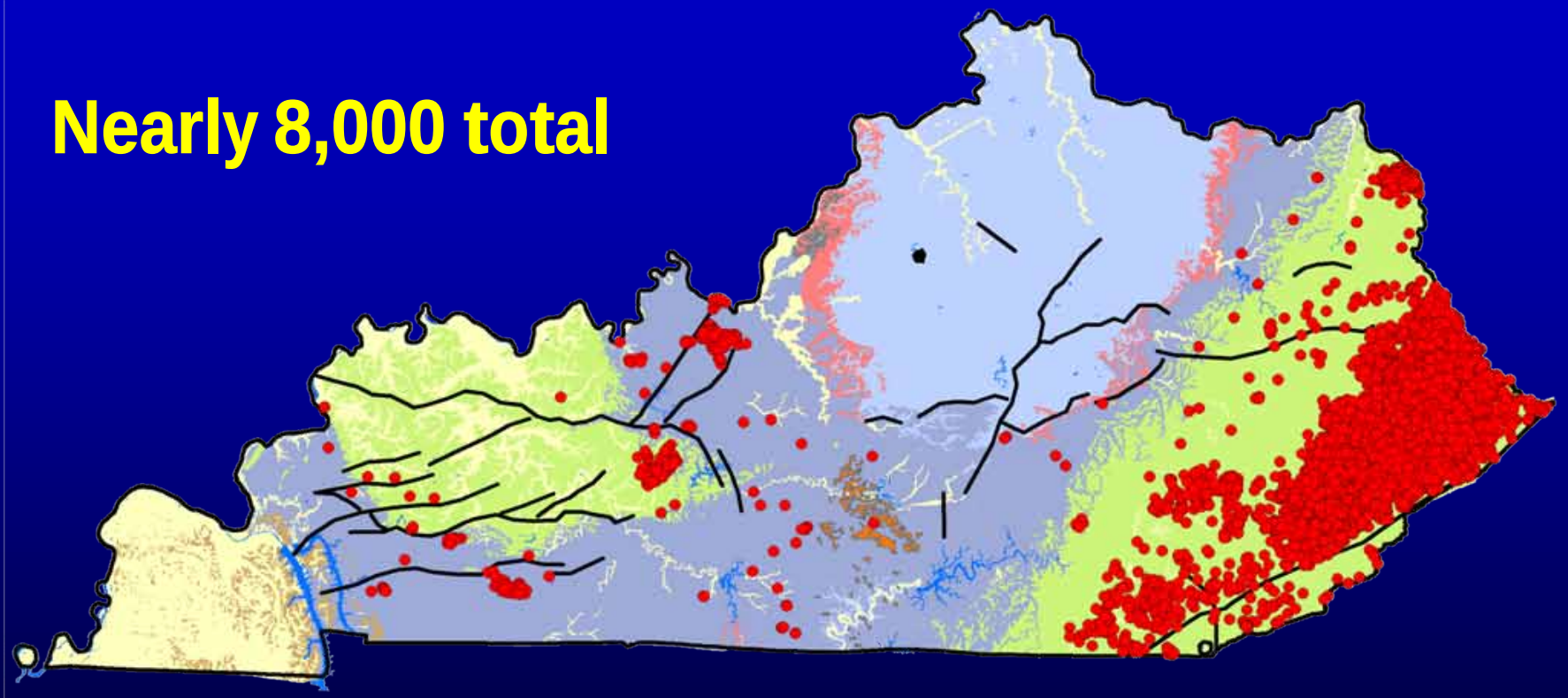
KGS

Project Outline

- Feasibility
  - Data collection, analysis, modeling
- Background
  - ESA, MVA
  - UIC Permit
- Injection
- Data analysis and reporting
  - Model refinement and confirmation
  - MVA

Shale Gas Wells in Kentucky

Nearly 8,000 total



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

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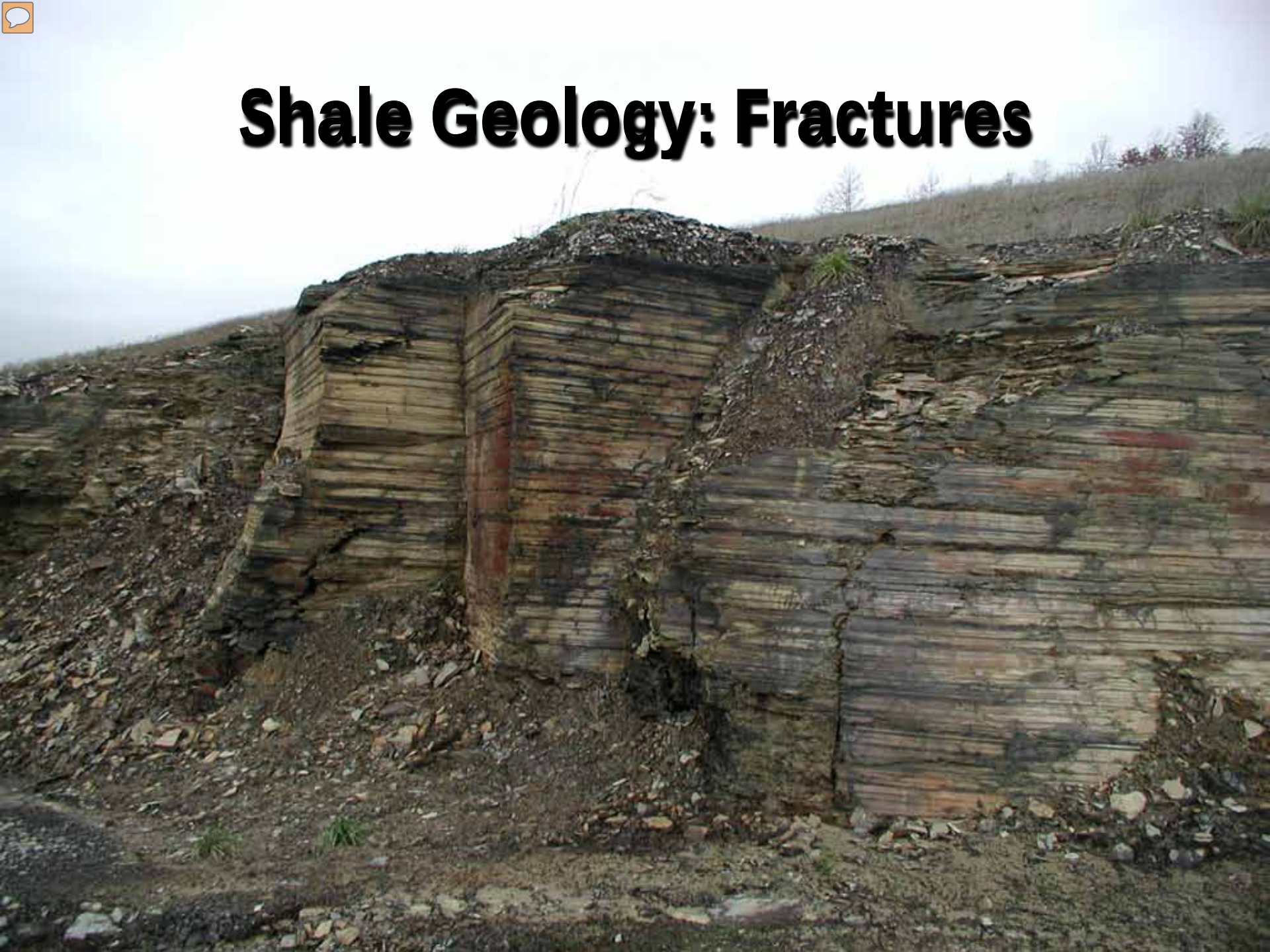
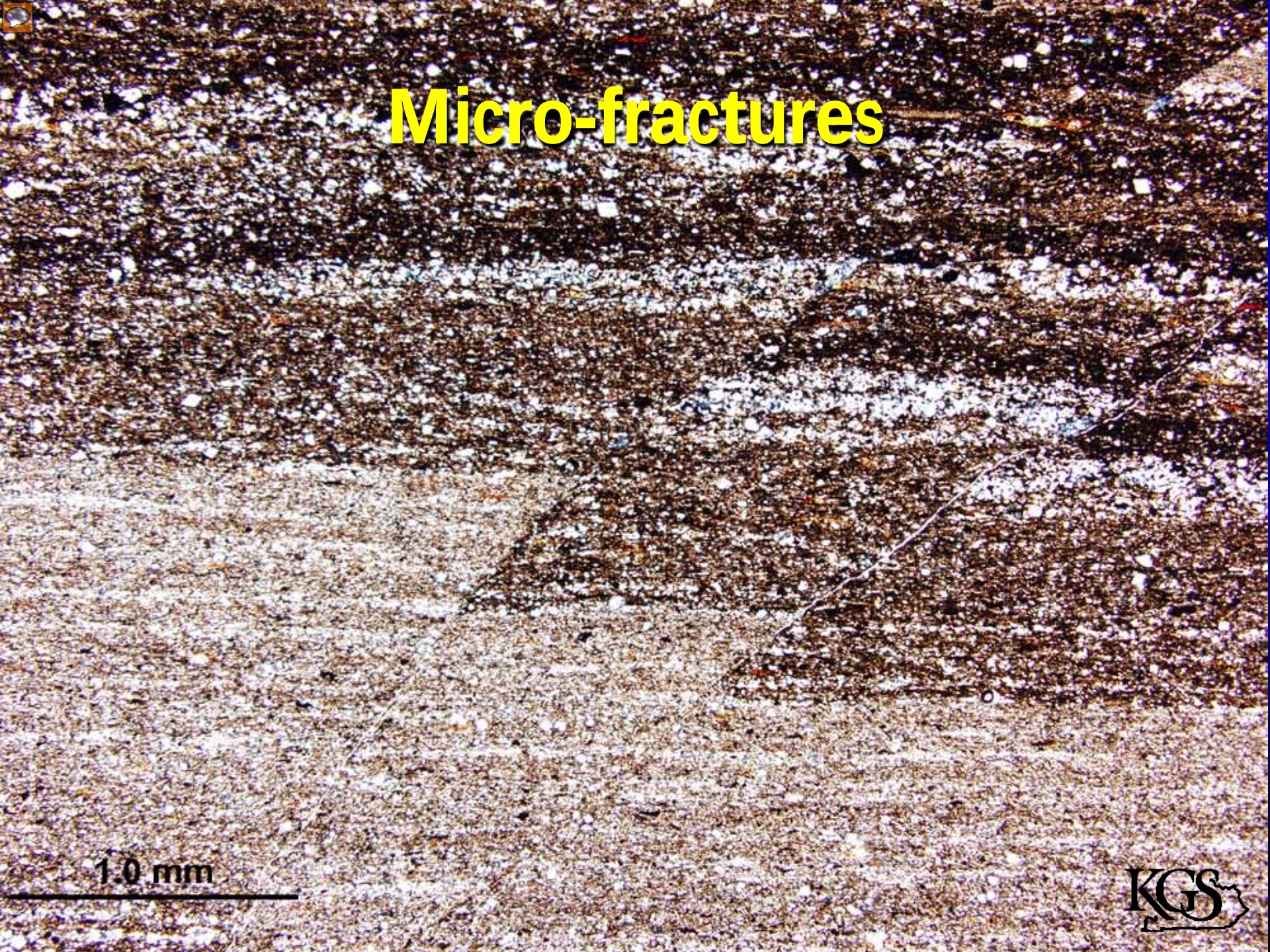
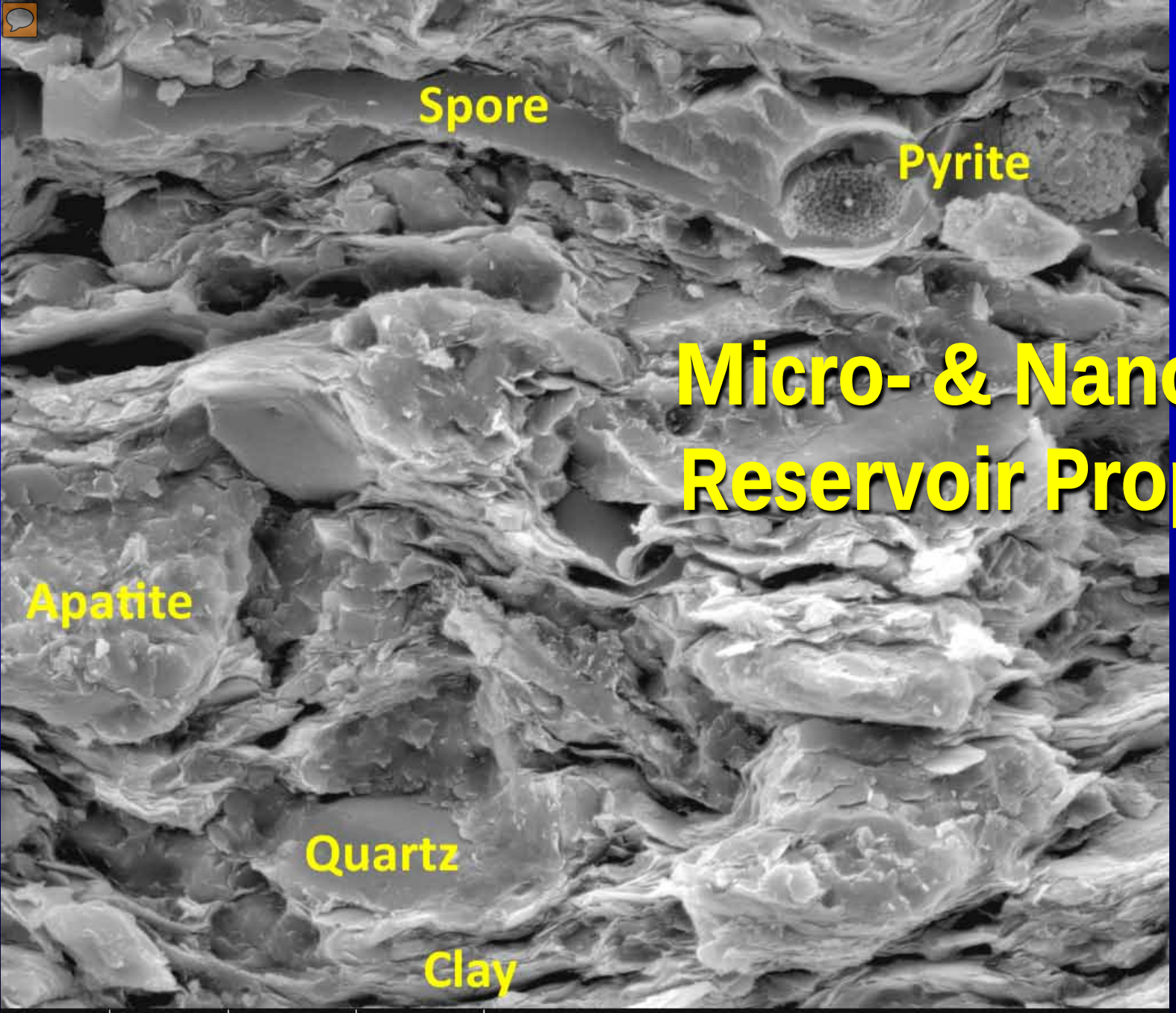
Shale Geology: Fractures




Micro-fractures
1.0 mm
KGS



Micro- & Nano-Scale Reservoir Properties

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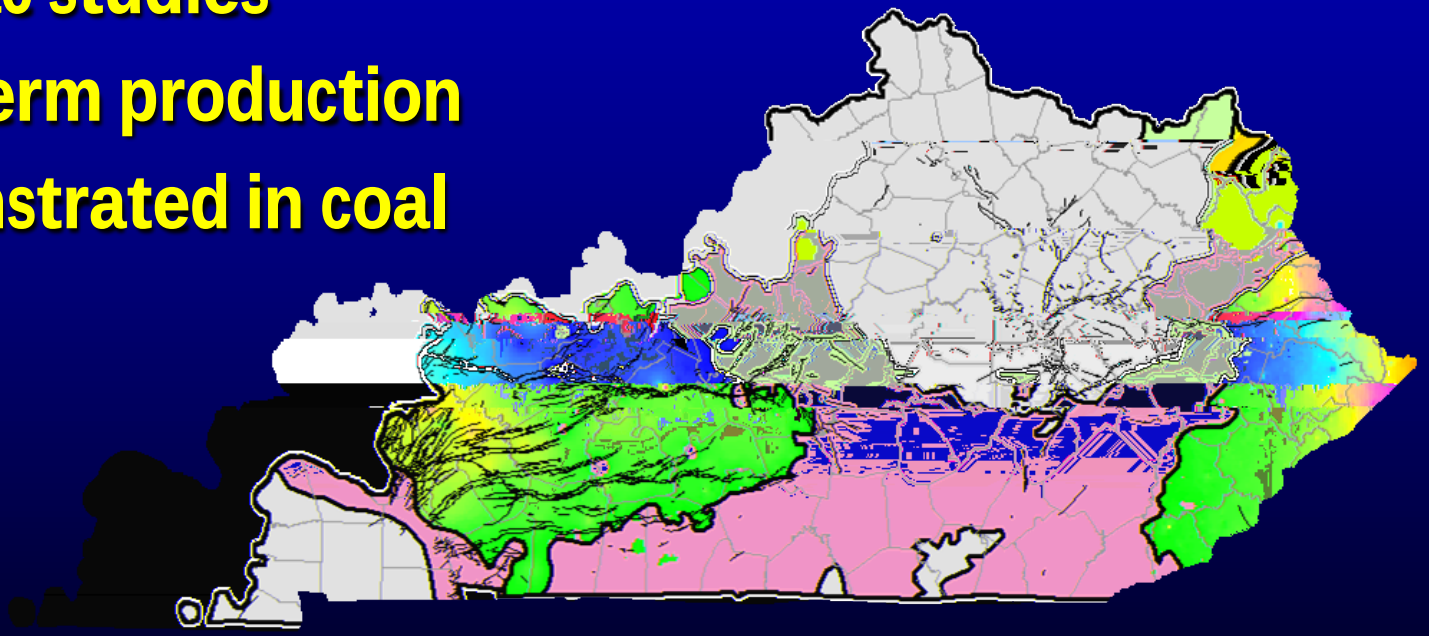
Devonian Shale Reservoir

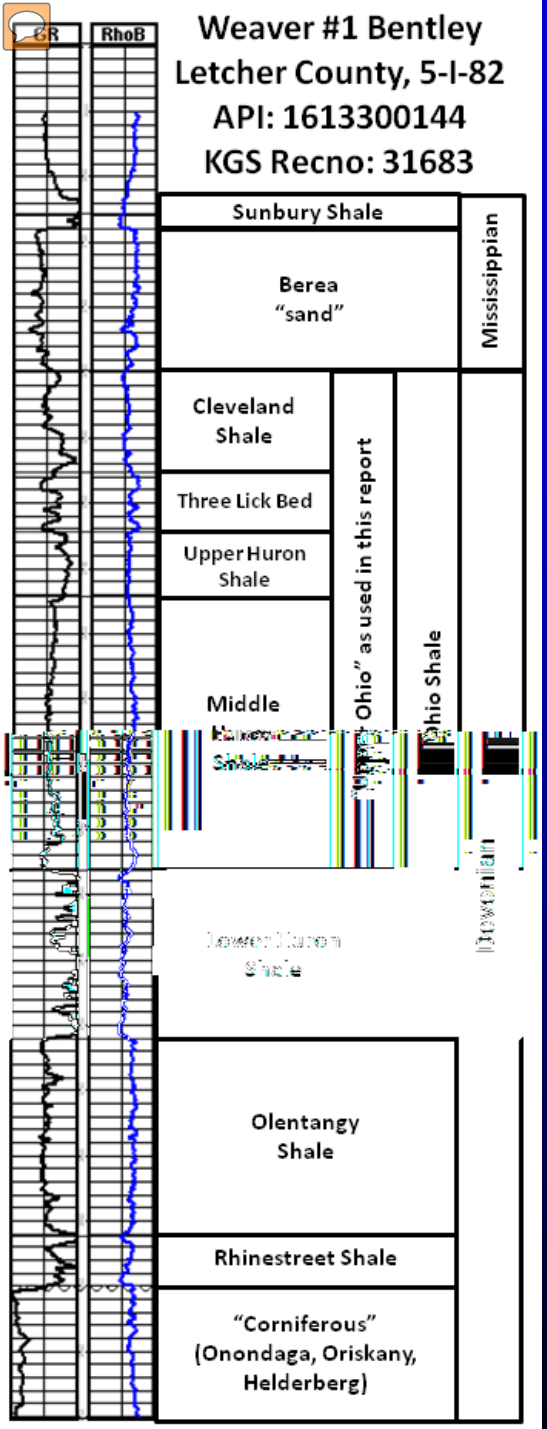
- Dual porosity (fractures and matrix)
- Dual permeability (fractures and matrix)
- Organic-rich (up to 25% TOC)
- Eastern Kentucky
  - Thickness > 1,600 feet
  - Most active and prolific gas producer (75%)

CO_2 Enhanced Gas Recovery

- **Indicators:**
  - Adsorption isotherms
  - CO_2 frac studies
  - Long-term production
  - Demonstrated in coal

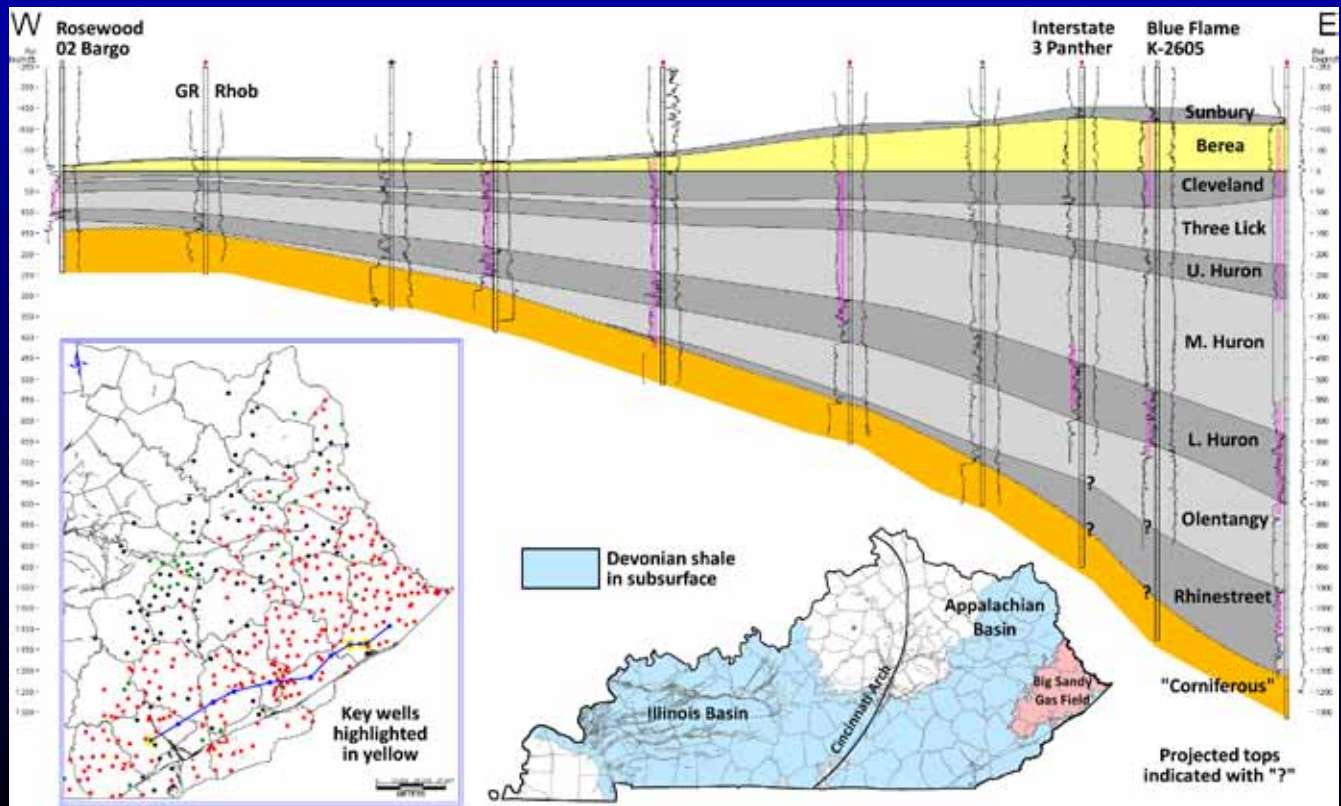


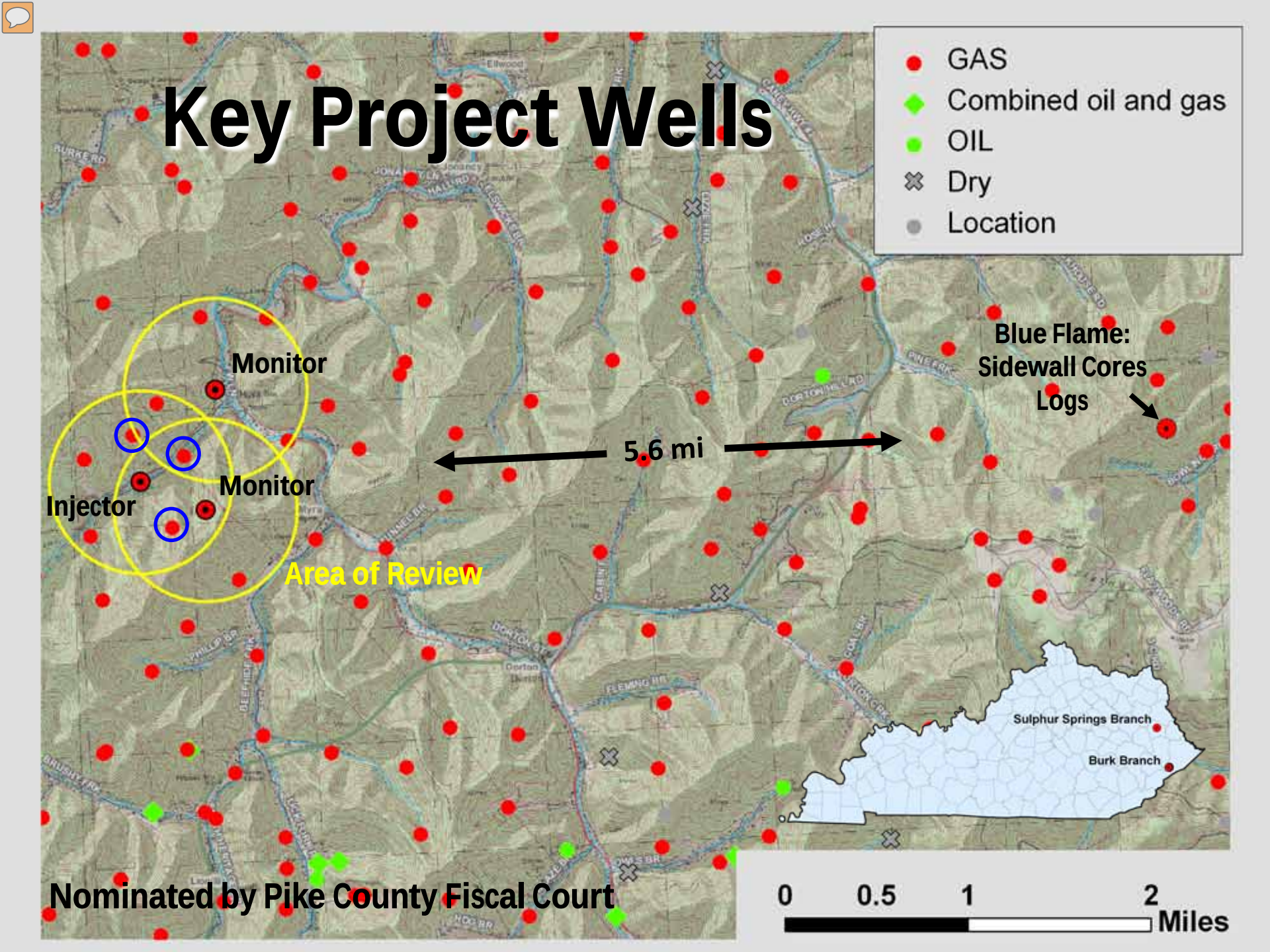
Deep (>=1,000') and thick (>=100') shale.


GR
RhoB
Weaver #1 Bentley
Letcher County, 5-I-82
API: 1613300144
KGS Recno: 31683
Sunbury Shale
Berea
"sand"
Mississippian
Cleveland
Shale
Three Lick Bed
Upper Huron
Shale
Middle
Ohio" as used in this report
Ohio Shale
Olentangy
Shale
Rhinestreet Shale
"Corniferous"
(Onondaga, Oriskany,
Helderberg)

Study Area


KGS 1 Blan
Burk Branch
Rosewood
02 Bargo

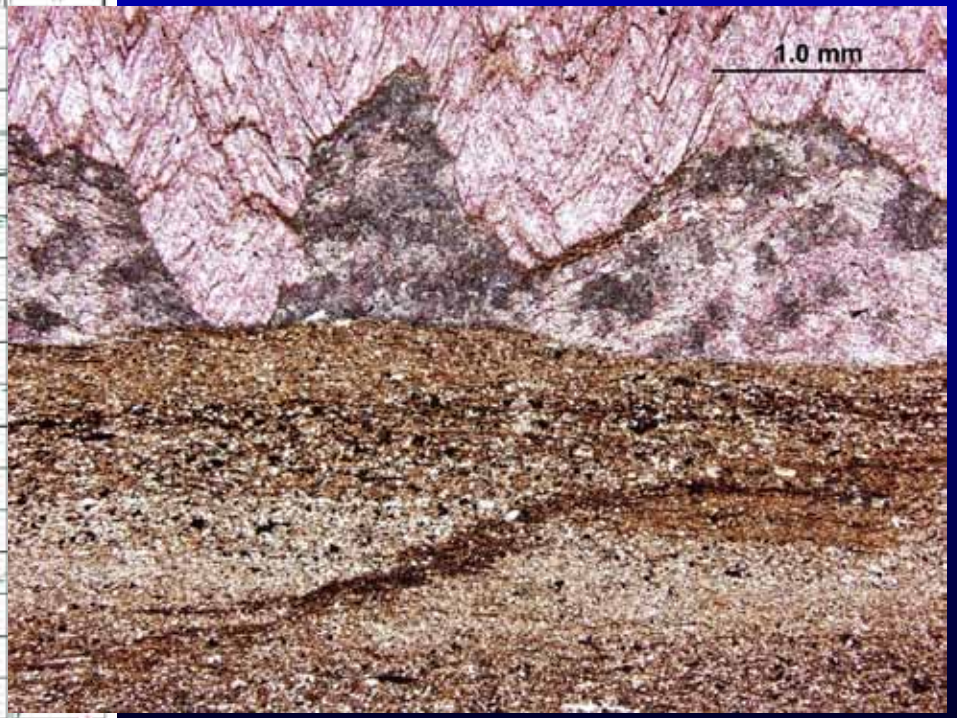

W
Rosewood
02 Bargo
GR Rhob
Interstate
3 Panther
Blue Flame
K-2605
E
Sunbury
Berea
Cleveland
Three Lick
U. Huron
M. Huron
L. Huron
Olentangy
Rhinestreet
"Corniferous"
Key wells
highlighted
in yellow
Devonian shale
in subsurface
Appalachian
Basin
Illinois Basin
Cincinnati Arch
Big Sandy
Gas Field
Projected tops
indicated with "?"


Key Project Wells
GAS
Combined oil and gas
OIL
Dry
Location
Monitor
Monitor
Injector
Area of Review
5.6 mi
Blue Flame:
Sidewall Cores
Logs
Sulphur Springs Branch
Burk Branch
Nominated by Pike County Fiscal Court
0
0.5
1
2
Miles

Rosewood 02 Bargo, Knox County

Available Data

- FMI, ECS
- Φ, k, XRD, TOC
- Thin sections



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Feasibility: Data Acquisition and Modeling

Logging and Coring:

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

DEDI
KENTUCKY DEPARTMENT for ENERGY DEVELOPMENT & INDEPENDENCE

KENTUCKY CONSORTIUM FOR CARBON STORAGE
KGS

Schlumberger

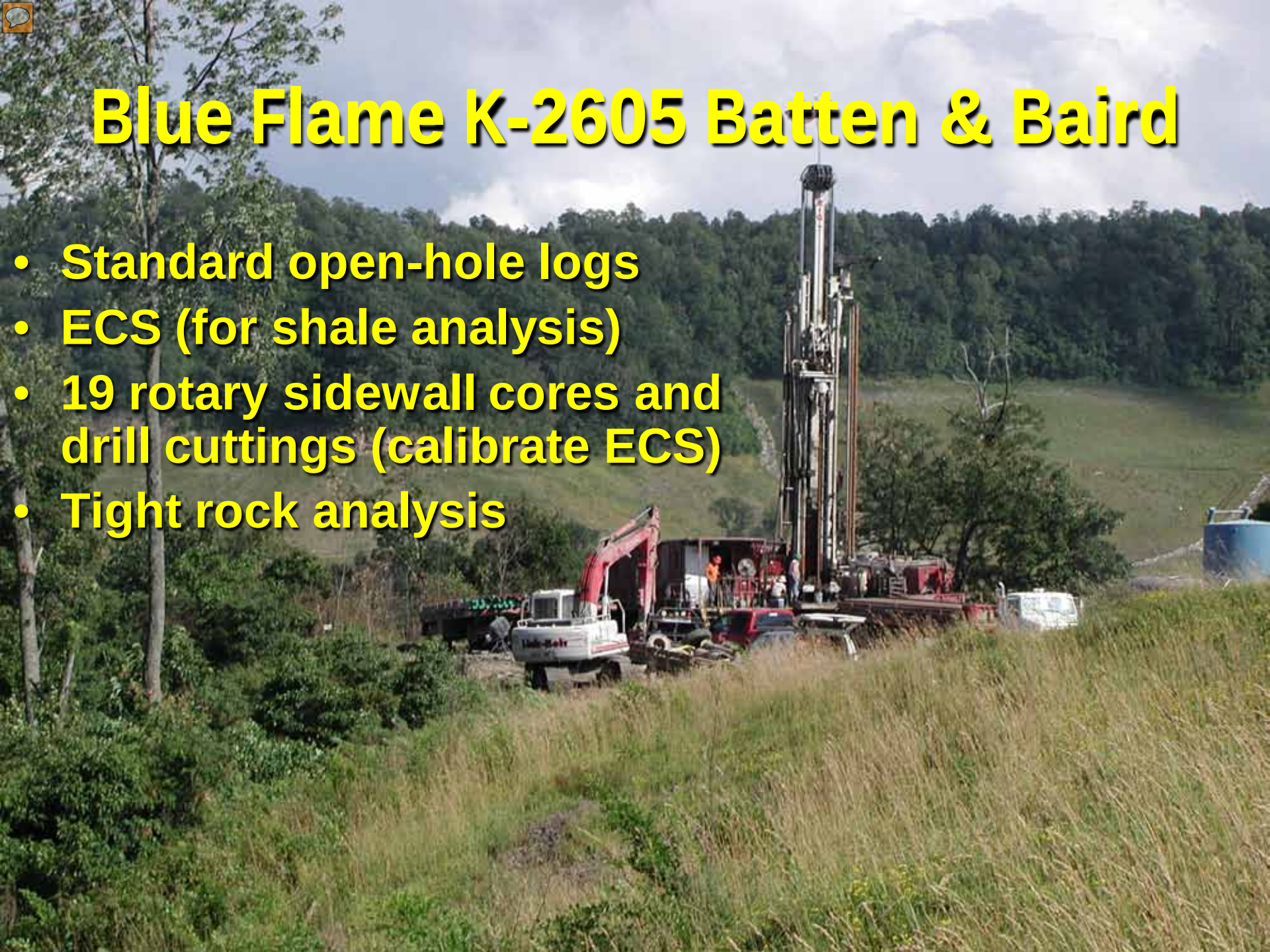
Shale analysis lab work:

Chesapeake ENERGY

Summit Engineering
Blue Flame
Pike County Fiscal Court
Crossrock Drilling

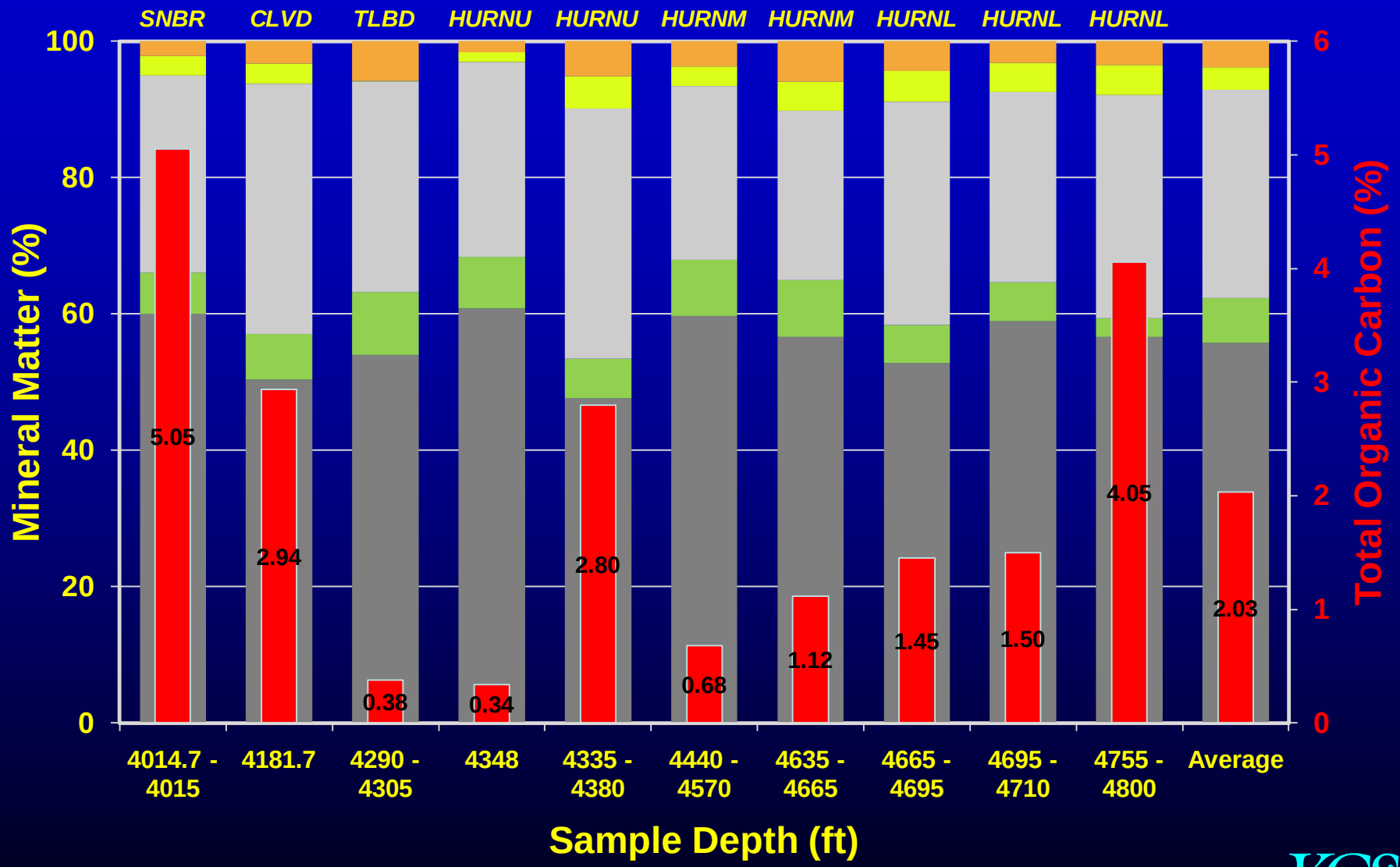
KGS

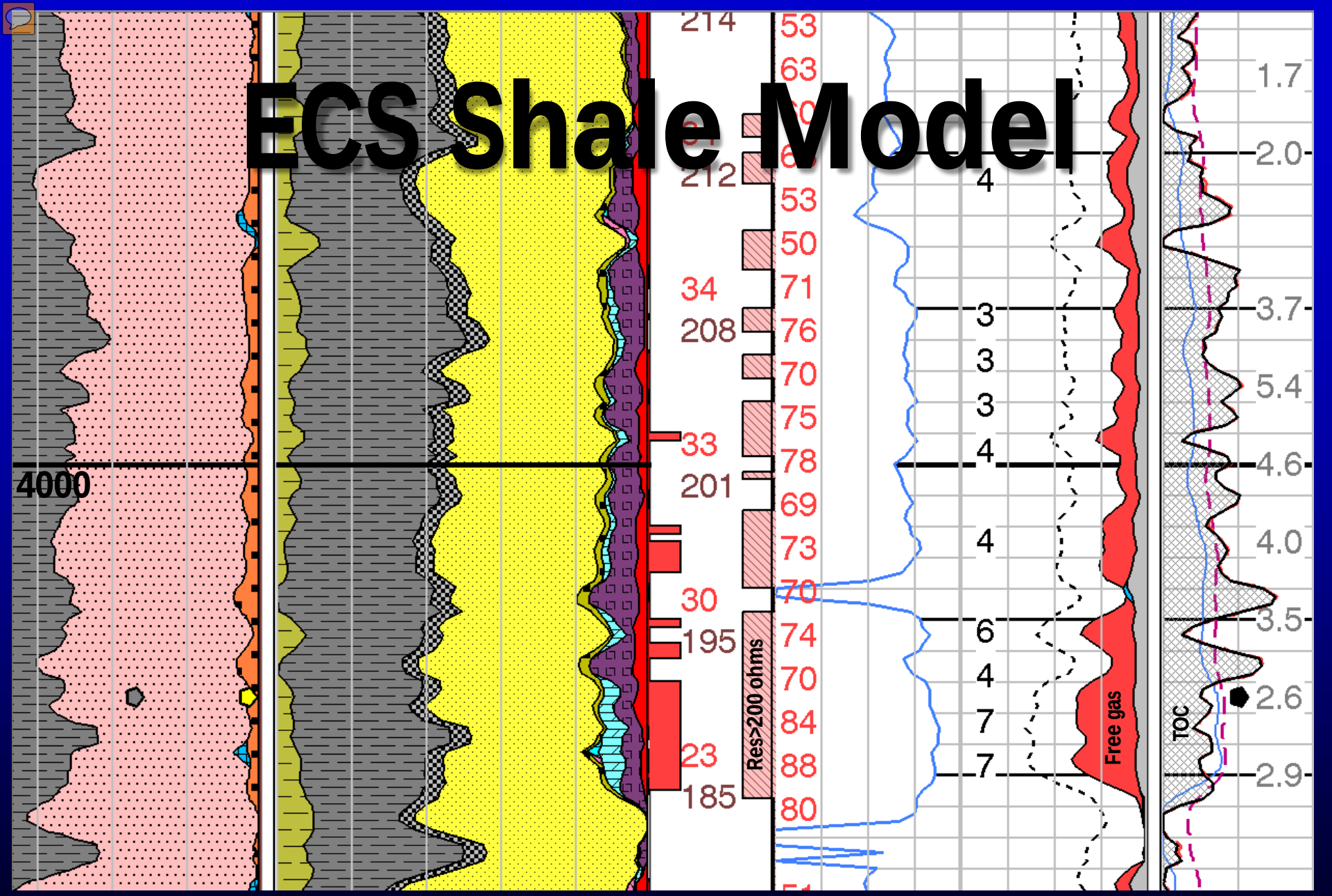
Blue Flame K-2605 Batten & Baird



- Standard open-hole logs
- ECS (for shale analysis)
- 19 rotary sidewall cores and drill cuttings (calibrate ECS)
- Tight rock analysis

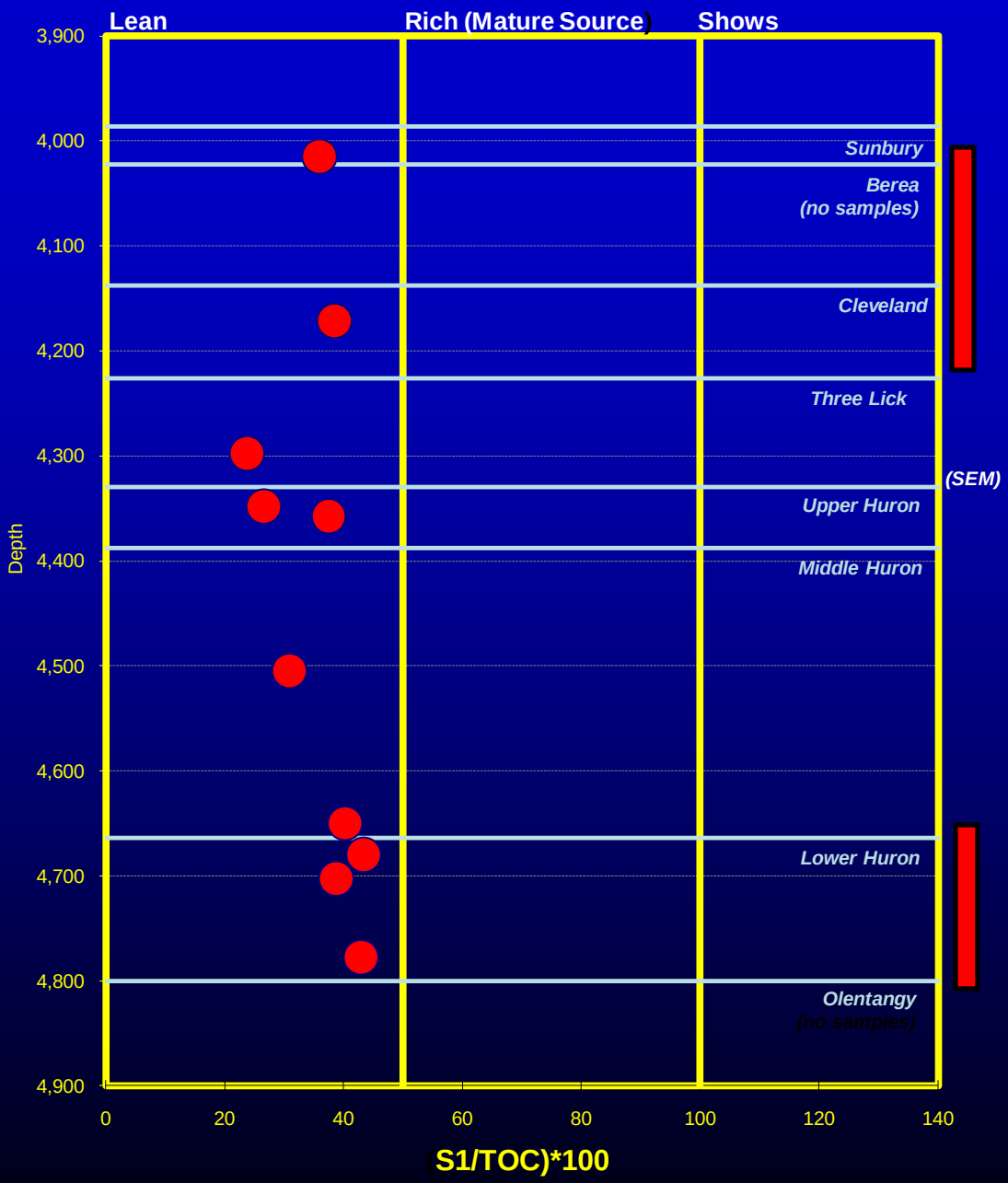
Blue Flame K-2605 Batten & Baird XRD & TOC Summary





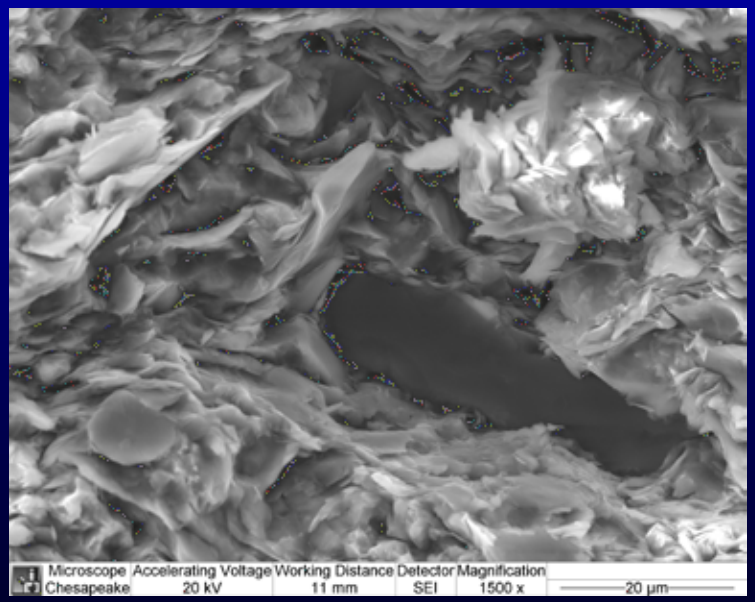
Blue Flame K-2605 Batten & Baird, Sunbury Shale

Blue Flame K-2605 Batten & Baird, Pike Co., Kentucky



Total clay: 53-68%
TOC: 0.68-5.06%
Φ: 3.7-5.6%
k: 0.056-0.106 µd

After frac: 643 Mcf
48-hour SIP: 570 lbs

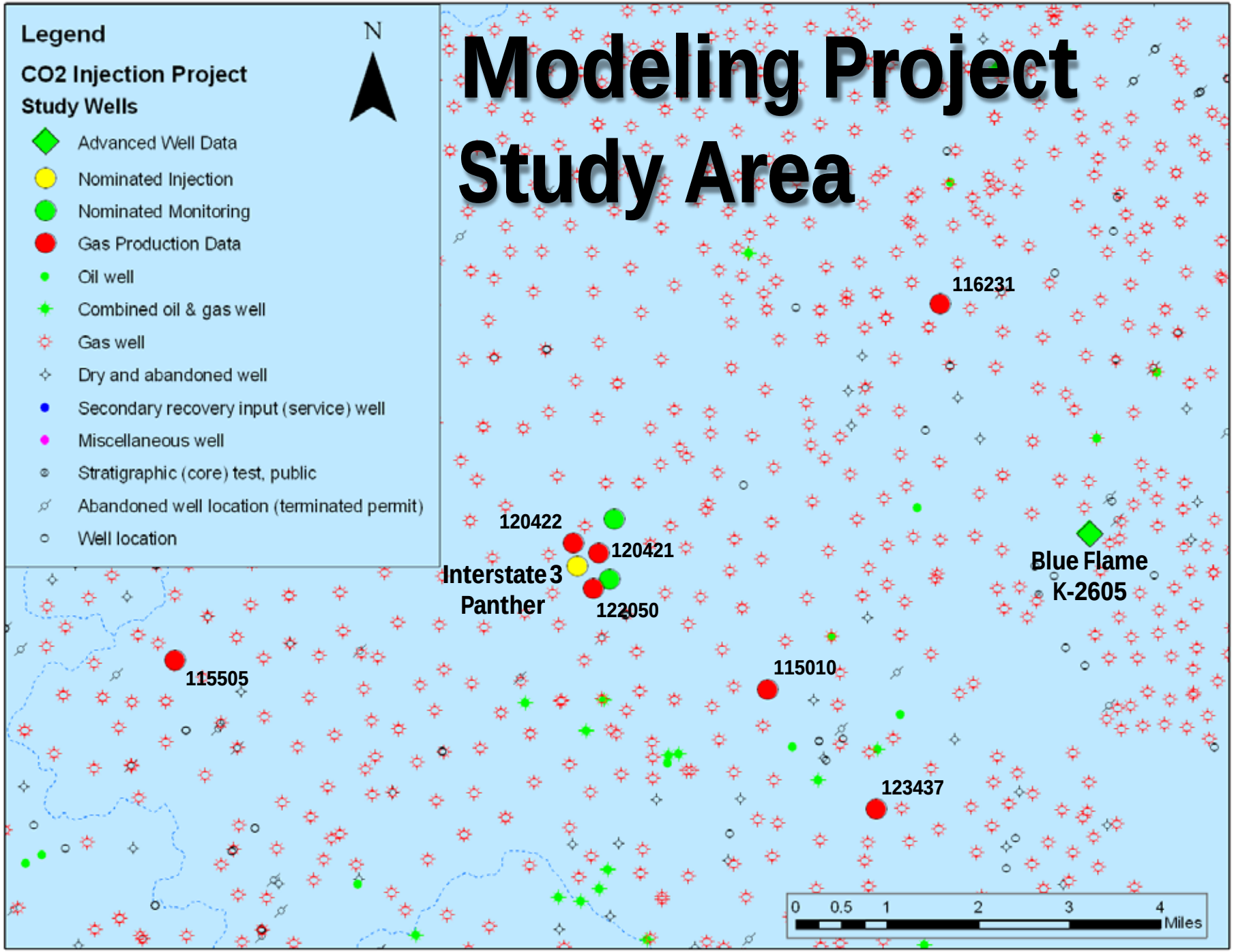


COMET3

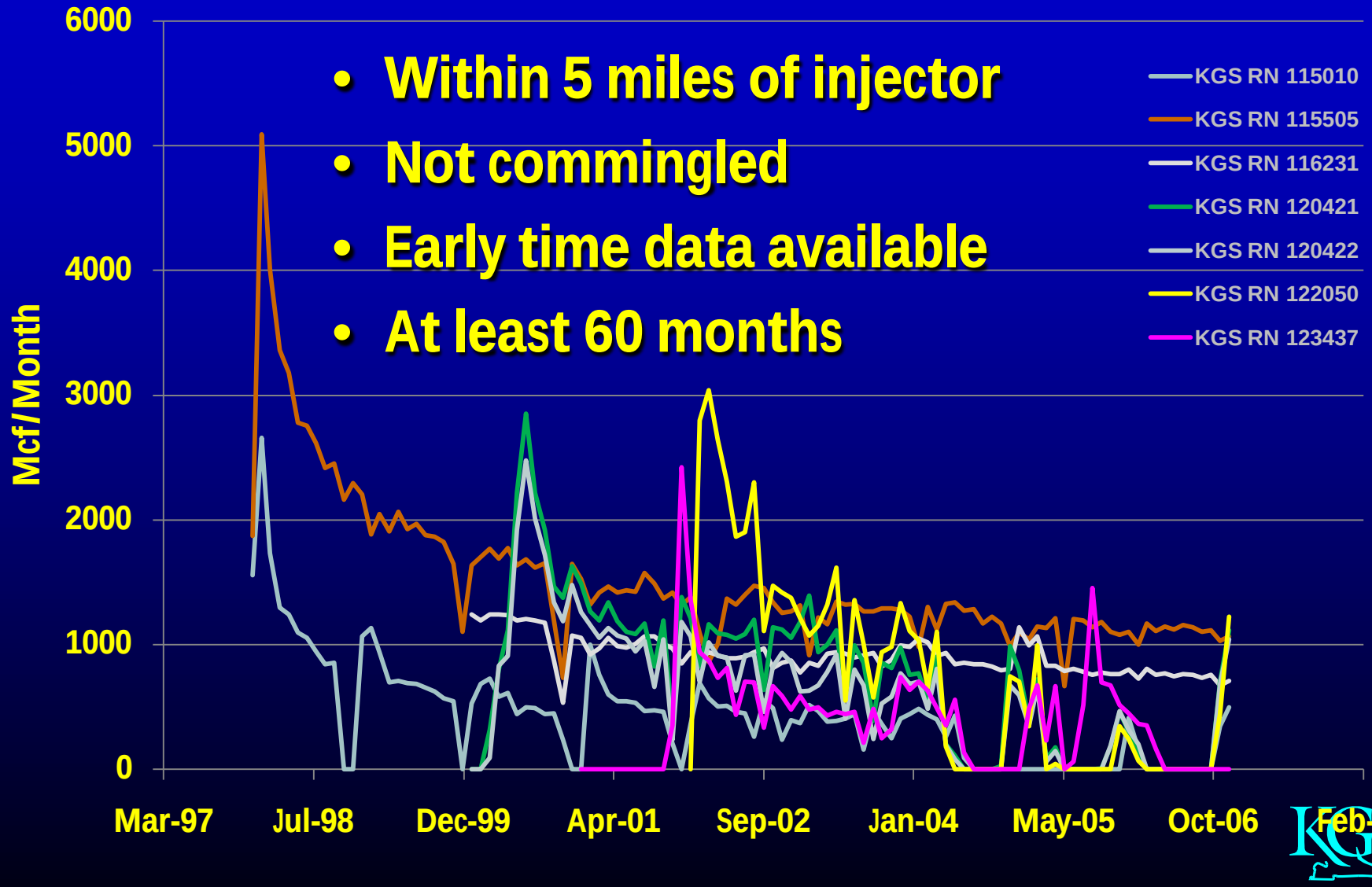
- Advanced Resources International
- Multi-phase
- Dual porosity
- Dual permeability
- Fractured reservoirs
- Used extensively for CBM

Reservoir Model

- 5,384 acres (8.6 mi^2) sector model
  - 3 offset producers, 1 injector
  - 7 area producers
- Grid refined around the injector to estimate CO_2 plume extension
- Two layer (based on Interstate 3 Panther Land):
  - Cleveland, Three Lick Bed, Lower and Middle Huron
  - Lower Huron
- Dual porosity single permeability
  - Average of modeled matrix and fracture permeability

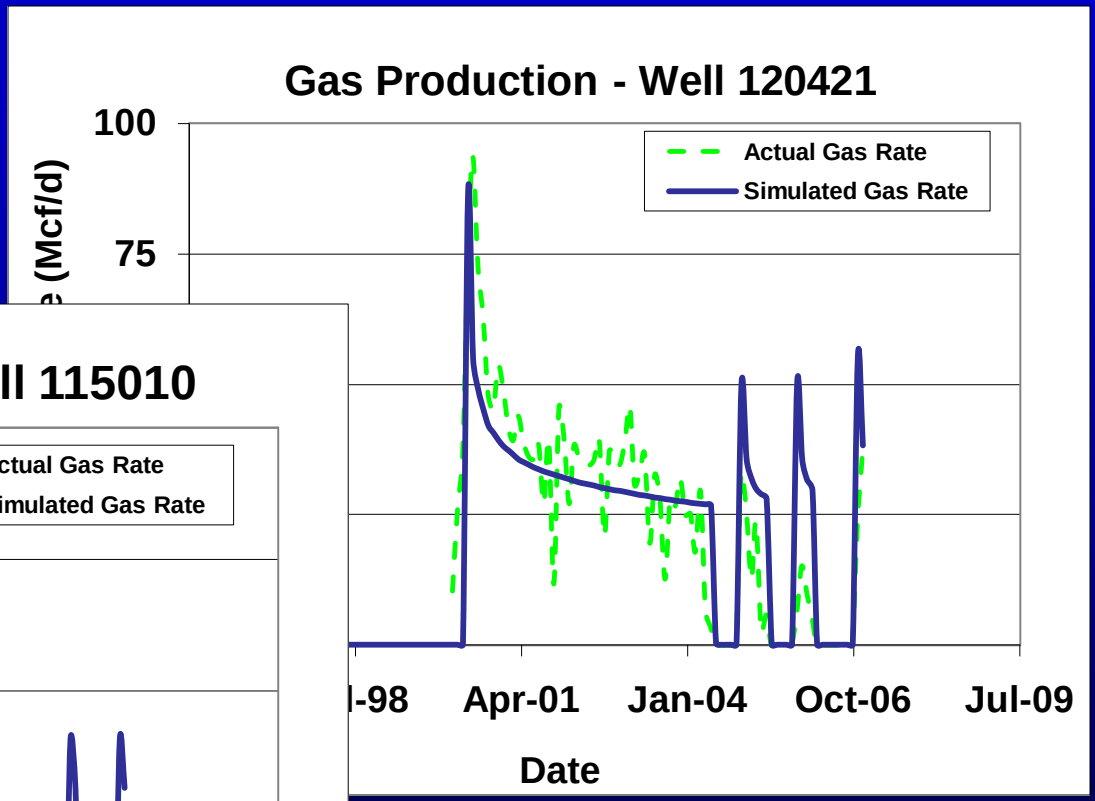

Legend
CO2 Injection Project
Study Wells
Advanced Well Data
Nominated Injection
Nominated Monitoring
Gas Production Data
Oil well
Combined oil & gas well
Gas well
Dry and abandoned well
Secondary recovery input (service) well
Miscellaneous well
Stratigraphic (core) test, public
Abandoned well location (terminated permit)
Well location
N
Modeling Project
Study Area
116231
120422
120421
Interstate 3
Panther
122050
Blue Flame
K-2605
115505
115010
123437
0
0.5
1
2
3
4
Miles

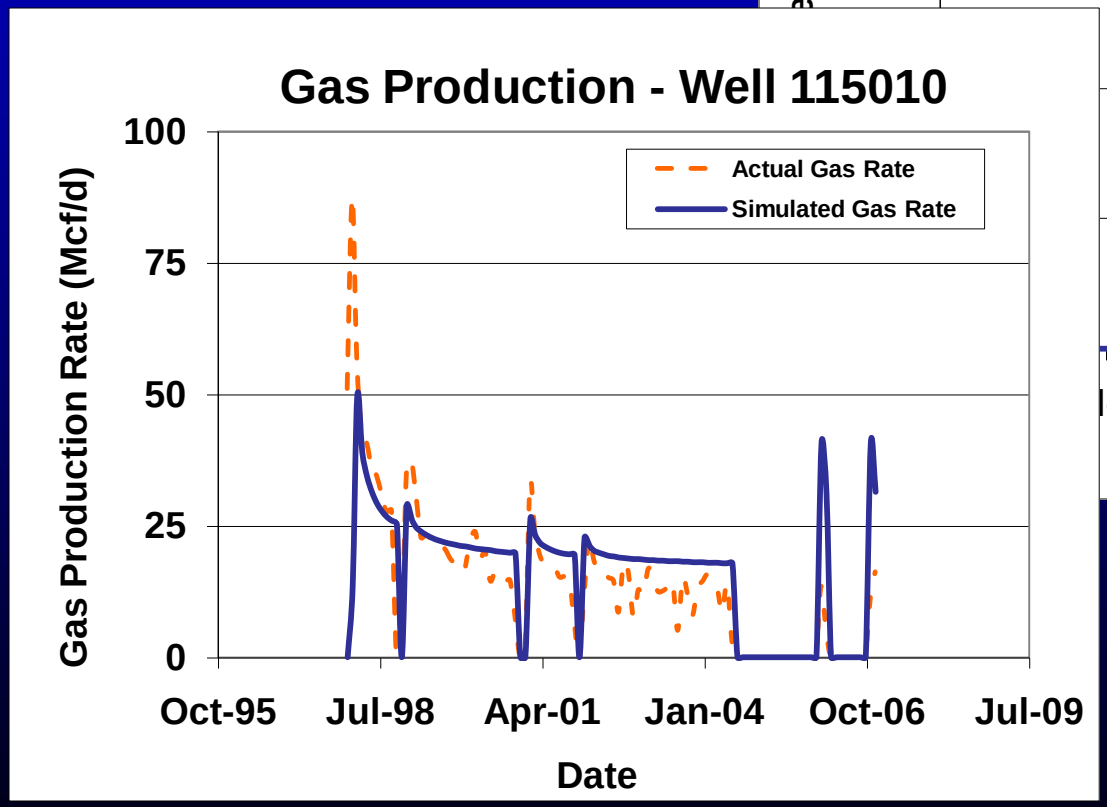
Shale Gas Production



History Matching

Analysis provides statistical analog to average permeability



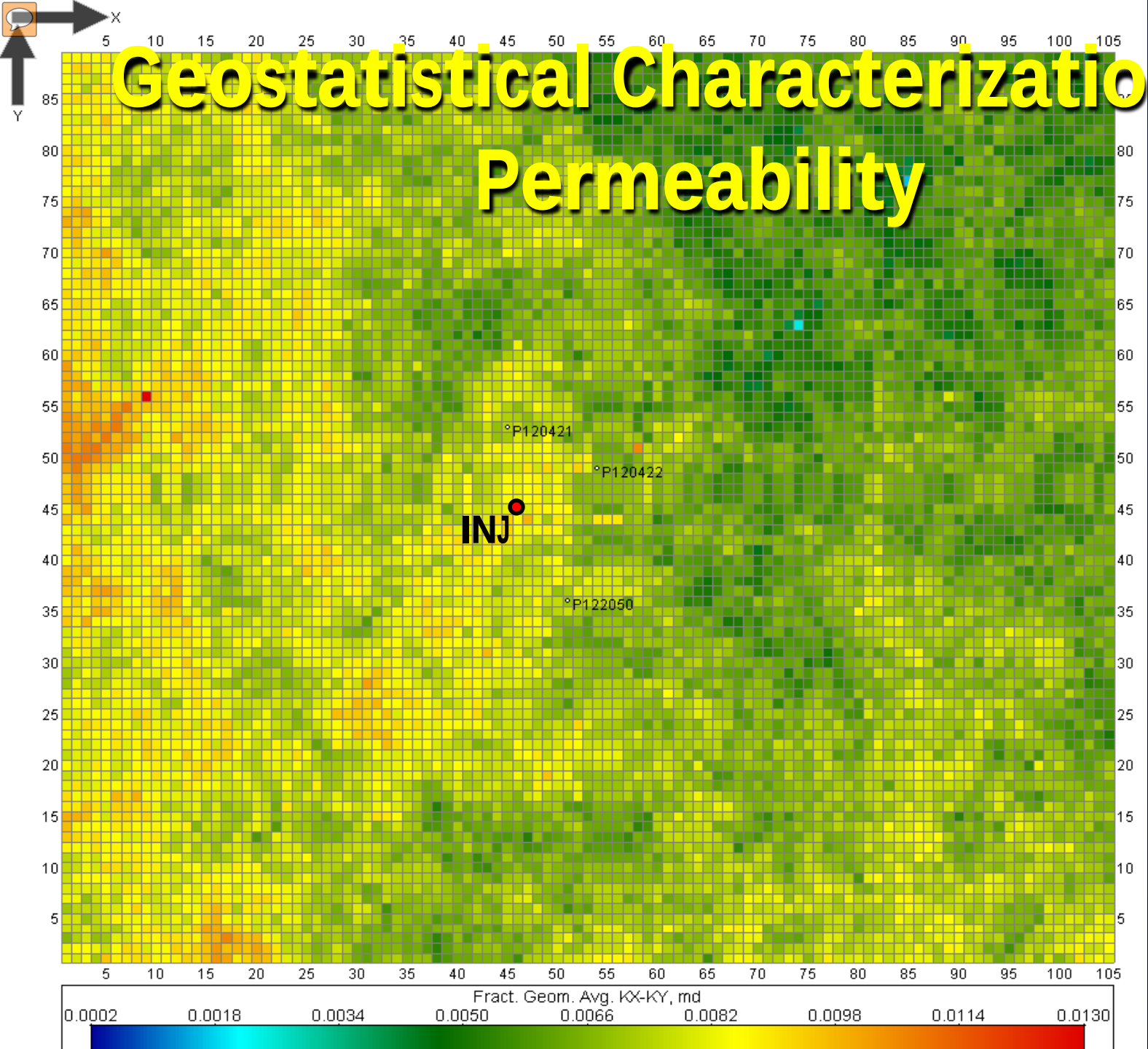


Porosity model:

$\Phi = ak^{0.33}$

Parameter "a" varied

Geostatistical Characterization of Permeability



***NB*: Modeled *k* is average of matrix and fracture**

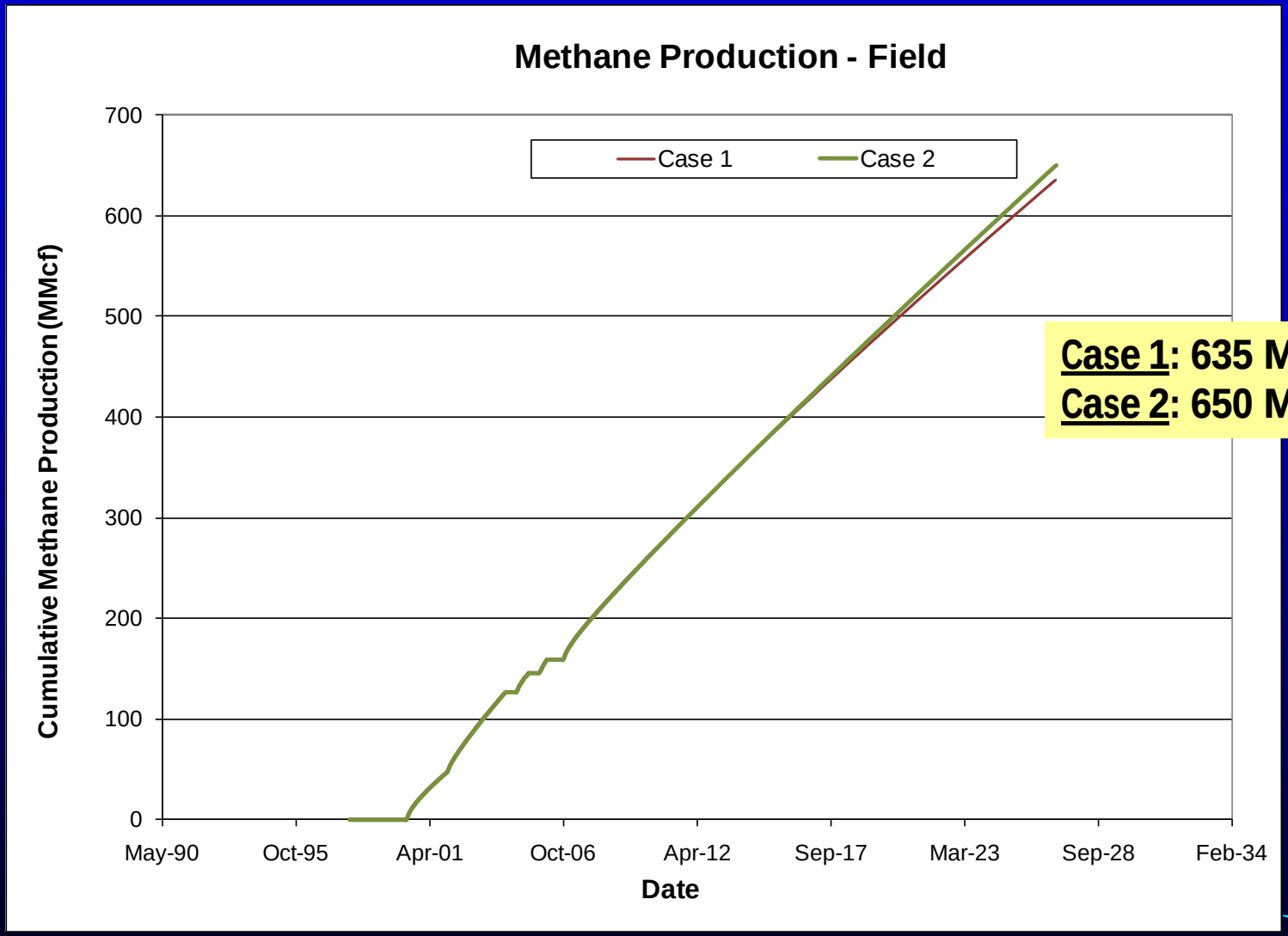
Full-field Injection Scenarios

- Production forecast 20 years from end of history match period
- Case 1: Base case, no CO_2 injection
- Case 2: CO_2 injection in Lower Huron starting at the end of the history match
  - 300 tons (minimum test volume)
    - 200 ft. thickness
    - 1/2 thickness
    - 1/10th thickness
  - 1,000 tons (maximum test volume) in 1/10th thickness

Production and Injection Design

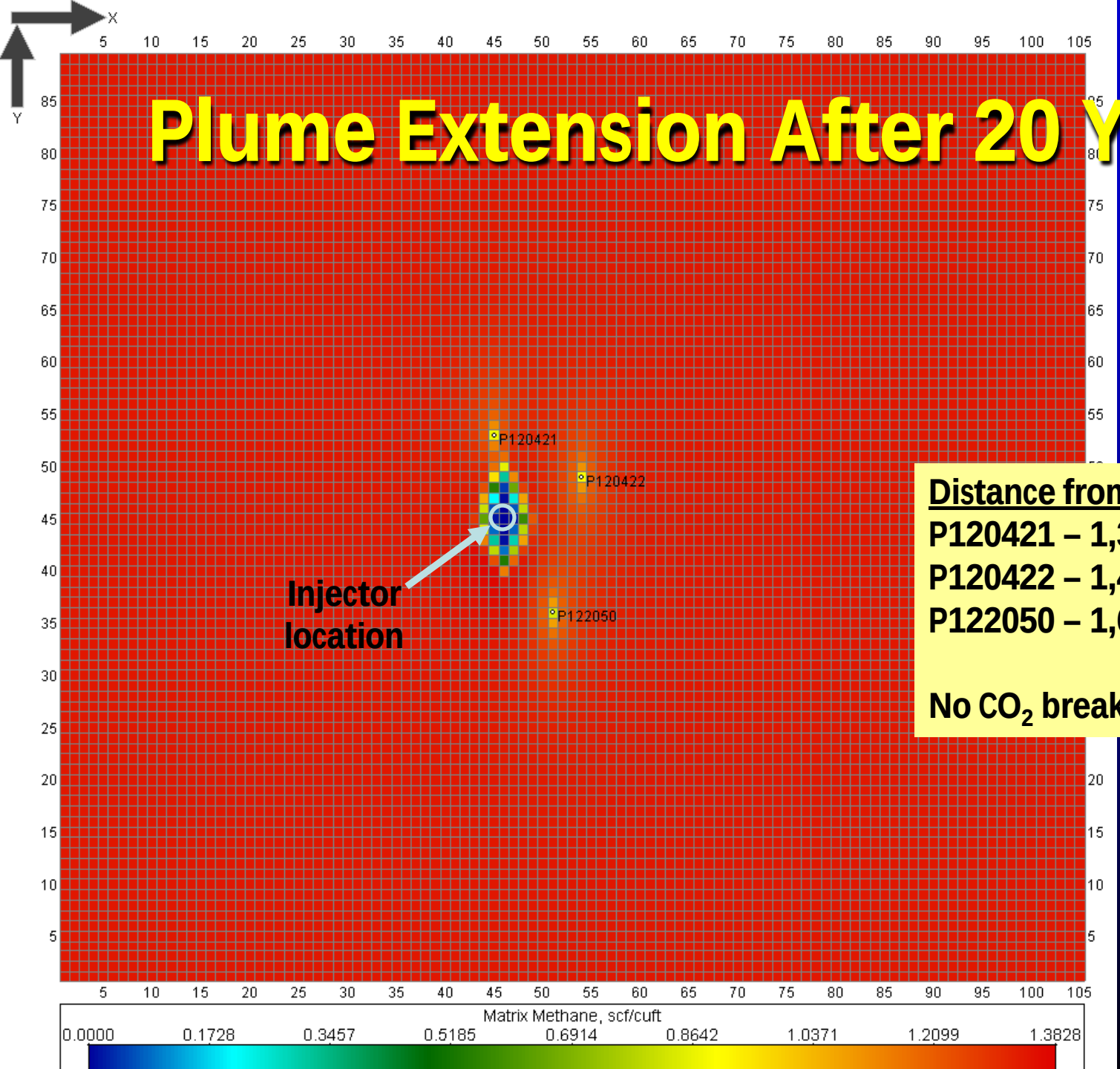
- Wells producing at 30 psia
- Injection at pressure gradient of 0.6 psi/ft
- CO_2 injected only in Lower Huron

20-year Methane Recovery



Case 1: 635 MMcf
Case 2: 650 MMcf

Plume Extension After 20 Years



Distance from injector:

P120421 – 1,300 ft

P120422 – 1,431ft

P122050 – 1,647 ft

No CO_2 breakthrough

Huff-and-Puff Investigation

- Sensitivity analyses to optimize injection, soaking and production periods at varying layer thicknesses
- No incremental recovery over base case was observed
- Flow-back of CO_2
- Increasing soaking period was not beneficial
- Small-volume huff-and-puff may not be applicable

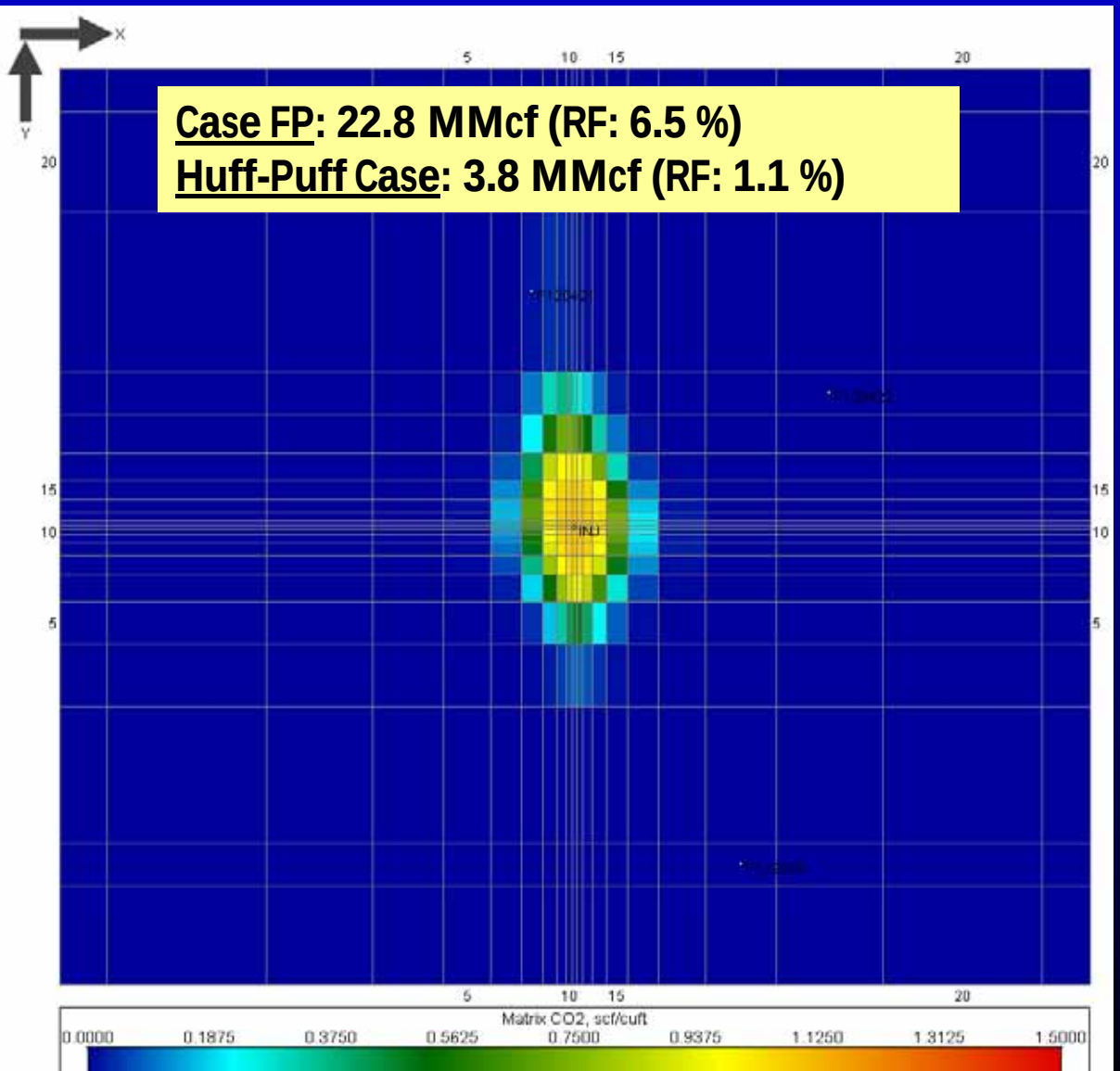
Full-pattern Scenarios for Sensitivity Analysis

- 320 acre area
- Thicknesses
  - Full, half, tenth
- 300 tons CO_2 injected in each
  - Minimum planned volume
- Tenth thickness, 1,000 tons CO_2 case
  - Maximum planned volume

Comparison of Recoveries

320 Acres, 300 tons CO_2		Injection		Base Case (no injection)	
Case		Cum Prod (MMcf)	Recovery (%)	Cum Prod (MMcf)	Recovery (%)
Full thickness (200 ft. L. Huron)	Huff-n-Puff	7.5	0.2	7.9	0.2
	Continuous Injection	43.6	1.4		
Half thickness	Huff-n-Puff	5.8	0.4	6.1	0.4
	Continuous Injection	33.8	2.2		
Tenth thickness	Huff-n-Puff	3.8	1.1	4	1.2
	Continuous Injection	22.8	6.5		

Plume Extension in the Lower Huron



Tenth thickness case with continuous injection

Incremental recovery observed

Modeling & Design Conclusions

- Averages from production history match are in agreement with core-derived values
  - $k \equiv 1.3 \times 10^{-2}$ mD, $\Phi \equiv 1.5\%$
- Huff-n-Puff flows back CO_2 quickly
  - Extended soak times don't help
  - Success not indicated
- Full-field continuous injection potentially successful
  - Simulated injection of 300 tons in 1.5 months
  - Sequestration indicated

500 psi

Entrance to Site

- Flat area outside traffic flow ideal for staging

Interstate #3 Panther Land

- Well pad will require work to access with service rig and logging trucks

Drainage Diversion Around Pad

- Have to maintain
  - Ditch (under construction)
  - Piezometer
  - Road right of way

Well Site Instrumentation

Radio, Sensors, Digital Readout

Communications Center

- Software and internet connectivity
- SCADA
  - Real time
  - Remote access

ARI

- Assessment of Factors Influencing Effective CO_2 Storage Capacity in Eastern Gas Shales
- $200k for logging
- Contract negotiations with DOE

Memoranda of Agreement

- Pike-Letcher Land, access Burk Branch site
  - ESA, staging area, well pad
- Interstate, access injection well
  - #3 Panther Land
- Kinzer, access producers
  - Pike-Letcher Land well #'s 963, 964, 1111
  - Sampling, instrumentation, & monitoring

Near-term Tasks

- Memoranda of Agreement for site access
- UIC Class V injection well permit
  - ESA
  - Initial logging (CB, CCL and pre-injection reservoir info)
  - MIT
- Instrument monitoring wells

Contact Info

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