Enhanced Gas Recovery: Devonian Shale

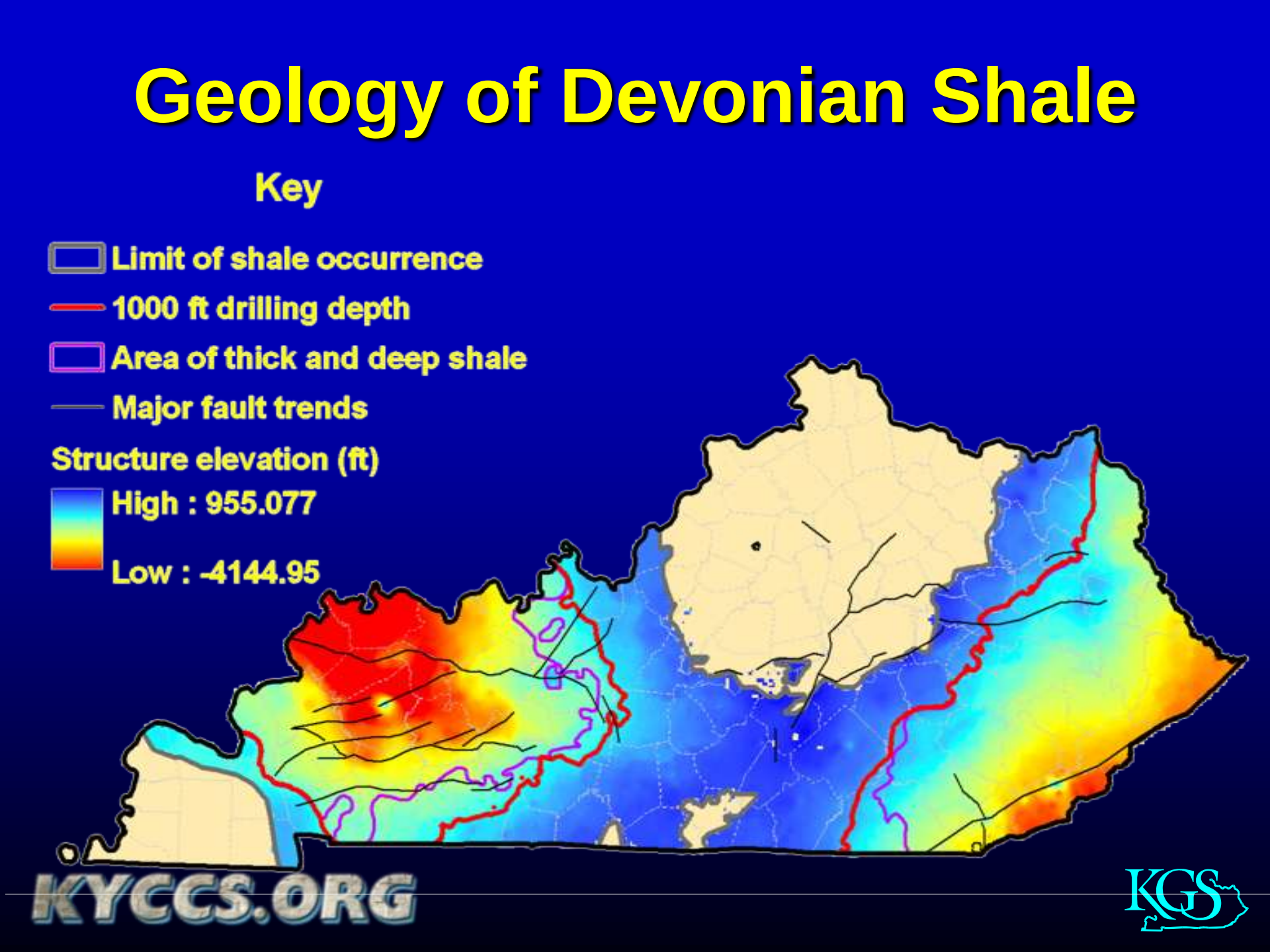
KYCCS Focused Research

11-Jan-2008

HB-1, Section 57

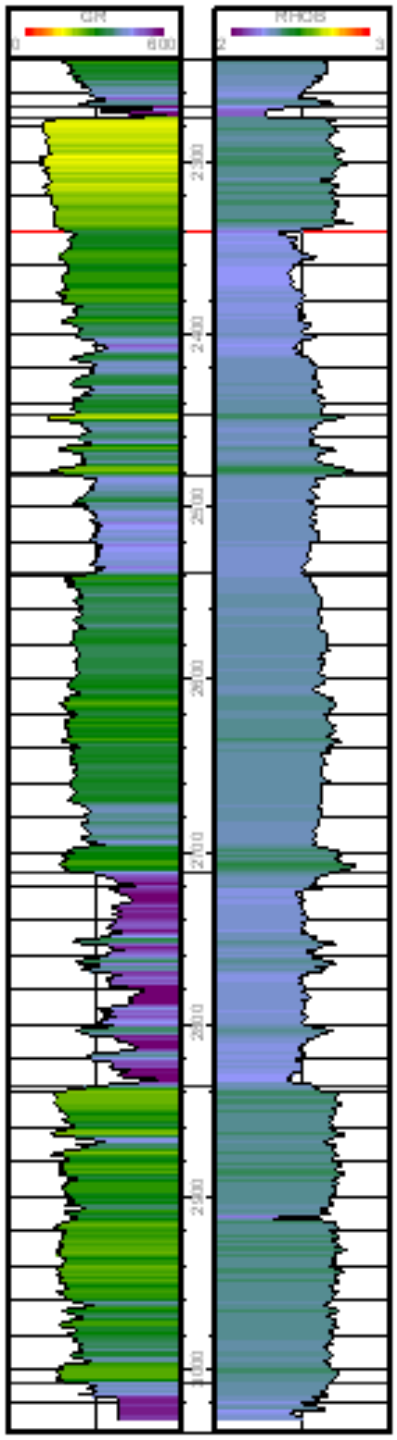
- Specifies: “At least one of the wells will test the Devonian shale for enhanced gas recovery and sequestration potential.”
- Encourages: the Survey to “…use these funds to match available federal and private funds to the extent possible.”

Geology of Devonian Shale



Devonian Shale Reservoir

- Low permeability (microdarcies)
- Micro-porosity
- Organic-rich (up to 25% TOC)
- Thickness
  - > 1,600 feet (eastern Kentucky)
  - > 400 feet (western Kentucky)
- Kentucky's most active and prolific gas producer



Sunbury

Berea

Ohio

Cleveland

Three Lick Bed

Upper Huron

Middle Huron

Lower Huron

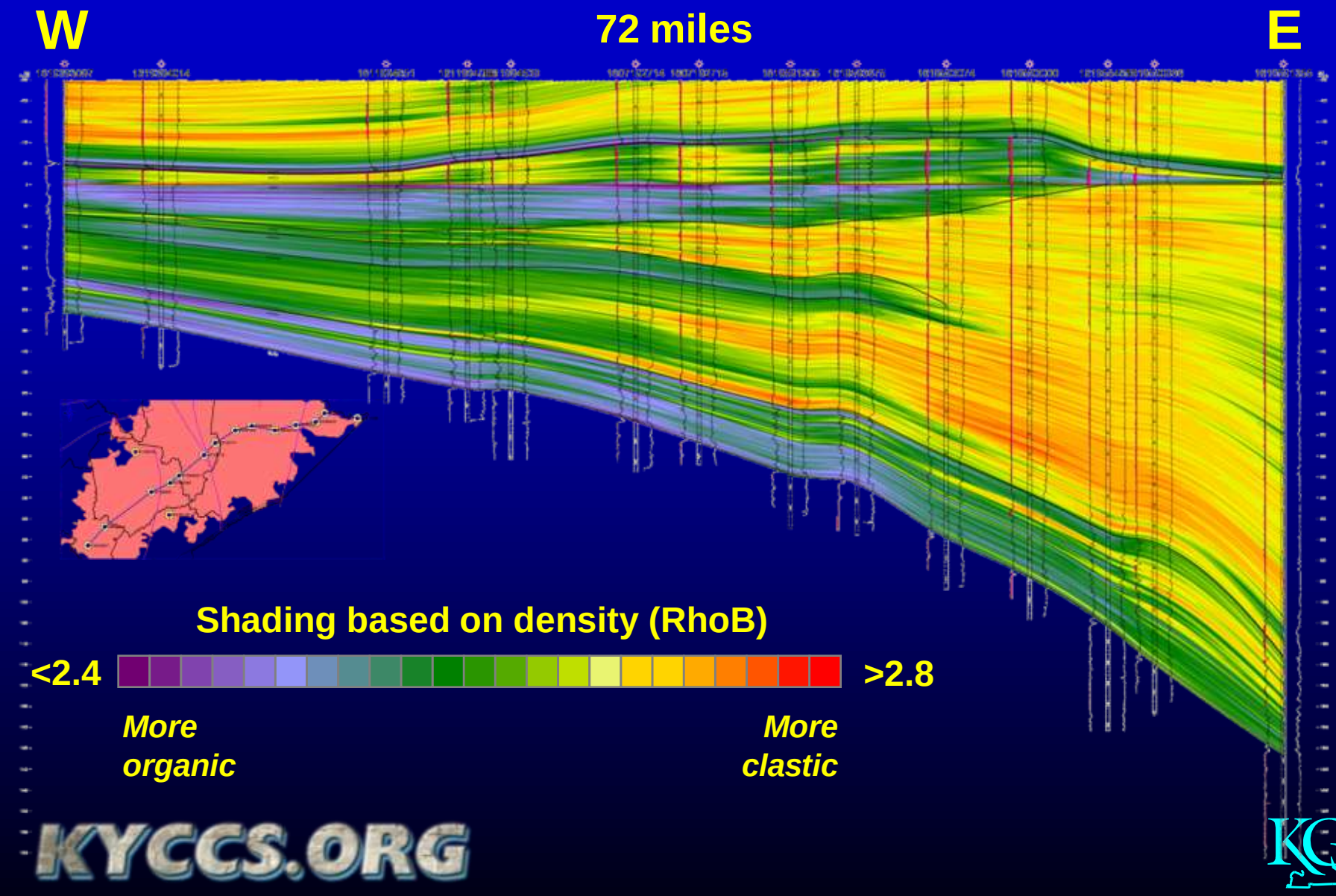
Olentangy

Rhinestreet

A “shale” well is…?

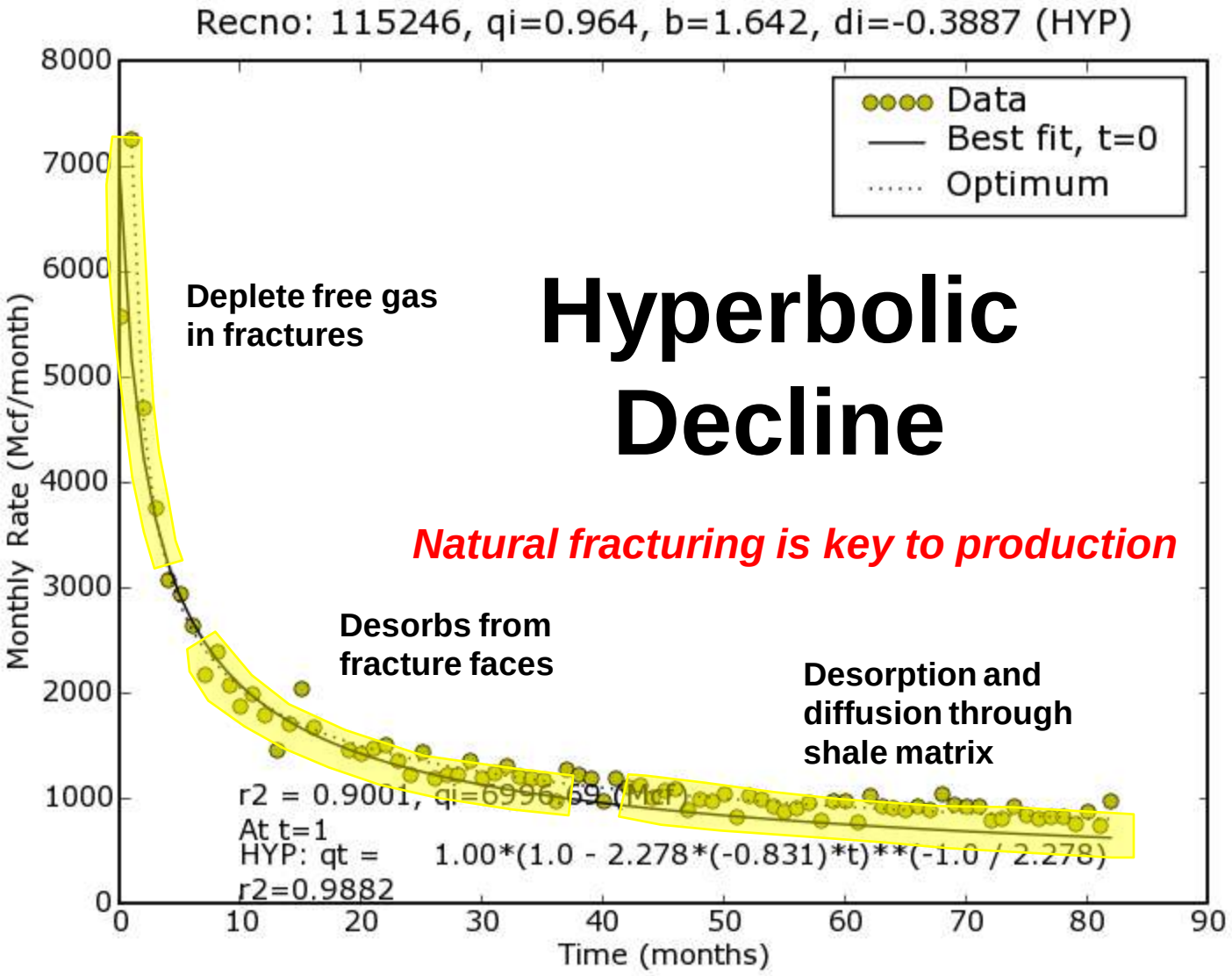
- Top Sunbury to top underlying carbonates

Cross Section



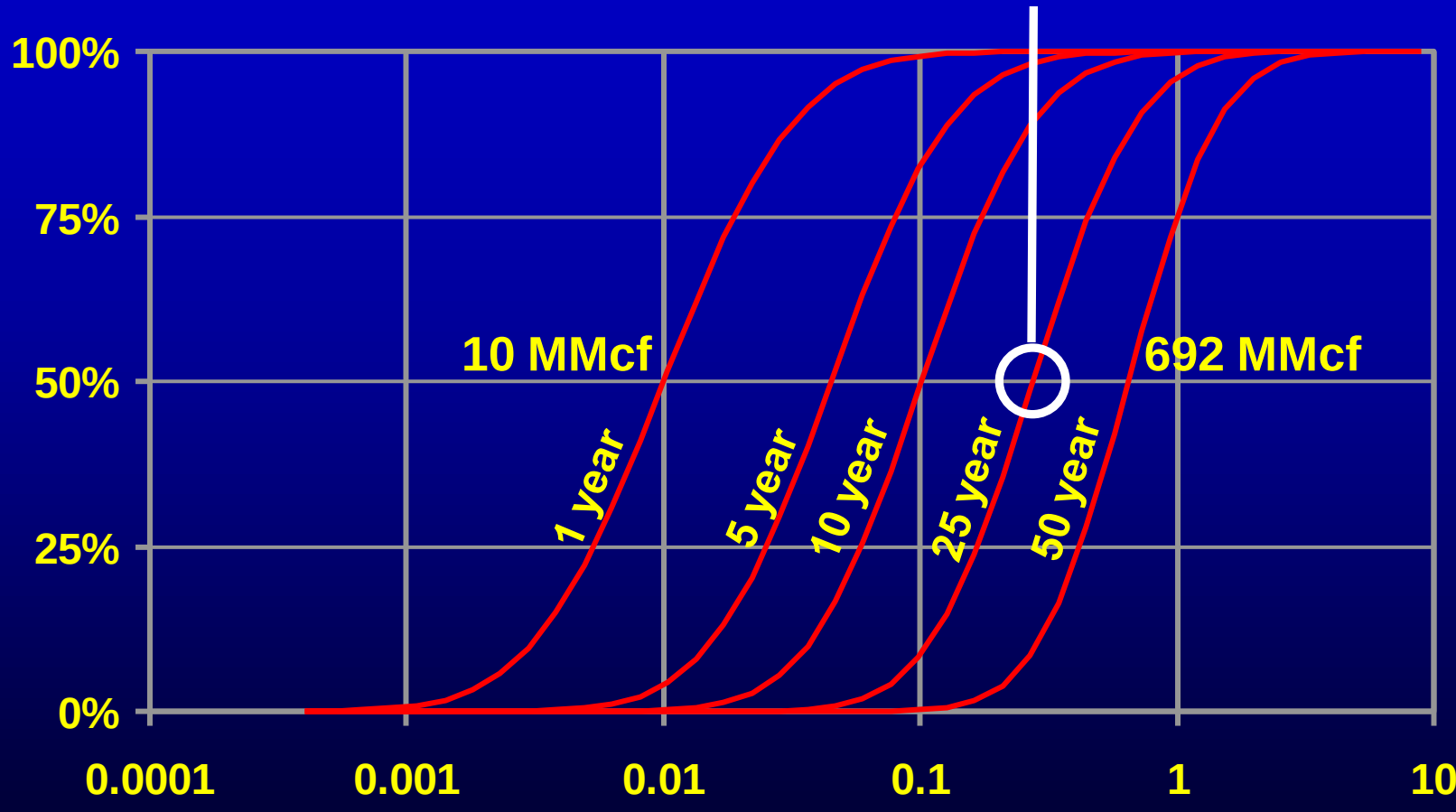
Cross Section Notes

- Perry to Pike Counties, eastern Kentucky
- Thickens across the Big Sandy Gas Field
- More organic-rich zones (blue & green)
- Grayer, less organic shales (yellow & red)
- Some organic-rich zones pinch out


Recno: 115246, qi=0.964, b=1.642, di=-0.3887 (HYP)
Data
Best fit, t=0
Optimum
Monthly Rate (Mcf/month)
Time (months)
Deplete free gas in fractures
Hyperbolic Decline
Natural fracturing is key to production
Desorbs from fracture faces
Desorption and diffusion through shale matrix
r2 = 0.9001, qi=6996.39 (Mcf)
At t=1
HYP: qt = 1.00*(1.0 - 2.278*(-0.831)*t)**(-1.0 / 2.278)
r2=0.9882

GTI Cumulative Production

Industry rule of thumb is 300 MMcf per well



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Cumulative Production Notes

- 50% of shale wells produce at least 692 million cubic feet (MMcf) in 50 years
- Long production history indicates large adsorbed gas content


Why Test the Devonian Shale?
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CO_2 Enhanced Gas Recovery

- Demonstrated in coal
  - Low-permeability
  - Organic-rich
  - Fractured
  - Continuous
- Potentially huge storage volume
  - > 25 billion tonnes

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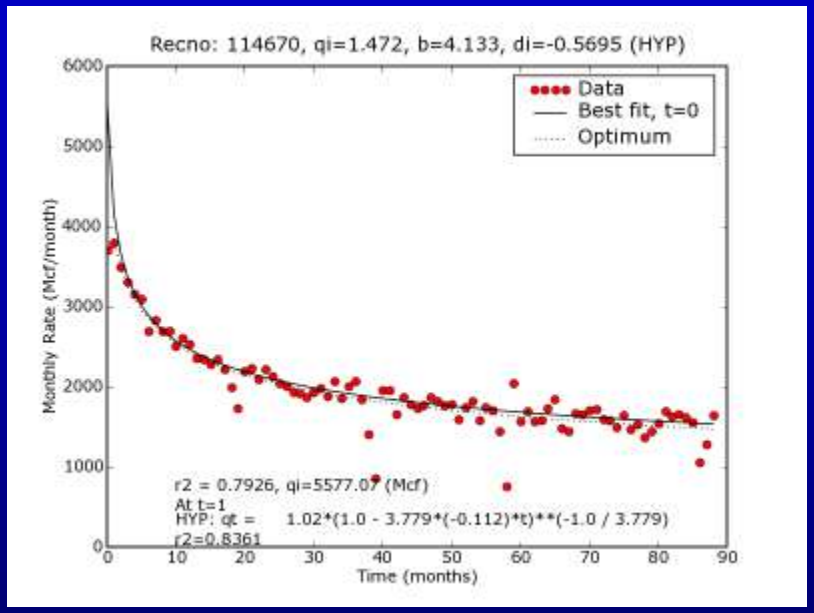
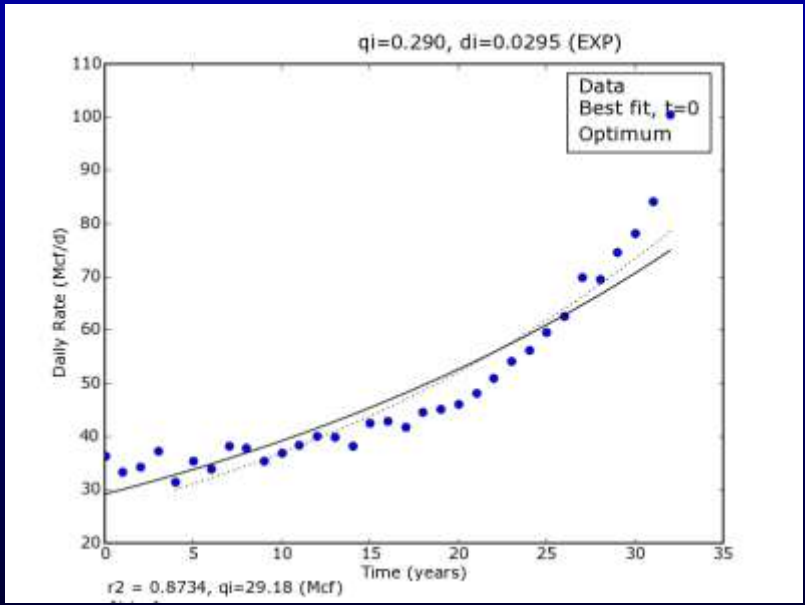
Production Data



Long-term, nearly flat decline

Production for some wells inclines



GTI Proprietary Data

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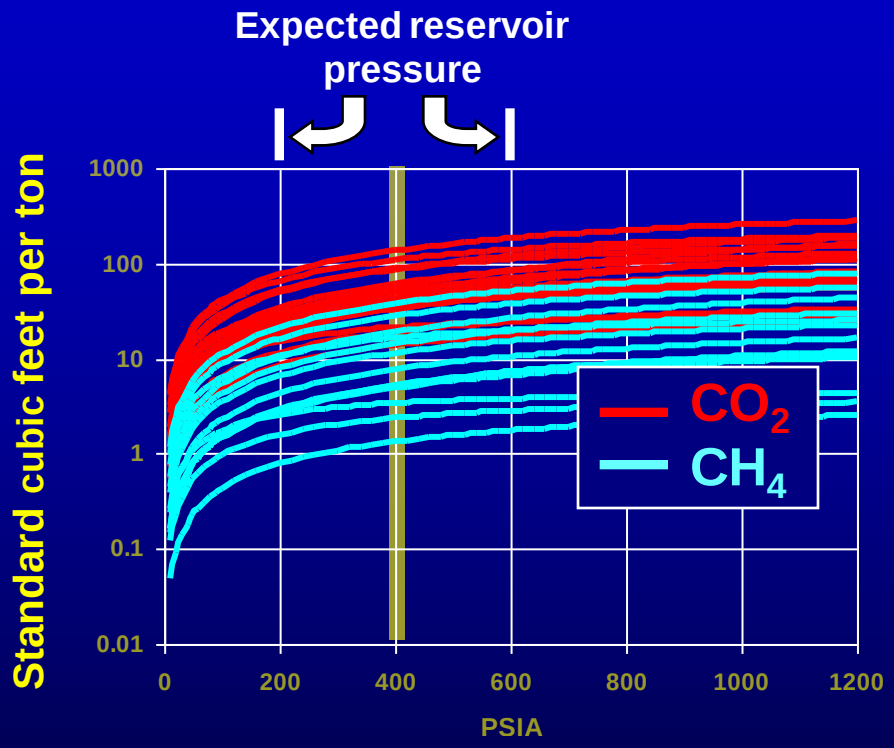
Production Data Notes

- Long-term, nearly flat production suggests diffusion of adsorbed gas over time
- Some wells exhibit production incline, again suggesting adsorbed gas
- Indicates large volume of gas available to trap CO_2 as an adsorbed gas

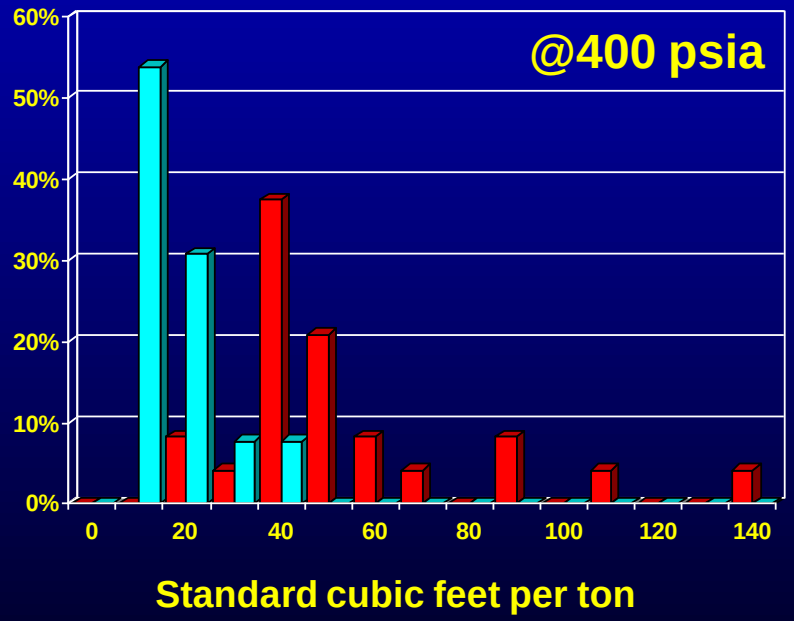
Isotherms Indicate Preferential Adsorption



$CO_2 = 5.3 \times CH_4$

Average CO_2: 42.9 scf/ton

Average CH_4: 8.1 scf/ton



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Isotherm Notes

- At a given temperature, as pressure is increased, the amount of gas adsorbed increases
- 5.3 volumes of CO_2 could displace a single volume of natural gas (CH_4)

CO_2/Sand Frac Study

- Yost, Mazza, & Gehr, 1993, SPE 26925
- Fast flowback (2 to 3 days)
- Preliminary production
  - 56% > N_2 frac wells
  - 4.8 x shot wells
- Consistent with CO_2 adsorption


Testing CO_2 Injection for Enhanced Gas Recovery in the Shale
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Well Selection Criteria

- Standard of open-hole nuclear logs
- Uncased for logging and sampling
  - Rotary sidewall cores, ECS, and others
- Detailed production data (line pressures?)
- Preferred: Nitrogen/foam or slickwater frac, sand propped (or not yet stimulated)

Site Selection Criteria

- Sufficient size pad for equipment
- Access for CO_2 delivery
- Operated by company willing to risk future production (assume liability)
  - Surface, royalty, and working interest owners agree
- Control of all wells within "area of review" for EPA Class V permit

Pre-injection: Data Acquisition

- Well sampling
  - Digital Logs, Φ, k, mineralogy, TOC, cores
  - Gas composition
  - Microseismic (VSP) or logging for fracture identification
- Stimulation
  - Injection rate, volume, pressure, breakdown pressure, flowback period
- Background MMV

Pre-injection: Modeling

- Simulation
  - Multi- Φ, multi-k model
  - Production history match
  - Cyclic Huff-'n'-puff (single well)
  - CO_2 flood (multi-well)
  - Determine optimum shut-in (soak) times and injection rates
- EPA permitting (must submit required data)
- Background MMV

Injection

- Injection volume, rate, pressure, and shut-in times
- Production data
  - Continuous, for injection and monitor wells
  - Rate & composition (variations in CO_2 content)
  - Pressure
  - Mass balance calculations

Post-injection

- History match & model verification
- Assessment & analysis
- MMV continues
- Reporting

Indicators of Success

- Increase in gas production rate
- Mass balance indicates CO_2 adsorption
- After flowback and cleanup, pipeline quality gas

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