Pore Structure and Gas Recovery in Barnett Shale

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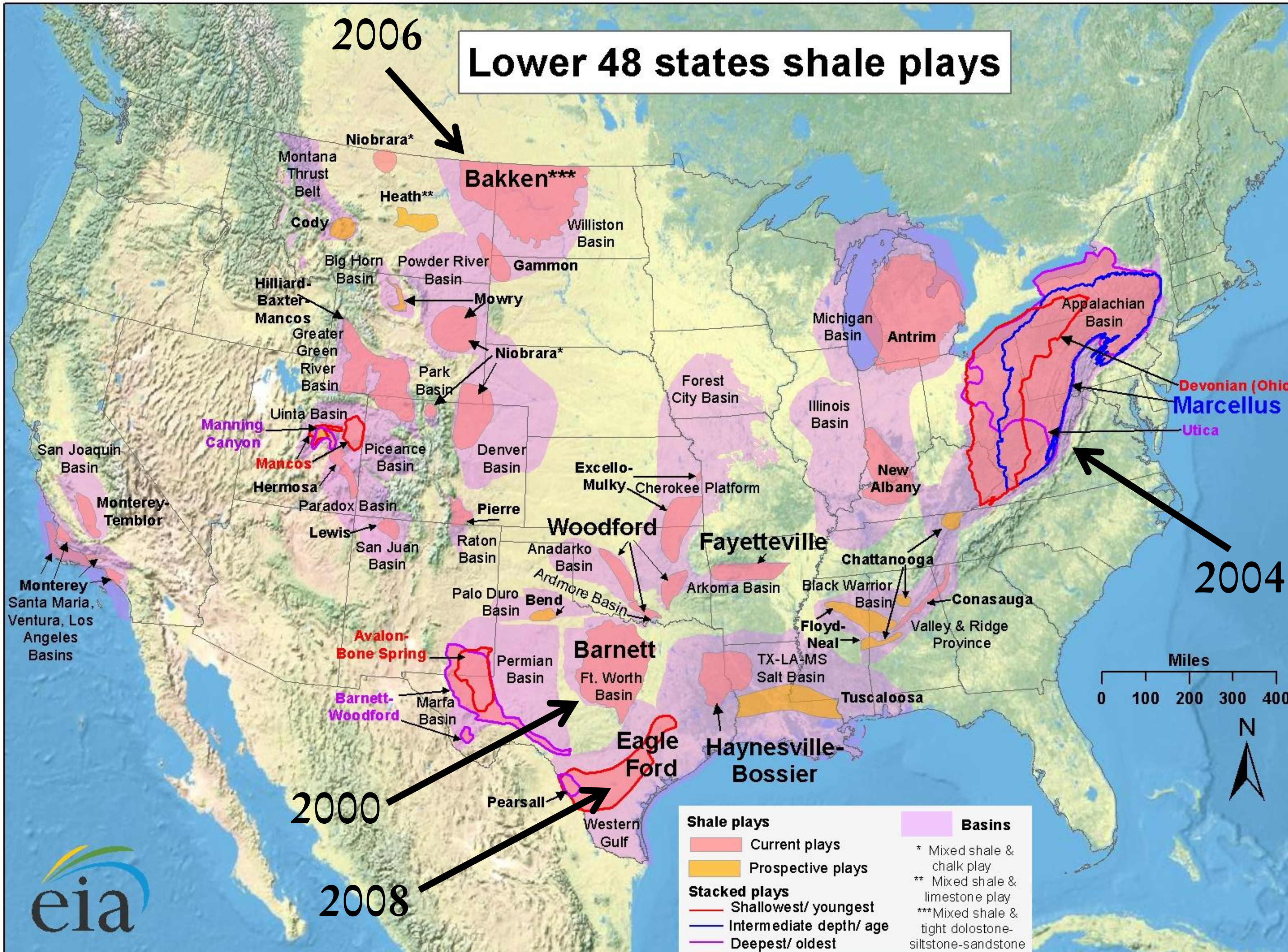
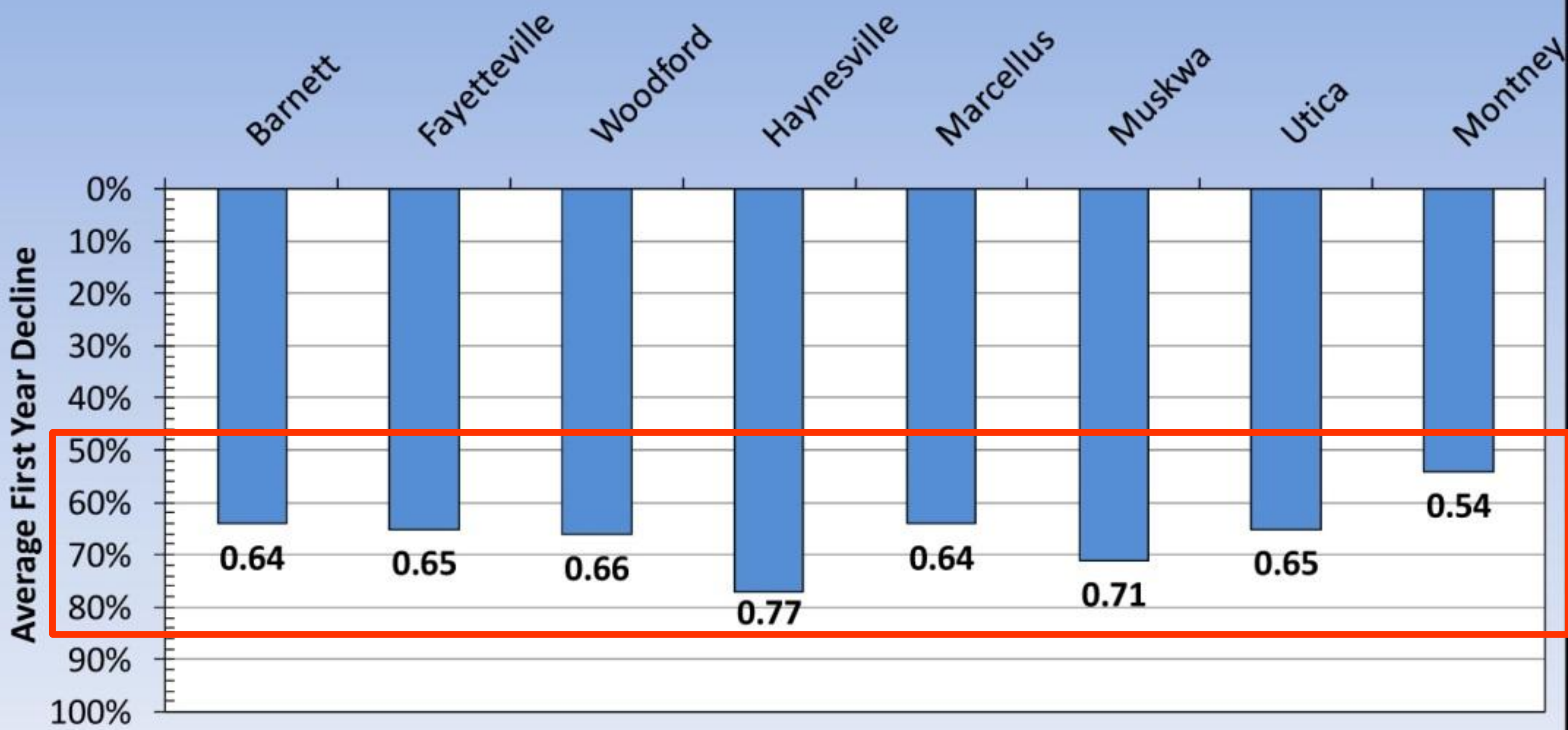


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

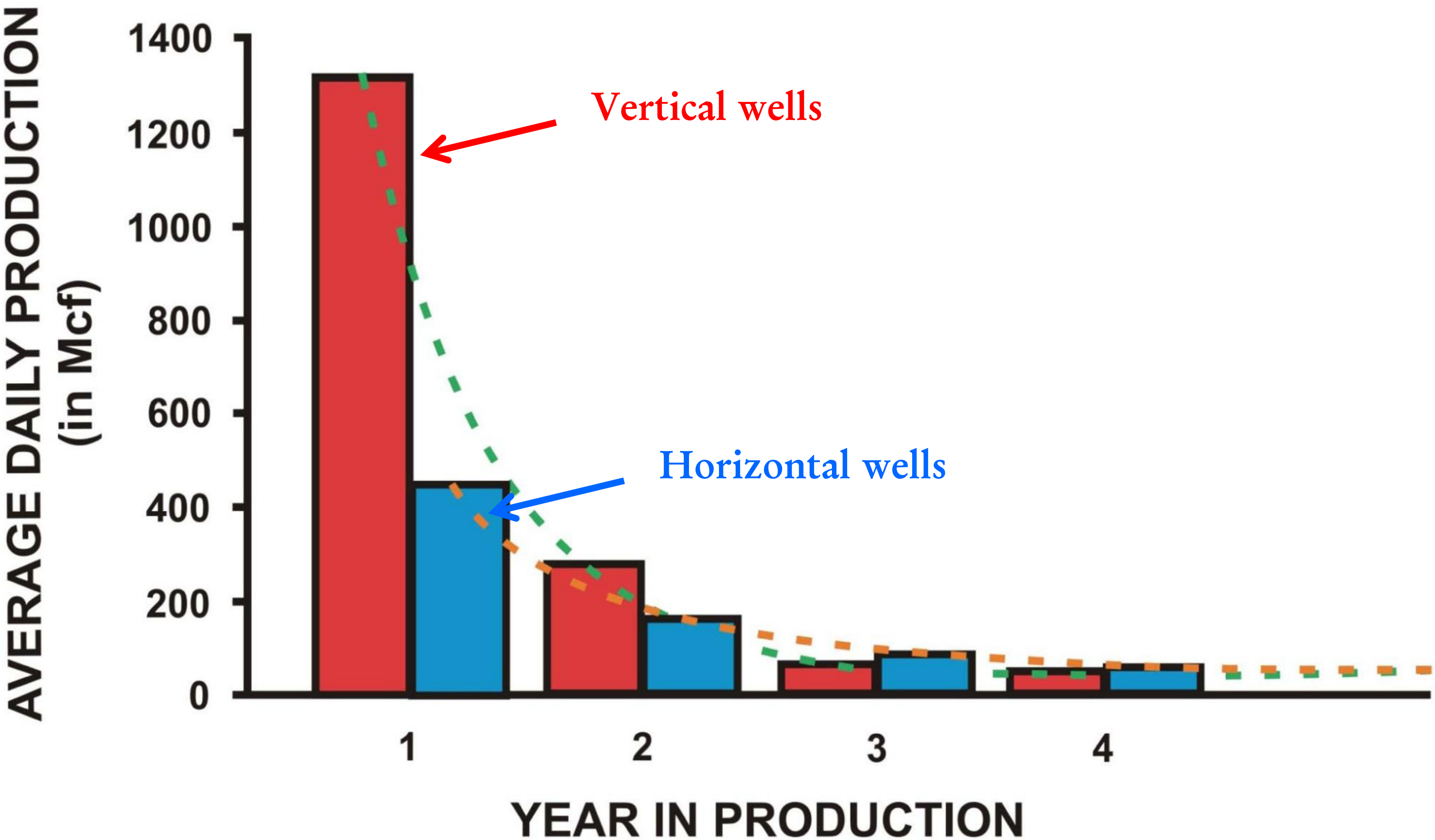
http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm

Average First Year Decline



Low gas recovery factor 15-30% for Barnett Shale (King, 2012)

MARCELLUS PRODUCTION COMPARISON OF VERTICAL AND HORIZONTAL WELLS

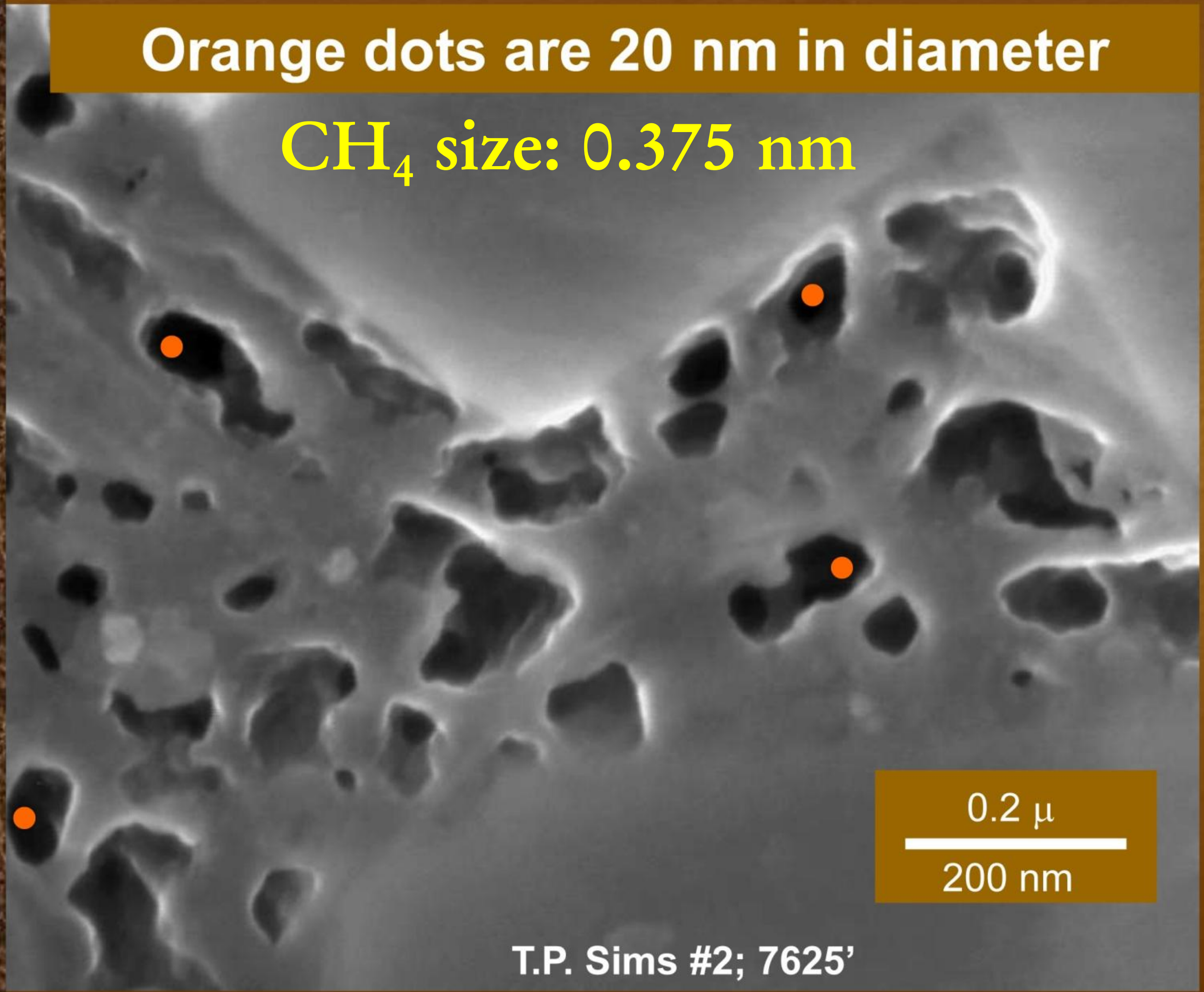


Harper and Kostelnik (2010)

Barnett Shale

Nanopores in Organics

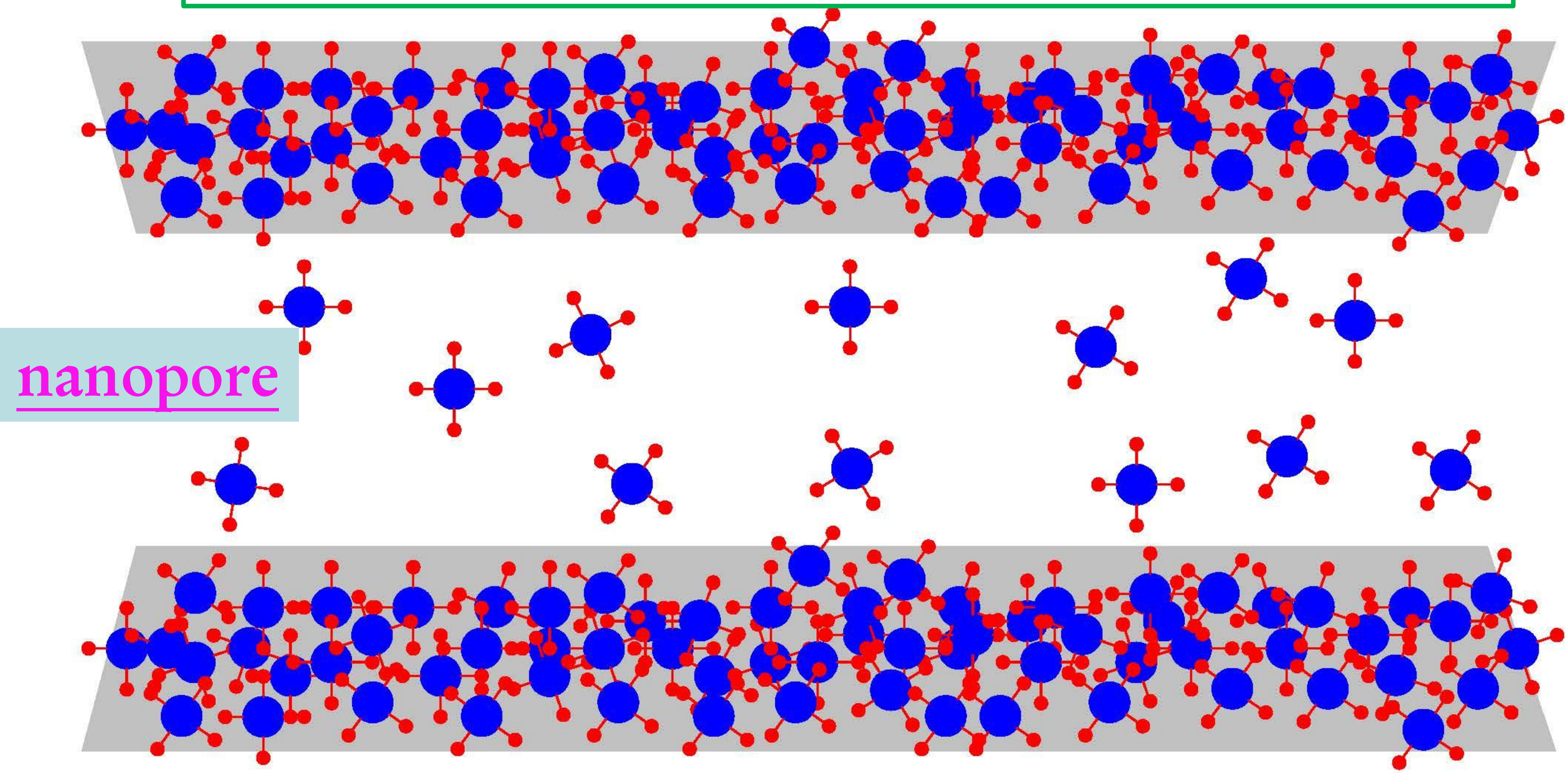
Tinker, 2012



After Reed, BEG

Shale Gas Storage: "Sorbed" vs. "Free" gas

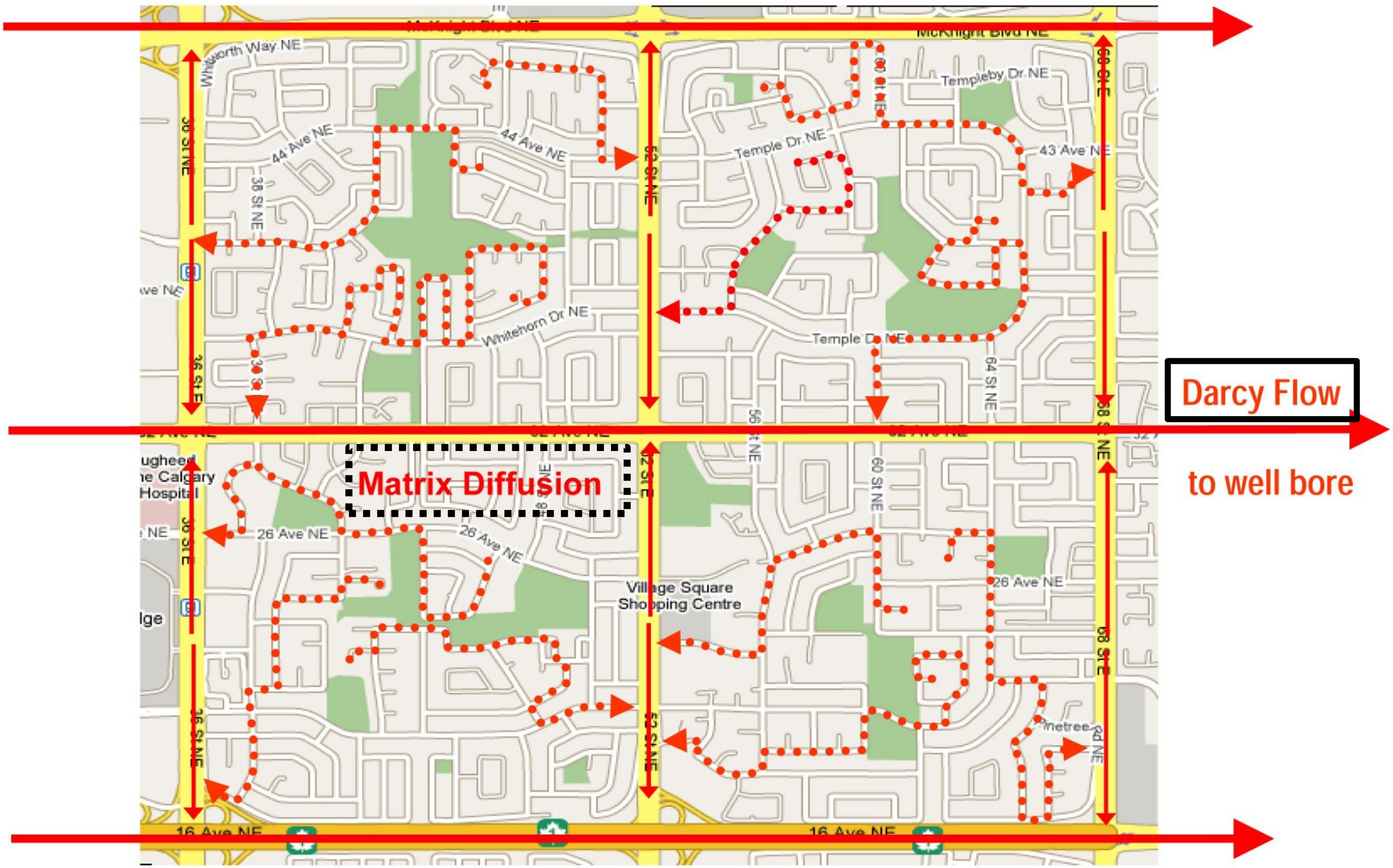
http://www.transcanada.com/customerexpress/docs/presentations_general/2009_North_American_Shale_Gas_Overview_NECA.pdf



CH_4 - Methane molecule 0.375 nm

TransCanada

Shale Gas Flow: Matrix "diffusion" vs. "Darcy" flow



http://www.transcanada.com/customerexpress/docs/presentations_general/2009_North_American_Shale_Gas_Overview_NECA.pdf

TransCanada

Three Data Points

- Gas molecule movement in shale on the order of 10 feet in the lifetime of a well - Dr. Mohan Kelcar, University of Tulsa.

- Gas molecule movement of about a meter/year modeled by Nexen's Unconventional Team, presented at Global Gas Shales Summit, Warsaw, Poland.

- Gas molecule movement of a few feet/year modeled by Dr. Chunlou Li, Shale Gas Technology Group.

→ ~1 m/yr movement (advection vs. diffusion ?)

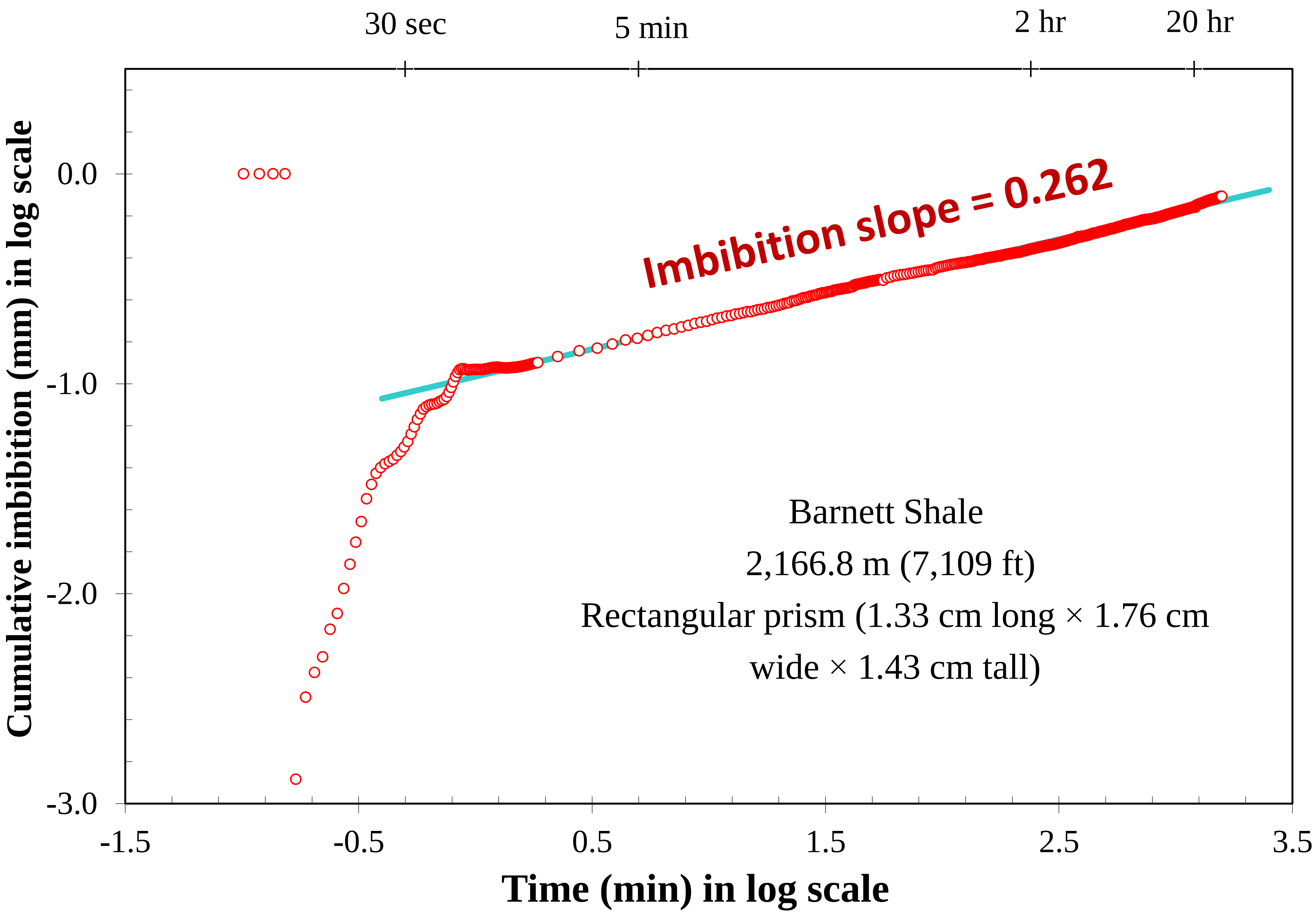
LaFollette, R. 2010. Key Considerations for Hydraulic Fracturing of Gas Shales. Manager, Shale Gas Technology, BJ Services Company, September 9, 2010. www.pttc.org/aapg/lafollette.pdf

Multiple Approaches to Studying Pore Structure

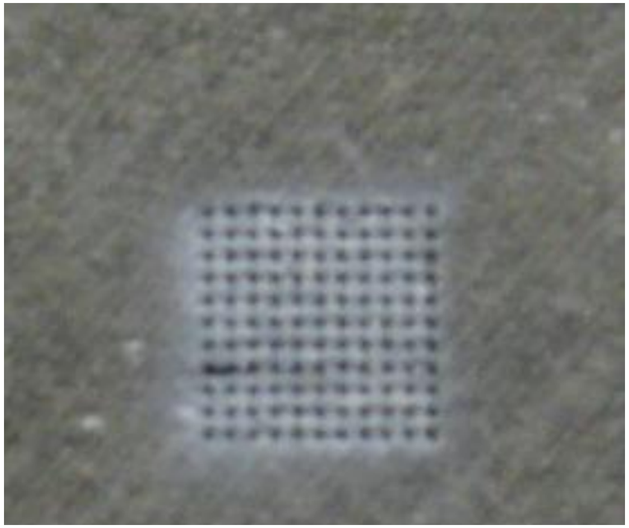
- Imbibition with samples of different shapes
- Edge-accessible porosity
- Liquid and gas diffusion
- Mercury injection porosimetry
- N_2 adsorption/desorption isotherms
- Vapor absorption
- Nuclear Magnetic Resonance Cryoporometry
- SEM imaging after Wood's metal impregnation
- Focused Ion Beam/SEM imaging
- Pore-scale network modeling

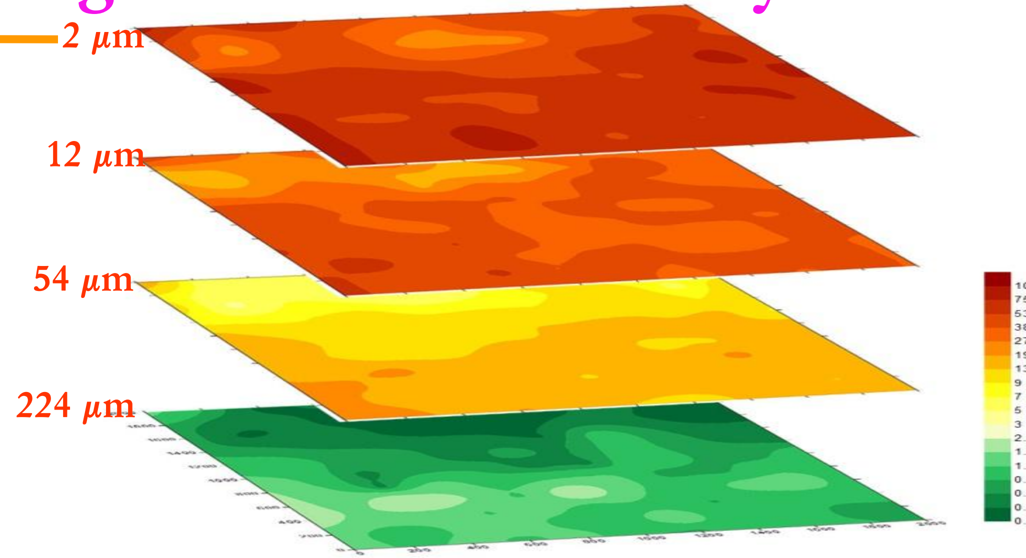
Oral at Session T98: 4:55 pm (Mon.), Rm. 213BC

Imbibition: Low Pore-Connectivity of Shale Samples

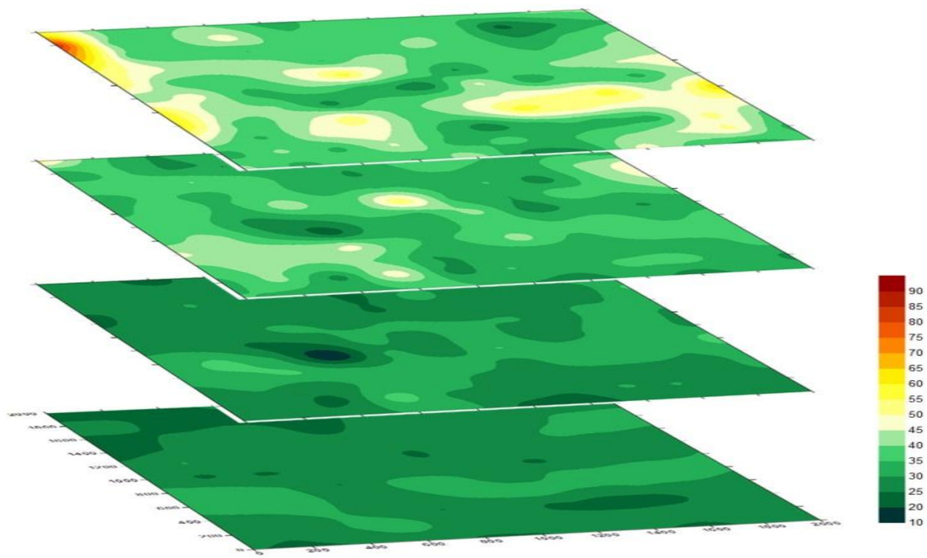


3D Elemental Mapping: Edge-Accessible Porosity

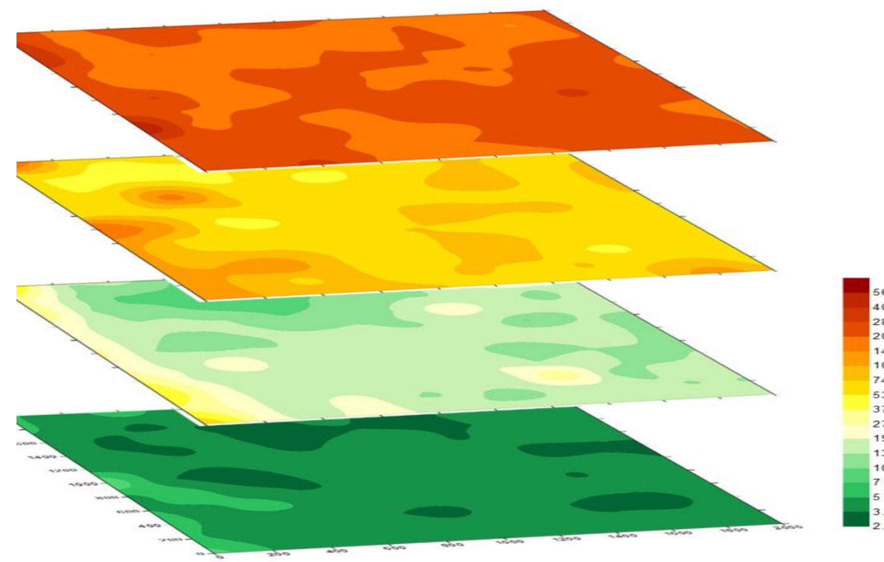




ReO_4^- (non-sorbing)



Rb (intrinsic)

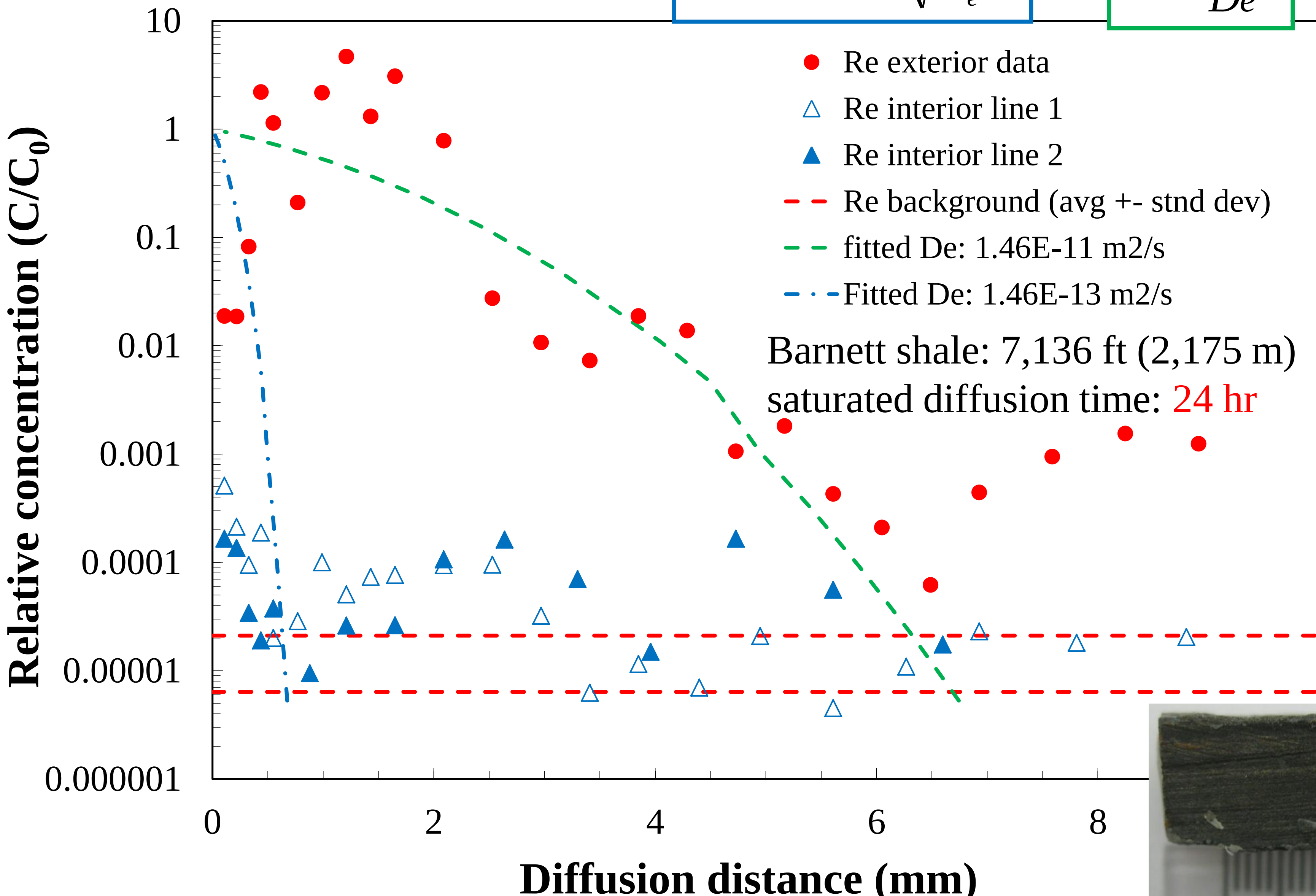


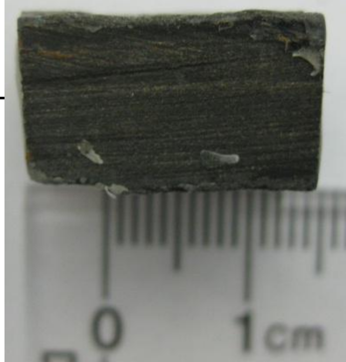
Co^{2+} (sorbing)

Saturated Diffusion

$$\frac{C}{C_0} = \frac{1}{2} erfc \frac{x}{2\sqrt{D_e t}}$$

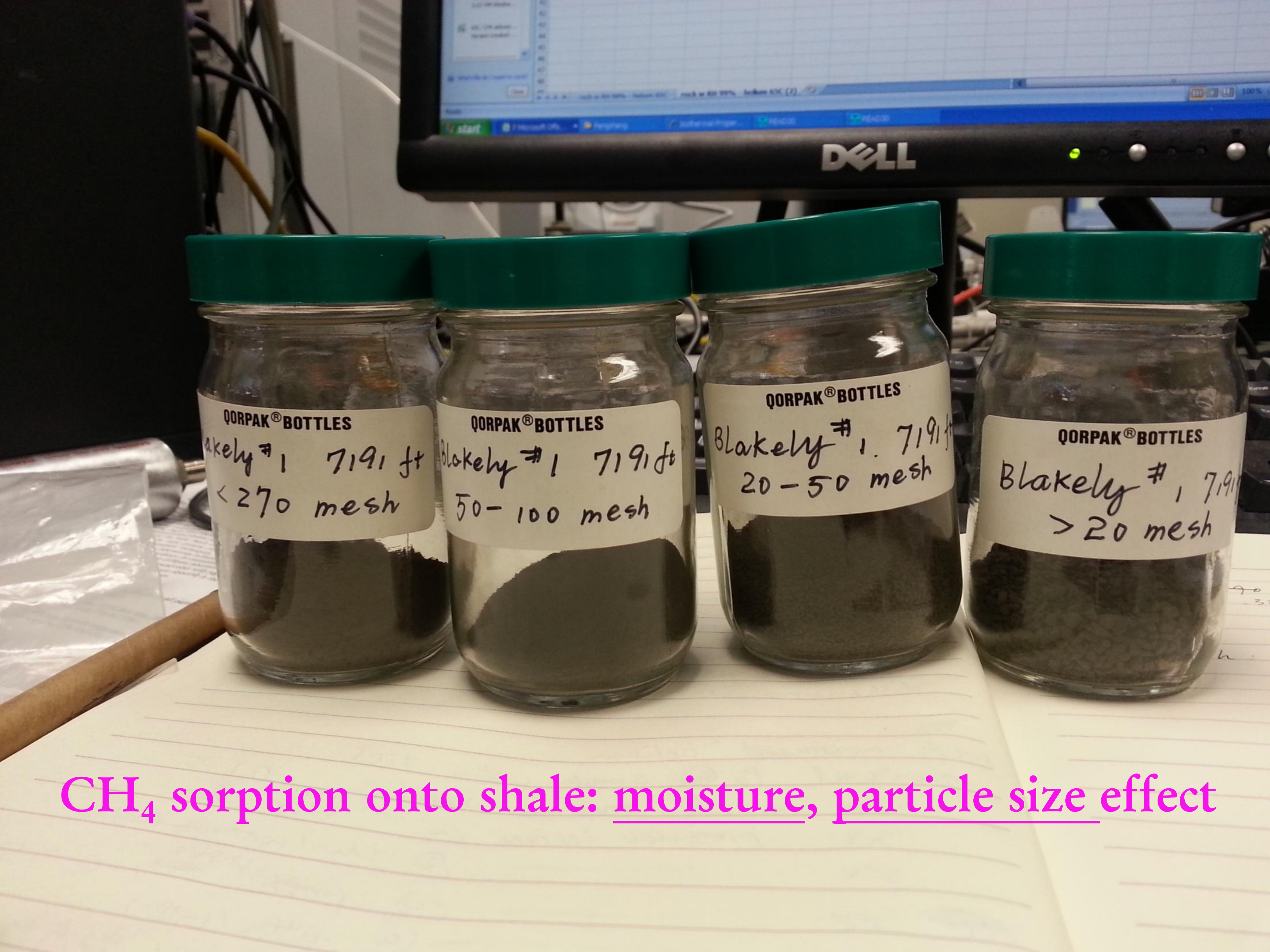
$$\tau = \frac{D_0}{De}$$





Fitted tortuosity: 100 (exterior) and 10,000 (interior)

CH$_4$ sorption isotherm (ongoing at BEG)



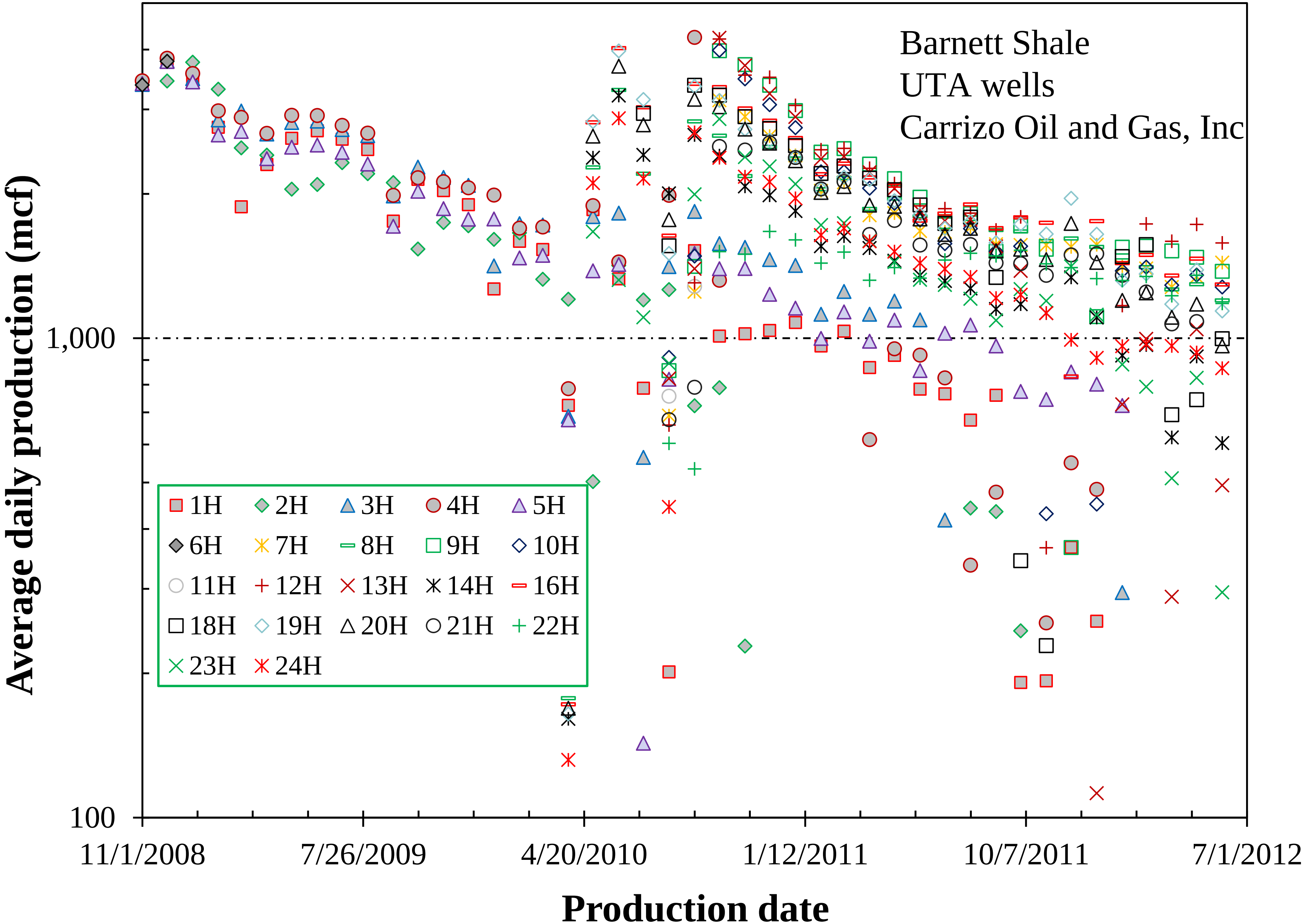
CH_4 sorption onto shale: moisture, particle size effect

Barnett drilling location at 2008
University of Texas at Arlington

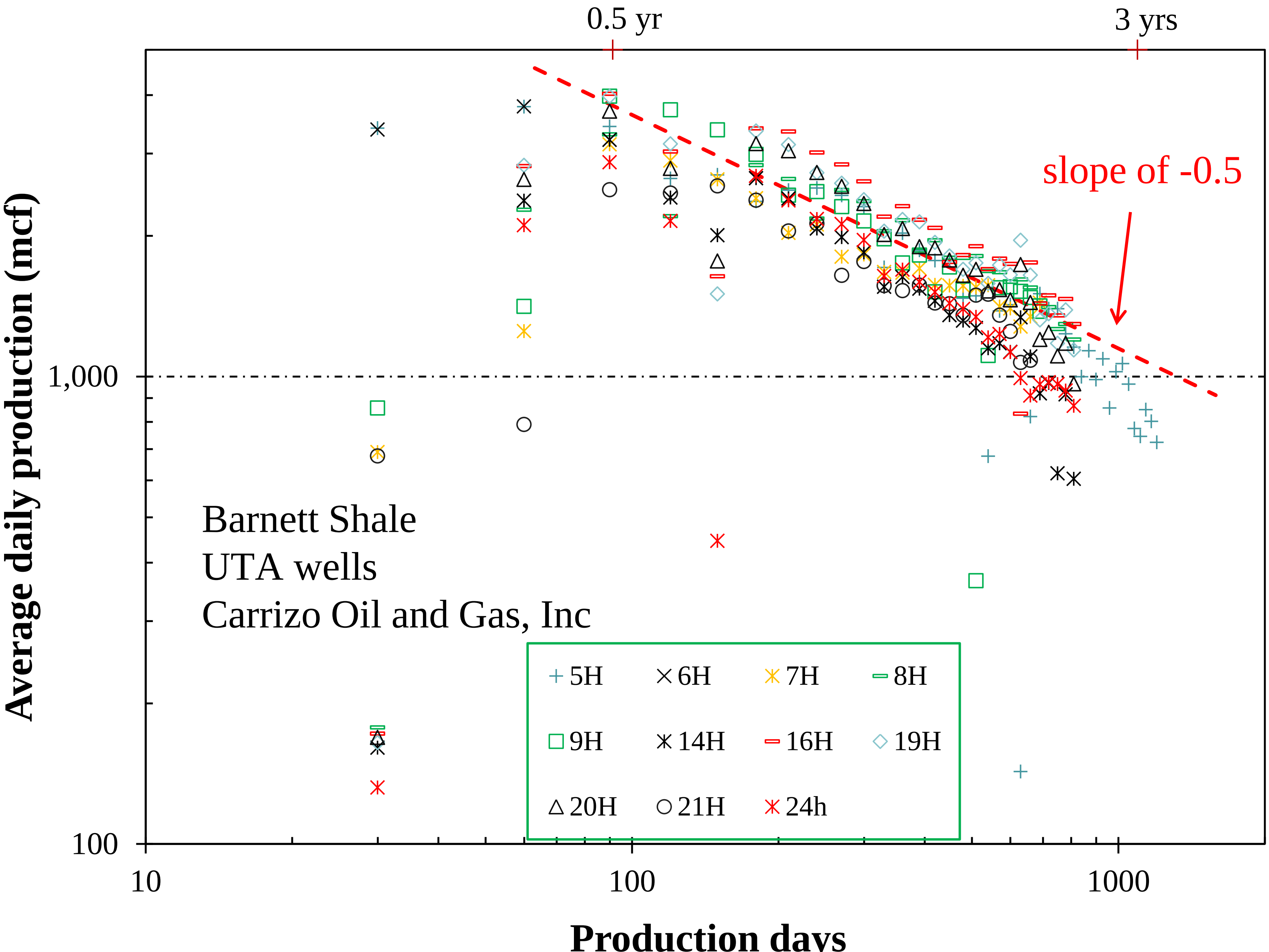
http://www.star-telegram.com/2010/09/30/2510136/u
arlington-pad-site-exemplifies.html


1 mile (1,609 m; 5,280 ft)
Arlington
University of Texas at Arlington
B
A
University Of Texas At Arlington: Administrative Office
24 horizontal wells from a well pad
Barnett drilling location
University of Texas at Arlington
From XTO annual report

All 22 Producing UTA Horizontal Wells



Decline Slope for 11 Wells (50% of All)



Gas Production Rate in a Fractured Shale System

Dmitriy Silin (RPSEA presentation in 2011)
Silin and Kneafsey (2011; SPE 149489)

"Early" ($t < t_*$) recovery rate

$$|Q(t)| = 2AD\frac{1}{\varrho_*}\frac{M}{Z_R RT}\sqrt{\left(\phi + Z_R\frac{RT}{M}\varrho_0\varrho_K S_K c_f\right)\frac{k}{\mu p_R}}\,\frac{p_R - p_W}{\alpha\boxed{\sqrt{t}}}$$

$$t_* \approx \left(\phi + Z_R\frac{RT}{M}\varrho_0\varrho_K S_K c_f\right)\frac{\mu D^2}{k p_R}\frac{1}{\alpha^2}$$

"Late" ($t > t_*$) recovery rate

$$|Q(t)| = 2A\frac{1}{\varrho_*}\frac{k}{\mu}\frac{M}{Z_R RT}(p_R - p_W)\boxed{\exp}\left(-3\sqrt{\frac{p_W}{p_R}}\left(\frac{1}{\phi + Z_R\frac{RT}{M}\varrho_0\varrho_K S_K c_f}\frac{k p_R}{\mu_R D^2}\boxed{t} + \frac{1}{\alpha^2}\right)\right)$$

c_f: gas desorption rate [$m^3/(kg\ Pa)$]

Summary

- Steep 1st year decline and low gas recovery observed in shales
- Pore structure information is essential in understanding hydrocarbon storage and transport
- Nano-pore shales show low pore connectivity, which reduces gas diffusion from matrix to stimulated fractured network
- Gas sorption, affected by moisture and sample size, further contribute to steep decline and low recovery
- How to link pore structure and gas sorption mechanism to field-scale gas recovery ?