Senior Petroleum Engineering Design

Recommendations for Developing a Barnett Gas Field

Fort Worth Basin, Texas

Group 2

Jason Zhang

April 30, 2018

Chemical and Petroleum Engineering Department

KU SCHOOL OF ENGINEERING
The University of Kansas

Outline

- Motivation and Objective
- Study Area
- Workflow
- Rock Quality/Petrophysical Evaluation → Geological Modelling
- Completion Quality Evaluation → Hydraulic Fracture Modelling
- Field Evaluation → P_{50} Well Determination
- Operation Quality Evaluation → DCA, RTA
- Well Spacing Optimization
- Economic Viability of Development
- Conclusions and Recommendations
- Acknowledgements

Motivation and Objective

Motivation: ***Operation "Stealthy Paws"***

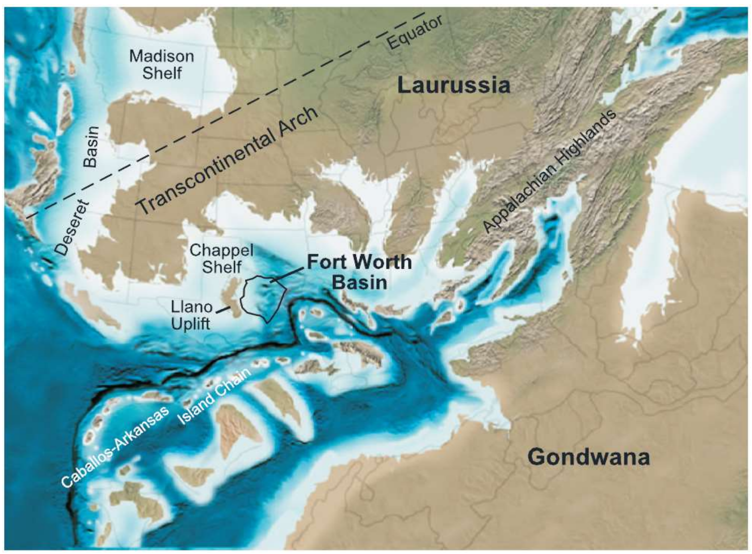
- ***Phase 1: Locate the package***
- ***Phase 2: The Stakeout***
- ***Phase 3: Steal Kalantari's dog***
- ***Phase 4: Pet it.***
- ***Phase 5: Return***

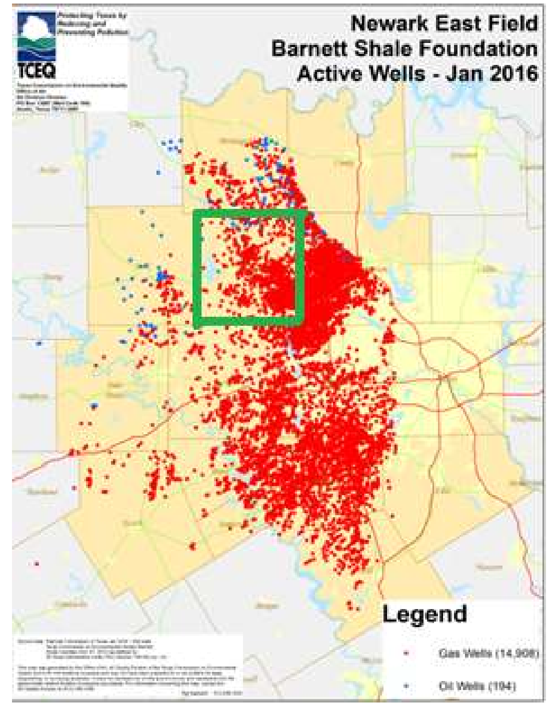
The Barnett Shale-Gas Play

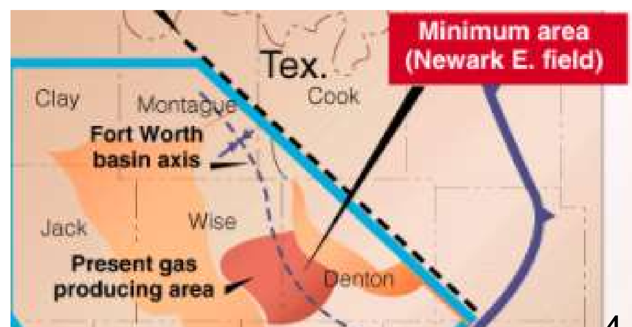
Play: *Barnett shale*

Location: *Northwest of Dallas*

Field: *Newark East*



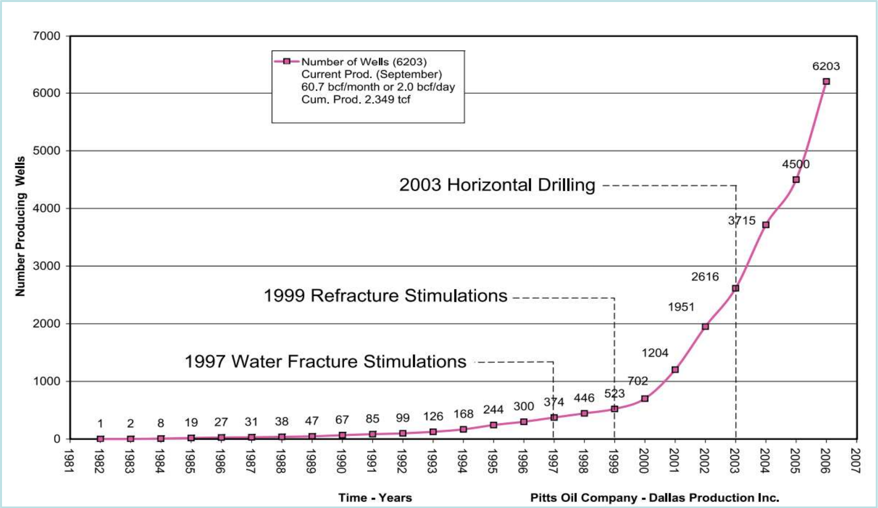




KU SCHOOL OF ENGINEERING
The University of Kansas

Field History

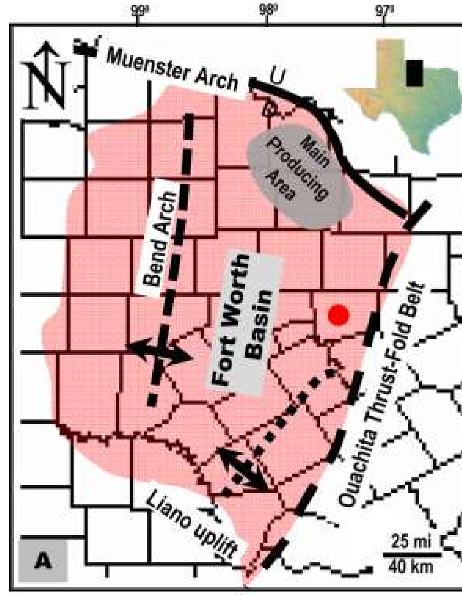
- Founded by MEC in 1981,bought out by Devon in 2002
- Original target was the Viola and Ellenburger formation
- Newark East field: Started in Wise county, expansion into Denton
- 2006: Largest field in Texas, 3rd in the nation.
- Technology advances improved field performance.

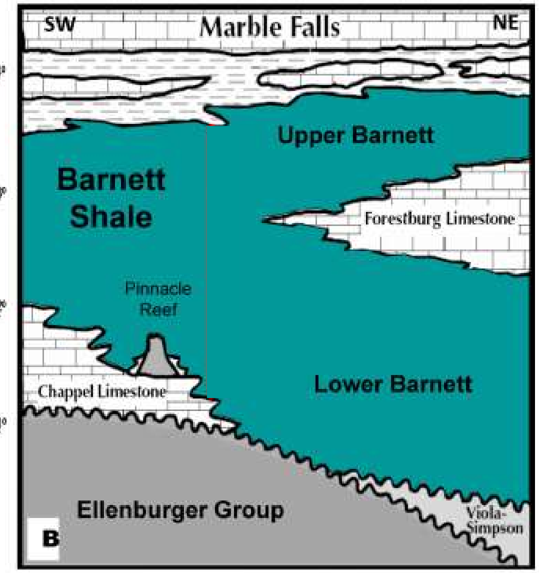


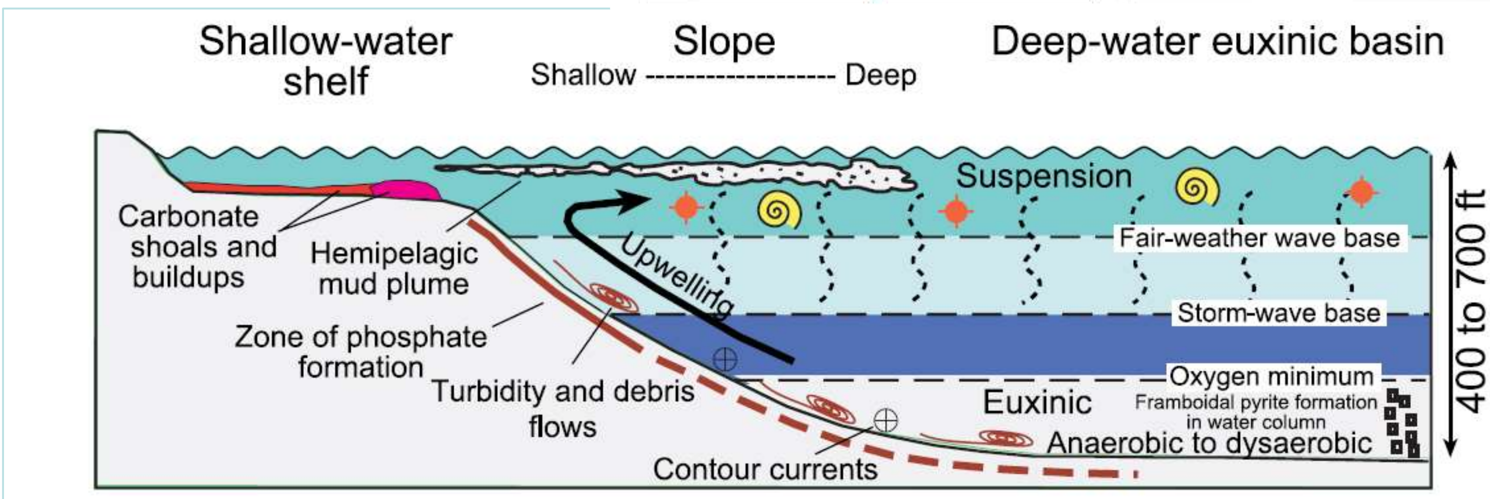
Barnett Shale	
Geologic Age	Late Mississippian
Area size,mile squre	5,400(4,065 active)
Depth, ft	6,500-8,500
Thickness, ft	100-600
TOC,%	4-5
Thermal Maturity, Ro%	1.3-2.1
Porosity, %	4-8
Well Avg.IP,MMcfd	2.5
Horizontal lateral, ft	3,950-4,350
TRR,Tcf	43
EUR/Well, Bcf	1.6
Pressure Gradient,psi/ft	0.43-0.45
Well Spacing, AC	116
First Production	1981

Depositional Setting

- Mississippian age
- Fort Worth Basin
- Deposition: 25 M.Y
- Shale gas system
- Debris transported from shelf region
- Lithofacies: clay to silt

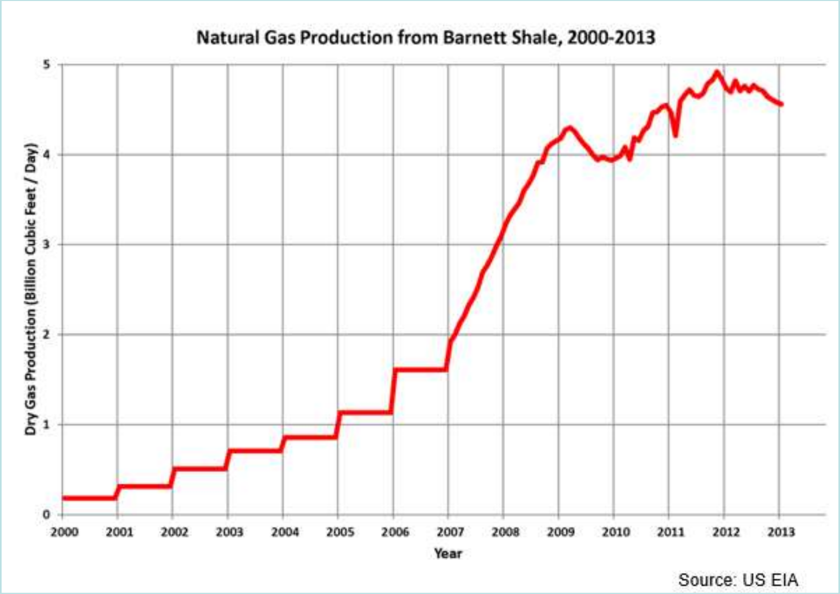




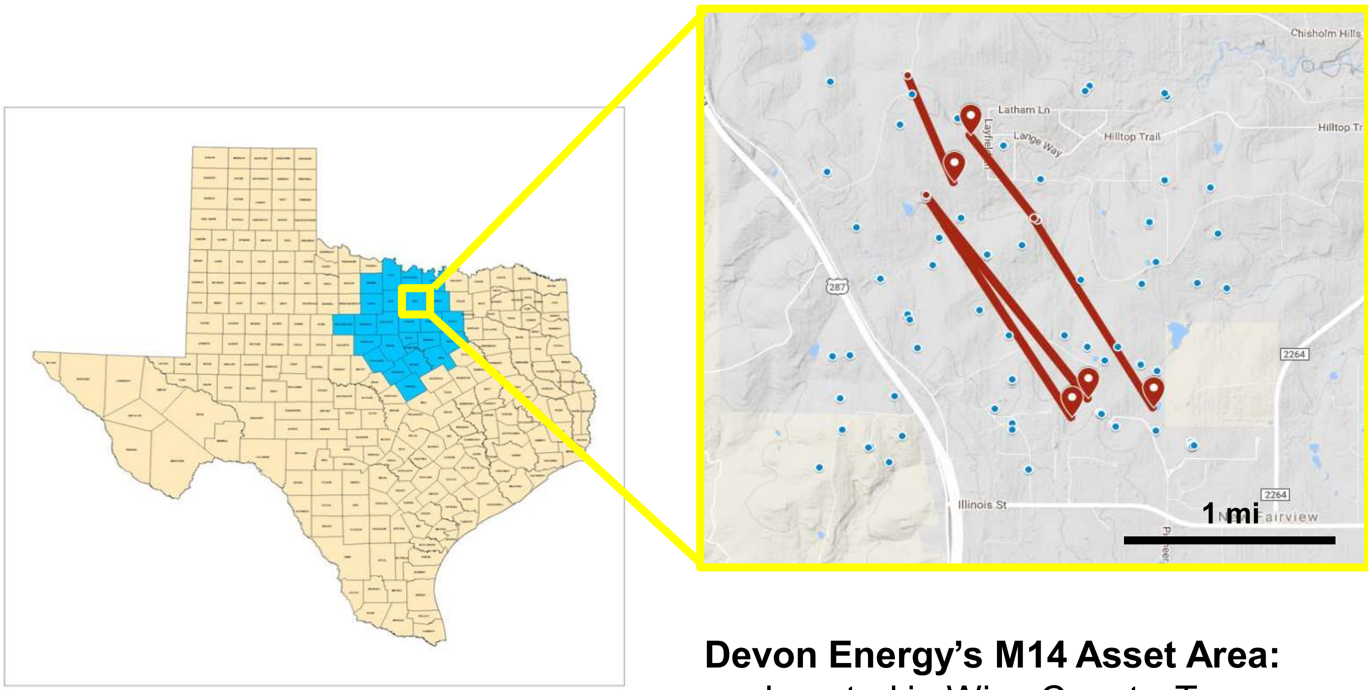


Economics

- Higher gas price and horizontal drilling
- Contributes 8% of natural gas to U.S
- Total production estimated at 4TCF in 2008
- Updated estimated 39 TCF



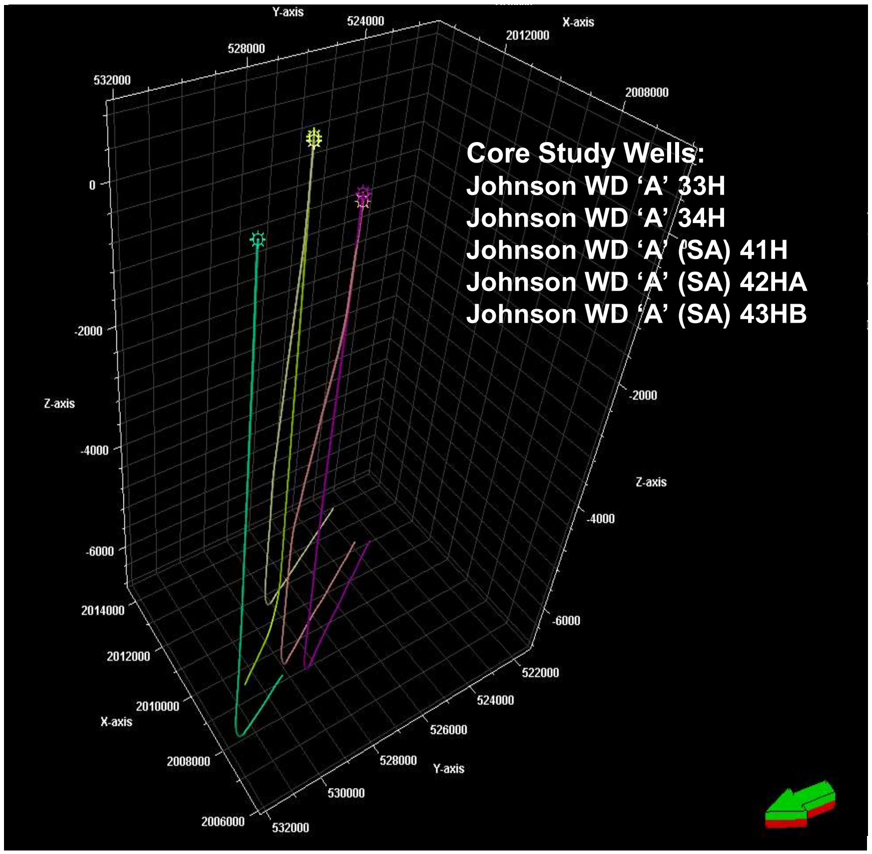
Study Area

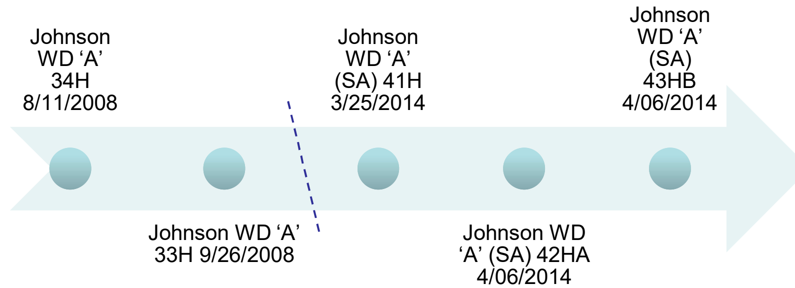


Devon Energy's M14 Asset Area:

- Located in Wise County, Texas
- 81 deviated and horizontal wells
  - Focus group of 5 core wells
- Targets reserves in the Newark East Gas Field

Study Area

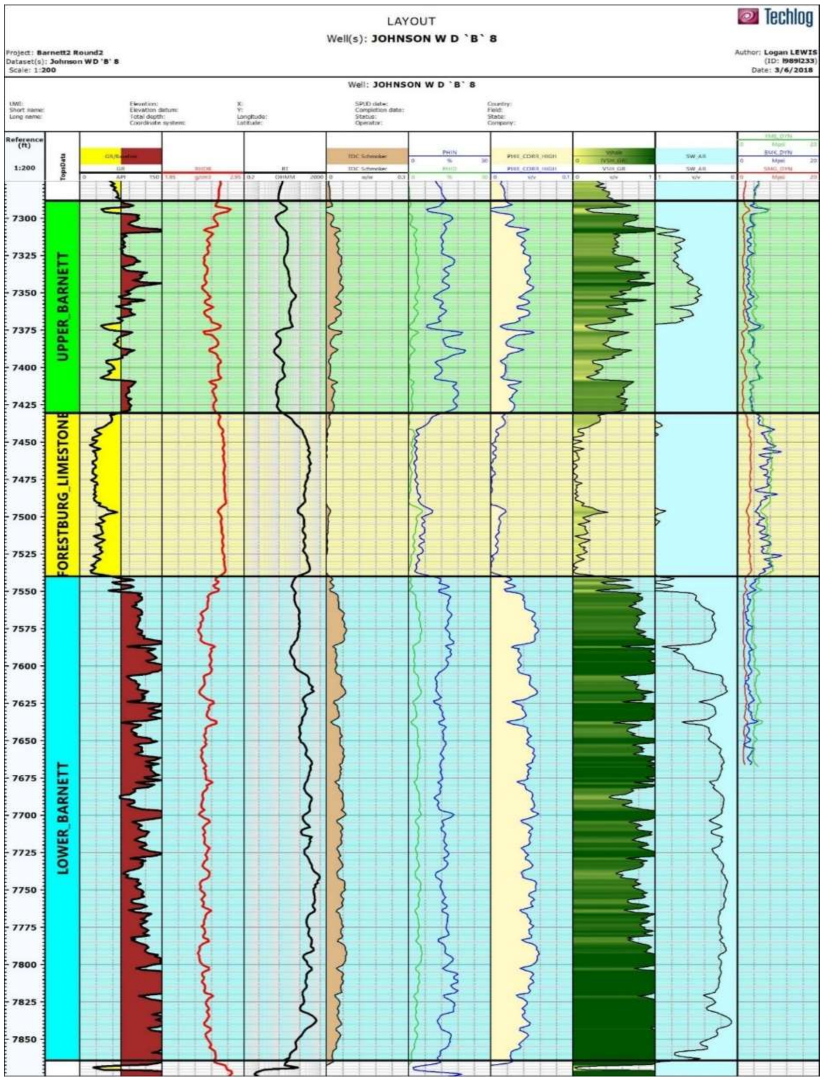




	Date Competed	I.P. (MSCFD)	Gp (MMSCF)	Wp (MSTB)
33H	9/26/2008	2007	1298	29.59
34H	8/11/2008	1691	1207	22.57
41H	4/22/2014	755	581	7.47
42HA	5/12/2014	3609	1216	33.87
43HB	5/12/2014	3635	1188	25.10

Rock Quality/Petrophysical Evaluation

Petrophysical Evaluation



Shale Volume:

$$V_{SH,GR} = \frac{\gamma_{matrix} - \gamma_{log}}{\gamma_{matrix} - \gamma_{shale}}$$

γ_{matrix} = 23 API
γ_{shale} = 130 API

Total Organic Content [(1)]:

$$TOC = \left(A/\rho_b\right) - B$$

A = 154.497
B = 57.261

Porosity [(2)]:

$$\phi = \frac{\rho_b - \rho_{ma} + TOC(\rho_{ma} - \rho_{TOC})}{\rho_g(1 - S_w) + \rho_w S_w - \rho_{ma}}$$

ρ_{ma} = 2.71 g/cc
ρ_{fluid} = 1.0 g/cc
ρ_{TOC} = 1.4 g/cc
ρ_g = 0.3 g/cc

Water Saturation [(3,4)]:

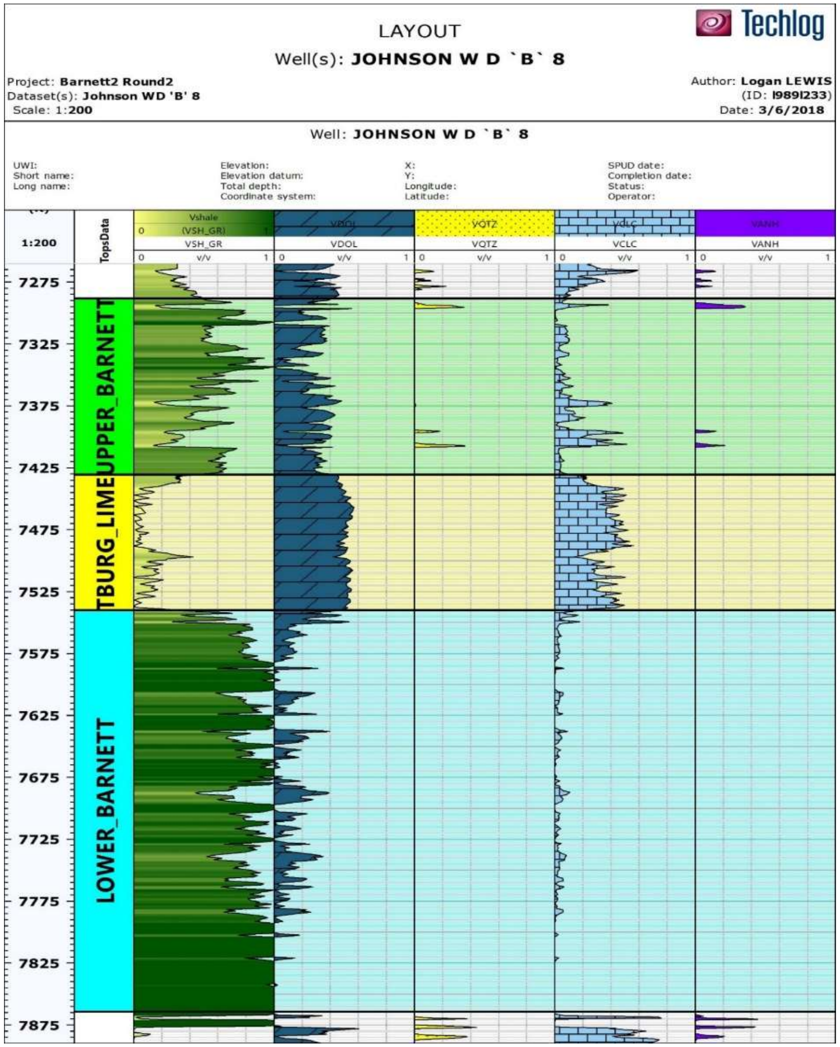
$$S_w^n = \frac{R_w}{\phi^m \times R_t}$$

R_w = 0.03 Ωm [(3)]
n = 2
m = 1.9

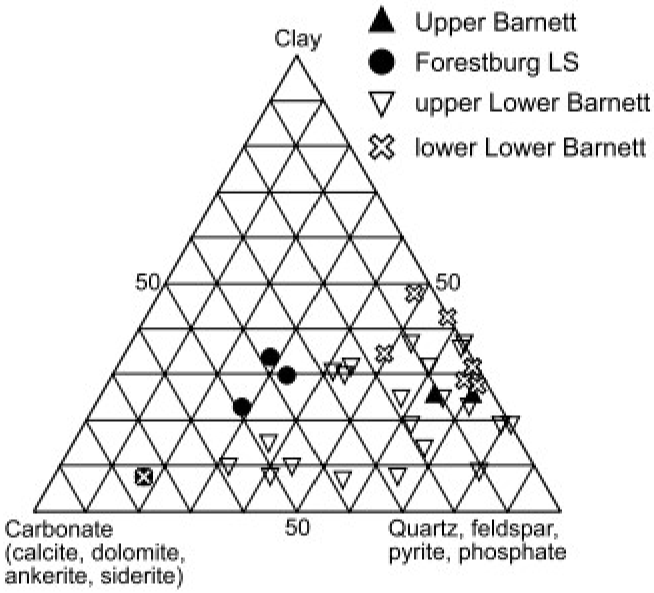
(1) Schmoker, 1983
(2) Sonergeld *et. al*, 2010 (modified by Lewis, 2018)
(3) Archie, 1941
(4) Zhang, 2016

KU SCHOOL OF ENGINEERING
The University of Kansas

Rock Quality Evaluation

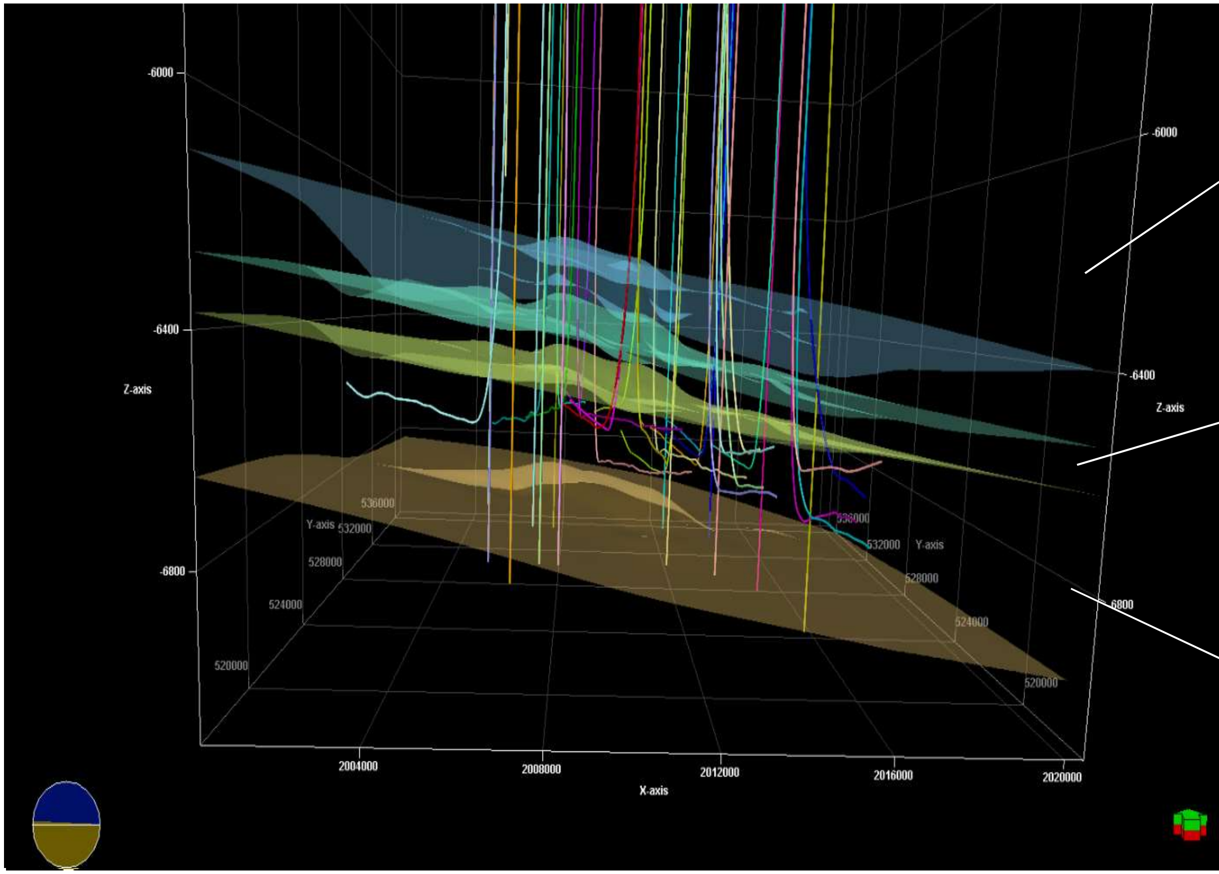


Multi-Mineral Lithology Analysis:



(5) Loucks and Ruppel, 2007

Geological Model



Upper Barnett
- h_{ave} = 138 ft
- Gr_{ave} = 120 API
- R_t = 22.4 Ωm

Forestburg Limestone
- h_{ave} = 120 ft
- GR_{ave} = 40.7 API
- R_t = 192 Ωm

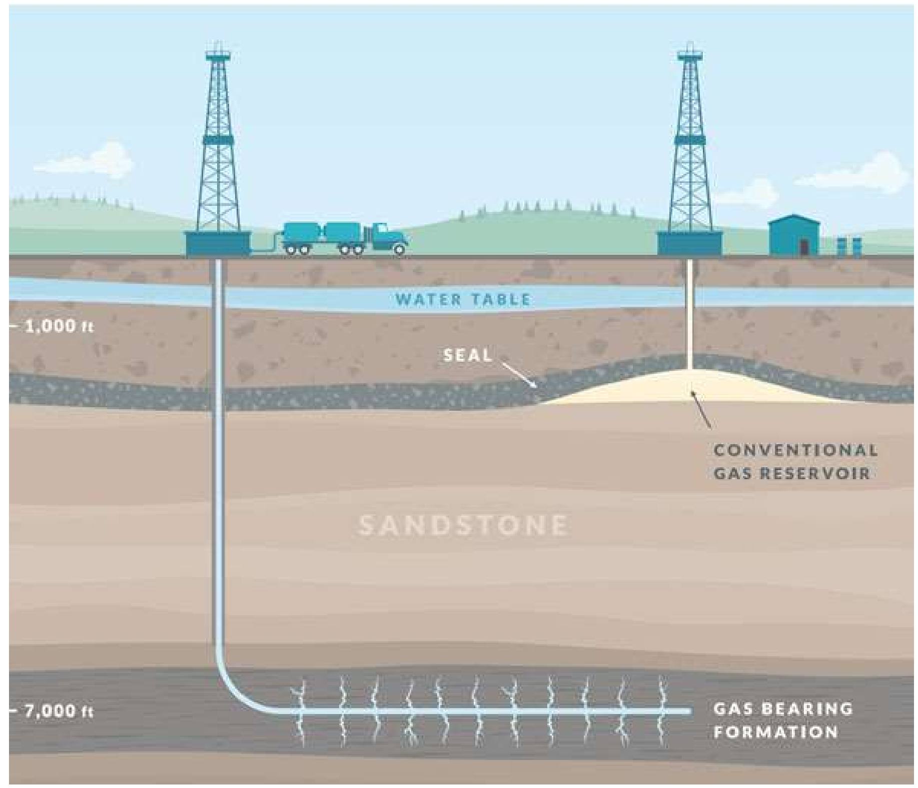
Lower Barnett
- h_{ave} = 307 ft
- GR_{ave} = 141 API
- R_t = 187 Ωm

Completion Quality Evaluation

Hydraulic Fracture Design

- **The purpose of doing a hydraulic fracture in a shale formation is to widen the pore space in order for hydrocarbons to mobilize.**

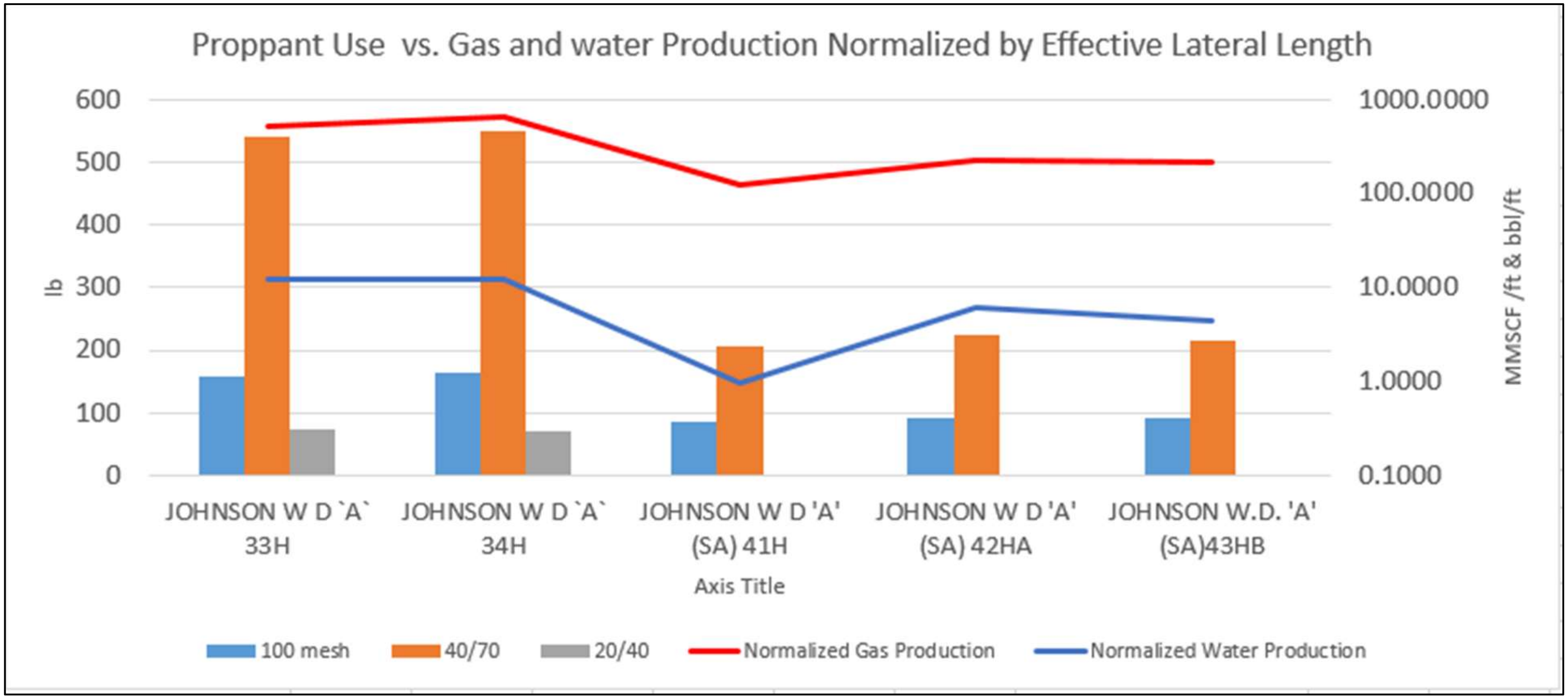
--Montgomery et al., 2005



https://www.watertechonline.com/distillation-hydraulic-fracturing-flowback-treatment/

KU SCHOOL OF ENGINEERING
The University of Kansas

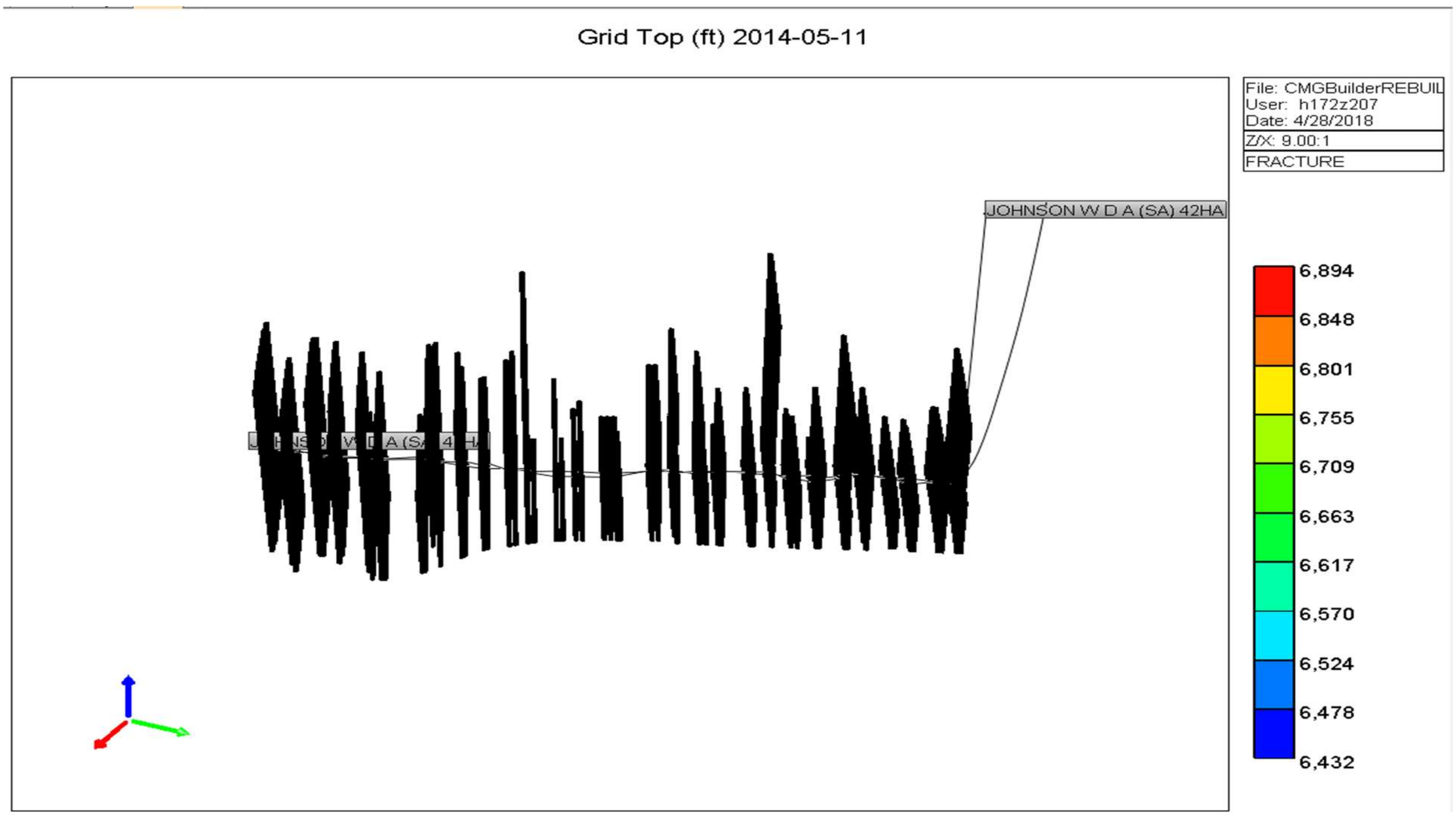
Hard Data



- **41H 42HA 43HB are only using 100 mesh and 40/70**

NAME	Effective Lateral Length
JOHNSON W D `A` 33H	2474
JOHNSON W D `A` 34H	1883
JOHNSON W D 'A' (SA) 41H	4799
JOHNSON W D 'A' (SA) 42HA	5445
JOHNSON W.D. 'A' (SA)43HB	5656

Simulated Frac Model



Field Evaluation

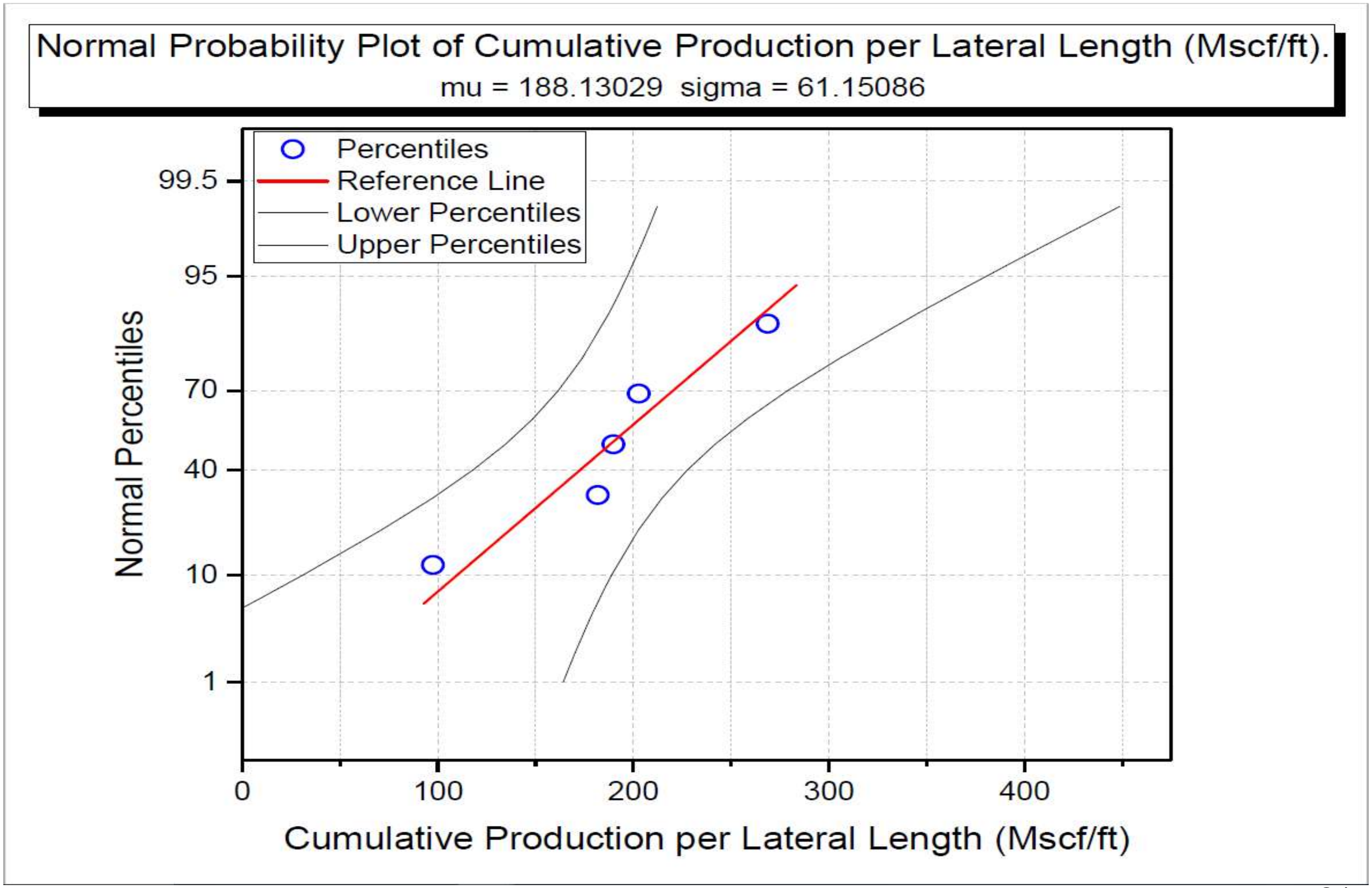
P_{50} Well Determination

- P_{50} is targeted because it is close to the mean value of the data.
- Knowing the P_{50} well allows for the best average value to be used as a reference as to what is to be expected.

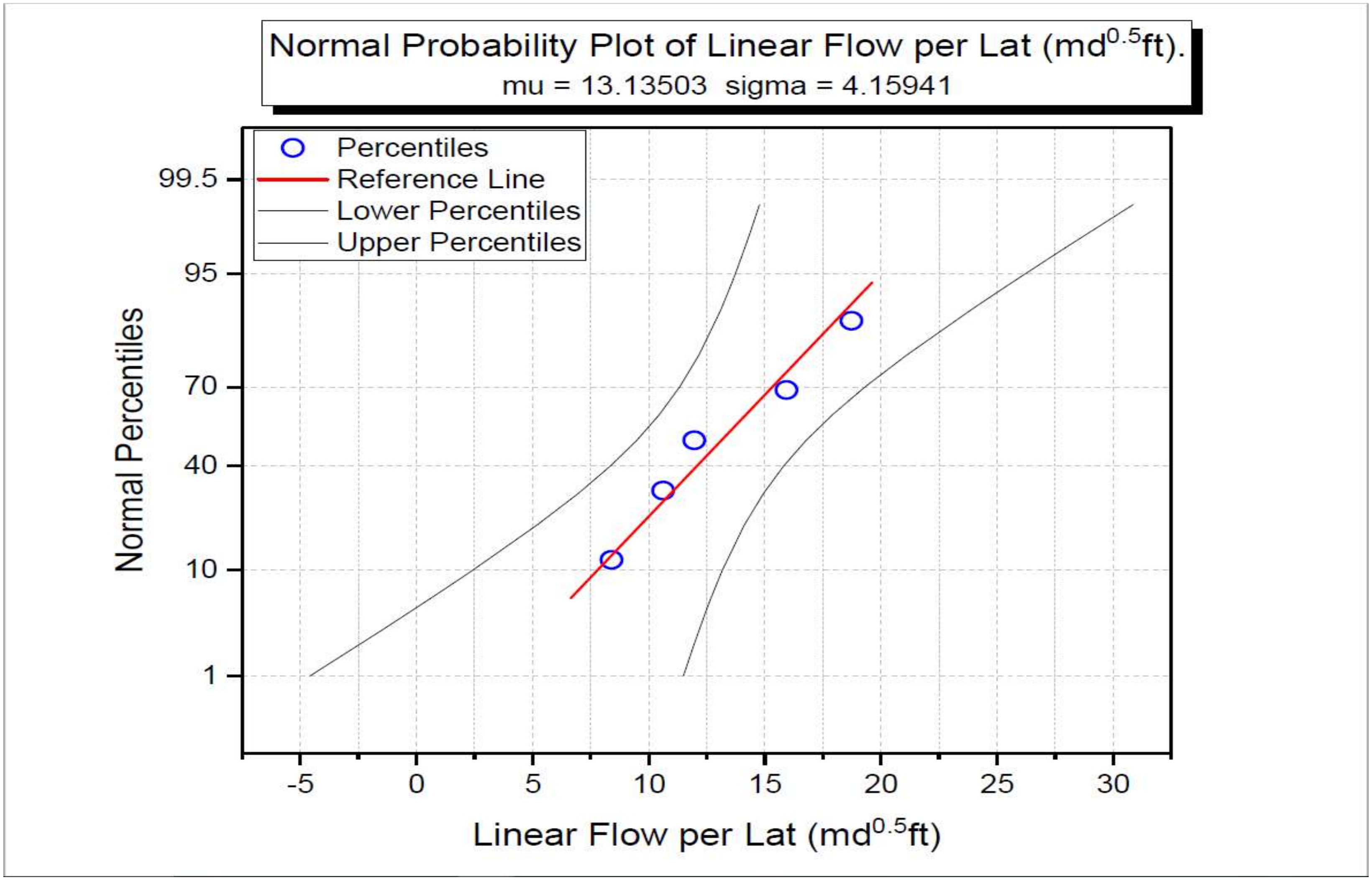
Process

- The production indicator chosen was 800 days of cumulative gas.
- Normalized production data.
- Identified P_{50} well based on cumulative production, linear flow, and proppant data.

P_{50} Cum. Production/Lat. Length

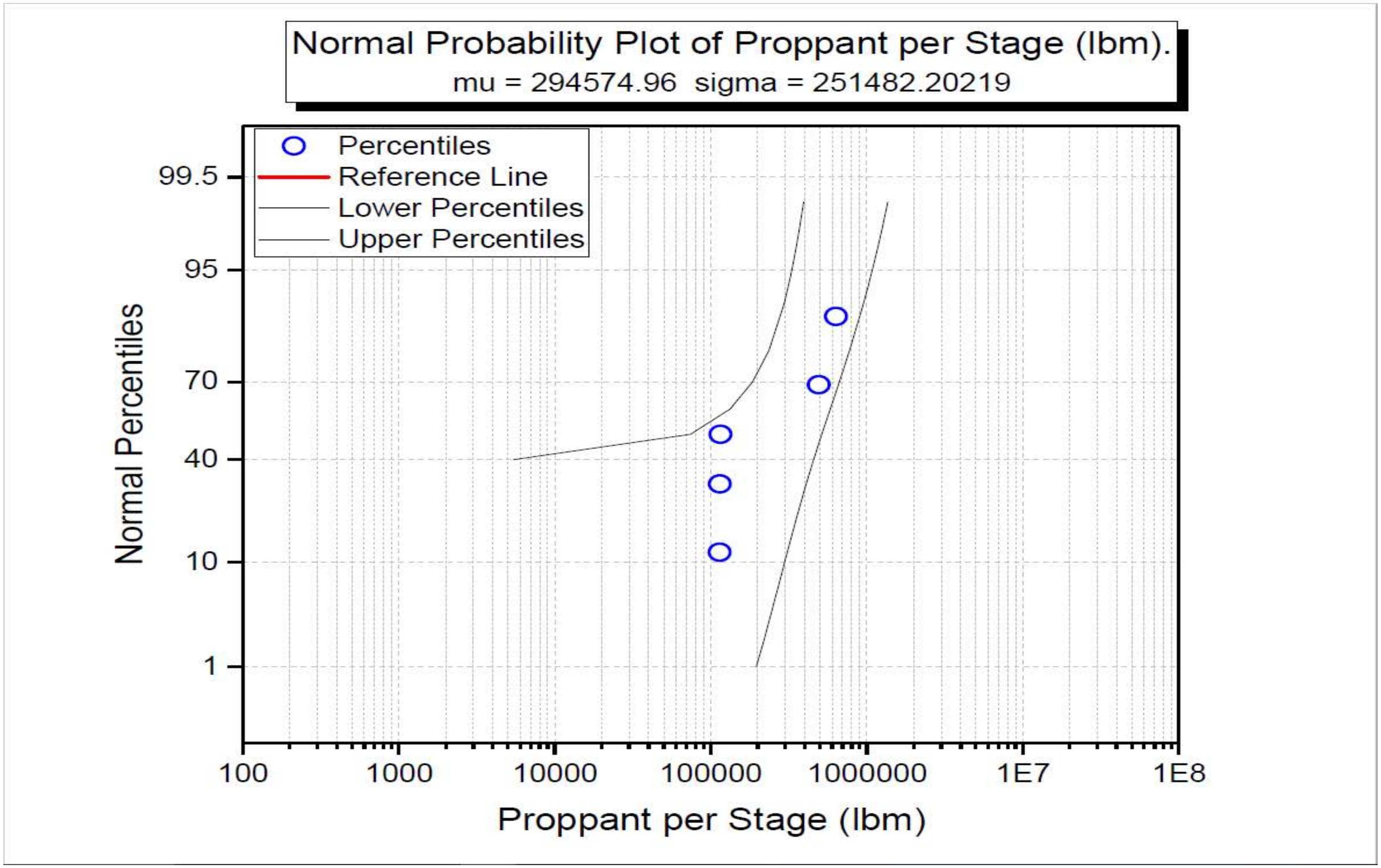


P_{50} Linear Flow/Lat. Length

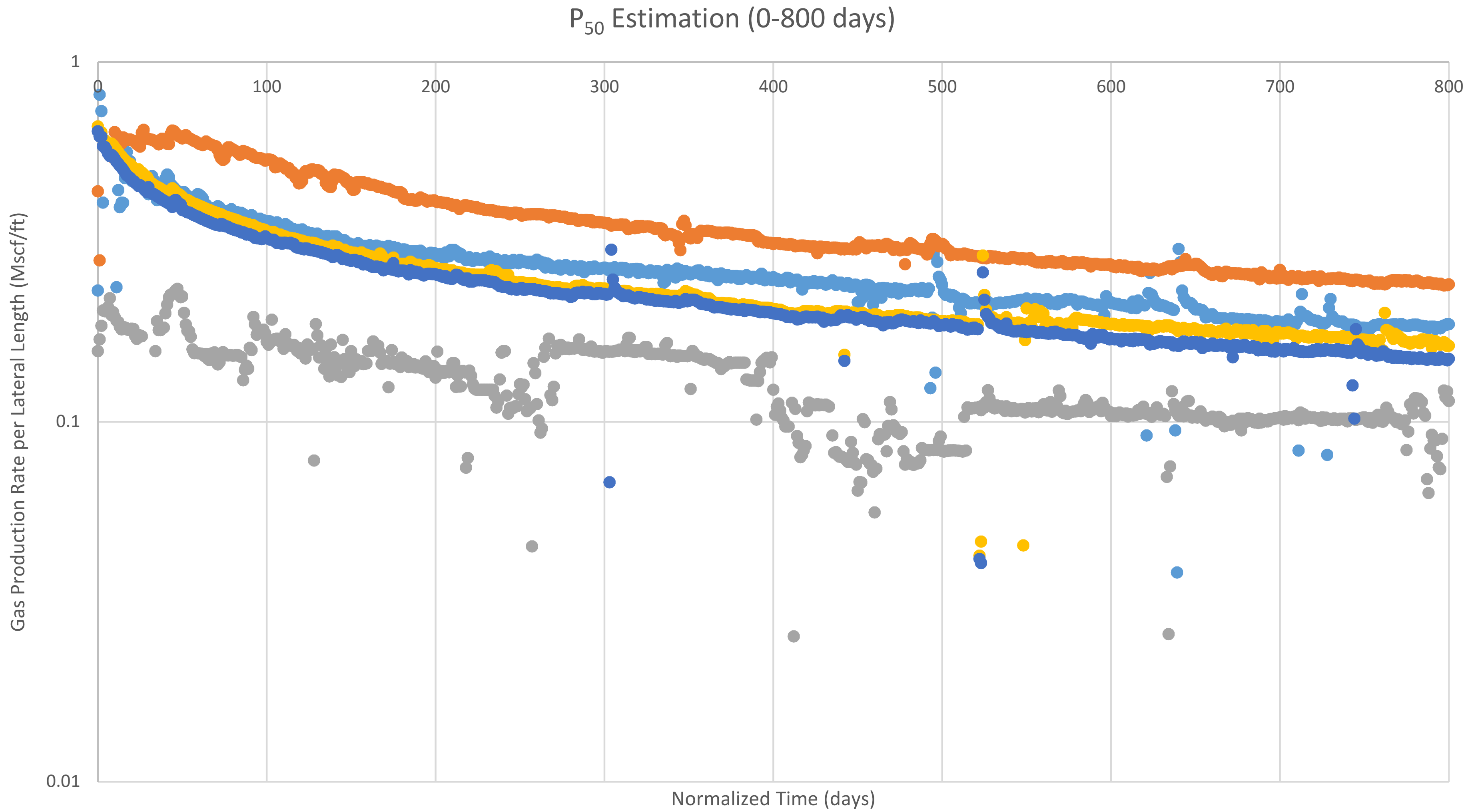


KU SCHOOL OF ENGINEERING
The University of Kansas

P_{50} Proppant/Stage

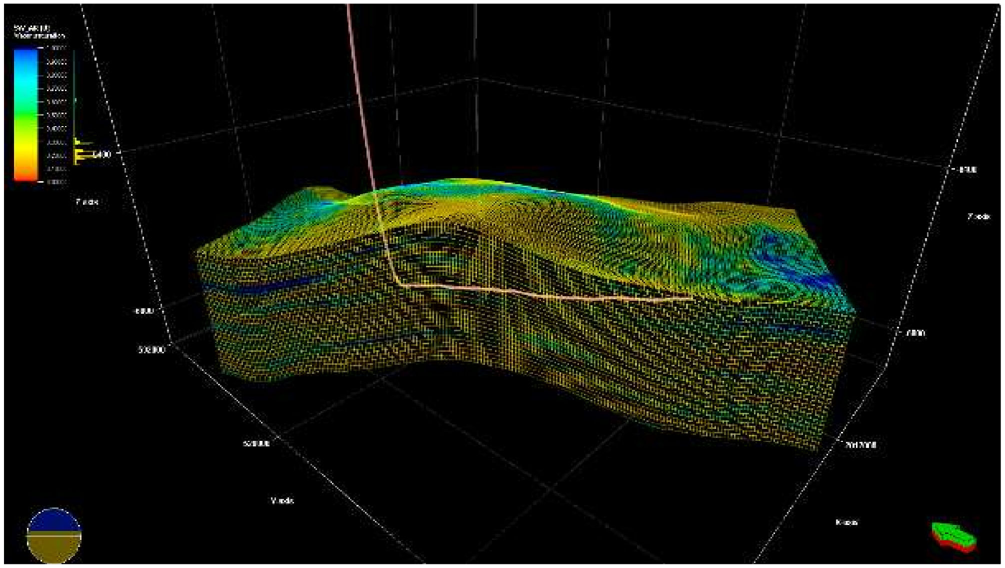


P_{50} (800 Days)



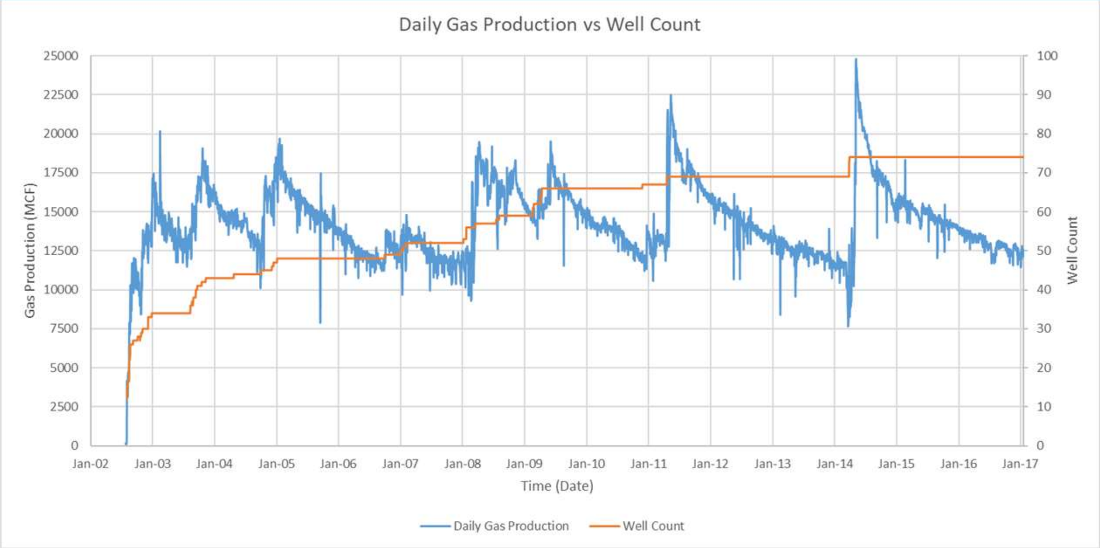
P50 Estimation (0-800 days)
Gas Production Rate per Lateral Length (Mscf/ft)
1
0.1
0.01
0
100
200
300
400
500
600
700
800
Normalized Time (days)

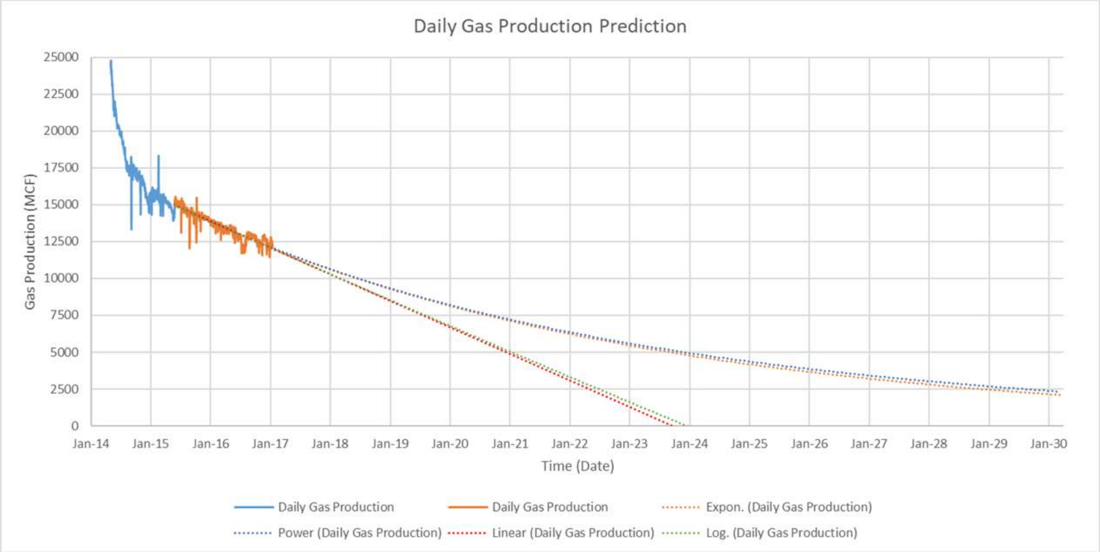
Chosen P_{50} Well



Operation Quality Evaluation

Field Production Data

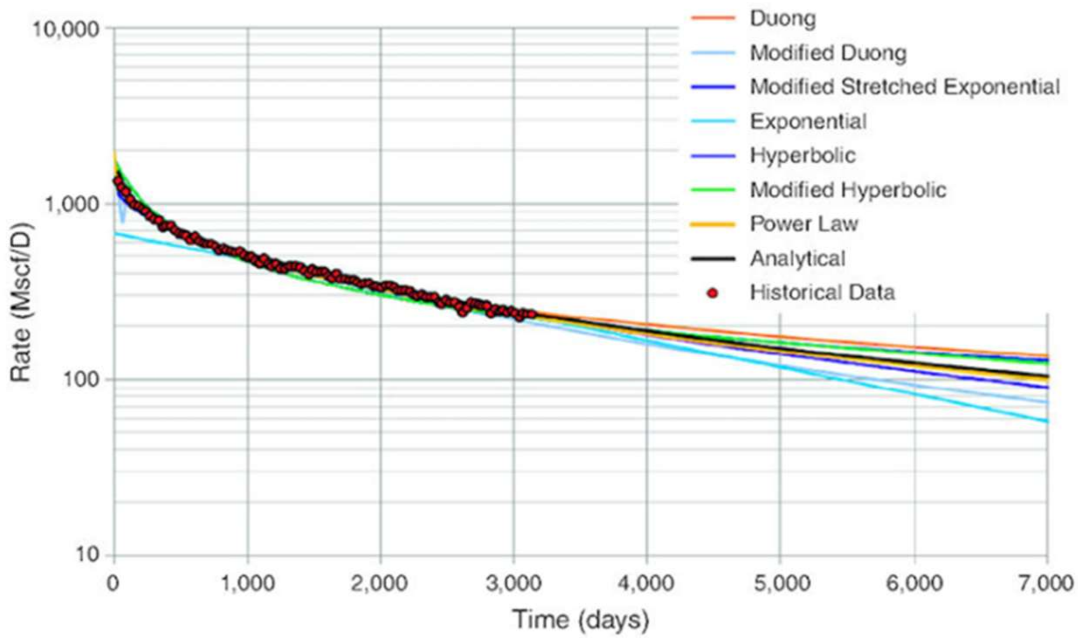




KU SCHOOL OF ENGINEERING
The University of Kansas

Decline Curve Analysis

- **Methodology:** Multiple decline curves were applied to the 5 target wells and field as a whole in IHS Harmony. The goal was to determine the representative trends that projects the well's economic life and forecast future cumulative production.



Decline Curve Analysis

- **Parameters:**
  - Devon Energy has a set cutoff rate of 20 Mscf/day for gas wells
  - By using DCA, it is predicted that gas production will fall to 900Bscf/yr by 2030 from the peak of about 2Tscf/yr
    - From this DCA forcast, it is likely the Barnett field as a whole will no longer be a major contributor to natural gas production in the year 2030

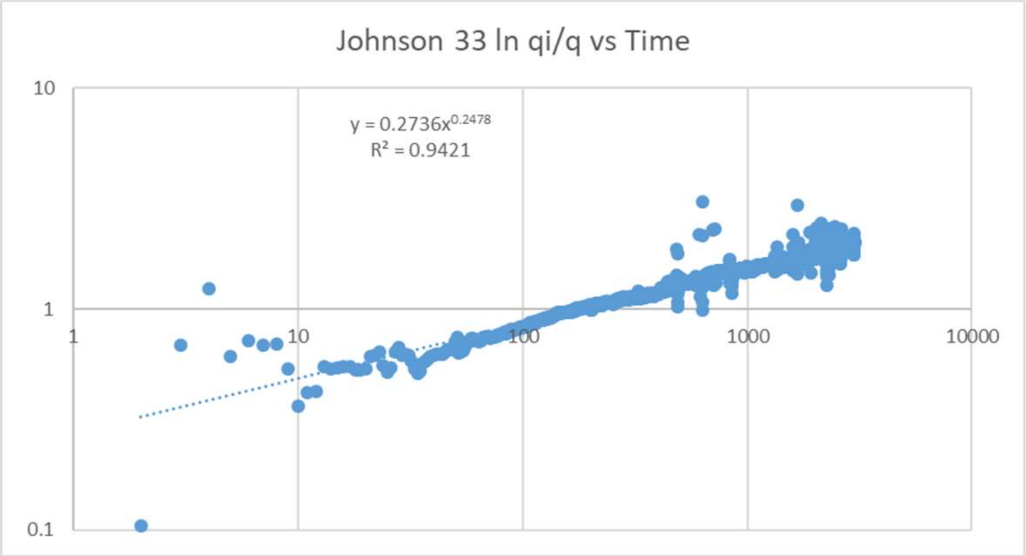
- **Reasons for production decline of Barnett shale gas wells**
  - Due to a shrinkage of viable space and the decrease of sweet spots, future drilling in the Barnett has been waning
  - Production analysis has found that older wells tend to have better decline performance than new wells
    - Likely due to poorer reservoir rock quality and well interface (well spacing and drainage area)

Decline Curve Analysis

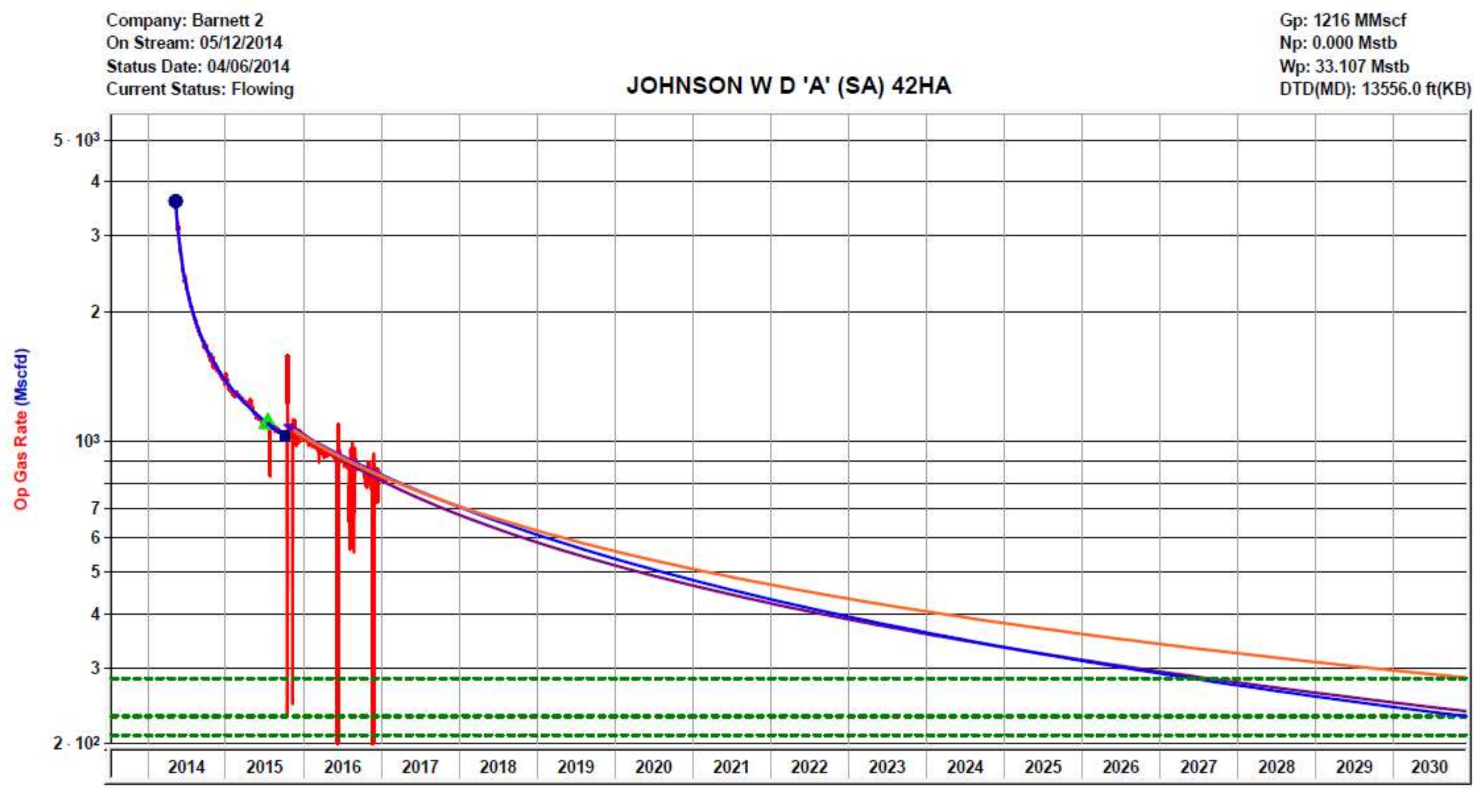
- **Curves Considered:**
  - Arps Equations – Exponential, Harmonic, Hyperbolic
  - Power-Law Exponential Method
  - Duong Method
  - Stretched-Exponential Production Decline
    - Known to be conservative prediction for decline models in tight formations
- **Best Fits:**
  - Stretched Exponential “Best Fit Whole”
    - Matched 5/5 target wells within P 50 range
    - Underestimates EUR
  - Stretched Exponential – with calculated values
    - Matched 4/5 target wells within P50 range
    - Overestimates EUR

Decline Curve Analysis

– **Stretched Exponential**
  - Calculated from Observed behaviors of q(t)
    - $q(t) = q_1 e^{-(\frac{t}{\tau})^n}$
  - n is found and τ is calculated
    - $\tau = e^{\frac{-\ln intersect}{n}}$
    - $\tau = (\frac{n}{D_i})^{\frac{1}{n}}$



Decline Curve Analysis



Curve Fit	EUR (MMSCF)	Qf (MSCFD)
Stretched Best Fit Whole	9629.0	10845.4
Stretched Calculated Values	5605.5	6821.9

Decline Curve Analysis

Conclusions:

- Duong's method is generally accurate for Barnett unconventional wells, especially in early production
- Stretched exponential produces similar results
- Hyperbolic and Harmonic decline (and b>1) are useful in modelling early flow regimes
- The stretched exponential model with calculated and best fit whole curves yielded realistic forecasts that agreed with RTA and the probabilistic analyses

RTA

Data

- Production Rates
- Langmuir Curves
- Pressure Data
  - Tubing
  - Casing
- Reservoir Data
  - Initial Pressure
  - Temperature
- Completion Design
  - Stages
  - Clusters

Analysis

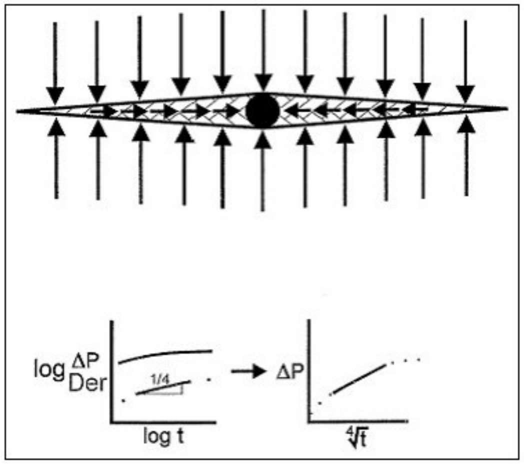
- Log-log rate vs. time
  - Flow regime
- Analytical Model:
  - Type curve
  - FMB
  - History matching
- Probabilistic Analysis:
  - Altered-case scenarios and their likelyhood

Results

- Reservoir Parameters:
  - OGIP
  - EUR
  - Permeability
  - A_{SRV}
  - Geomechanical influence
- Fracture Parameters:
  - x_f
  - F_{CD}
  - X_l

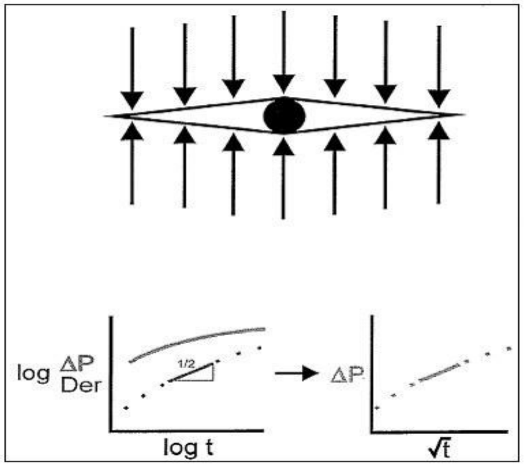
Background and Theory

Flow Regimes of Interest:



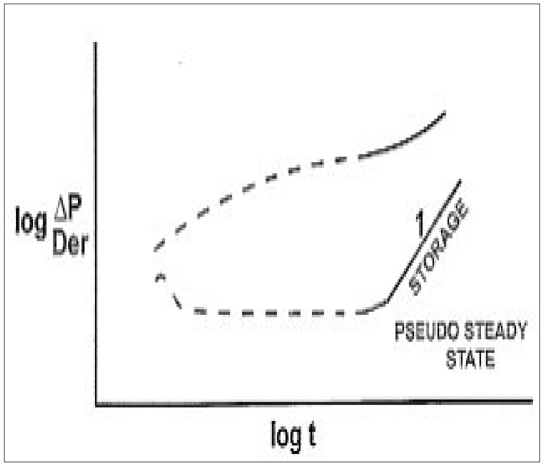
Bilinear Flow:

- ¼ slope
- Early flow
- Fracture drainage



Linear Flow:

- ½ slope
- Majority of flow
- Occurs after fractures have stabilized



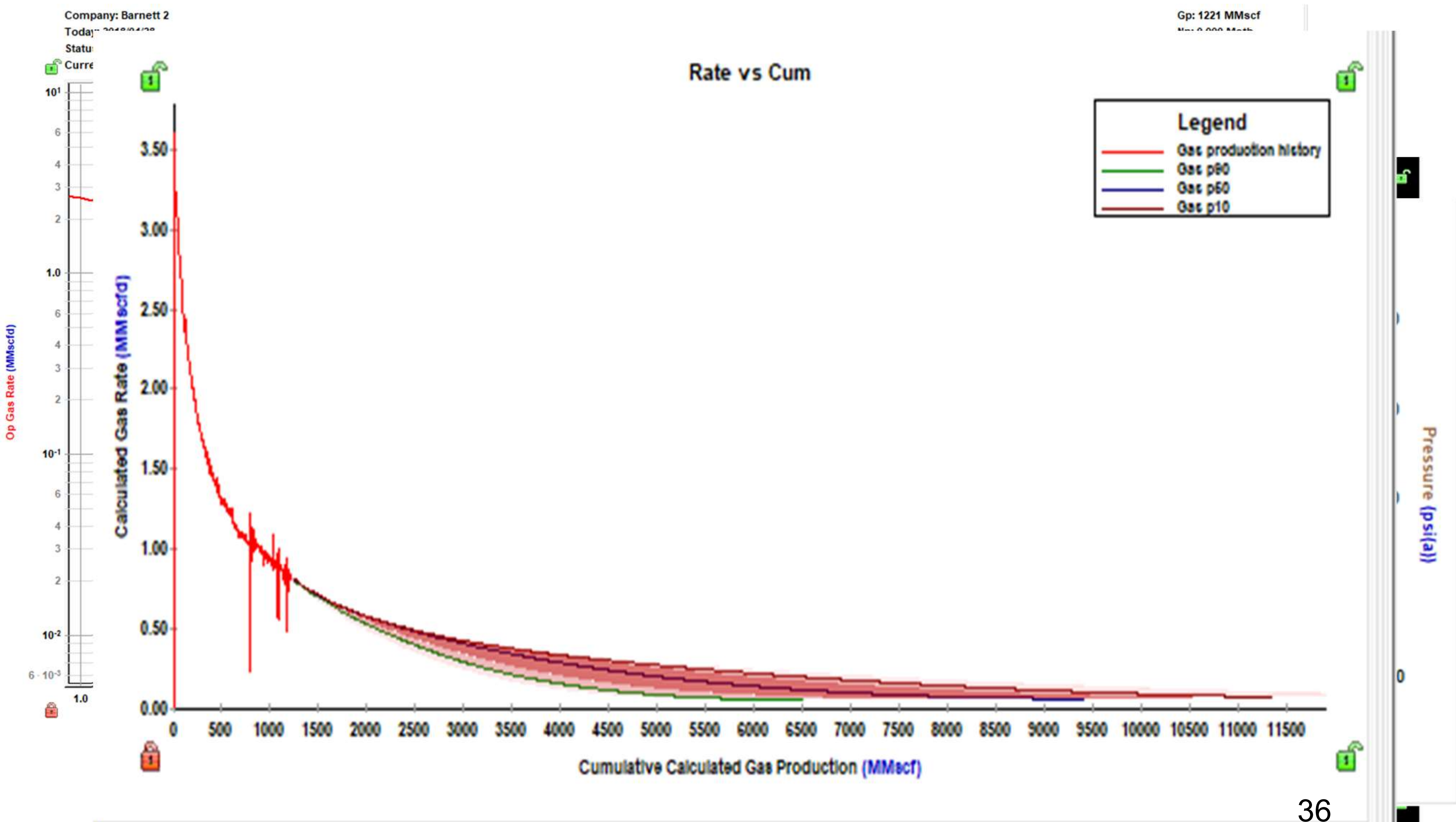
Boundary Dominated Flow:

- Unit slope
- Late flow
- Reservoir boundaries have been realized

**Can occur prevalently in naturally fractured systems or when $x_f > h_f$*

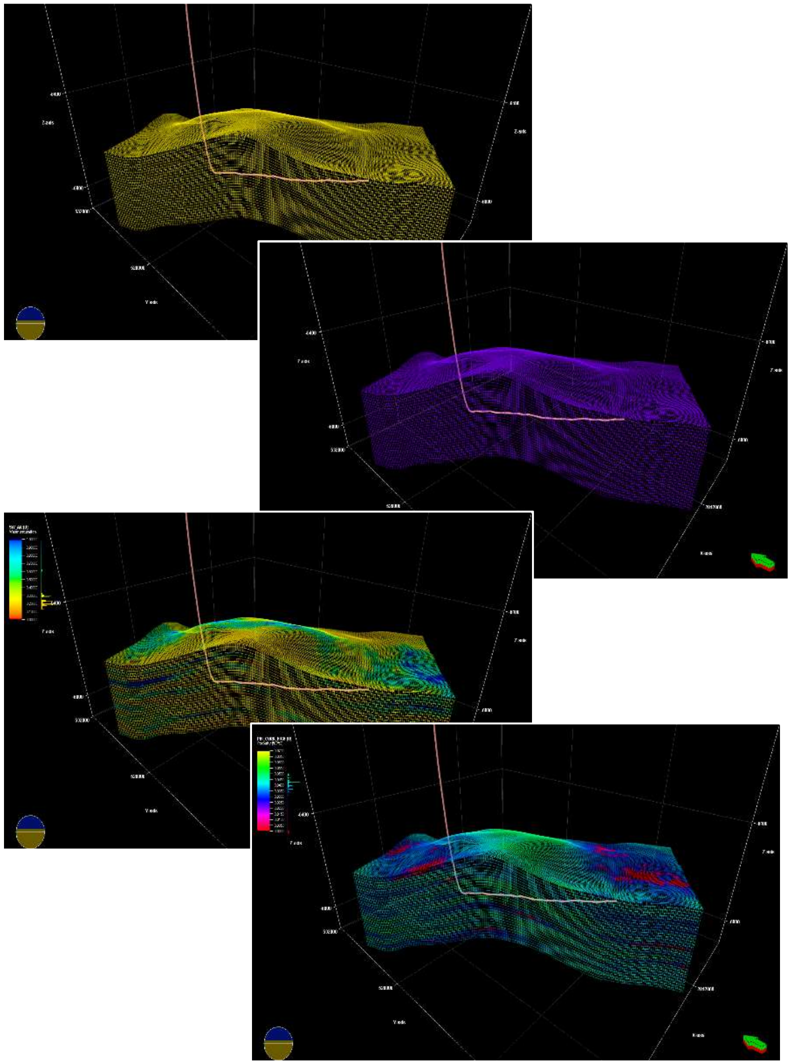
[1] Fekete.com

RTA: Johnson WD 'A' (SA) 42H



Well Spacing Optimization

Base Model



Base Properties:	
P_i (psia)	3500.0
k_m (nD)	350.0
S_w (%)	30.1
Φ (%)	4.0
F_{CD}	Gohfer
$X_{f,1/2}$ (ft)	Gohfer

Economic Viability

Acknowledgements

- We would like to thank Dr. Amirmasoud Kalantari Dahaghi
- Devon Energy for the provided data
- Schlumberger, IHS Harmony, Gohfer, CMG for providing academic licenses

Thank you!

References

1. J. Schmoker and T. Hester, "Organic Carbon in Bakken Formation, United States Portion of Williston Basin," *The American Association of Petroleum Geologists Bulletin,* vol. 67, no. 12, pp. 2165-2174, December 1983.
2. C. Sondergeld, K. Newsham, J. Comisky, M. Rice and C. Rai, "Petrophysical Considerations in Evaluating and Producing Shale Gas Resources," in SPE Unconventional Gas Conference, Pittsburg, PA, 2010.
3. G. Archie, "The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics," Society of Petroleum Engineers, Dallas, TX, 1941.
4. B. Zhang and J. Xu, "Methods for the evaluation of water saturation considering TOC in shale reservoirs," Journal of Natural Gas Science and Engineering, pp. 800-810, November 2016.
5. R. Loucks and S. Ruppel, "Mississippian Barnett Shale: Lithofacies and depositional setting of a deep-water shale-gas succession in the Fort Woth Basin, Texas," *The American Association of Petroleum Geologists Bulletin,* vol. 91, no. 4, pp. 579-601, April 2007.

Questions? Photoelectric Logging

- Measures the average atomic number of the elements in formation as the Photoelectric Effect (PE). Known PE values for common lithologies are generally very accurate.
- Usually combined with density for a Litho-density Log
- Photoelectric absorption coefficient (U) and photoelectric absorption of matrix rock (U_{MA}) can be calculated:

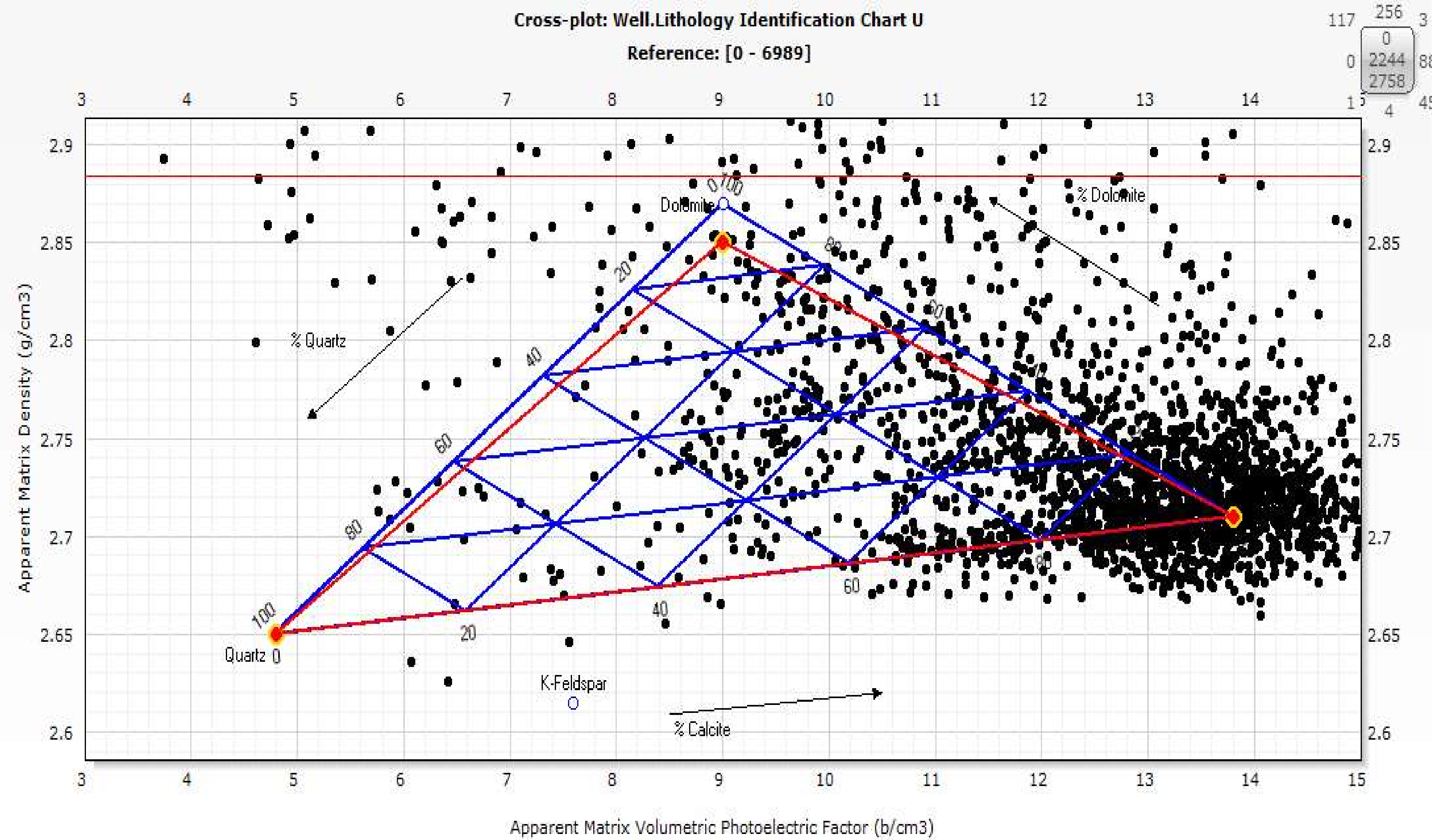
$$U = PE * RHOB$$

$$U = U_{MA} (1-PHIE-VSH)$$

- This U_{MA} can be plotted versus the apparent matrix density of known lithology types.

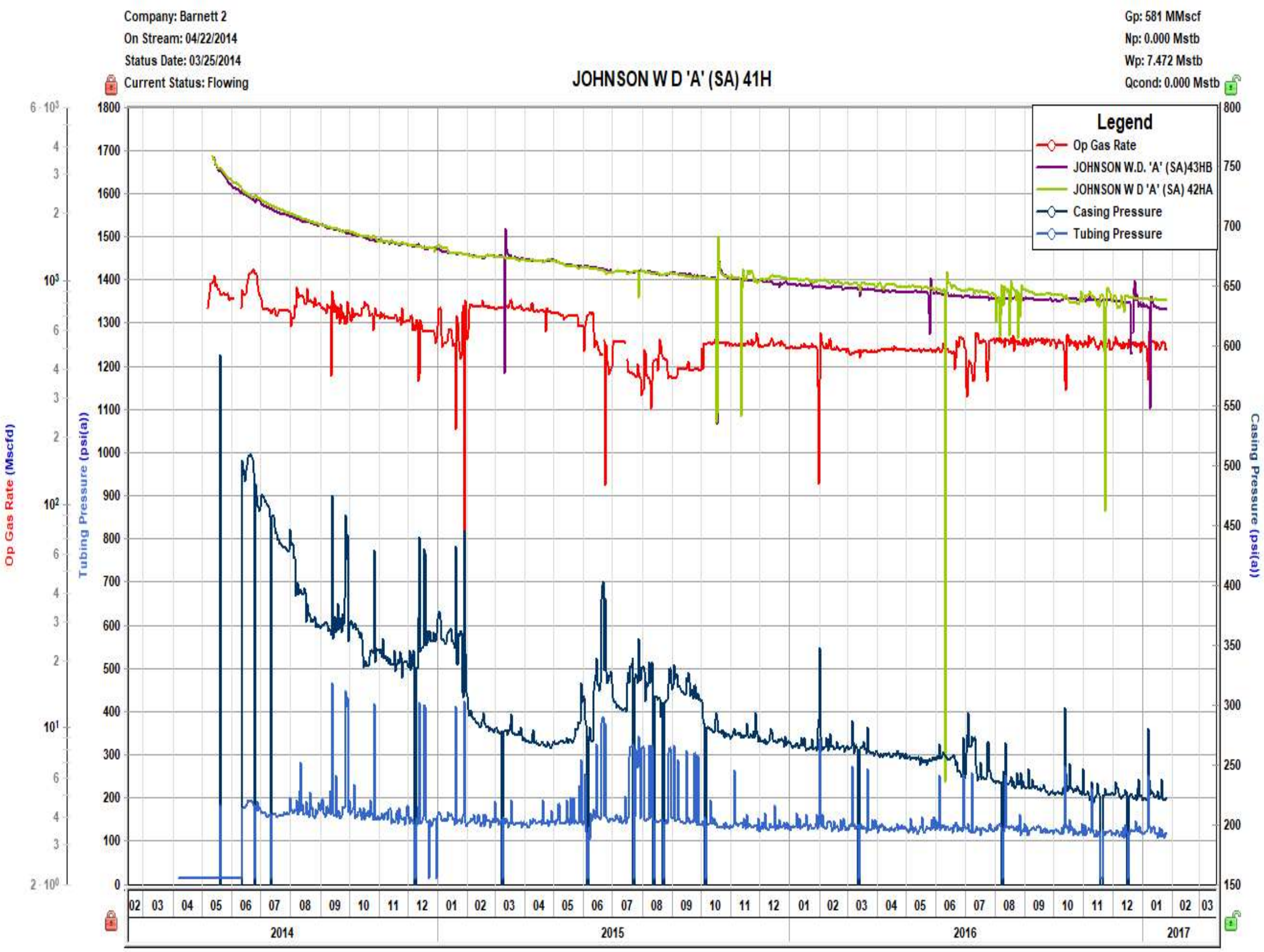
Source: Crain's Petrophysical Handbook (https://www.spec2000.net/13-lithpdn.htm)

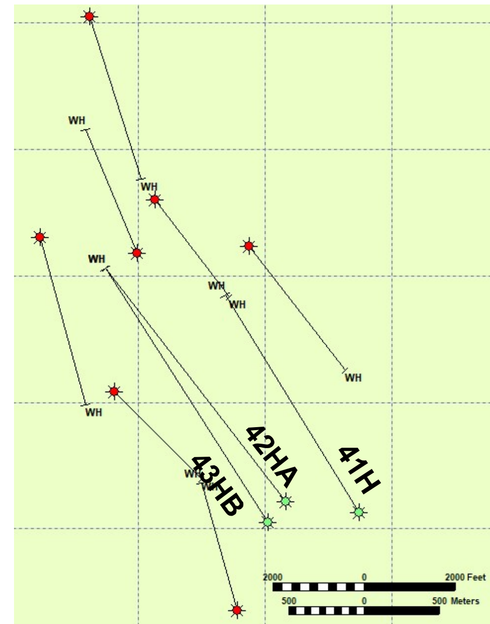
Questions? Photoelectric Logging



KU SCHOOL OF ENGINEERING
The University of Kansas

Johnson WD ‘A’ (SA) 41H





KU SCHOOL OF ENGINEERING
The University of Kansas