Evaluation and Application of Horizontal Granite Wash Well Performance Drivers into Completion and Fracture Stimulation Design*

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Abstract

Published studies identifying well performance drivers in Granite Wash reservoirs date back to the 1980s. Early Oklahoma Geological Survey studies investigating well performance drivers were reservoir quality focused with well log and pressure data sets from large scale vertical well development. Results usually indicated reservoir quality parameters as more critical than completion and stimulation practices. Development of more sophisticated logging tools and analysis enabling better reservoir property evaluation in the complex fluid and mineralogy systems of the Granite Wash led to another phase of studies, mostly published by SPE, with the objective of identifying the impact of various reservoir and completion performance drivers. By this time stimulation diagnostics, modeling techniques, and stimulation products and an understanding of product performance had further evolved. These studies often indicated that performance was largely reservoir driven with influence from completion and stimulation.

Rapid Granite Wash economy of scale development with multi-stage hydraulic fractured horizontal wells followed the horizontal gas shale revolution. Similar to large source rock resource play evaluations, large sample size correlations of production and completion parameters were used to determine well performance drivers of completion and stimulation techniques and materials. Often this approach did discover loosely correlating common themes, but failed to produce definitive results outside small geographic and stratigraphic confines. Production results in the Granite Wash were simply not repeatable as were in gas shale where local optimized completion and stimulation designs were applied on a large scale. Naturally the quest for the best completion and stimulation blueprint had to be condensed to smaller sample sets with similar reservoir properties. This presentation reviews the results of those efforts and examines both where and why correlations occur and fail, and proposes techniques for improving well performance on individual wells and well groups in isolated fields and benches.

References Cited

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Ingram, S., I. Paterniti, R. Pauls, B. Rothkopf, C. Stevenson, and J. Conner, 2007, Enhancing and Sustaining well Production: Granite Wash, Texas Panhandle: Society of Petroleum Engineers, SPE 106351.

Ingram, S., I. Paterniti, B. Rothkopf, and C. Stevenson, 2006, Granite Wash Field Study - Buffalo Wallow Field, Texas Panhandle: Society of Petroleum Engineers, SPE 104546.

Lee, Y., and D. Deming, 2001, Overpressures in the Anadarko Basin, Southwestern Oklahoma: Static or Dynamic?: Oklahoma Geological Survey Circular 106, p. 133-150.

Oberwinkler, Ruthammer, and Zangl, 2004, New Tools for Fracture Design Optimization: Society of Petroleum Engineers, SPE-86467.

Rothkopf, B., D.J. Christiansen, H. Godwin, and A.R. Yoelin, 2011, Texas Panhandle Granite Wash Formation: Horizontal Development Solutions: Society of Petroleum Engineers, SPE 146651.

Shelley, R., P.O. Scheurerman, C. Talley, and P.W. Smith, 2001, Analysis of Completions/Stimulation Practices on Red Fork Recovery in the Anadarko Basin Using Artificial Neural Systems: Oklahoma Geological Survey Circular 104, p. 65-70.

Shelley, R.F., and W.V. Grieser, 1999, Artificial Neural Networks Enhanced Completions Improve Well Economics: Society of Petroleum Engineers, SPE 52959.

Shelley, R.F., P. Scheuerman, D.R. Massengill, P.E. McRill, and R. Hamilton, 1998, Granite Wash Completion Optimization with the Aid of Artificial Neural Networks: Society of Petroleum Engineers, SPE 39814.

Smith, P.W., W.J. Hendrickson, and R.J. Woods, 2001, Comparison of Production and Reservoir Characteristics in Granite Wash Fields in the Anadarko Basin: Oklahoma Geological Survey Circular 106, p. 19-27.

Srinivasan, K., B. Dean, M. Belobraydic, and Z. Azmi, 2013, Evolution of Hydraulic Fracturing in the Granite Wash - Understanding Performance Drivers: Society of Petroleum Engineers, SPE 163857.

Srinivasan, K., B. Dean, W. Lam, M. Belobraydic, B.D. Strickland, D.L., Purvis, S.A. Cox, J.C. Brinska, and R.D. Barree, 2003, Analysis of Stimulation Effectiveness in the Ammo Field Granite Wash Based on Reservoir Characterization and Completion Database: Society of Petroleum Engineers, SPE 80893.

Srinivasan, K., B. Dean, I. Olukoya, and Z. Azmi, 2011, An Overview of Completion and Stimulation Techniques and Production Trends in Granite Wash Horizontal Wells: Society of Petroleum Engineers, SPE 144333.

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Schlumberger

Granite Wash and Pennsylvanian Sand Forum

25 September 2014 | Oklahoma City, Oklahoma, United States

Introduction

- Production and Stimulation/Completion Correlations in the Granite Wash
  - SPE 144333, 2011
  - SPE 163857, 2012

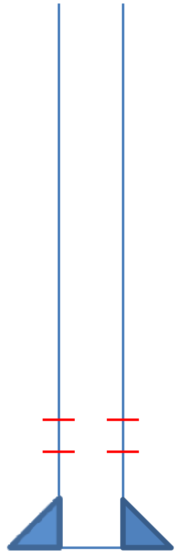
- Motivation
  - Prior studies (1998-2009) only vertical well development
  - Few published works on completion/stimulation & well performance on Granite Wash horizontal wells
  - Numerous published works on completion/stimulation & well performance in resource plays, most in gas shale; workflows established
  - Formulate solid base designs & gain knowledge of practices and results

Outline

- Historical Studies
  - Vertical well development
  - 1998-2009
  - Geological and reservoir emphasis
  - Completion/Stimulation content
- Historical Studies
  - Horizontal wells
  - 2009-2013
  - Completion/Stimulation emphasis
- Completion/Stimulation and Production Correlations
  - Initially large scale (SPE 144333)
  - Later refined to smaller and normalized sample sizes (SPE 163857)
- Recurring Themes
- Moving Forward

Historical Studies

- Oklahoma Geological Survey, Circular 104, 2001
  - Shelley, Smith, Scheuerman, Talley
  - Halliburton, I.H.S
  - Roger Mills & Custer Co., Red Fork
  - Artificial Neural System (ANN)

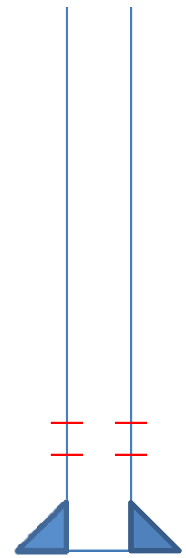


- Conclusions
  - Production is predictive with ANN *when reservoir parameters definable*
  - ANN application for optimizing completion/stimulation can enhance production and identify best opportunities
  - ANN alone is not a replacement for individual well conventional engineering methods

Shelley, R., Scheurerman, P.O., Talley, C., Smith, P.W., 2001, Analysis of Completions/Stimulation Practices on Red Fork Recovery in the Anadarko Basin Using Artificial Neural Systems; Oklahoma Geological Survey Circular 104, 2001. p. 65-70

Historical Studies

- Oklahoma Geological Survey, Circular 106, 2001
  - Smith, Hendrickson, Woods
  - Geologic Data Services
  - Texas Panhandle
  - Granite Wash; Marmaton, Red Fork, Skinner, Prue
  - Reservoir centric study; h, Φ, Sw, Pr



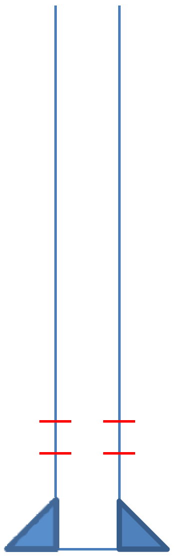
- Conclusions
  - Thickness most influential (EUR)
  - Spacing >= 80 acre often does not show pressure depletion influence, and can be >=40 acres for some reservoirs
  - Along with paper by of Lee & Deming (U. Oklahoma), suggests vertical and lateral compartmentalization

Smith, P.W., Hendrickson, W.J., Woods, R.J., 2001,Comparison of Production and Reservoir Characteristics in Granite Wash Fields in the Anadarko Basin; Oklahoma Geological Survey Circular 106, 2001. p. 19-27

Lee, Y. Deming, D., Overpressures in the Anadarko Basin, Southwestern Oklahoma: Static or Dynamic?. Oklahoma Geological Survey Circular 106, 2001. p. 133-150

Historical Studies

- SPE 39814, 1998
  - Shelley, Scheuerman, Massengill, McRill, Hamilton
  - Pioneer Natural Resources, Halliburton
  - Roberts Co., TX Granite Wash, Desmoinsian
  - Artificial Neural Networks (ANN)
  - Investigate reservoir quality & completion impact on production



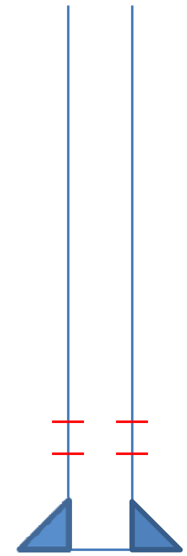
- Conclusions
  - Gas production is dominated by 1 of 3 pay intervals in the gross thickness
  - Water production is dominated by 1 of 3 pay intervals with low gas potential and can be avoided by completion/stimulation method
  - Cleaner gel systems with low to moderate viscosity Frac fluids and use of CO_2 aids production (Frac cleanup)
  - Consistent with a later paper, SPE 52959, using ANN completion designs, more proppant at higher concentrations is not a simplified solution. Smaller treatments if well designed can be as or more effective

Shelley, R.F., Scheuerman, P., Massengill, D.R., McRill, P.E., Hamilton, R. SPE 39814. Granite Wash Completion Optimization with the Aid of Artificial Neural Networks. 1998. Society of Petroleum Engineers

Shelley, R.F., Grieser, W.V. ,SPE 52959. Artificial Neural Networks Enhanced Completions Improve Well Economics. 1999. Society of Petroleum Engineers

Historical Studies

- SPE 80893, 2003
  - Strickland, Purvis, Cox, Brinska, Barree
  - BJ Services (Now Baker), Marathon Oil Co., Barree & Assoc.
  - Washita Co. OK, Granite Wash
  - Correlate Production with Completion Practices & Reservoir Quality

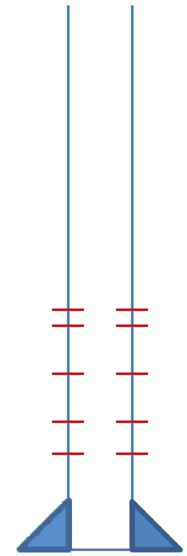


- Conclusions
  - Frac height (Hf) barriers exist in conglomerate layers, not just shale
  - Effective Frac lengths (Xf) often < half design Xf
  - Stimulation parameter Frac length correlates to production with normalized reservoir quality (RQ)
  - Overall, area production is reservoir quality, not completion quality dominant, but completion/stimulation can impact average RQ wells
  - Treatment fluid and proppant selections can impact well performance in average RQ wells
  - Every case is a bit different and requires optimization on well level

Strickland, B.D., Purvis, D. L., Cox S.A., Brinska, J.C., Barree, R.D., SPE 80893. Analysis of Stimulation Effectiveness in the Ammo Field Granite Wash Based on Reservoir Characterization and Completion Database. 2003. Society of Petroleum Engineers

Historical Studies

- SPE 104546, 2006
  - Ingram, Peterniti, Rothkopf, Stevenson
  - Forest Oil, Halliburton
  - Hemphill Co., Granite Wash
  - Correlate Production with Completion Practices
  - High Rate WaterFracs



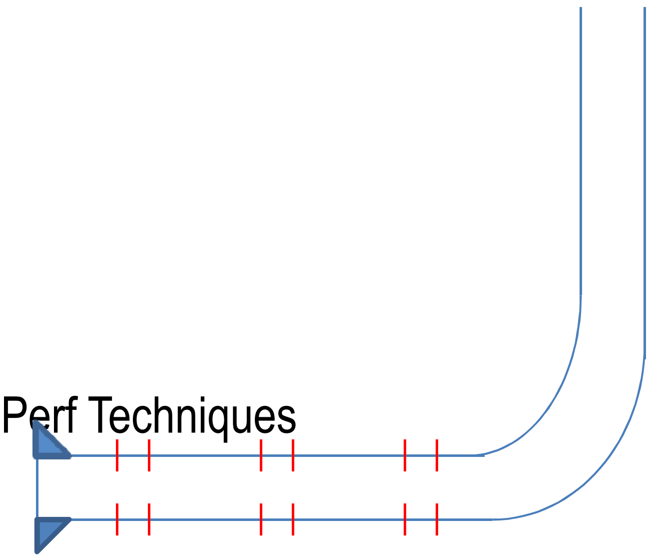
- Conclusions
  - Early (IP) and later term (60 day+) correlations vary
  - Higher rate treatments yield higher IP, but not always higher longer term production
  - Fluid volume/ft correlates best, with exceptions
  - Prop mass/ft correlates as well, but not as strong as fluid
  - Net pay is not well defined with logs & interpretation in many cases
  - Follow up paper, SPE 106531, showed that fluid chemistry for minimizing damage and aiding Frac fluid cleanup in low permeability high capillary pressure rock improved well performance

Ingram, S., Paterniti, I., Rothkopf, B., Stevenson, C., SPE 104546. Granite Wash Field Study-Buffalo Wallow Field, Texas Panhandle. 2006. Society of Petroleum Engineers

Ingram, S., Paterniti, I., Pauls, R., Rothkopf, B., Stevenson, C., Conner, J. SPE 106351. Enhancing and Sustaining well Production: Granite Wash, Texas Panhandle. 2007. Society of Petroleum Engineers

Historical Studies

- SPE 138445, 2010
  - Edwards, Braxton, Smith
  - Jones Energy
  - Hemphill & Roberts Co. TX, Granite Wash
  - Compare OH-Packer-Sleeve and Cemented Plug & Perf Techniques



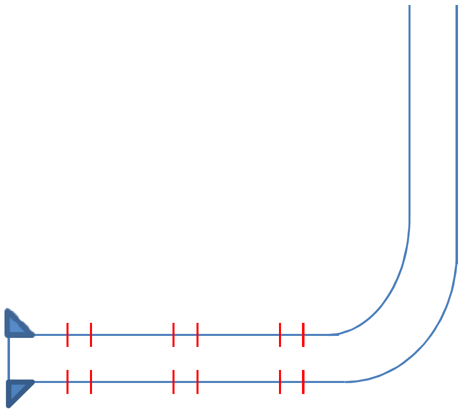
- Conclusions
  - OH system outperform cemented Plug & Perf by 33% (6 & 12 mos)
  - OH system saves completion cost
  - OH system may limit number of created fractures and WB-Fracture contact points
  - In certain stress conditions, magnitude and anisotropy, OH system may inhibit desired fracture growth and/or placement success

Conclusions suggest Perf & Plug technique through multiple clusters may have efficiency issues

Edwards, W.J., Braxton, D., Smith, V. SPE 138445. Tight Gas Multistage Horizontal Completion Technology in the Granite Wash. 2010. Society of Petroleum Engineers

Historical Studies

- SPE 146651, 2011
  - Rothkopf, Christiansen, Godwin, Yoelin
  - Forest Oil Co.
  - TX Panhandle, Granite Wash
  - Evaluate Horizontal Plug & Perf Technique Completions



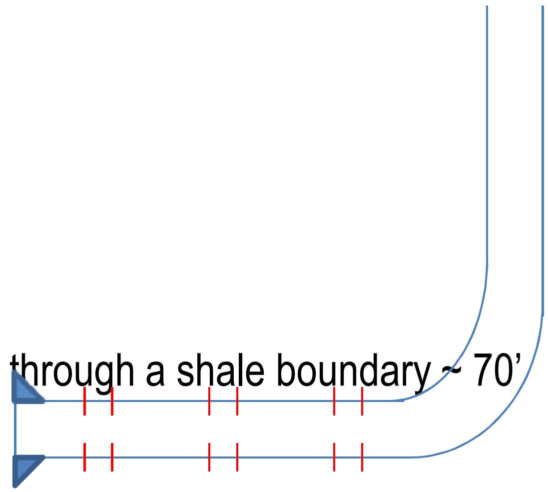
- Conclusions
  - Horizontal well multi-stage, multi-cluster/stage completions have similar production as a series of vertical wells with similar completions in terms of proppant placed per Frac
  - Perforation cluster inefficiency within a stage is evident, but not simply attributed to V-qtz, clay, etc
  - An EUR practical limit to number of fractures in a lateral exists, and it approaches 20 acre spacing (16 Fracs)
  - Closer cluster spacing, on the order of 10 acre spacing (30 to 40 Fracs), can accelerate production by factors of 1.5 to 2 in early years, without much EUR benefit
  - Linear flow interference between fractures occurs early in well life

Conclusions state Perf & Plug technique through multiple clusters has efficiency issues and clusters possibly tighter spaced than necessary in standard completions

Rothkopf, B., Christiansen, D.J., Godwin, H., Yoelin, A.R., SPE 146651. Texas Panhandle Granite Wash Formation: Horizontal Development Solutions. 2011. Society of Petroleum Engineers

Historical Studies

- SPE 164496, 2013
  - Crawford, Tehan, Launhardt
  - Linn Energy, Pinnacle Technology (Halliburton)
  - TX Panhandle, Granite Wash, Cherokee
  - Evaluate frac height and multiple layer connection to laterals through a shale boundary ~ 70'



- Conclusions
  - Stacked laterals show little hydraulic Frac pressure communication and incidences of slight pressure communication occur up, not down through the shale boundary
  - Where pressure communication does occur, it is isolated and repeatable in short lateral section
  - Microseismic agrees with pressure data, only isolated hydraulic frac height communication through the shale in short lateral section
  - When reducing post Frac leakoff time between upper & lower lateral stages with zipper Frac technique, greater microsiesmic Frac height development across boundary layer observed
  - Post Frac tracer analysis indicates some communication between layers early, that rapidly dissipates on production
  - Areas of prolonged tracer cross flow associated with close vertical wells in completed in both layers
  - Multiple stacked laterals required to adequately drain both layers

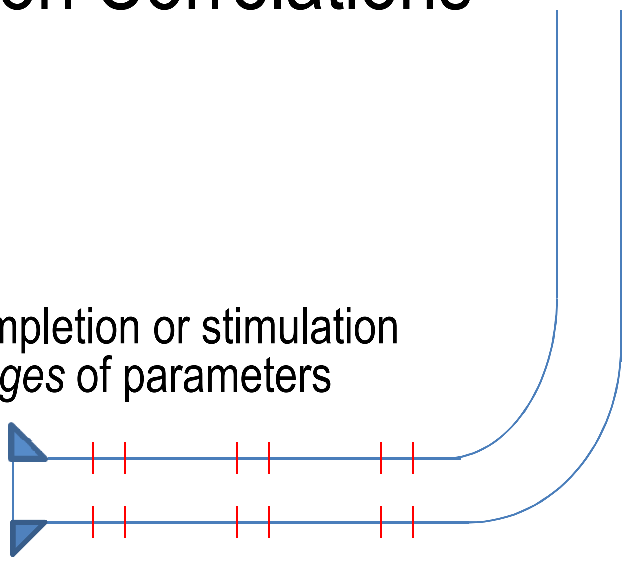
Conclusion suggests that increasing stress in target layers raises the stress closer to that of boundary layer, making it a less effective Frac boundary.

Conclusions also suggest that even if the boundary breached, if not well propped, heals.

Crawford, E.M., Tehan, B., Launhardt, B., SPE 164496. Examination of Treatment Connectivity between Granite Wash Layers Using Microseismic, Tracer and Treatment Data. 2013. Society of Petroleum Engineers

Production and Stimulation/Completion Correlations

- SPE 144333, 2011, Schlumberger
  - 2 large datasets, 1 TX, 1 OK
  - Missourian & DesMoinesian
  - Determine if well performance correlates with any completion or stimulation parameters on a basin scale. Determine optimum *ranges* of parameters
  - No reservoir quality input
  - Completion/Stimulation Parameters
    - Lateral length
    - Number of Frac stages
    - Frac stage length
    - Lateral length normalized Frac fluid volume
    - Lateral length normalized proppant mass
    - Average proppant concentration
  - Production data
    - All public. Monthly Gas & Oil (condensate). No water in dataset
    - Average of best 3 (B3) months correlates with shorter term (max month) and longer term trends (B6, B12, B24) and provides larger sample size



Production and Stimulation/Completion Correlations

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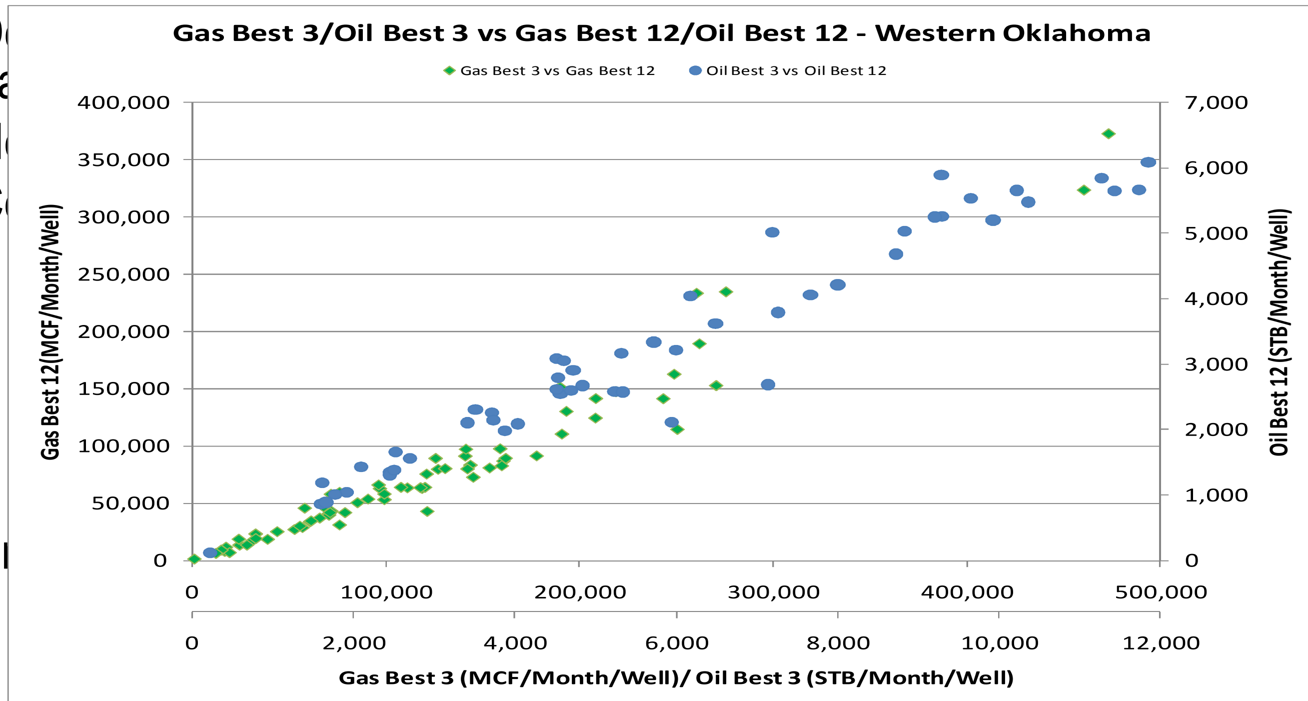
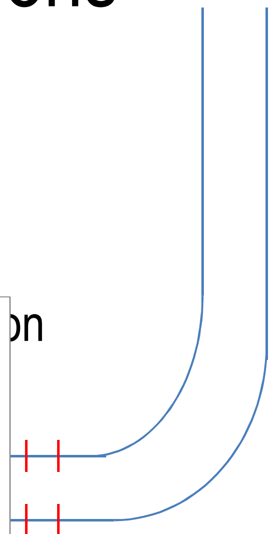
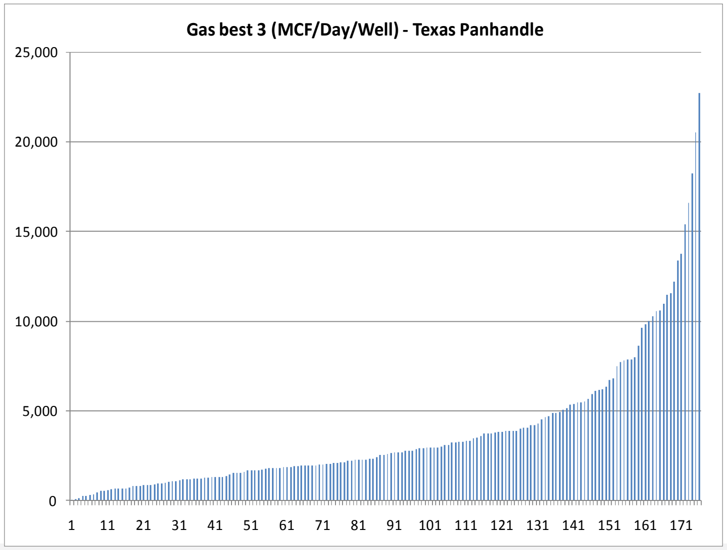


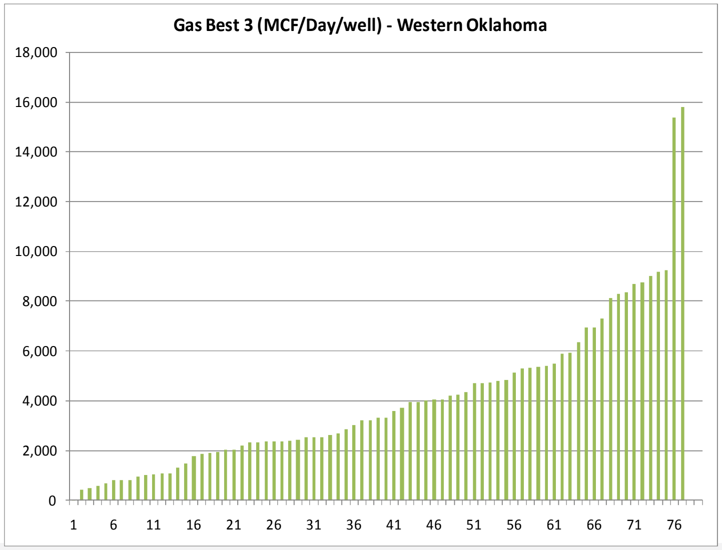


  - Pr... m trends

Production and Stimulation/Completion Correlations

- SPE 144333, 2011: Process
  - Organize B3 oil & gas producers in order, lowest to highest B3 gas
    - Technique first used by Fan, Thompson, . Grant, R. B. Martin, K. T. Kanneganti, G. J. Lindsay. 2010. *An Overview of Horizontal Well Completions in the Haynesville Shale*. Paper SPE-136875

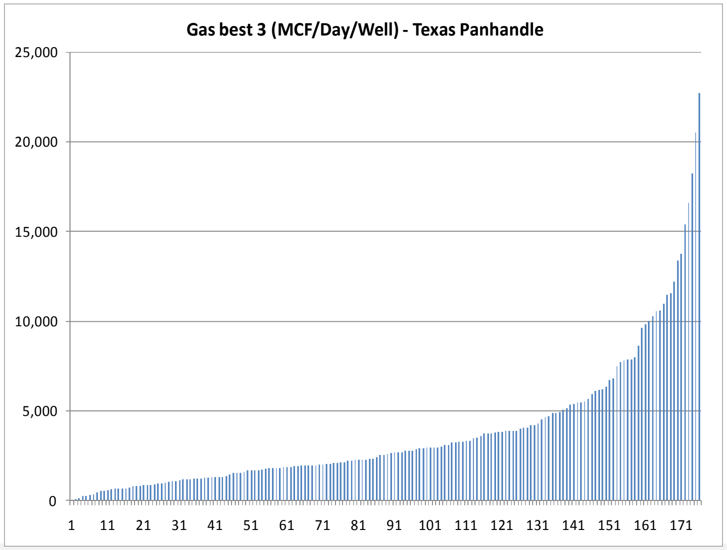


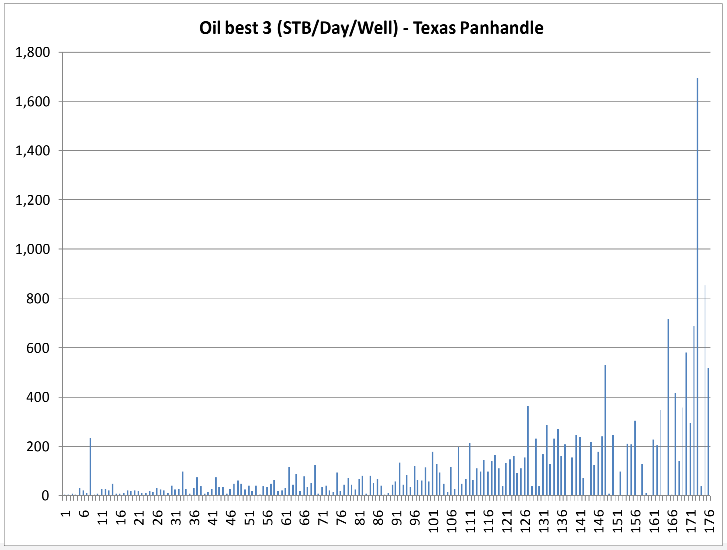


Production and Stimulation/Completion Correlations

- SPE 144333, 2011: Process
  - Retain producer order in completion/stimulation parameter plots
  - Manual analysis

Oil & Gas production show general correalation

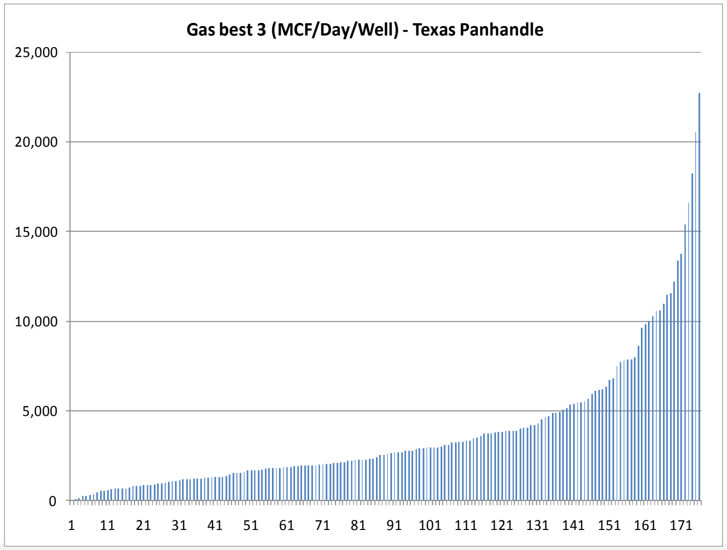


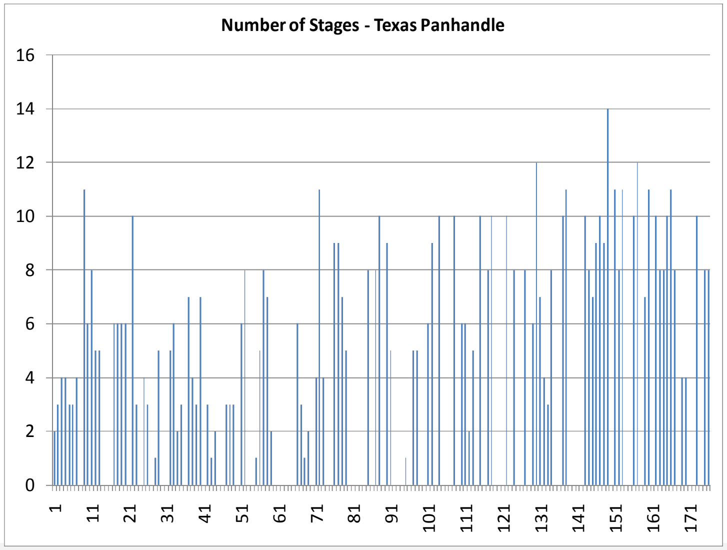


Production and Stimulation/Completion Correlations

- SPE 144333, 2011: Process
  - Retain producer order in completion/stimulation parameter plots
  - Manual analysis

Poor number of stages correlation





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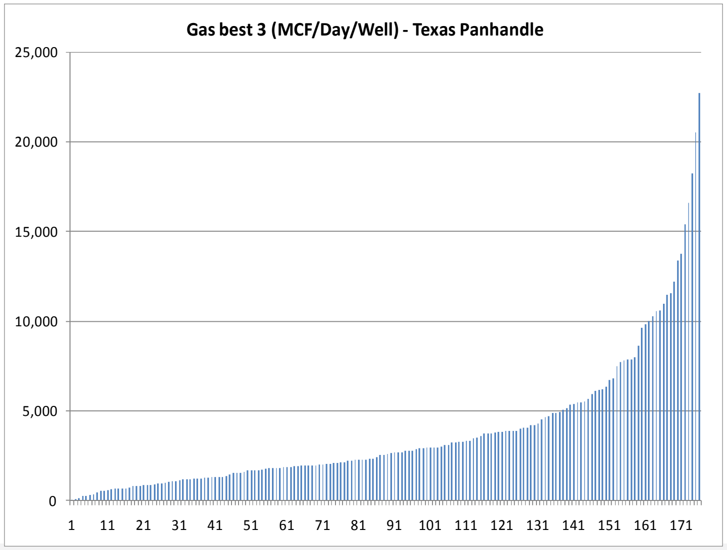
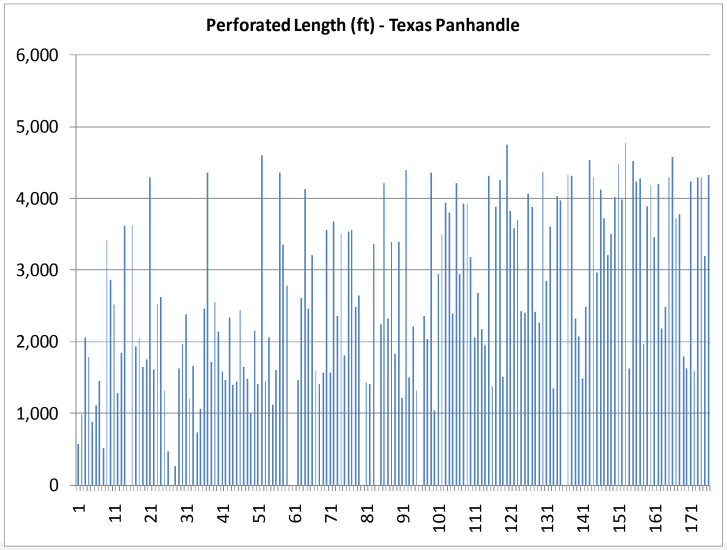
Production and Stimulation/Completion Correlations

- SPE 144333, 2011: Process
  - Retain producer order in completion/stimulation parameter plots
  - Manual analysis

Poor lateral length correlation

Overall, these poor correlations continue with Frac materials, both in TX & OK wells





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Production and Stimulation/Completion Correlations

- SPE 144333, 2011: Process
  - Utilize alternate technique, unsupervised neural network plotted in 2 dimensions on a self organized “cluster” map (SOM)
    - Technique also used in a publication by Fan, Thompson, . Grant, R. B. Martin, K. T. Kanneganti, G. J. Lindsay. 2010. *An Overview of Horizontal Well Completions in the Haynesville Shale*. Paper SPE-136875
    - Technique developed and first used by Oberwinkler, Ruthammer, Zangl, Economides. 2004. *New Tools for Fracture Design Optimization*. Paper SPE-86467
    - Reduces the noise of multiple single parameter 2D plots with inter-related parameters
    - No attempt to match an output, such as cumulative production

Production and Stimulation/Completion Correlations

TX Results

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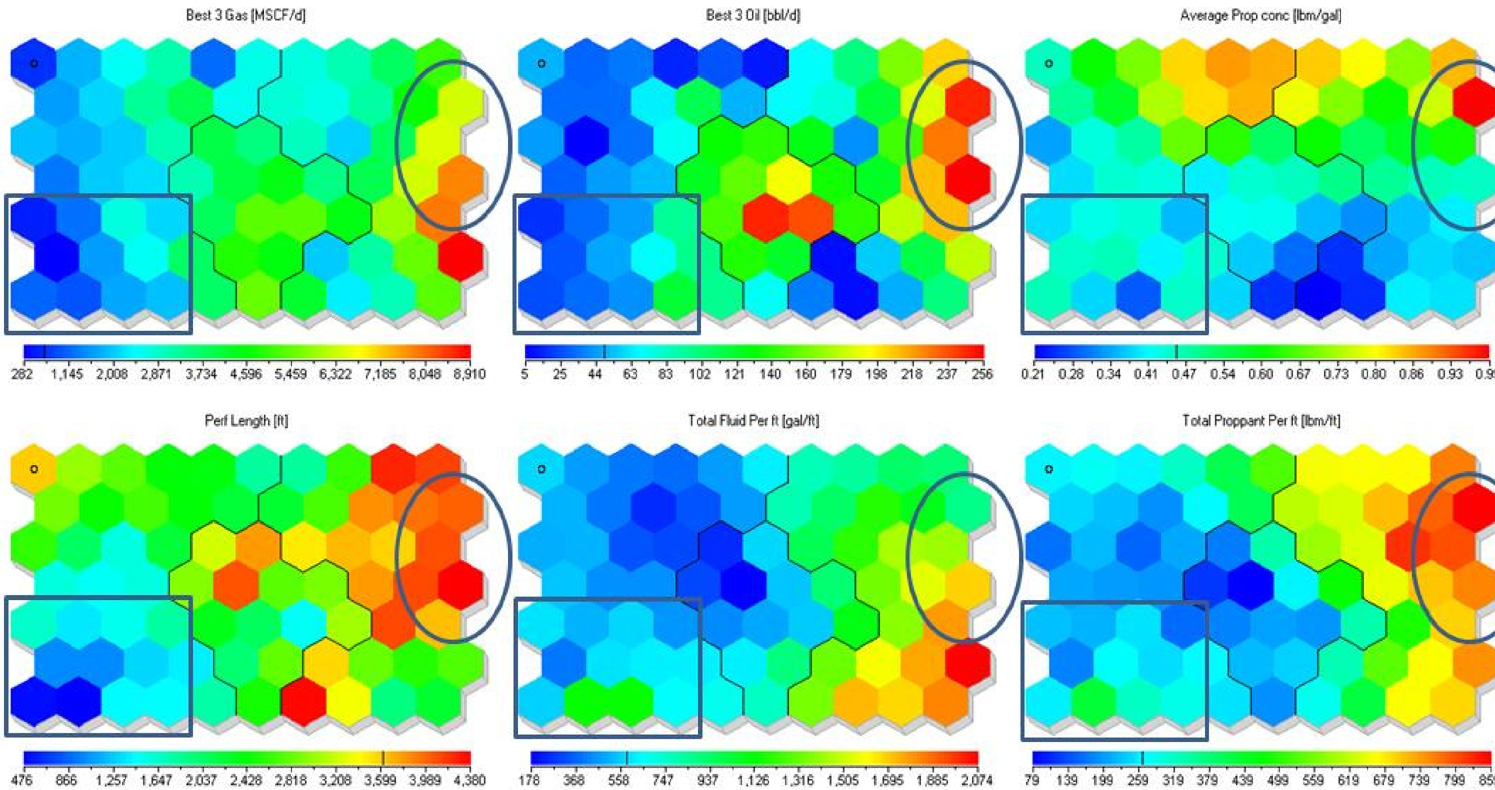

4.

Parameter	Lower Range	Upper Range
Average proppant Concentration (ppg)	0.54	0.99
Total Proppant per unit lateral length (lbs/ft)	740	840
Total Clean Fluid per unit lateral length (gallons/ft)	750	1650
Perforated Lateral Length (ft)	3890	4380

Production and Stimulation/Completion Correlations

OK Results

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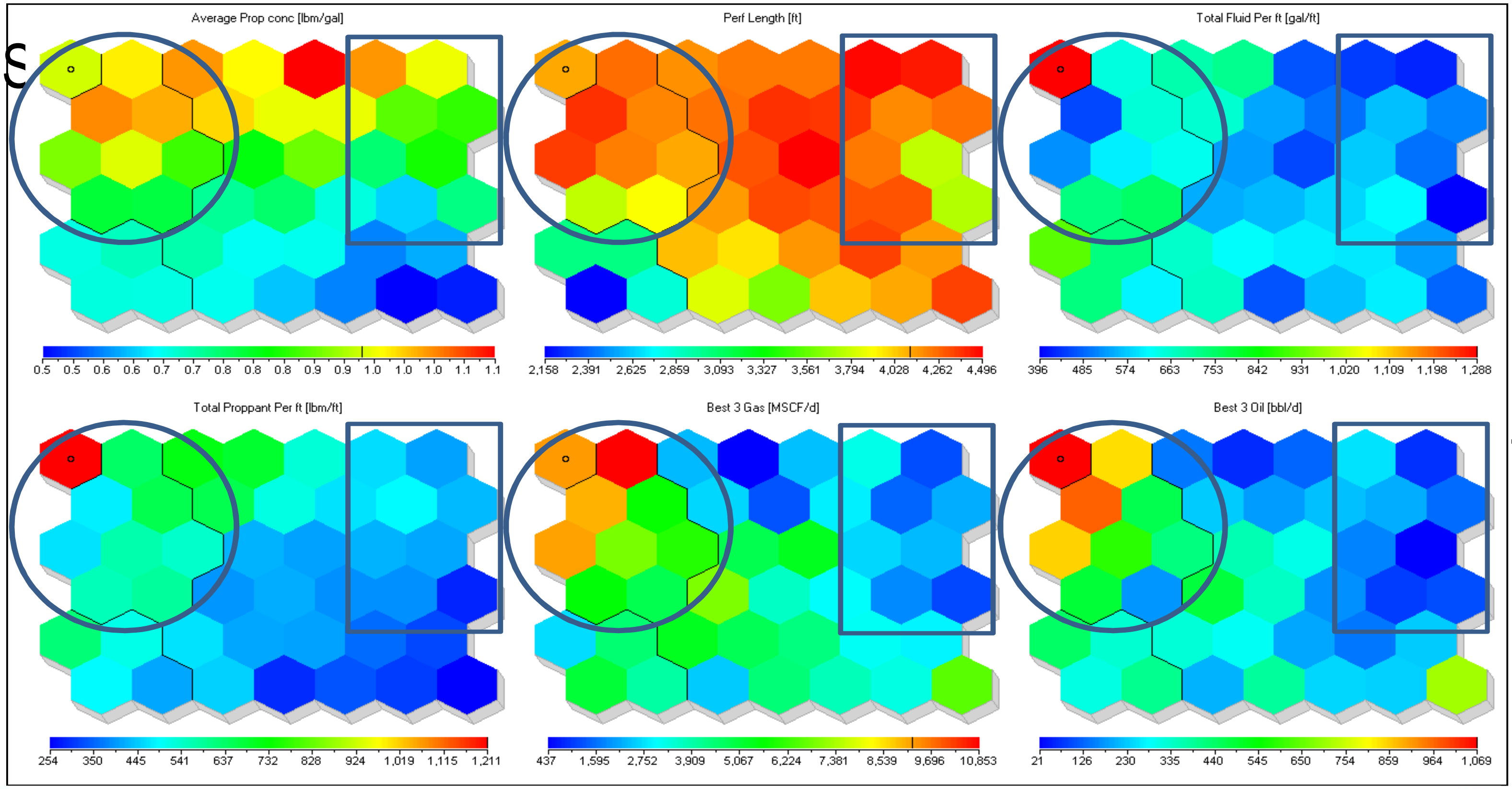
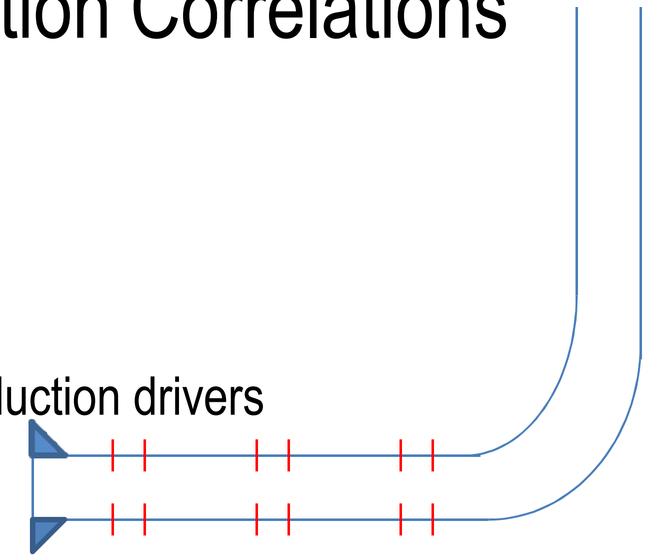


Parameter	Lower Range	Upper Range
Average proppant Concentration (ppg)	0.9	1.0
Total Proppant per unit lateral length (lbs/ft)	500	1250
Total Clean Fluid per unit lateral length (gallons/ft)	400	1200
Perforated Lateral Length (ft)	4100	4300

Production and Stimulation/Completion Correlations



- Conclusions; TX Panhandle B3 Gas
  - Simple cross-plot analysis does not reveal production drivers
  - Oil rate is related to gas rate
  - SOM results in OK
    - Lateral length and proppant mass correlates with better wells
    - Number of stages correlates with lateral length
    - Wide range of values for total fluid and proppant concentration

Results suggest is does not matter how you place the proppant, but how much.

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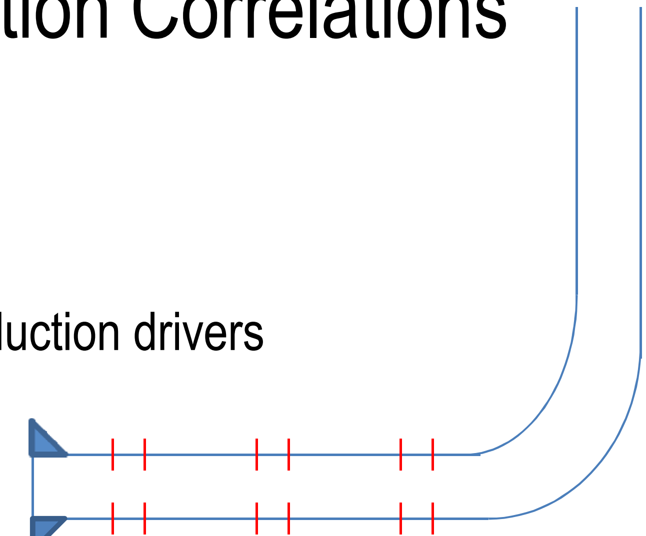
Production and Stimulation/Completion Correlations



- Conclusions; Western OK B3 Gas
  - Simple cross-plot analysis does not reveal production drivers
  - Oil rate is related to gas rate
  - SOM results in OK
    - Narrow and high end range of values for proppant concentration, yet a weaker total proppant correlation than in TX
    - Total fluid does not correlate except in cases of the worst wells

Results suggest more reservoir quality dependency than in TX, with shorter and more conductive Fracs effective.

In both areas, TX & W. OK, resulting parameter ranges are wide and require reservoir quality and narrower scope for completion/stimulation optimization. Unlike thick gas shale resource plays, no “recipes” discovered by the process, only some general ideas on a few parameters..

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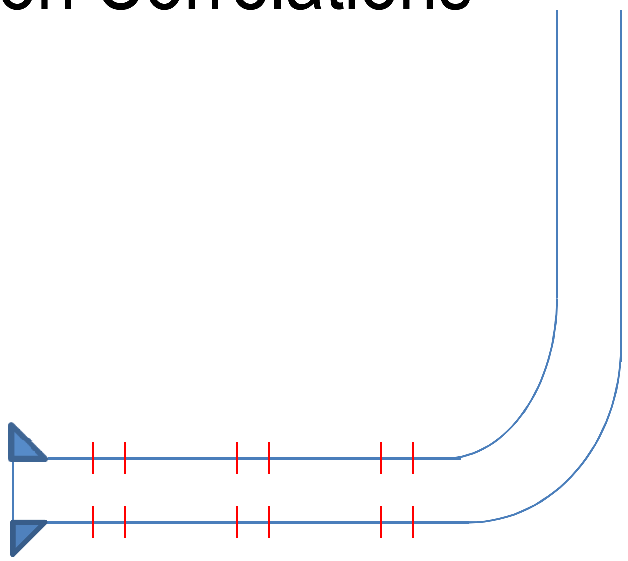
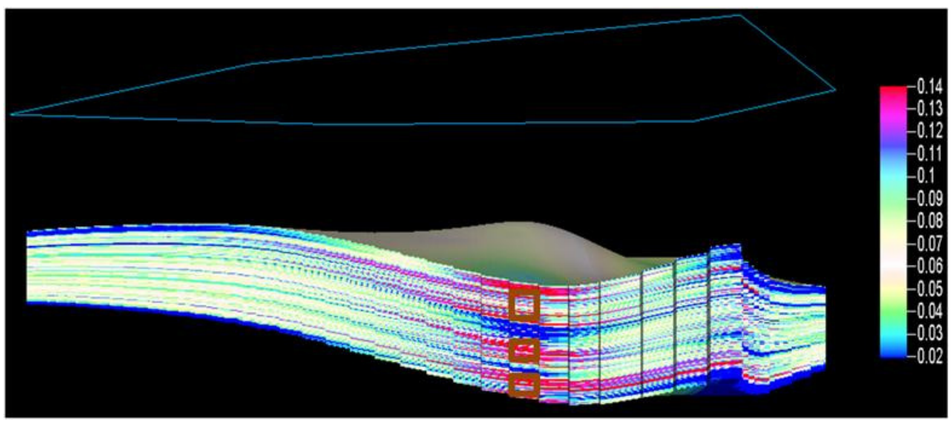
Production and Stimulation/Completion Correlations

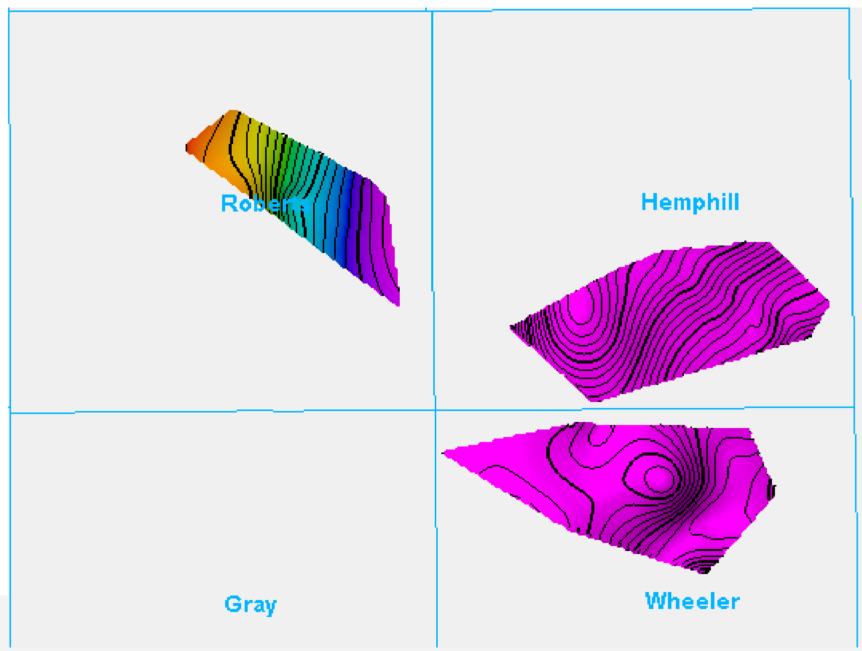
- SPE 163857, 2012, Schlumberger
  - Larger dataset than SPE 144333
  - TX Panhandle
  - Field subsets
  - Bench subsets
    - SS Depth
    - Gross, pay and non-clay Thickness
    - GOR
    - 84 public well triple combo Geomodel
  - Reservoir parameters
    - Porosity
    - Computed Sw
    - Computed perm
  - Completion/Stimulation Parameters
    - Lateral length
    - Number of Frac stages
    - Frac stage length
    - Lateral length normalized Frac fluid volume
    - Lateral length normalized proppant mass
    - Average proppant concentration
  - Production data
    - All public. Monthly Gas & Oil (condensate). No water in dataset
    - Average of best 3 (B3) months correlates with shorter term (max month) and longer term trends (B6, B12, B24) and provides larger sample size
  - Isolate similar reservoir quality and determine if and which reservoir, completion and stimulation parameters correlate with well performance on a field and bench level



Production and Stimulation/Completion Correlations

- SPE 163857, 2012: Process
  - Determine field and bench subsets
    - 3 Models, 1 each in Wheeler, Hemphill & Roberts Counties
    - 1 to 5 fields in each model, 9 total
    - 1 to 3 benches in each field
    - Where reservoir properties are similar, create bench-field subset
    - Where reservoir properties vary, exclude





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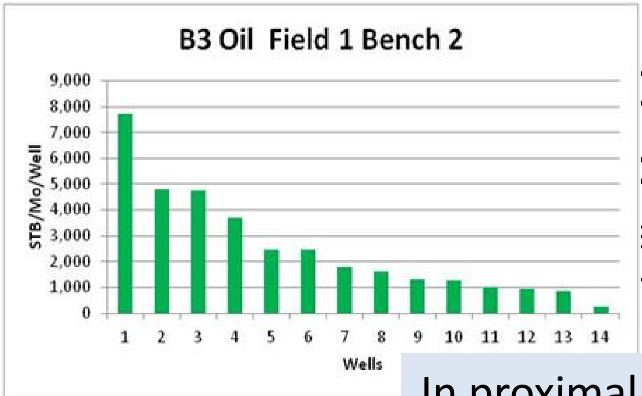
Production and Stimulation/Completion Correlations



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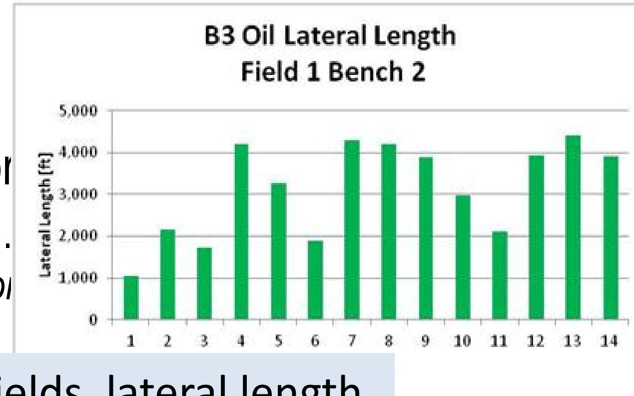
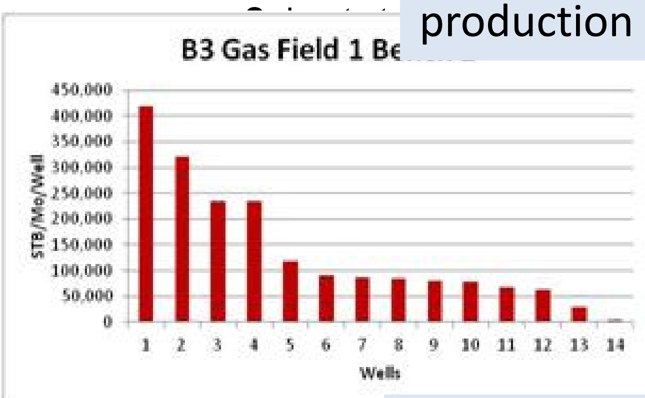
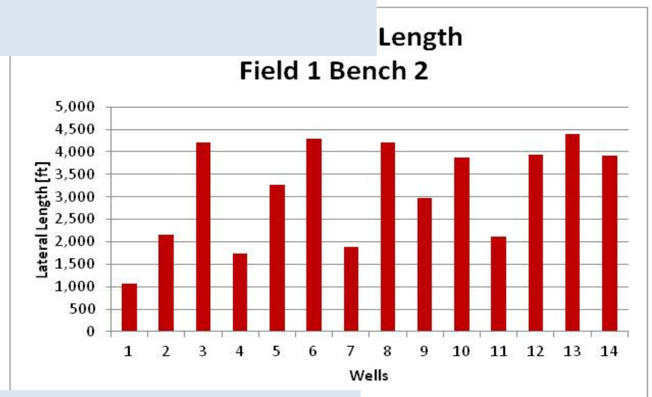


– Determine … with well performance in field and b…

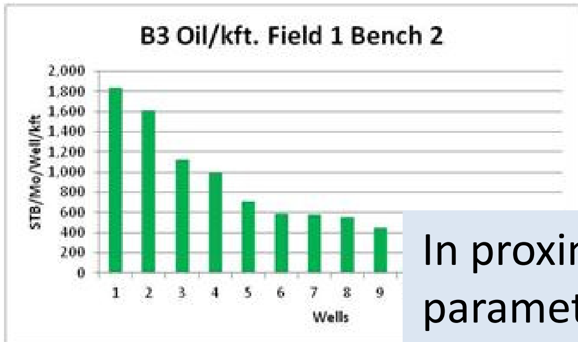
In proximal and distal fields, lateral length almost never correlates with oil and gas production

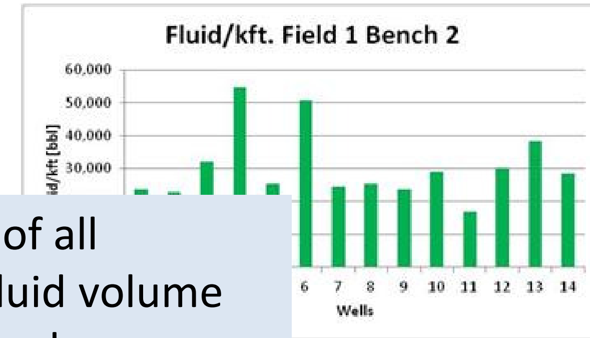




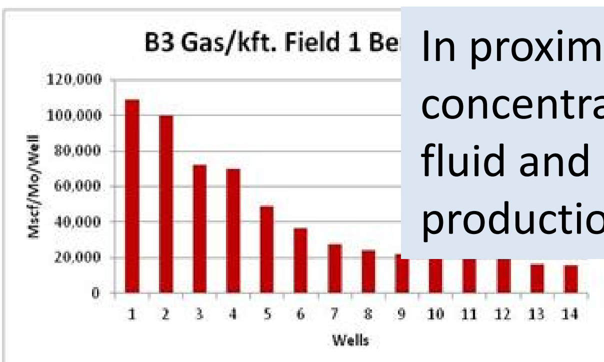
Shorter and more Frac stages in some areas do correlate with better production.

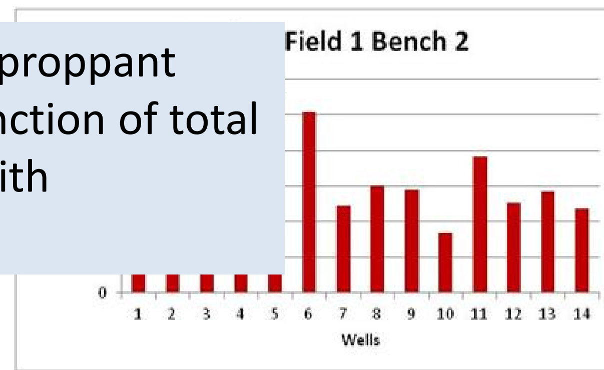
Production and Stimulation/Completion Correlations





In proximal and distal fields, of all parameters evaluated, frac fluid volume correlates the least with oil and gas production.





In proximal and distal fields, proppant concentration is usually a function of total fluid and correlates poorly with production.

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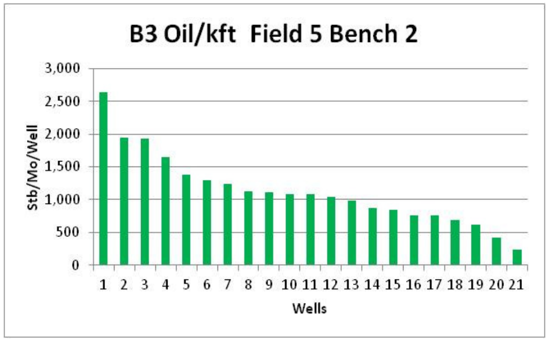
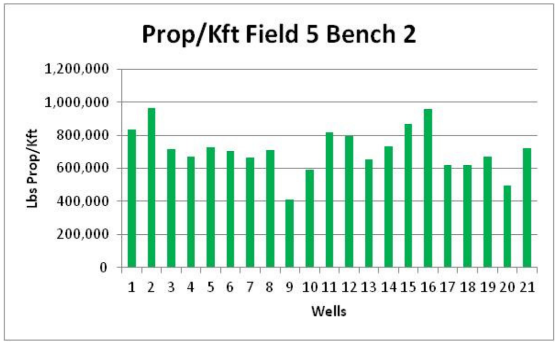
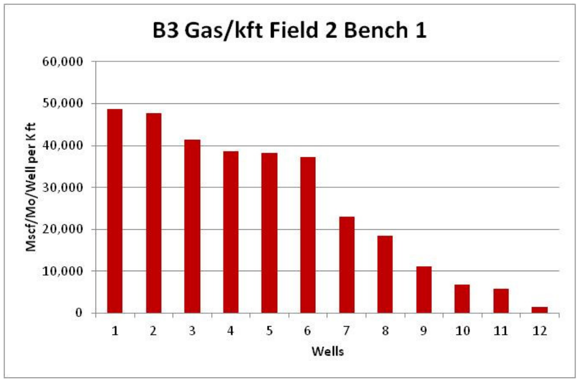
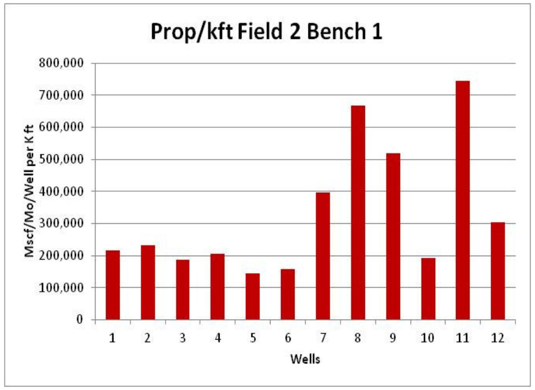
Production and Stimulation/Completion Correlations





Proppant placed has erratic correlations with oil and gas production, less in distal fields.





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Production and Stimulation/Completion Correlations

SPE 163857, 2012

Overall Results Matrix, SE to NW and shallow to deeper

County	Field	Bench	Longer Lateral ft	Larger Lbs prop/ft	Larger Fluid vol/ft	Higher Prop con	Shorter Stage ft	Number Stages	Higher Porosity	Lower Sw
Wheeler	5	1	Poor	Mod	Poor	Poor	Mod	Poor	Strong	Strong
Wheeler	5	2	Poor	Mod	Lim V	Lim V	Mod	Poor	Mod	Mod
Wheeler	5	3	Lim V	Mod	Mod	Mod	Strong	Lim V	Mod	Mod
Hemphill	2	2	Poor	Poor	Poor	Poor	No data	No data	Mod	Mod
Hemphill	2	3	Poor	Mod	Mod	Lim V	No data	No data	Mod	Mod
Roberts	2	1	Poor	Poor	Poor	Poor	Mod	Poor	Mod	Mod

Lim V	=Limited parameter variability

Reservoir quality is by far the only consistent driver

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Wheeler	5	3	Lim V	Mod	Mod	Mod	Strong	Lim V	Mod	Mod
Hemphill	2	2	Poor	Poor	Poor	Poor	No data	No data	Mod	Mod
Hemphill	2	3	Poor	Mod	Mod	Lim V	No data	No data	Mod	Mod
Roberts	2	1	Poor	Poor	Poor	Poor	Mod	Poor	Mod	Mod

Lim V	=Limited parameter variability

Prop mass has an influence, more so moving S & E, but concentration not critical.

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Hemphill	2	3	Poor	Mod	Mod	Lim V	No data	No data	Mod	Mod
Roberts	2	1	Poor	Poor	Poor	Poor	Mod	Poor	Mod	Mod

Lim V =Limited parameter variability

Fluid volume more often correlates poorly, with no directional bias

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Hemphill	2	2	Poor	Poor	Poor	Poor	No data	No data	Mod	Mod
Hemphill	2	3	Poor	Mod	Mod	Lim V	No data	No data	Mod	Mod
Roberts	2	1	Poor	Poor	Poor	Poor	Mod	Poor	Mod	Mod

Lim V =Limited parameter variability

Lateral length and number of stages correlate consistently poor

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Production and Stimulation/Completion Correlations

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Conclusions

- Poor Lateral length correlation
  - Reservoir heterogeneity
  - Steering; may be in zone, but positioned high or low not optimal for the stimulation
  - Retention of Frac and wellbore connection
  - Proppant production shutting off part of the lateral
- Proppant is often a driver, fluid a means of delivery

Recurring Themes

- Reservoir quality dominance
- Inconsistent results along the laterals
  - Longer wells not better wells
  - Perforation efficiency issues
- Staging treatments
  - Increased Fracs per lateral effective early, but with diminishing returns. More stimulated contact points with reservoir increase early rates, ROR.
  - Poor cluster efficiency performing comparable to offsets with older and newer techniques. Improvement can only help well performance
  - OH completion systems with likely 1 dominant Frac/stage performing reasonably well and sometimes better compared to cemented perf & plug with multiple clusters/stage offsets
- Forecasting well performance may be getting harder, not easier
- Well performance results vary greatly over small geographic and stratigraphic distance, just like the rock composition and depositional complexity
- There is no broad optimal completion and stimulation “recipe”. Wells or small groups of close proximity require customized completion, maybe at the stage level and well level for best combination of well performance and completion cost

Moving Forward

- Data
  - Large dispersion of operators in one area, older public well data often insufficient for reservoir characterization
  - Very large data sets of vertical wells in most horizontal development areas
  - Improve geomodels
  - Wells logged through part of the curve above targets are of high value to future shallower wells
  - Logs below curve cost less today due to technology, deployment innovations, and market conditions
  - Even through laterals, data acquisition can cost less than 1 frac stage.
  - Not every well needs to be a “science well”, but better knowledge is required to rely solely on lowest cost or current standard measurements

Moving Forward

- Frac design
  - Focus is often on effective Frac length in a given drainage area. Frac height is not well understood, and can vary with position from top or base of the target
  - Effective Frac height is not well understood, and can vary with position from top or base of the target, cluster efficiency
  - Opportunity to link more than one layer may exist, but likely require some change from broadly used techniques
  - Vertical layer stress models not well understood, particularly in under or over pressure environments
  - Linkage to multiple reservoirs better understood when boundary layers are thick, but not when thin

Recommended

Greiser, B., Shelley, B., What Can Injection Falloff Tell About Job Placement and Production in Tight Gas Sand. SPE 125732. 2009. Society of Petroleum Engineers

Greiser, B., Hill, B., Brinska, J., Stout, R. Zone Selection and Production Prediction Using Advanced Logging Technology. SPE 67198 2001. Society of Petroleum Engineers

Reishman, R.L., A New Method of Acquiring Open Hole Logs In Unconventional Wells. SPE 143963. 2011. Society of Petroleum Engineers

Mitchell, John. Horizontal Drilling of Deep Granite Wash Reservoirs, Anadarko Basin, Oklahoma and Texas. Shale Shaker, The Journal of the Oklahoma City Geological Society. Sept.-Oct. 2011. p 118-167