# Utilizing Measured Drilling Parameters to Optimize Completions Design*

**Jason VanderKooi**[1]

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## Abstract

Current best practices in North America's shale basins deliver inconsistent production results due to a lack of reservoir understanding in the laterals. Reservoir data is difficult and expensive to attain in laterals and therefore most completions are designed geometrically, with little or no concern for reservoir heterogeneity along the lateral. This leads to dramatic variability in productivity between neighboring wells, typically described as the statistical nature of the play.

In this study we demonstrate a reliable, cost effective methodology that empowers shale operators with reservoir data on every well. This technique will enable operators to engineer their designs using reservoir-based data on every completion, resulting in improved productivity on every well. This productivity improvement will be realized without any significant cost or inconvenience.

This methodology leverages commonly available drilling measurements (ROP, WOB, RPM, D) and mud motor parameters (Q, P, Kn, Tmax, Pmax) to derive Mechanical Specific Energy (MSE), using well established algorithms. The MSE parameter is then shown to be a good proxy for Unconfined Compressive Strength (UCS), a valuable reservoir parameter commonly used in hydraulic fracture designs. The MSE drives a facies-based answer product that allows the operator to position perforation clusters so that they breakdown at a common treating pressure, resulting in uniform fracture treatment within each hydraulic fracture stage.

This technique has been applied successfully on over 400 wells to date. It is validated through comparison to OH wireline logs, production logs and by comparing productivity to offsetting wells. The technique is shown to be superior to similar attempts done using OH wireline logs and production data confirms its' accuracy and reliability. This study demonstrates that drilling data can be effectively used to derive reservoir parameters that lead to completion designs that produce superior production results.

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# Utilizing Measured Drilling Parameters to Optimize Completions Design

Jason vanderKooi

Business Development Manager

C&J Energy Services

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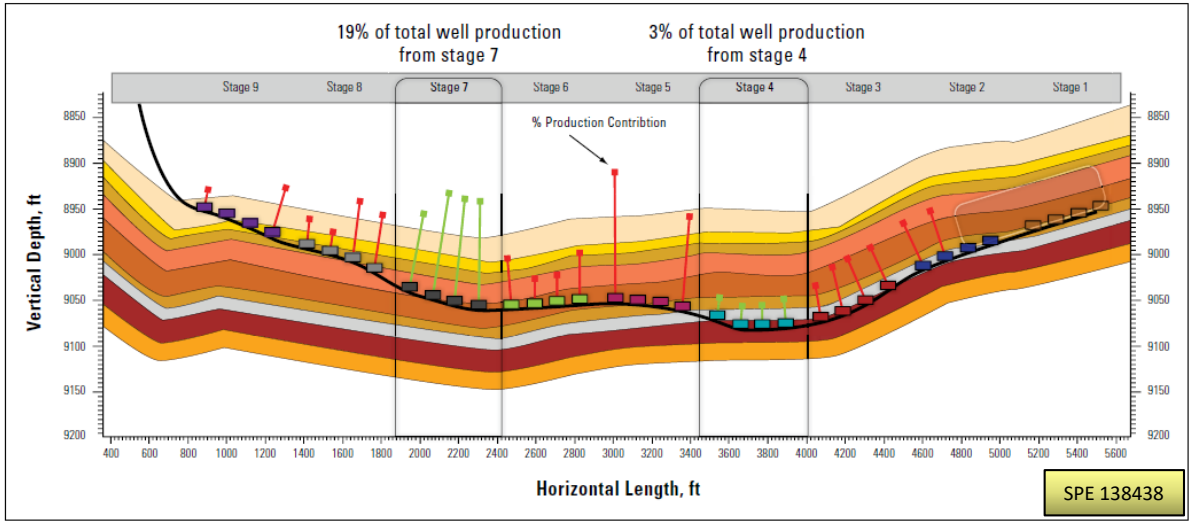
# Goal of Engineered Completions

- Heterogeneity exists along a horizontal well
- Geometric completions do not account for heterogeneity, resulting in inefficient completions
- Engineered completions use data acquired along the lateral to place stages/perfs in “like rock”, resulting in improved completions and improved production



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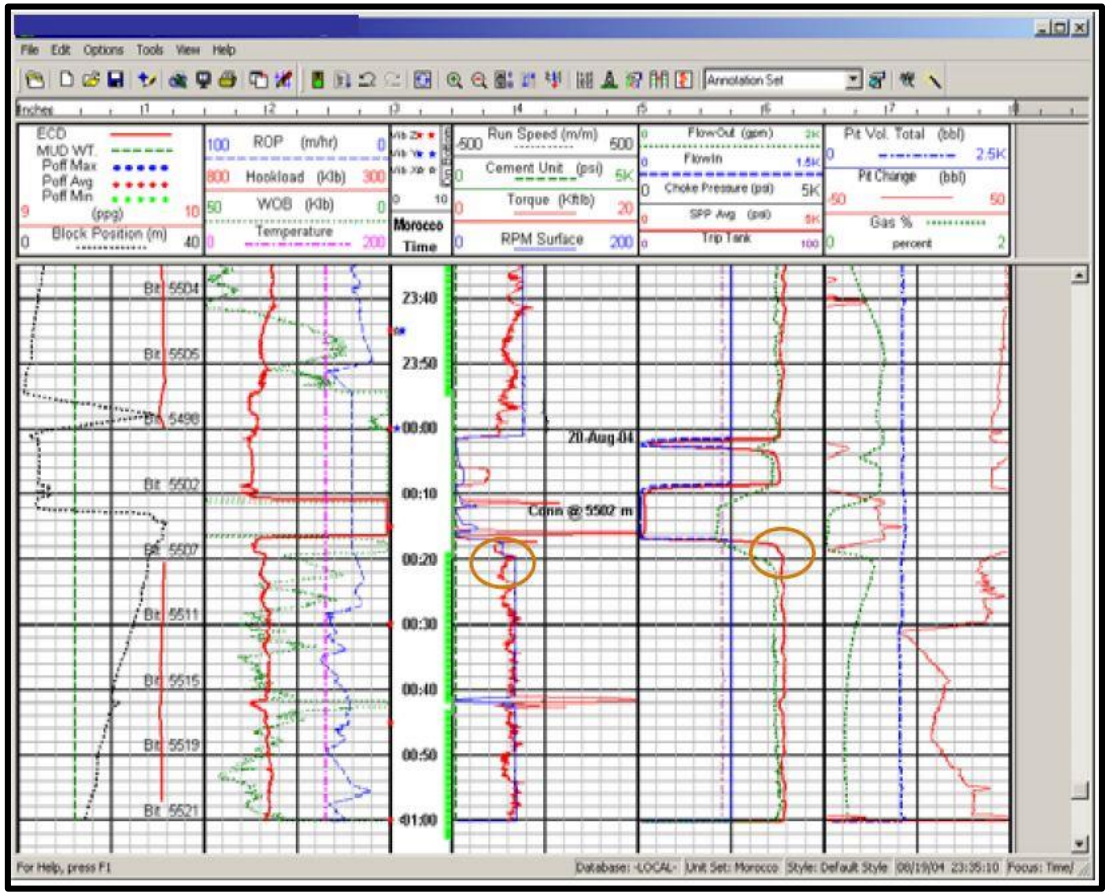
# What is LateralScience™

- Calculate Mechanical Specific Energy (MSE) using commonly available drilling data
  - Weight On Bit (WOB)
  - Drilling Speed (RPM)
  - Rotary Torque (TOR)
  - Rate of Penetration (ROP)
  - Differential Pressure (DIFP)
  - StandPipe Pressure (SPP)
  - Mud Flow Rate (Q)



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# MSE Equation (with Mud Motors)

$$MSE\ [ksi] = \frac{4 \cdot WOB}{\pi D^2} + \frac{480}{D^2} \frac{(N+K_N \cdot Q) \cdot ((T_{MAX}/\Delta P_{MAX}) \cdot \Delta P/1000)}{ROP}$$

$$MSE = UCS * Deff$$

| | | | |
|---|---|---|---|
| WOB | Weight on Bit (k-lbs) | Tmax | Mud motor max-rated torque (ft-lb) |
| N | Rotary Speed (RPM) | △Pmax | Mud motor max-rated △P (psi) |
| D | Bit diameter (in) | Kn | Mud motor speed to flow ratio (rev/gal) |
| ROP | Rate of Penetration (ft/hr) | △P | Differential Pressure (psi) |
| Q | Mud Flow Rate (gal/min) | | |

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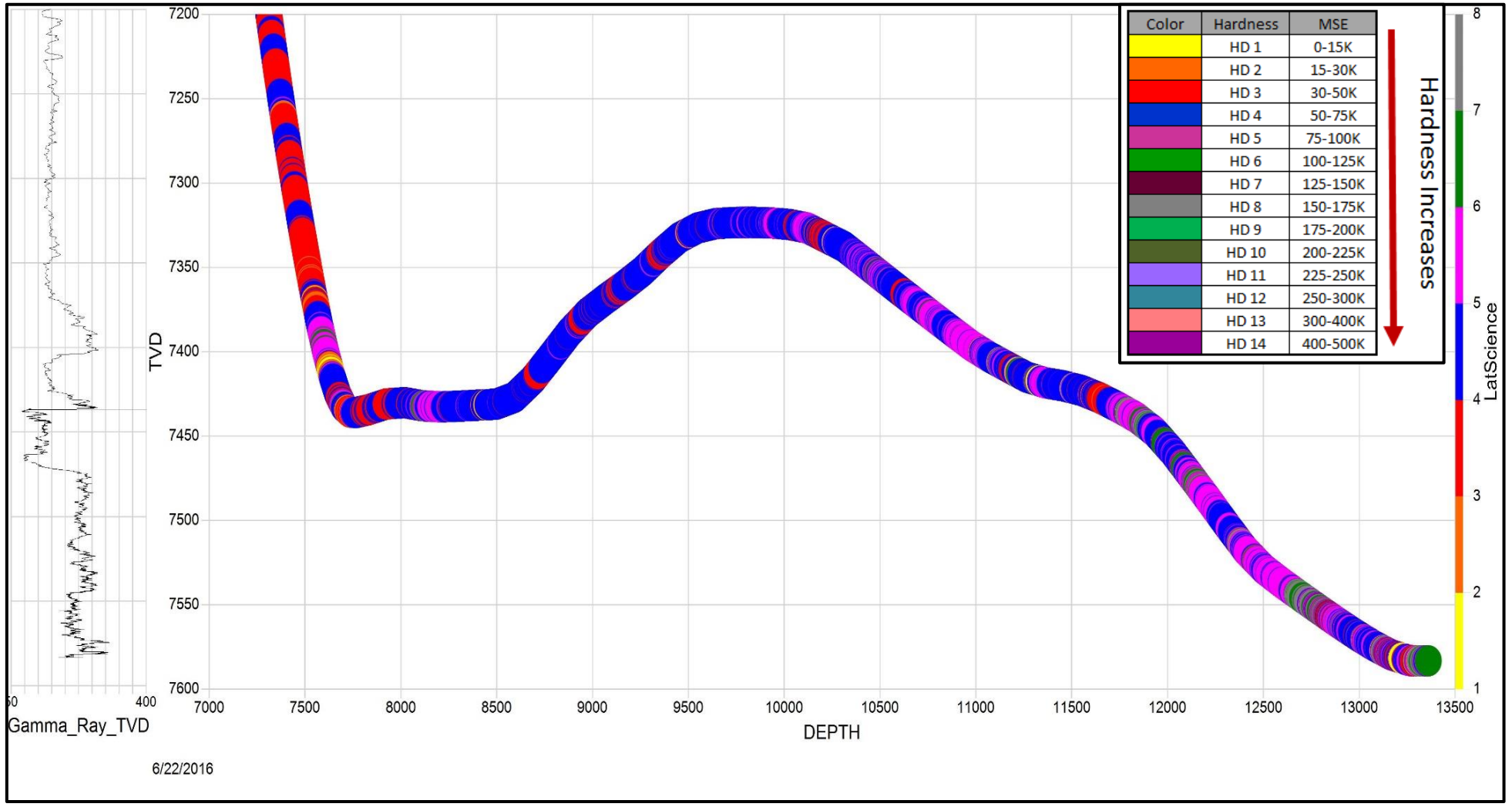
# Macro View of Hardness Index



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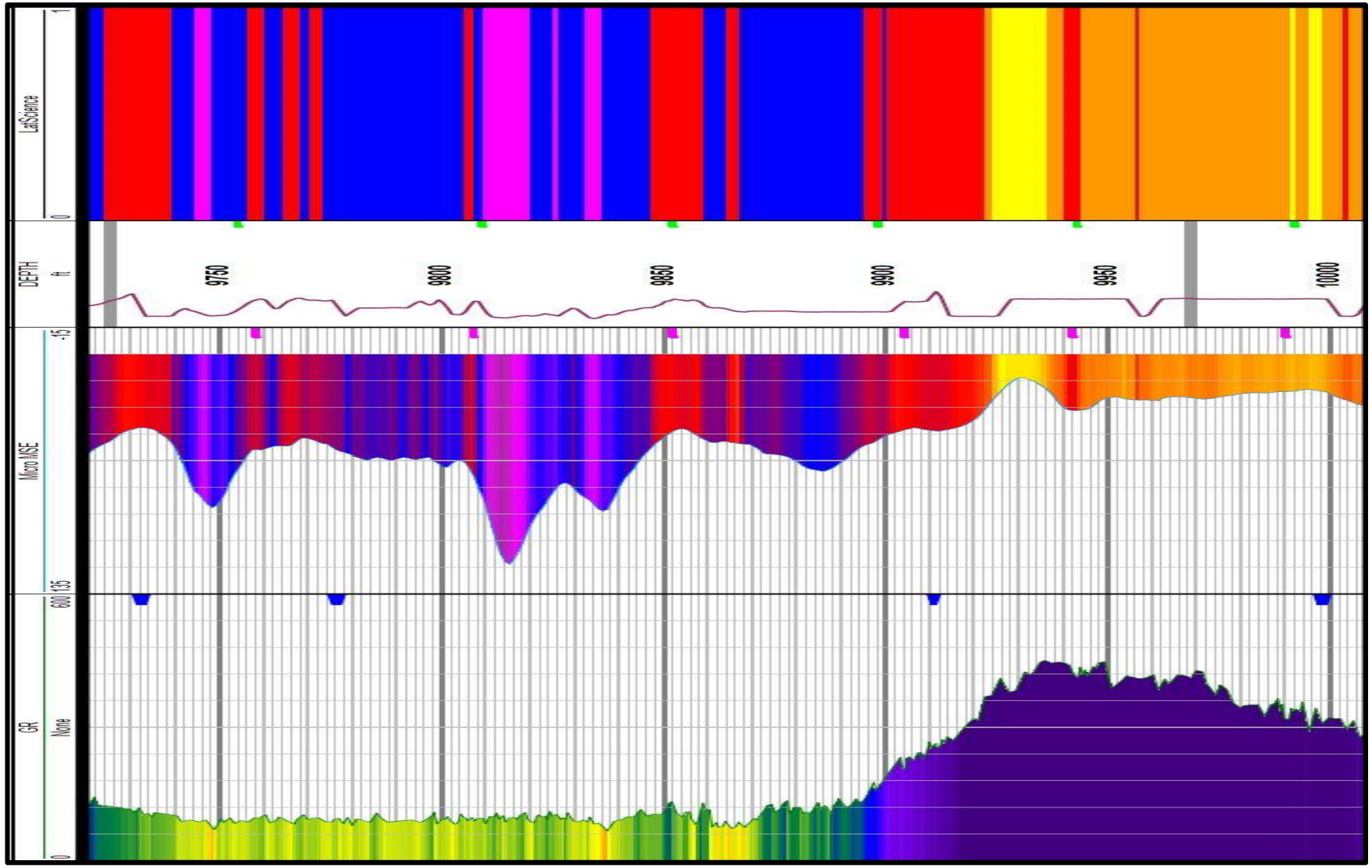
# Facies LogPlot




| Color | Hardness | MSE |
|---|---|---|
| | HD 1 | 0-20K |
| | HD 2 | 20-30K |
| | HD 3 | 30-50K |
| | HD 4 | 50-85K |
| | HD 5 | 85-135K |
| | HD 6 | 135-200K |
| | HD 7 | 200K + |

Hardness Increases

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# Facies Based Engineered Completions

## Geometric Design

| Stage | Plug Depth | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|---|---|---|---|---|---|---|
| 1 | | 15783 | 15734 | 15685 | 15636 | 15587 |
| 2 | 15563 | 15539 | 15490 | 15441 | 15392 | 15343 |
| 3 | 15319 | 15295 | 15246 | 15197 | 15148 | 15099 |
| 4 | 15075 | 15051 | 15002 | 14953 | 14904 | 14855 |
| 5 | 14831 | 14807 | 14758 | 14709 | 14660 | 14611 |
| 6 | 14587 | 14563 | 14514 | 14465 | 14416 | 14367 |
| 7 | 14343 | 14319 | 14270 | 14221 | 14172 | 14123 |
| 8 | 14099 | 14075 | 14026 | 13977 | 13928 | 13879 |
| 9 | 13855 | 13831 | 13782 | 13733 | 13684 | 13635 |
| 10 | 13611 | 13587 | 13538 | 13489 | 13440 | 13391 |
| 11 | 13367 | 13343 | 13294 | 13245 | 13196 | 13147 |
| 12 | 13123 | 13099 | 13050 | 13001 | 12952 | 12903 |
| 13 | 12879 | 12855 | 12806 | 12757 | 12708 | 12659 |
| 14 | 12635 | 12611 | 12562 | 12513 | 12464 | 12415 |
| 15 | 12391 | 12367 | 12318 | 12269 | 12220 | 12171 |
| 16 | 12147 | 12123 | 12074 | 12025 | 11976 | 11927 |
| 17 | 11903 | 11879 | 11830 | 11781 | 11732 | 11683 |
| 18 | 11659 | 11635 | 11586 | 11537 | 11488 | 11439 |
| 19 | 11415 | 11391 | 11342 | 11293 | 11244 | 11195 |
| 20 | 11171 | 11147 | 11098 | 11049 | 11000 | 10951 |

## LateralScience Design

| Stage | Plug Depth | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|---|---|---|---|---|---|---|
| 1 | | 15783 | 15734 | 15685 | 15630 | 15587 |
| 2 | 15563 | 15544 | 15508 | 15441 | 15392 | 15350 |
| 3 | 15319 | 15295 | 15246 | 15205 | 15148 | 15108 |
| 4 | 15075 | 15051 | 15002 | 14957 | 14900 | 14866 |
| 5 | 14831 | 14802 | 14758 | 14709 | 14660 | 14611 |
| 6 | 14587 | 14563 | 14514 | 14460 | 14416 | 14367 |
| 7 | 14343 | 14323 | 14270 | 14221 | 14179 | 14123 |
| 8 | 14099 | 14075 | 14026 | 13977 | 13920 | 13879 |
| 9 | 13855 | 13831 | 13782 | 13738 | 13696 | 13635 |
| 10 | 13611 | 13575 | 13538 | 13489 | 13440 | 13391 |
| 11 | 13367 | 13341 | 13294 | 13234 | 13198 | 13152 |
| 12 | 13123 | 13099 | 13046 | 13001 | 12952 | 12903 |
| 13 | 12879 | 12855 | 12806 | 12757 | 12708 | 12659 |
| 14 | 12635 | 12611 | 12562 | 12513 | 12464 | 12415 |
| 15 | 12391 | 12367 | 12318 | 12275 | 12220 | 12162 |
| 16 | 12147 | 12123 | 12078 | 12025 | 11976 | 11927 |
| 17 | 11903 | 11879 | 11823 | 11781 | 11740 | 11683 |
| 18 | 11659 | 11635 | 11586 | 11537 | 11480 | 11439 |
| 19 | 11415 | 11391 | 11342 | 11293 | 11240 | 11195 |
| 20 | 11171 | 11147 | 11098 | 11049 | 11000 | 10951 |

| Color | Hardness | MSE |
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| | HD 7 | 200K + |

Hardness Increases

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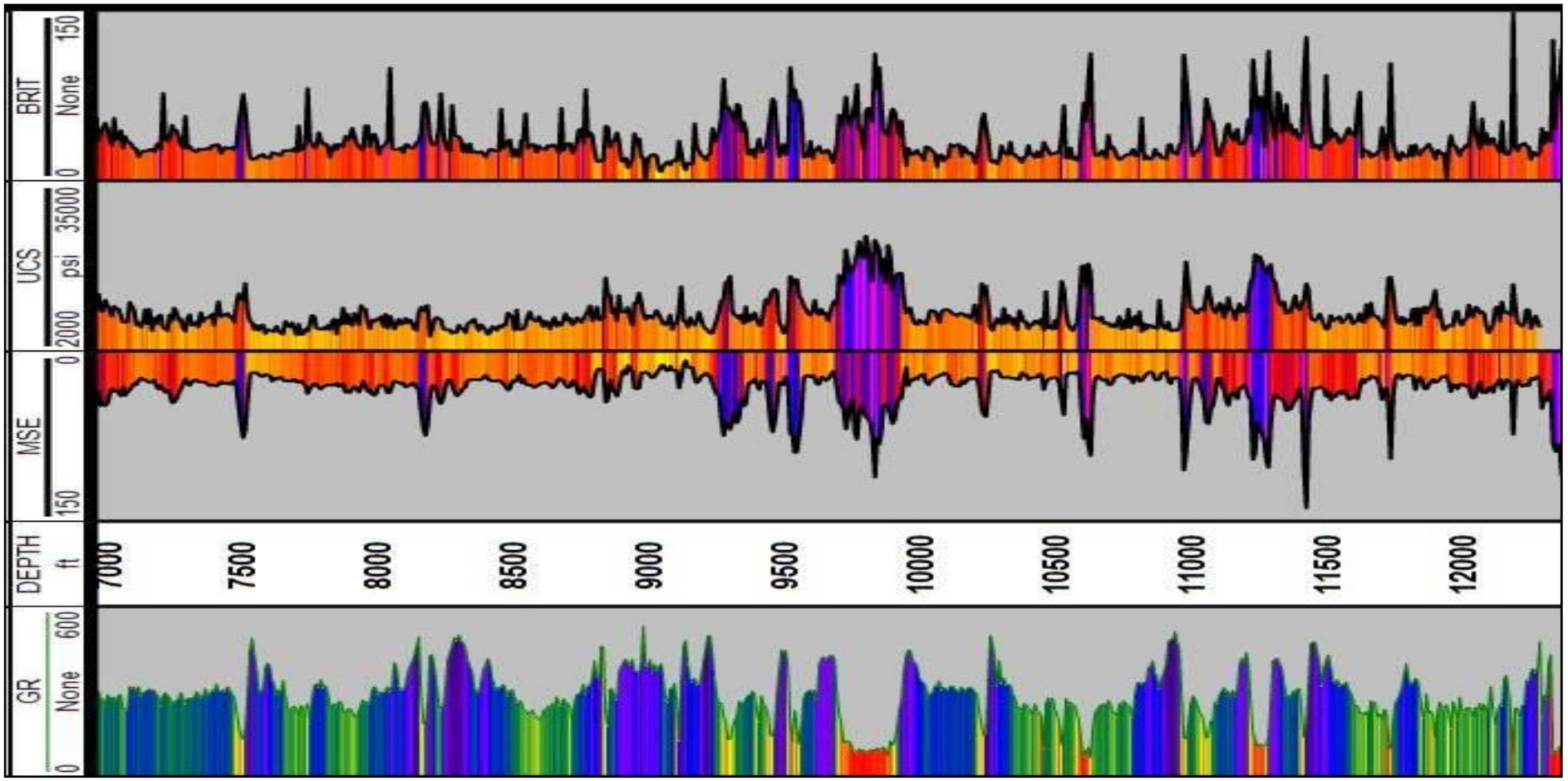
# Case Study – Comparison with OH Sonic

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Hardness Increases

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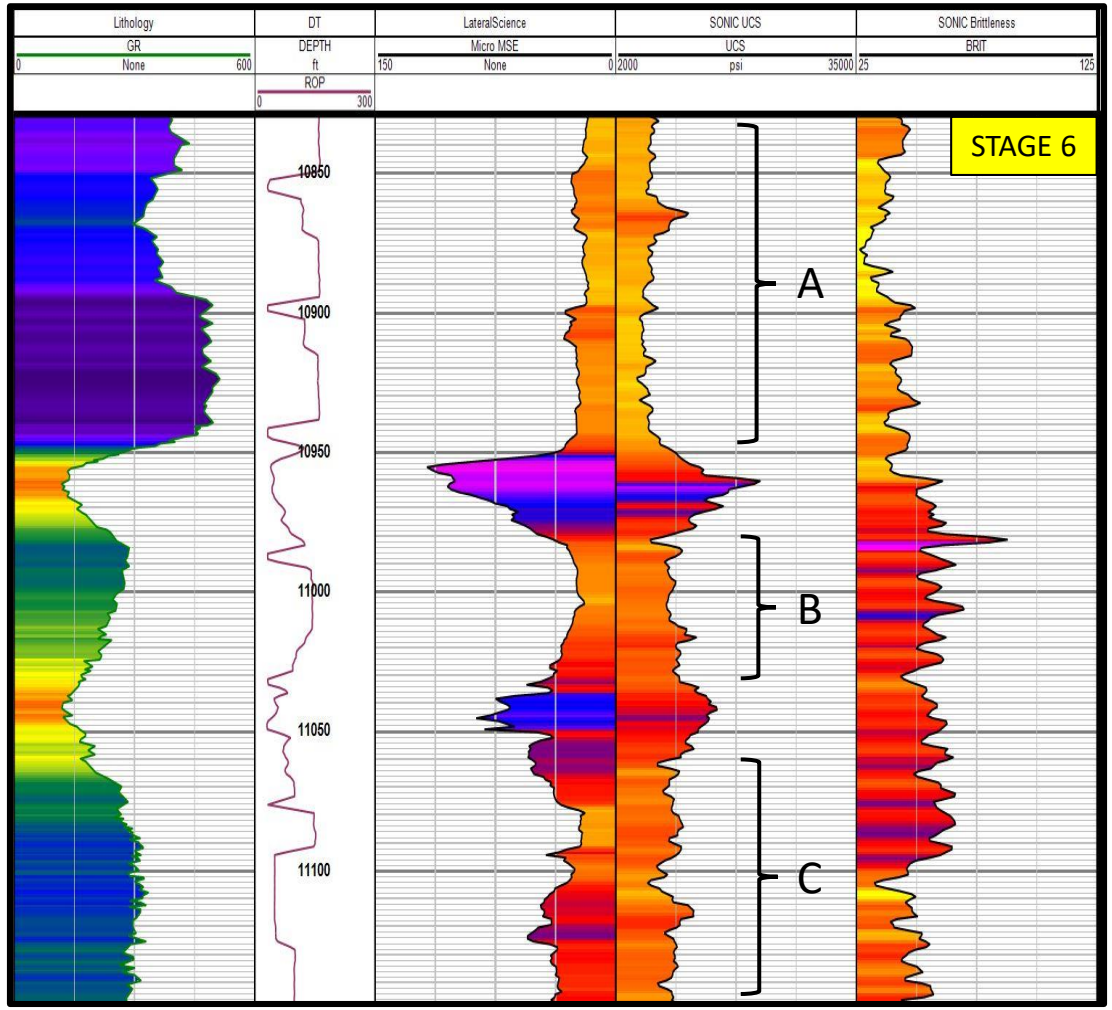
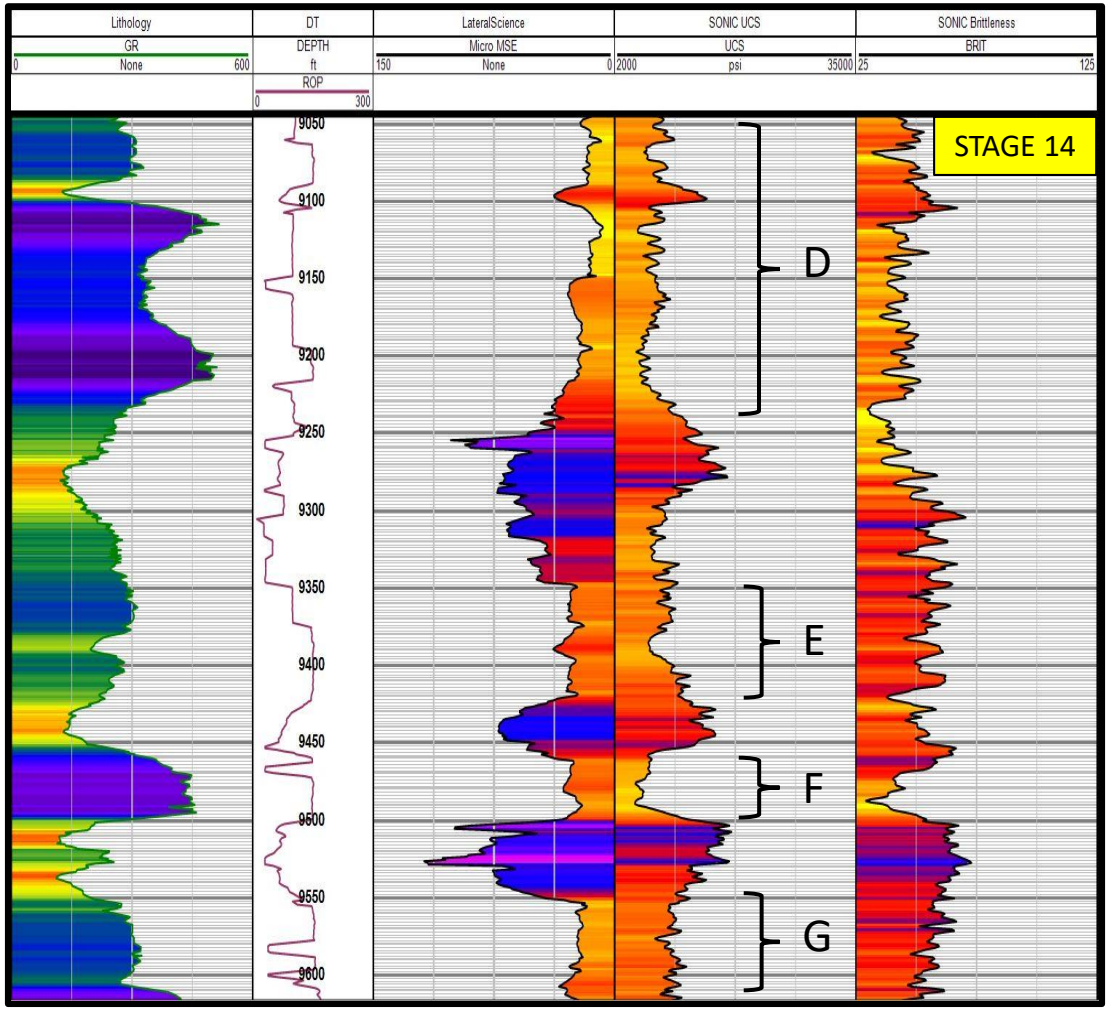
# Case Study – Comparison with OH Sonic



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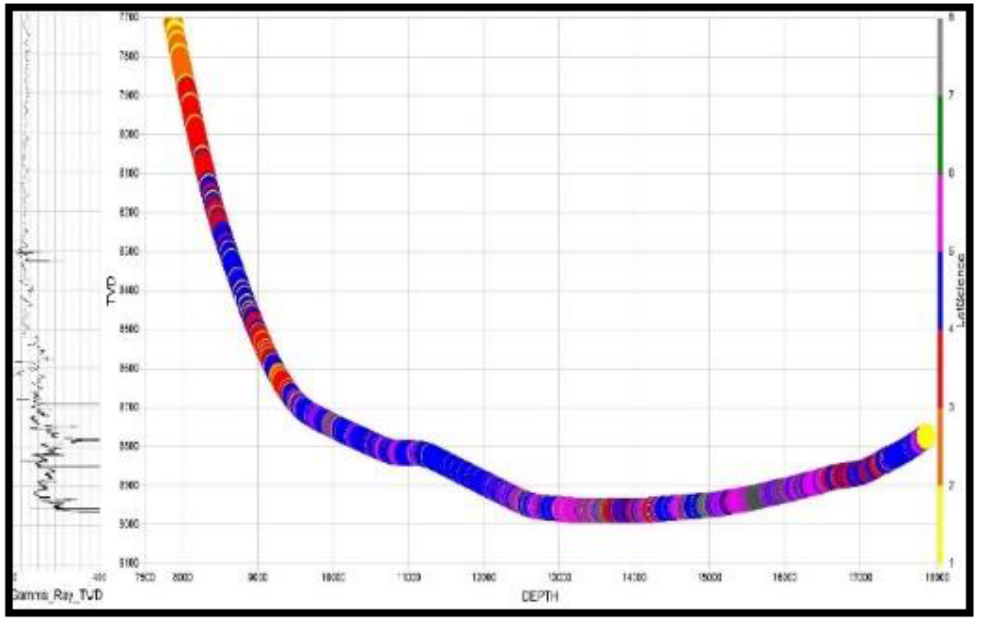
# Case Study – Production Log Comparison

- Lateral Science prediction
  - 9 stages with 3 clusters flowing
  - 5 stages with 2 clusters flowing
  - 10 stages with 1 cluster flowing
  - 5 stages with data issues
  - 58 flowing clusters

| Geometric Perf Design | | | | |
|---|---|---|---|---|
| Stage | Plug | Cluster 1 | Cluster 2 | Cluster 3 |
| 1 | | 17749 | 17650 | 17550 |
| 2 | 17500 | 17450 | 17351 | 17251 |
| 3 | 17201 | 17151 | 17052 | 16952 |
| 4 | 16903 | 16853 | 16753 | 16653 |
| 5 | 16604 | 16554 | 16454 | 16354 |
| 6 | 16305 | 16255 | 16155 | 16055 |
| 7 | 16006 | 15956 | 15856 | 15756 |
| 8 | 15707 | 15657 | 15557 | 15457 |
| 9 | 15408 | 15358 | 15258 | 15158 |
| 10 | 15109 | 15059 | 14959 | 14860 |
| 11 | 14810 | 14760 | 14660 | 14561 |
| 12 | 14511 | 14461 | 14361 | 14262 |
| 13 | 14212 | 14162 | 14062 | 13963 |
| 14 | 13913 | 13863 | 13763 | 13664 |
| 15 | 13614 | 13564 | 13464 | 13365 |
| 16 | 13315 | 13265 | 13165 | 13066 |
| 17 | 13016 | 12966 | 12867 | 12767 |
| 18 | 12717 | 12667 | 12568 | 12468 |
| 19 | 12418 | 12368 | 12269 | 12169 |
| 20 | 12119 | 12069 | 11970 | 11870 |
| 21 | 11820 | 11770 | 11671 | 11571 |
| 22 | 11521 | 11471 | 11372 | 11272 |
| 23 | 11222 | 11172 | 11073 | 10973 |
| 24 | 10924 | 10874 | 10774 | 10674 |
| 25 | 10625 | 10575 | 10475 | 10375 |
| 26 | 10326 | 10276 | 10176 | 10076 |
| 27 | 10027 | 9977 | 9877 | 9777 |
| 28 | 9728 | 9678 | 9578 | 9478 |
| 29 | 9429 | 9379 | 9279 | |



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# Case Study – Production Log Comparison


Exact Match – Green Shading

Mismatch – Red Shading

Incomplete Data – Yellow Shading

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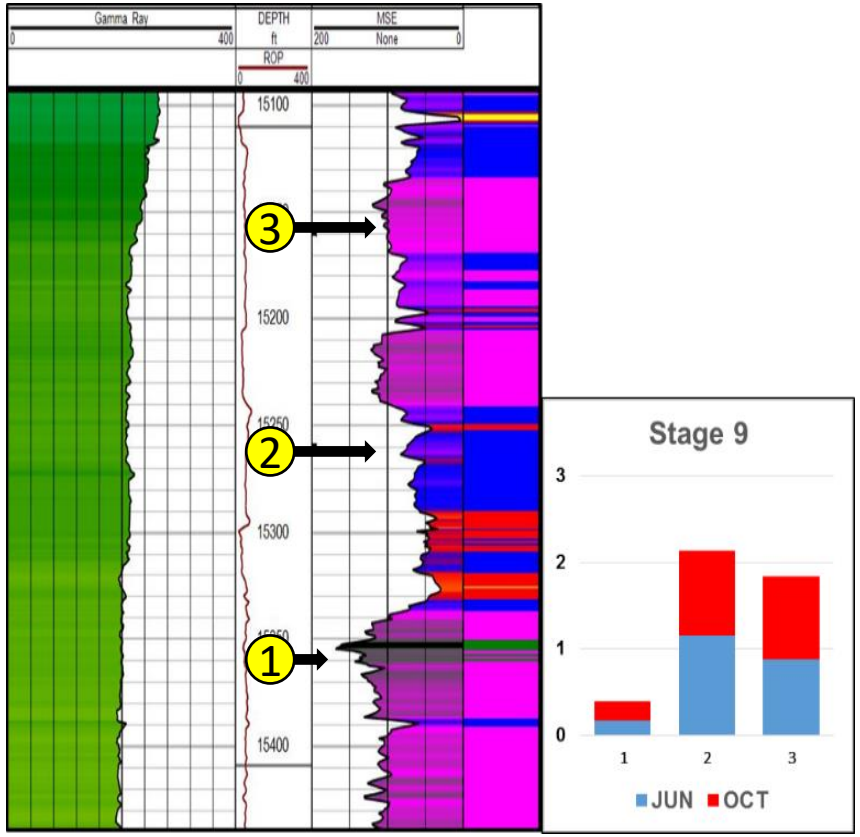
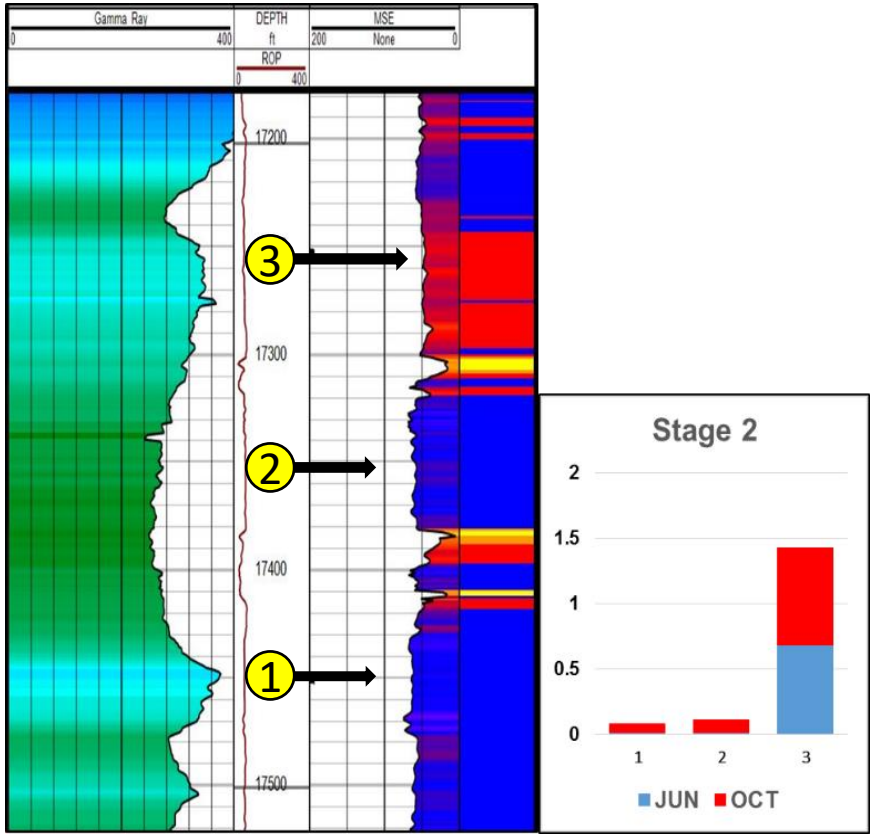
# Case Study – Stage Level Detail

## Stage 9




## Stage 2



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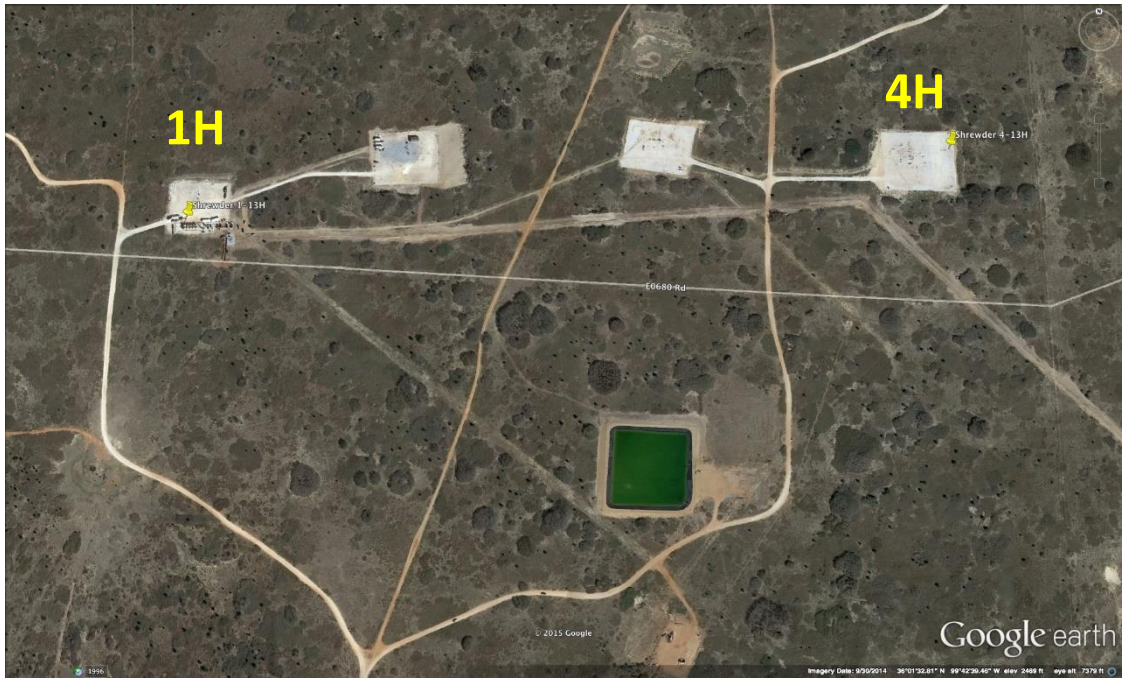
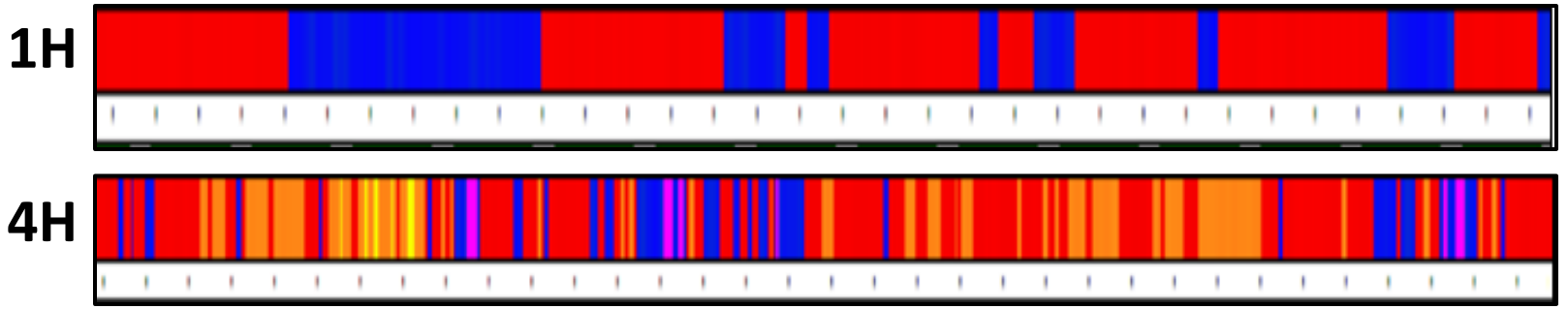
# Case Study – Cleveland Sands

- Completion
  - 20 stages
  - 4 clusters per stage
  - 235 ft stage length
- Well 1H
  - 3.9 MM lb of 40/70
  - 73,000 bbls slickwater
- Well 4H
  - 4.0 MM lb 40/70
  - 77,000 bbls slickwater



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# Case Study – Cleveland Sands

## Cleveland 1H

| Stage | Plug Depth | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 |
|---|---|---|---|---|---|
| 1 | | 14127 | 14067 | 14007 | 13947 |
| 2 | 13905 | 13892 | 13832 | 13772 | 13712 |
| 3 | 13670 | 13657 | 13597 | 13537 | 13477 |
| 4 | 13435 | 13422 | 13362 | 13302 | 13242 |
| 5 | 13200 | 13187 | 13127 | 13067 | 13007 |
| 6 | 12965 | 12952 | 12892 | 12832 | 12772 |
| 7 | 12730 | 12717 | | | 12537 |
| 8 | 12495 | 12482 | | | 12302 |
| 9 | 12260 | 12247 | | | 12067 |
| 10 | 12025 | 12012 | | | 11832 |
| 11 | 11790 | 11777 | | | 11597 |
| 12 | 11555 | 11542 | | | 11362 |
| 13 | 11320 | 11307 | 11247 | 11187 | 11127 |
| 14 | 11085 | 11072 | 11012 | 10952 | 10892 |
| 15 | 10850 | 10837 | 10777 | 10717 | 10657 |
| 16 | 10615 | 10602 | 10542 | 10482 | 10422 |
| 17 | 10380 | 10367 | 10307 | 10247 | 10187 |
| 18 | 10145 | 10132 | 10072 | 10012 | 9952 |
| 19 | 9910 | 9897 | 9837 | 9777 | 9717 |
| 20 | 9675 | 9662 | 9622 | 9582 | 9532 |

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## Cleveland 4H

| Stage | Plug Depth | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 |
|---|---|---|---|---|---|
| 1 | | 14160 | 14100 | 14040 | 13980 |
| 2 | 13950 | 13920 | 13860 | 13800 | 13740 |
| 3 | 13710 | 13680 | 13620 | 13560 | 13510 |
| 4 | 13470 | 13440 | 13380 | 13320 | 13260 |
| 5 | 13220 | 13190 | 13100 | 13050 | 13010 |
| 6 | 12910 | 12885 | 12860 | 12830 | 12790 |
| 7 | 12750 | 12730 | | | 12550 |
| 8 | 12510 | 12480 | | | 12300 |
| 9 | 12280 | 12250 | | | 12070 |
| 10 | 12024 | 11970 | | | 11820 |
| 11 | 11780 | 11740 | | | 11610 |
| 12 | 11560 | 11510 | | | 11330 |
| 13 | 11310 | 11300 | 11200 | 11115 | 11090 |
| 14 | 11030 | 11000 | 10950 | 10900 | 10850 |
| 15 | 10815 | 10800 | 10740 | 10710 | 10650 |
| 16 | 10545 | 10485 | 10460 | 10400 | 10370 |
| 17 | 10340 | 10325 | 10280 | 10225 | 10150 |
| 18 | 10135 | 10100 | 10030 | 9970 | 9890 |
| 19 | 9870 | 9850 | 9790 | 9750 | 9700 |
| 20 | 9660 | 9620 | 9550 | 9510 | 9470 |

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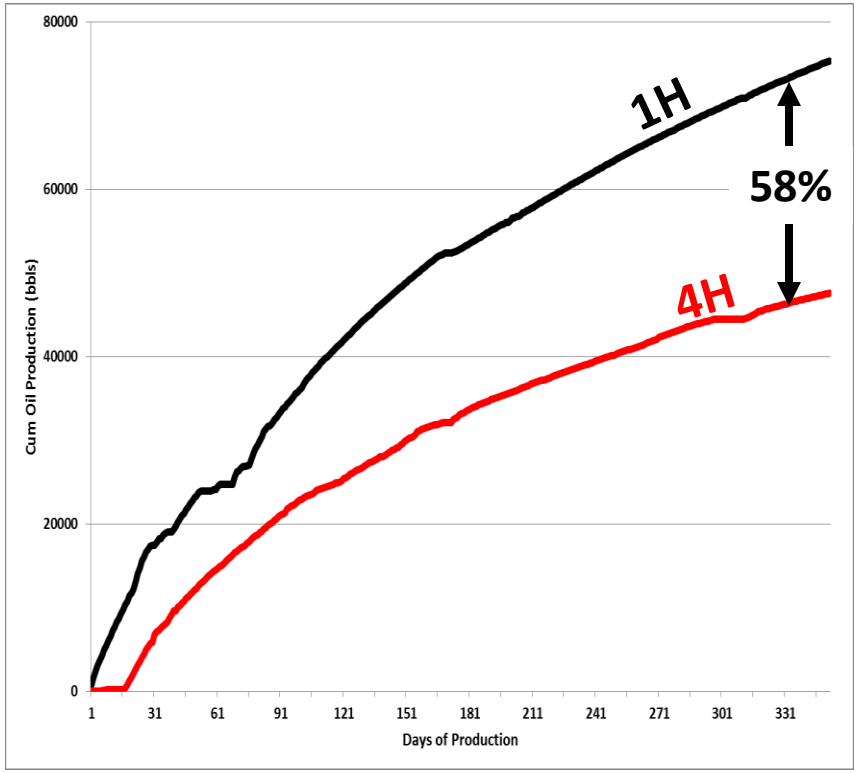
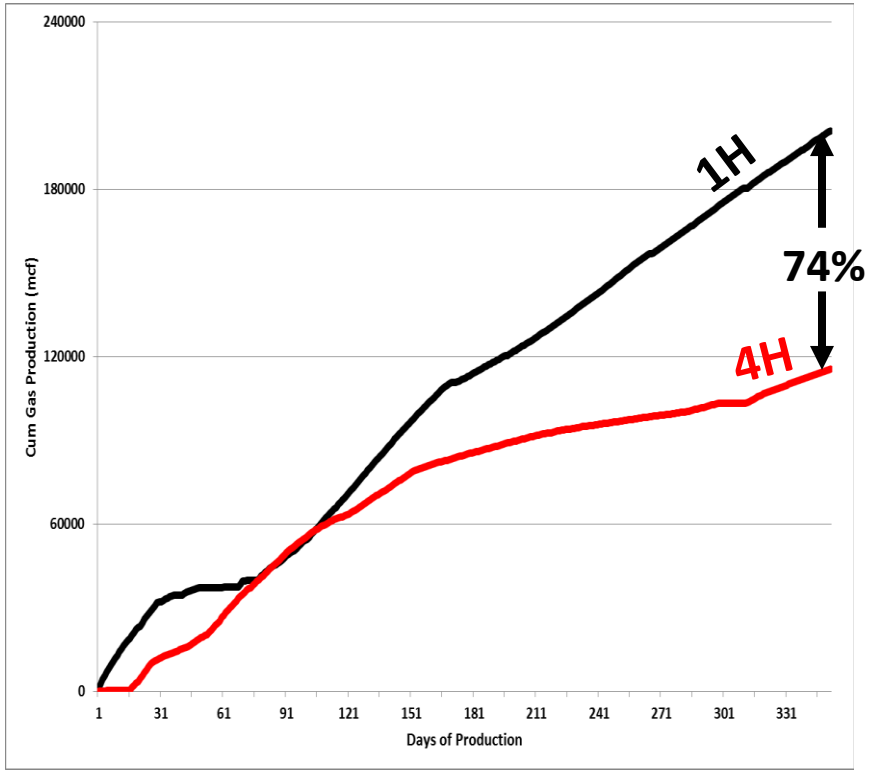
# Case Study – Cleveland Sands

## Oil Production




## Gas Production



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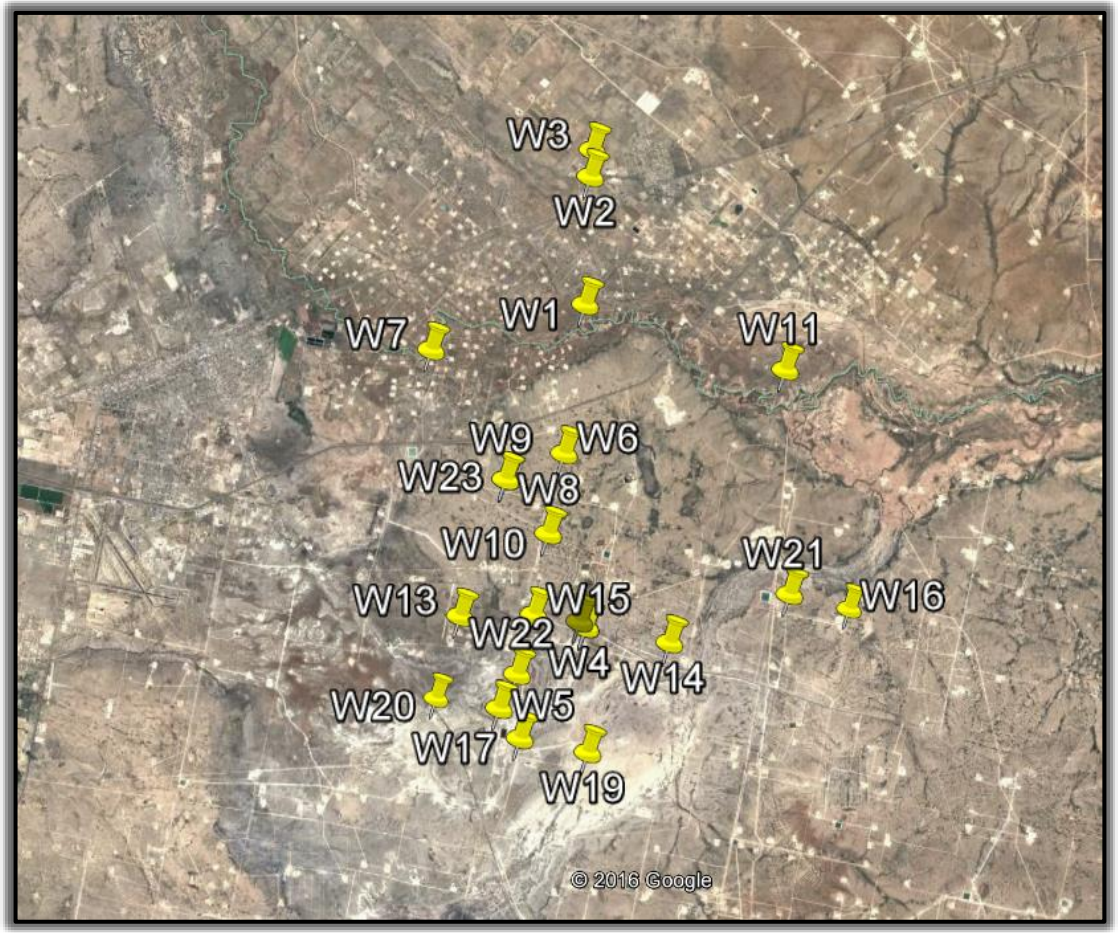
# Case Study
# Wolfcamp Engineered Completions

- 3 Wolfcamp completions in 2015 using MSE-based engineered designs
- 2 wells in close proximity and placed in a group of 23 wells all within a 4 mile radius
- 3rd well placed in a 9 well group, also within a 4 mile radius



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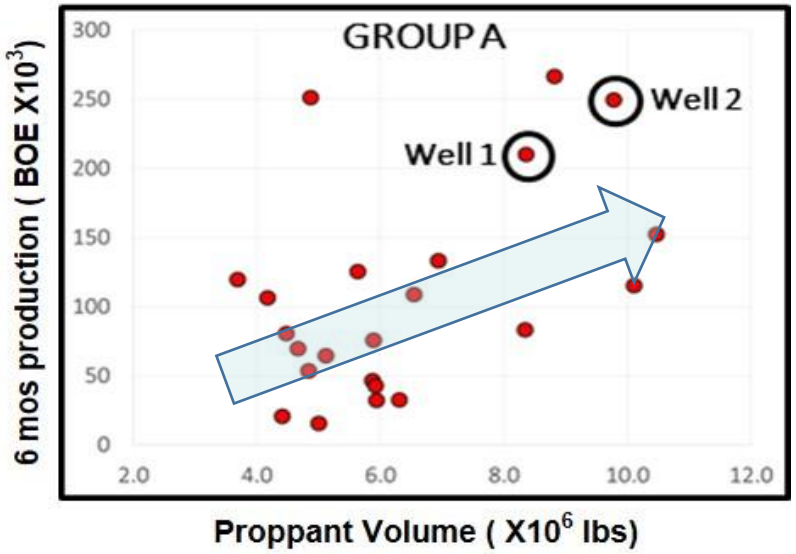
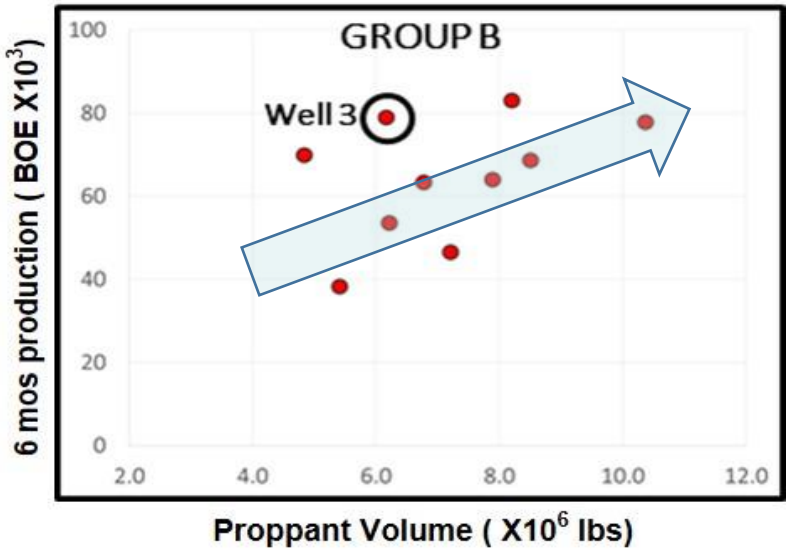
# Wolfcamp Engineered Completions



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# Case Study
# Wolfcamp Engineered Completions

| Group A | (BOE/mo)/ lateral ft | (BOE/mo)/ Proppant (k-lbs) |
|---|---|---|
| Avg for 23 wells | 3.4 | 2.79 |
| Subject well 1 | 5.7 | 4.24 |
| Subject well 2 | 5.2 | 4.17 |
| Impact | **+61%** | **+50%** |
| Ranking | 3,4 | 4,5 |

| Group B | (BOE/mo)/ lateral ft | (BOE/mo)/ Proppant(k-lbs) |
|---|---|---|
| Avg for 9 wells | 2.30 | 1.54 |
| Subject well 3 | 2.94 | 2.13 |
| Impact | **+28%** | **+38%** |
| Ranking | 1 | 2 |

Groups include wells that were:

- All drilled in same calendar year
- All within a 4 mile radius
- All had comparable TVD

Wells normalized for lateral length & proppant volume:

- BOE/mo/lateral (bbls/ft)
- BOE/mo/proppant (bbls/klbs)

This enables comparison of wells that used different completion strategies and to compare wells with different length laterals.

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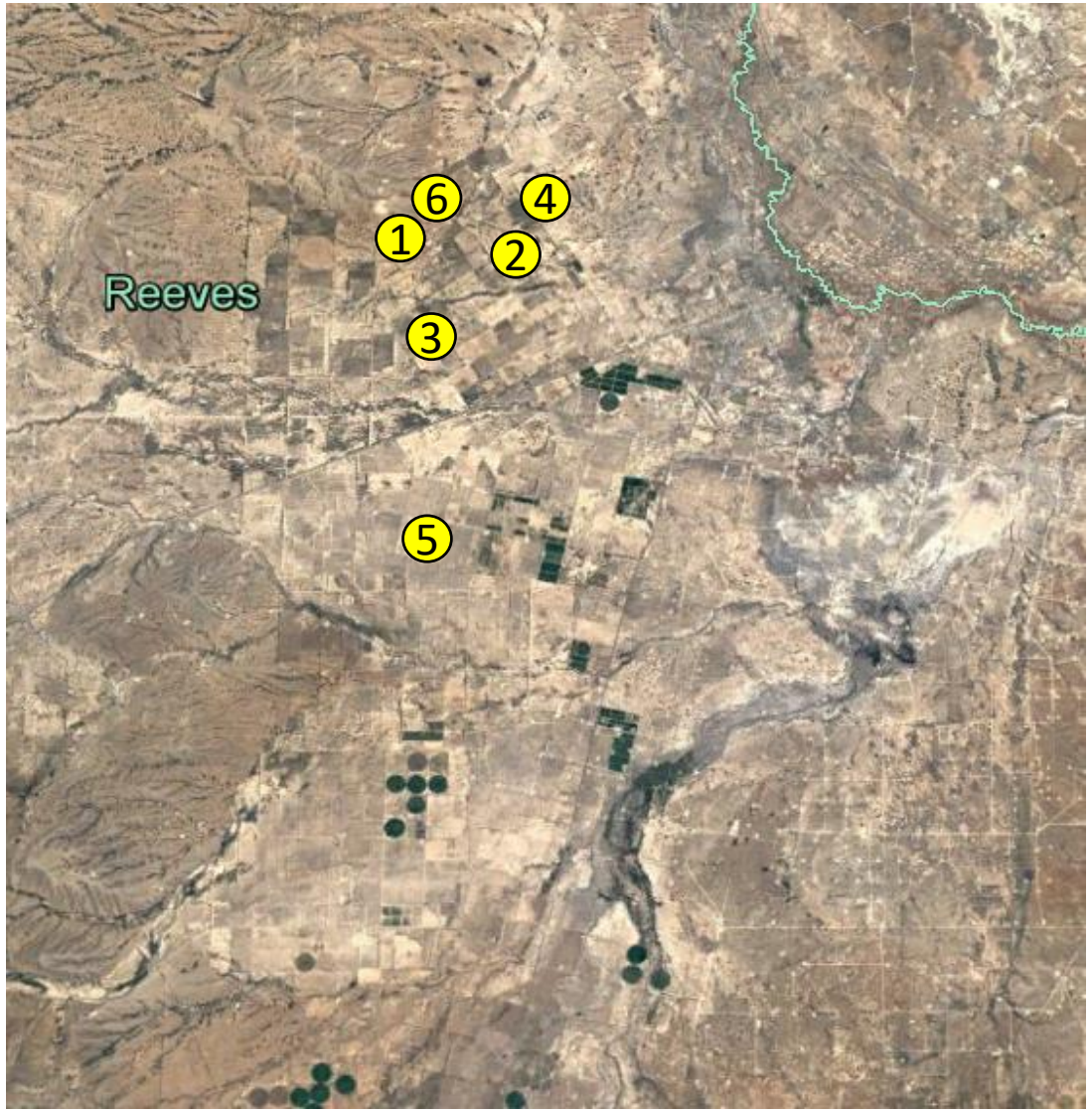
# Case Study – Wolfcamp Completions




- Silverback drilled 2 wells and completed using engineered designs (driven by sonic data)
- Both wells had Oil IP30 rates that exceeded 600 bbls/day and were considered a success
- Next 4 wells were engineered with LatScience
- Completions were done with 100 ft stages, 4-6 clusters per stage
- The average Oil IP30 rate for the 4 wells > 1000 bbls/day
- Centennial paid $855M for the acreage
- After normalizing for lateral length, Centennial determined that Silverback wells were outperforming CDEV wells by 28%. They also stated that the EUR estimates were 33% higher.

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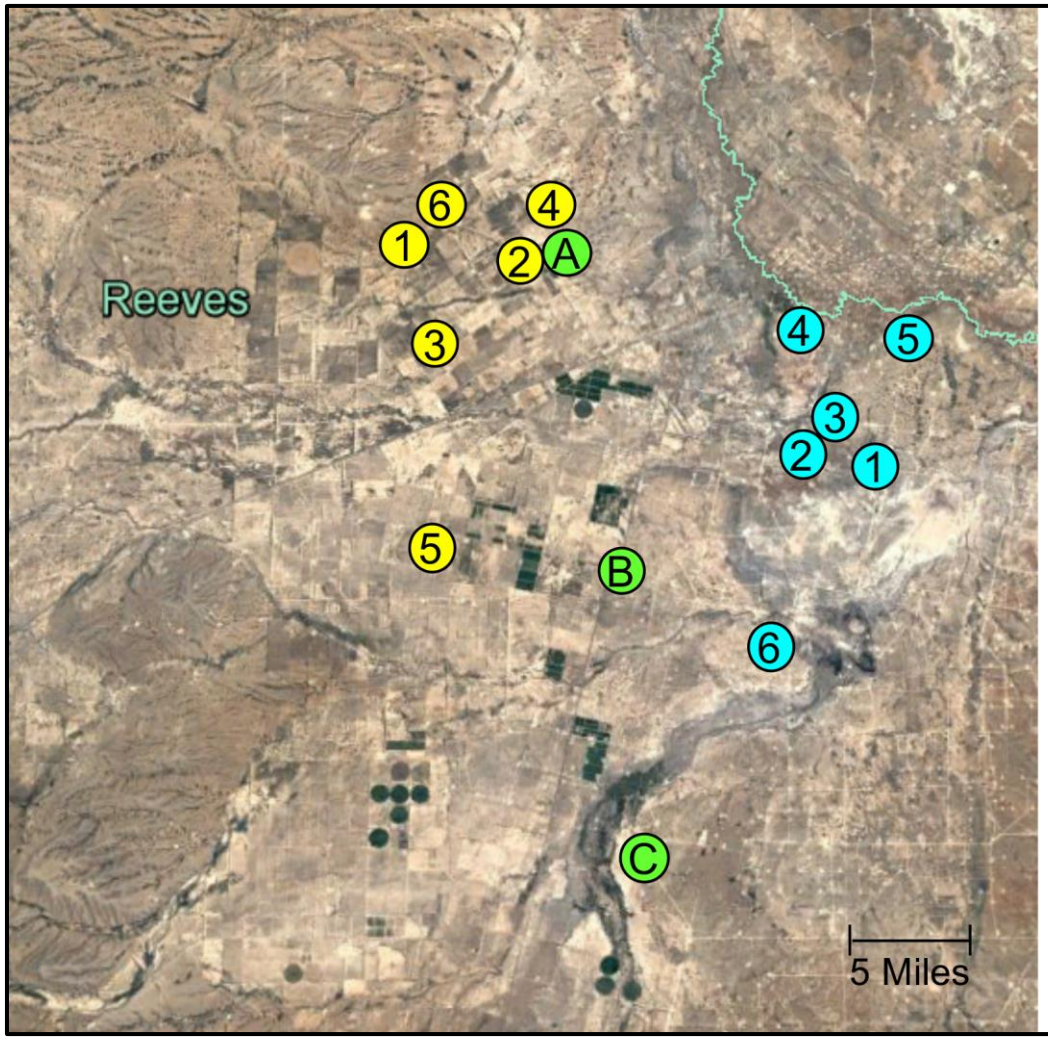
# Case Study – Wolfcamp Completions



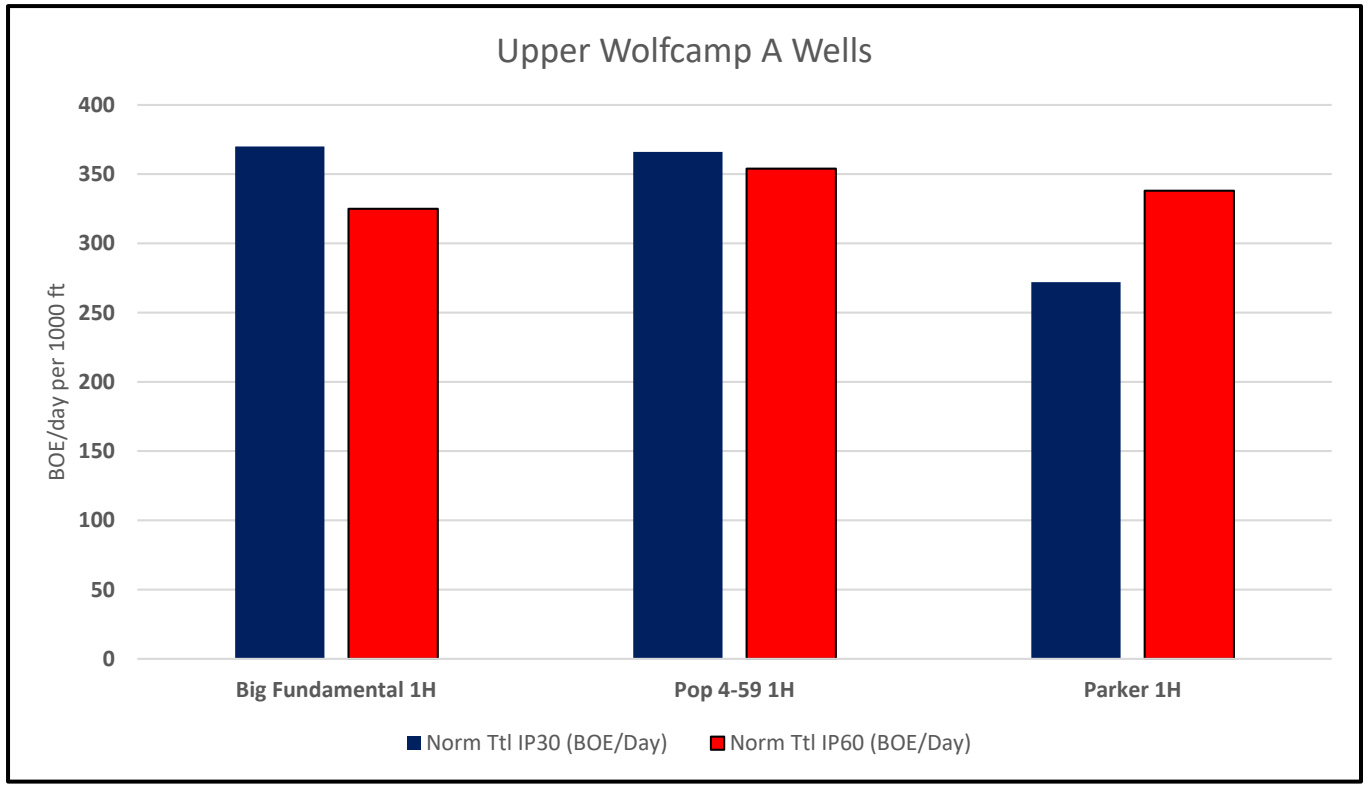

1. Silverback Folk Rowling 1H
2. Silverback Williams 2H
3. Silverback Admiral 1H
4. Silverback Pop 1H
5. Silverback Parker 1H
6. Silverback 1H

1. Centennial Cabrito St 5H
2. Centennial Layden 2H
3. Centennial Layden 3H
4. Centennial Stingray 3H
5. Centennial Sieber Trust 4H
6. Centennial CWI St 7H

A. Centennial Big Fundamental 1H
B. Centennial Balmorhea St 2H
C. Centennial Collins 2H

# Case Study – Wolfcamp Completions

| Centennial Q1 2017 Wells | Lat Length (ft) | Oil IP 30 (BO/day) | Ttl IP 30 (BOE/day) |
|---|---|---|---|
| Big Fundamental 1H | 4600 | 1135 | 1700 |
| Collins 2H | 6315 | 976 | 1183 |
| Balmorhea St 2H | 5750 | 1079 | 1311 |




- New Centennial completions done with 15 clusters/stage
- The best of the 3 new wells still struggling to keep up with Upper Wolfcamp A LateralScience wells

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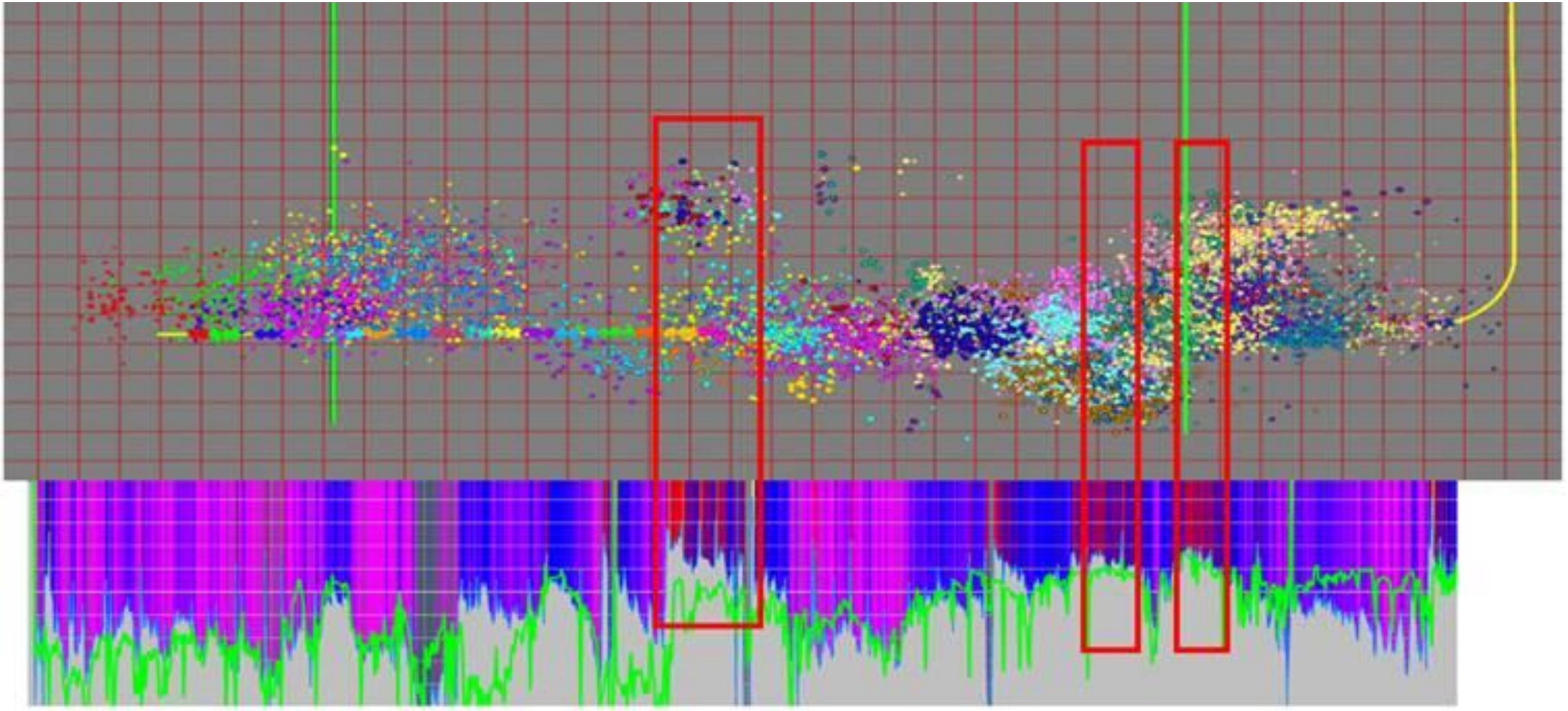
# Lateral Science and MicroSeismic Comparison



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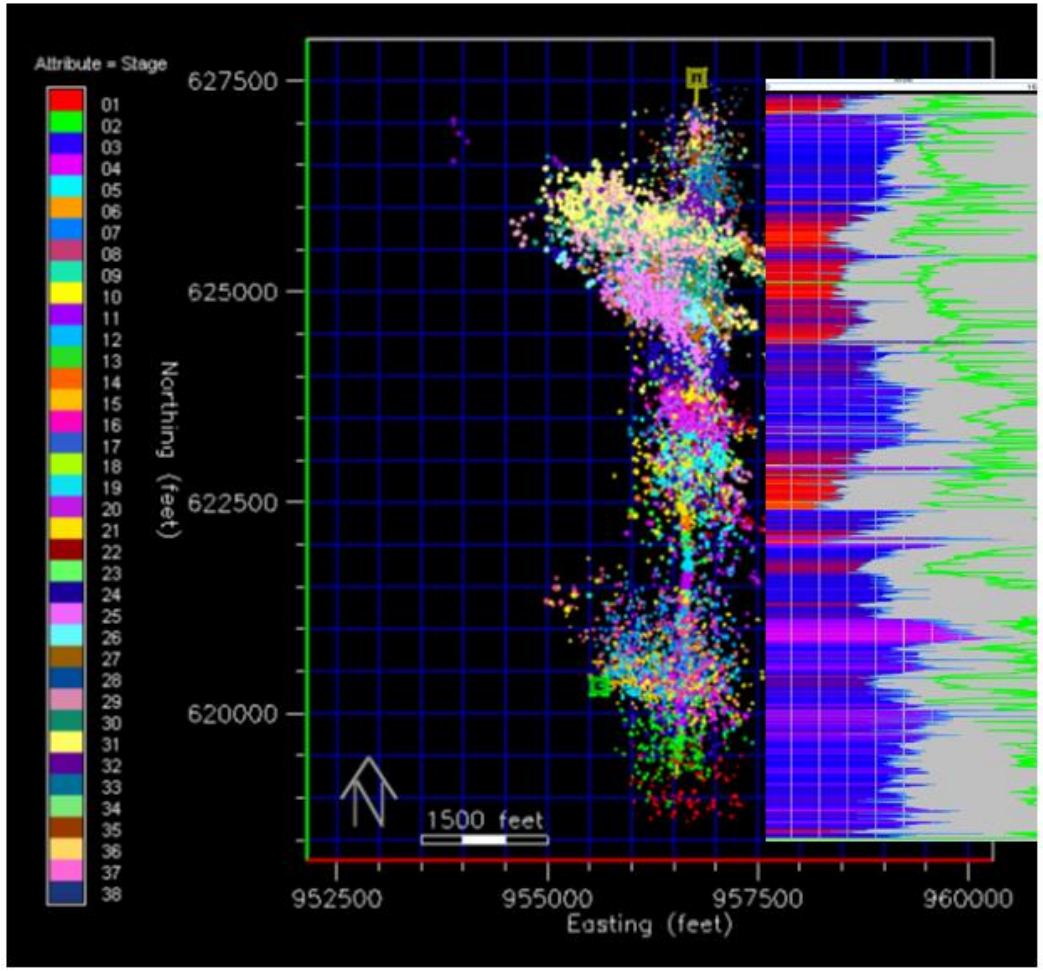

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# Data Requirements

- Mandatory
  - ROP, WOB, RPM, D
  - DIFP, PRAT/SPM, SPP
  - Kn, Tmax, ΔPmax
  - Daily Drilling Reports
- Preferred
  - Directional data
  - Mudlog data
  - LWD GR
  - Completion Design Preferences
- Nice To Have
  - Production Logs
  - Production History
  - Geological cross section
  - Any FE data available in the area