FEEDING THE "FRAC MACHINE"

Maarten Propper
maarten.propper@cordax.com

WELL CONSTRUCTION EFFICIENCY

- Figure A & B show the drilling and completion cost efficiency gains have been mostly achieved.
- The next challenge is to increase the production per well while maintaining achieved drilling and completion efficiency.

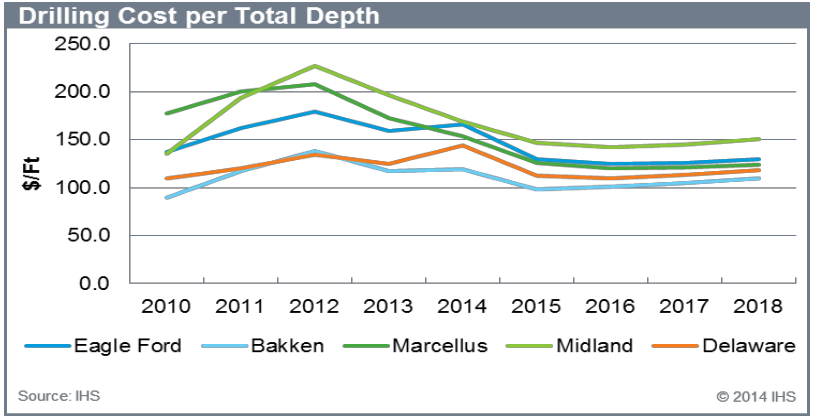


Fig. A: Drilling cost rate per foot.

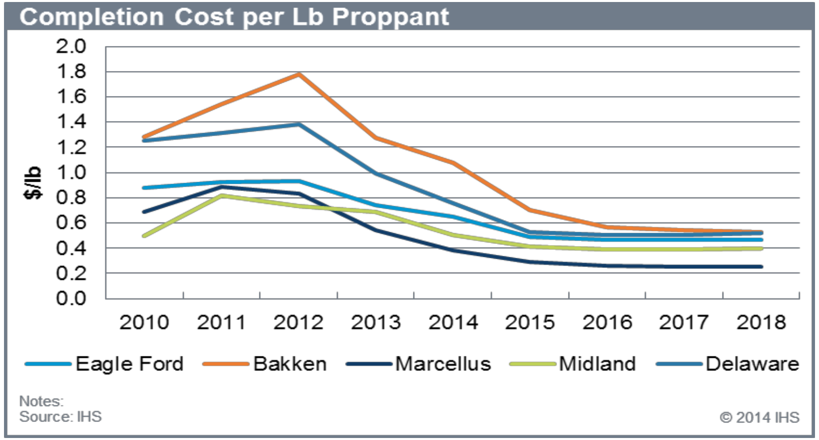


Fig. B: Completion cost rate per lb. of proppant

Source: EIA, Trends in US Oil and Nat. Gas Upstream Costs

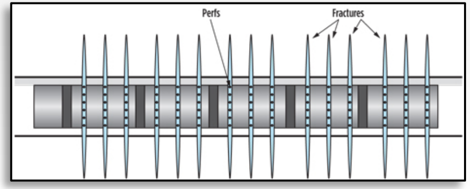
COMPLETION DESIGN

Status Quo – Geometrical Completion Design

- Geometrically spaced clusters without regard to heterogeneity of the formation
  - Clusters may not be fractured adequately
  - Increased probability of screen-outs
  - Uneven proppant distribution
  - Not prioritizing the sweet spots
  - Increased fracture initiation time from fracturing more ductile rock

"Production logs indicate that, due to sub-optimized completions, 30%–40% of perforation clusters contributed no production whatsoever, leaving considerable reserves in place."

– OILPRO, January 8, 2016



"Engineered" Completion Design

- Design based on Geomechanical and Producibility criteria for perforation placement and Frac design

Geomechanical	Producibility
▪ Rock Mechanical Properties ▪ Lithology ▪ Brittleness / Stress ▪ Natural Fractures	▪ Lithology ▪ TOC ▪ Porosity / Permeability ▪ Saturation ▪ Stimulation Analysis

- Only an indication of geomechanical formation properties can derived from drilling and mud logging data
- Proper grading of the well requires additional data: resistivity, density, porosity, spectral gamma ray

"ENGINEERED" COMPLETION DESIGN

- Engineered completion designs are proven, methodical approaches to horizontal well completions, focusing on determining optimal staging and perforation / frac placement for increased well performance.
- Numerous papers (SPE, URTeC) have been written documenting case studies demonstrating improved well performance after switching to an engineered design methodology
- Most, if not all of them focus on how perforation cluster performance was improved by taking a methodical approach to cluster placement along the lateral.

1) SPE138477

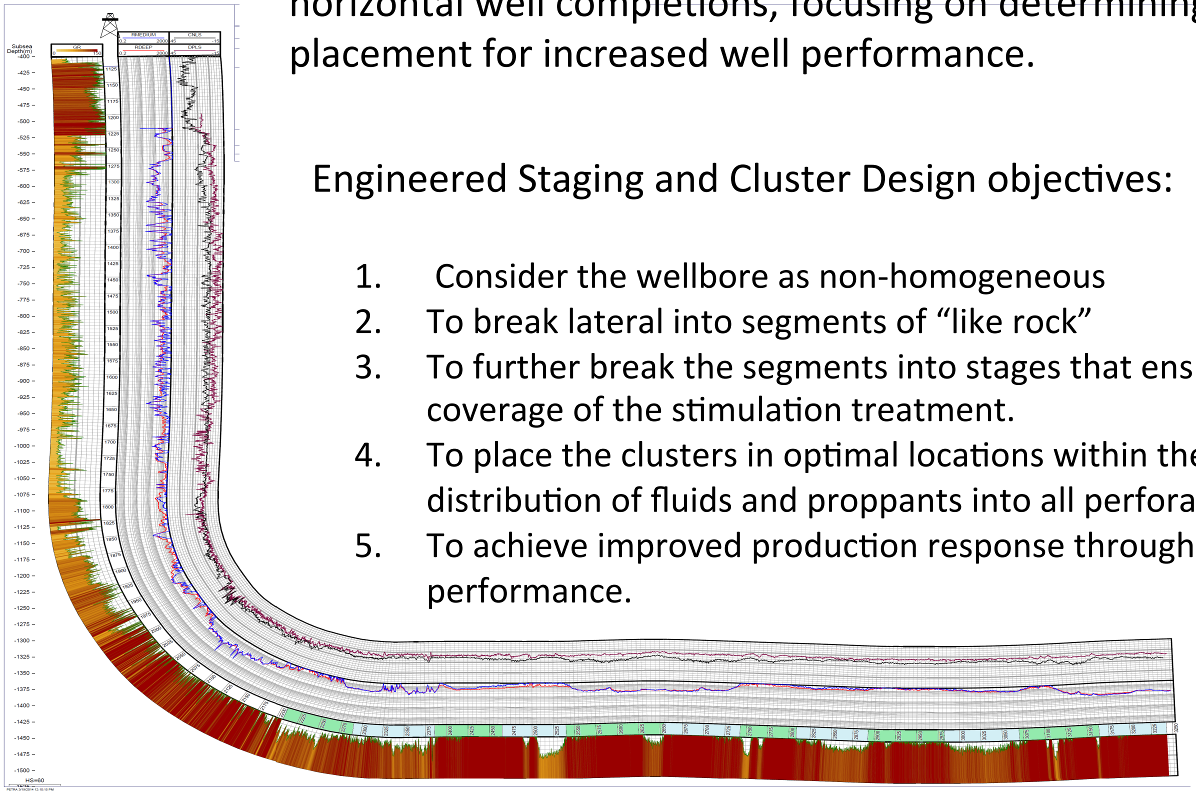
- 125 Production Logs, multiple Shale Plays
- Average 68% total perforation clusters contribute to production
- Better production from wells with more clusters contributing
- Increasing cluster performance = $

2) URTeC: 2461822 - *Completion Optimization Using Both Vertical and Horizontal Measurements, an Eagle Ford Shale Case Study*

- In Area 2 average production of engineered completed wells were 86% better than offset wells based on 90 day BOE cum per 1000 ft. of lateral length

ENGINEERED COMPLETION DESIGN

Engineered completion designs are industry proven, methodical approaches to horizontal well completions, focusing on determining optimal staging and cluster placement for increased well performance.

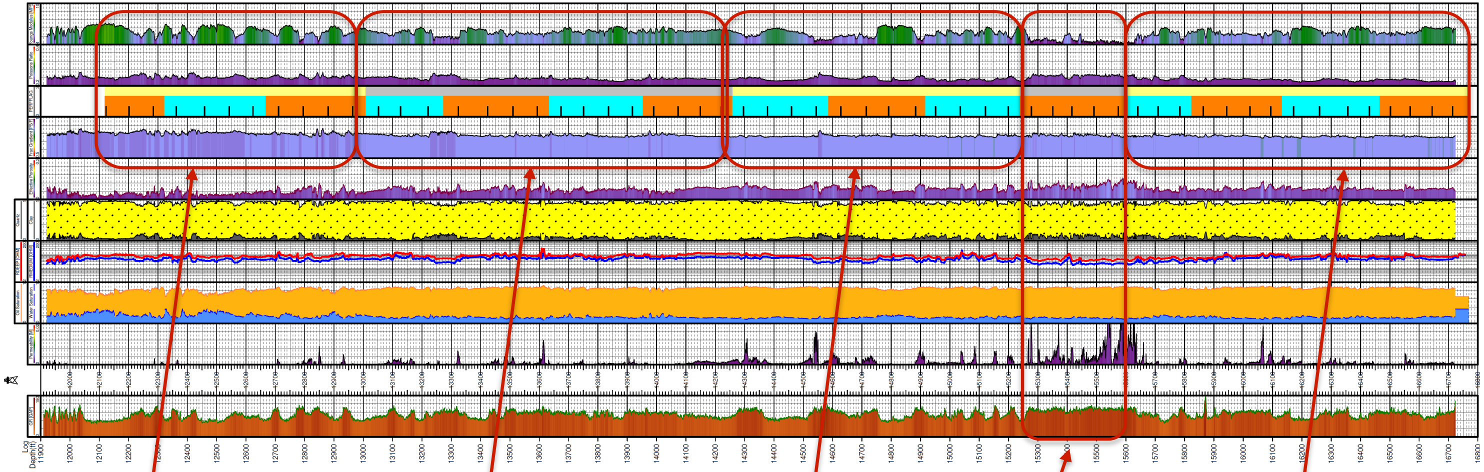


Engineered Staging and Cluster Design objectives:

1. Consider the wellbore as non-homogeneous
2. To break lateral into segments of "like rock"
3. To further break the segments into stages that ensure optimized reservoir coverage of the stimulation treatment.
4. To place the clusters in optimal locations within the stages that ensure equal distribution of fluids and proppants into all perforation clusters
5. To achieve improved production response through improved perforation cluster performance.

LATERAL SEGMENTING AND STAGING

Using processed log data, group the lateral into "like" rock segments



Stress change, Higher Sw, Erratic YM

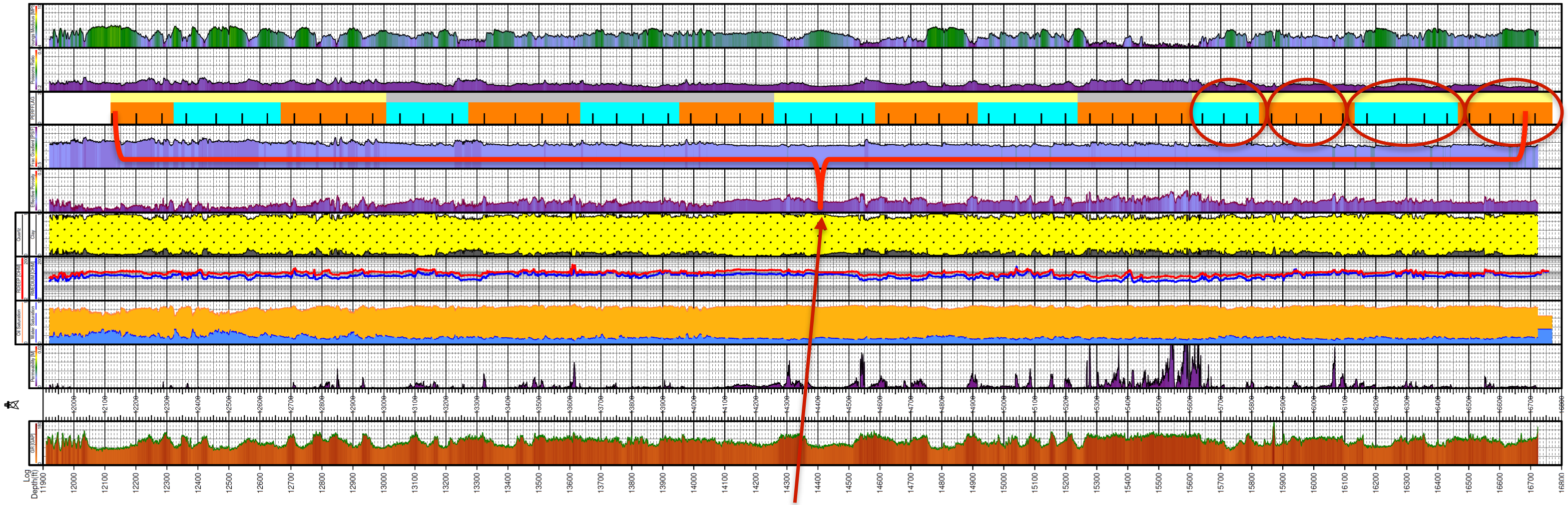
Consistent stress, PR and YM

Erratic stress, Poisson's Ratio and Young's Modulus

High GR, Permeable, Erratic Stress, Low YM, Higher PR, Higher Clay Volume, Unlike rest of lateral

Consistent stress, PR and YM

LATERAL SEGMENTING AND STAGING

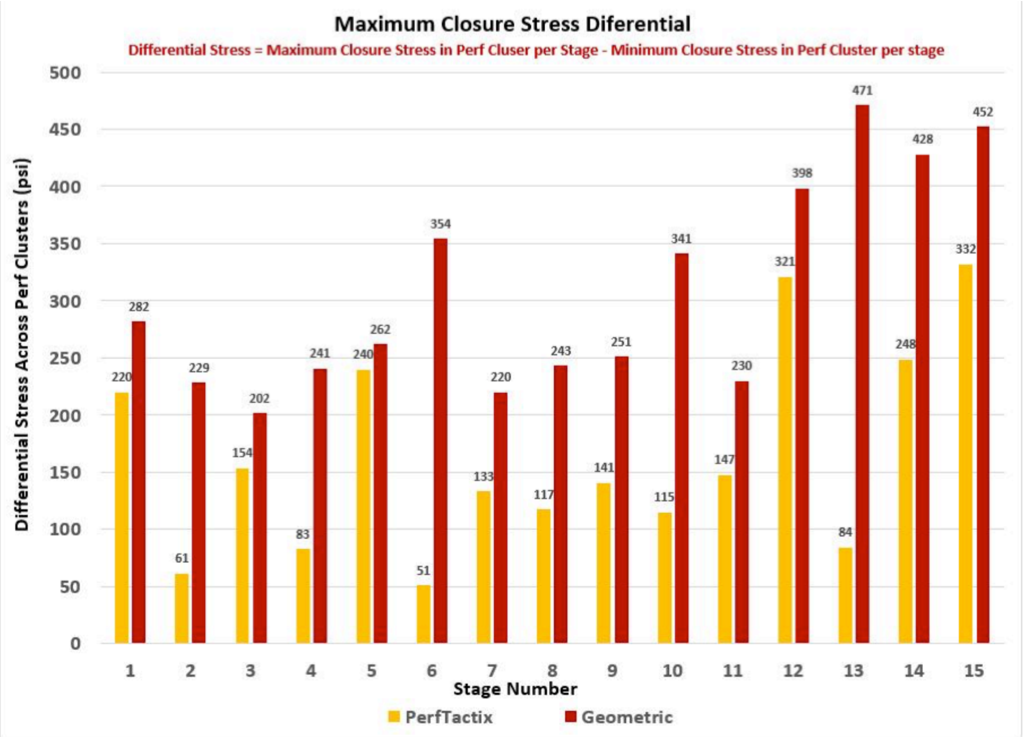


- Divide individual segments into appropriate Frac stages
- Start with a baseline stage length and work from there.
- Try to maintain consistent rock and reservoir properties in each stage
- Try to maintain consistent cluster spacing, while keeping stress as close to the same at each cluster to ensure limited entry fracturing

ENGINEERED ANSWER PRODUCT EXAMPLE

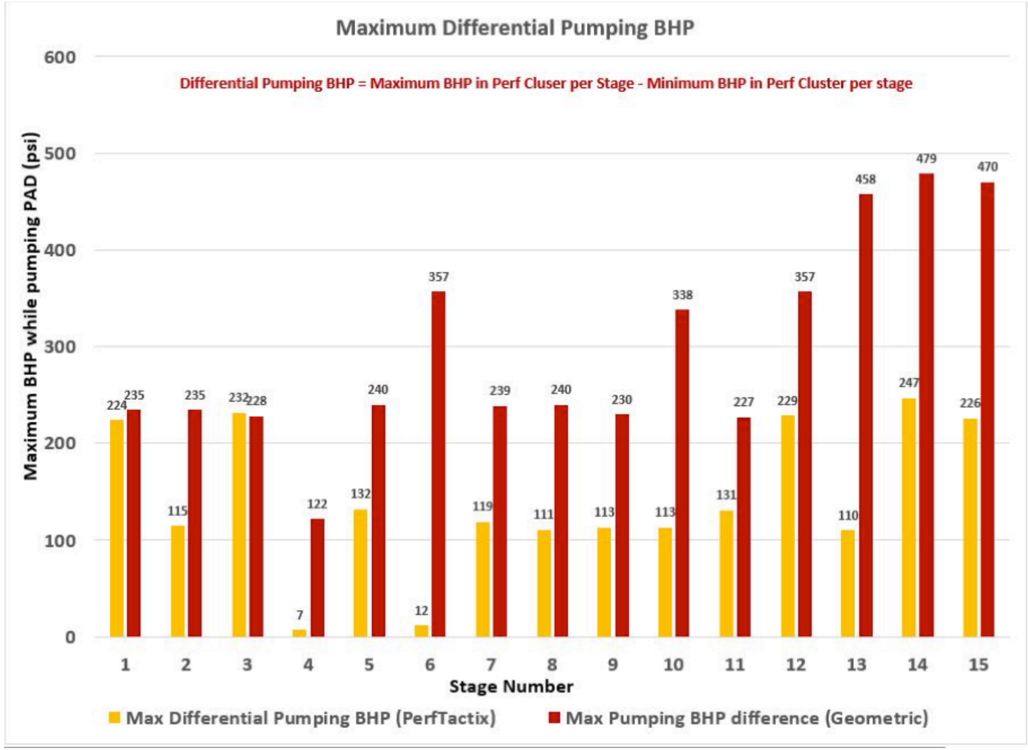
- This plot shows the comparison between the differential closure stresses across all the perforation clusters in a Frac stage for both the Geometric and PerfTactix Engineered design approaches.

- Industry experience has taught that to minimize this value, staying below 200 psi whenever possible, will provide the best chance to break down all clusters.



ENGINEERED ANSWER PRODUCT EXAMPLE

- The plot compares the differential pumping bottom-hole pressure (BHP). The smaller this difference, the greater the likelihood of breaking down and effectively distributing the treatment across all clusters in a Frac stage.



"ENGINEERED" COMPLETION DESIGN - INPUTS

- The measured and calculated inputs shown at the below graph are needed for the Engineered completion methodology:

Formation Producibility

- Clay Volume
- Porosity
  - Density
  - Neutron
  - Effective & Total
- Permeability
- Water, Oil, Gas Saturations
- TOC

How much of the lateral is in the desired reservoir interval?
How good is the reservoir?
How laminated is it?
TIV Anisotropy?
What fluids are there?
Producibility of those fluids ?

Rock Geomechanics

How the rock will respond to hydraulic fracturing ?
The likelihood (or not) of proppant embedment ?
The types of proppant to consider ?
Achieving (or not) adequate, connected fracture conductivity ?

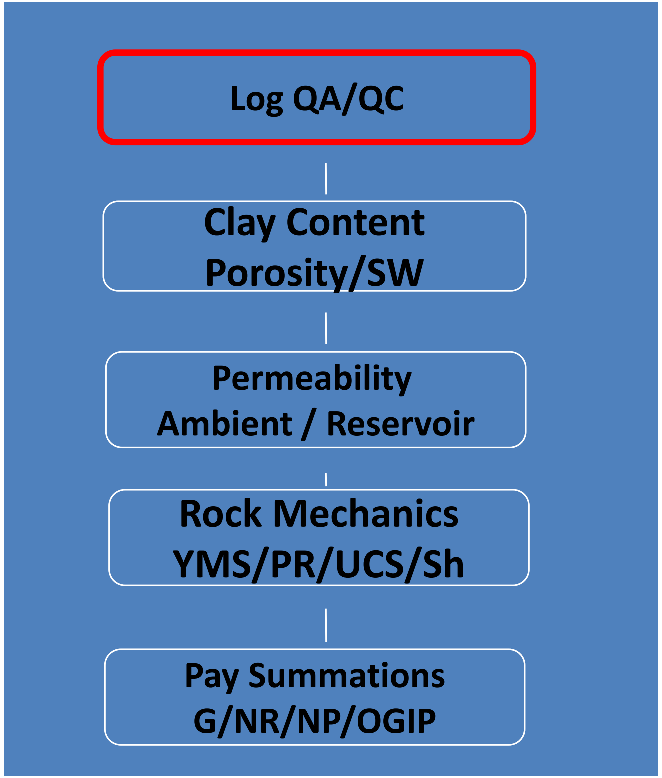
- Matrix Clay Volume
- Matrix Quartz Volume
- In-Situ Stress (& Stress Gradient
- Pore Pressure
- Poisson's Ratio
- Young's Modulus

DATA ANALYSIS ⟶ DATA CAPTURE

- Currently readily available data is:
  - ROP & WOB
  - MWD – Gammy Ray
  - Mud Logging (Gas detection & Cuttings)

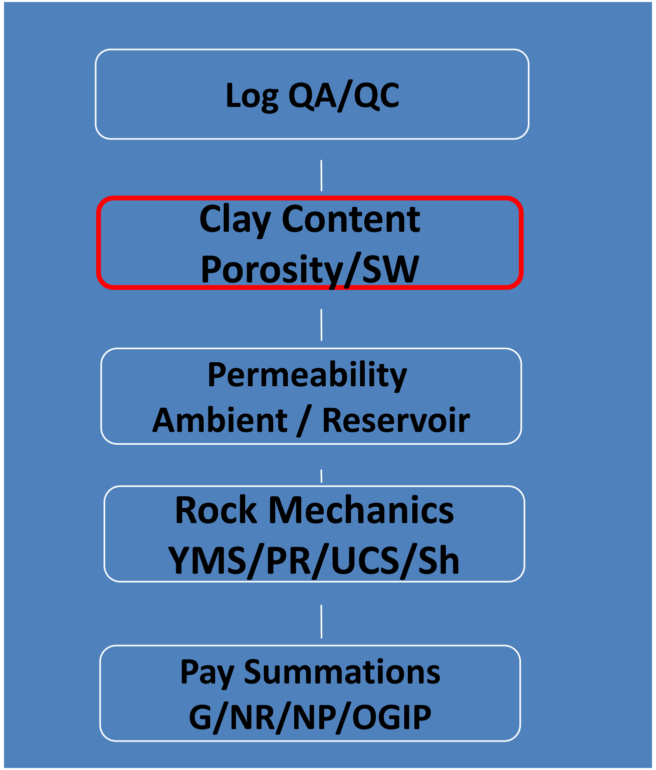
- Minimum extra information needed to derive and calculate with the needed accuracy the engineered completion methodology input parameters is:
  - Formation Resistivity
  - Formation Density
  - Formation Porosity
  - Formation Spectral Gamma Ray

DATA ANALYSIS



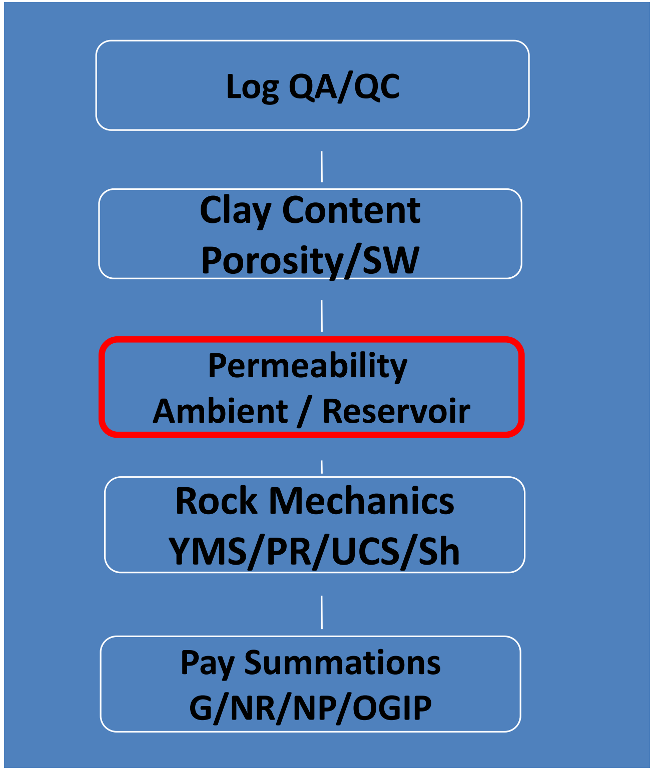
- In today's environment, very few wells are truly lone wolf wildcats. There are usually a plethora of data around to compare the log readings over large intervals of wellbore.
- Consistency is the key when it comes to using log data for stimulation petrophysics.
- The objective is to keep the petrophysical model constant and have the log data going into it at least fall in the same range.

DATA ANALYSIS



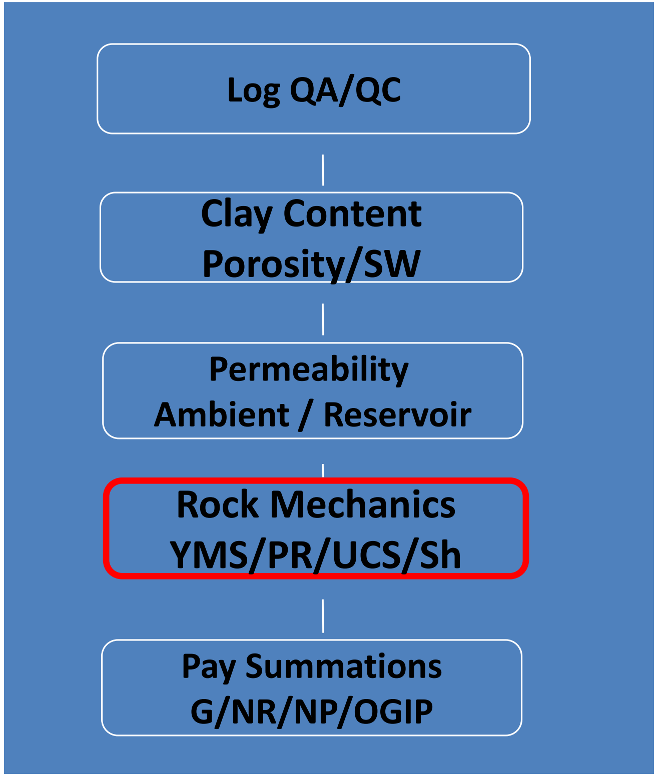
- Clay Volume Determination
  - Traditionally – use the GR or SP
  - Spectral GR works nice if available
  - Modern elemental analysis tools when available
  - Modern techniques use the Density Neutron and often resistivity in addition to the GR
  - All models should be validated using XRD total clay
- Water Saturation Determination
  - Most all models can be made to work
  - Simandoux or Rocky Mountain Method often used
  - Validate with core or production modeling as much as possible

DATA ANALYSIS



- Porosity based model
- Corrected for Klinkenberg
- Relative perm to hydrocarbons
- Does not represent the system permeability which is determined by DFIT tests, Step Down tests or production modeling

DATA ANALYSIS

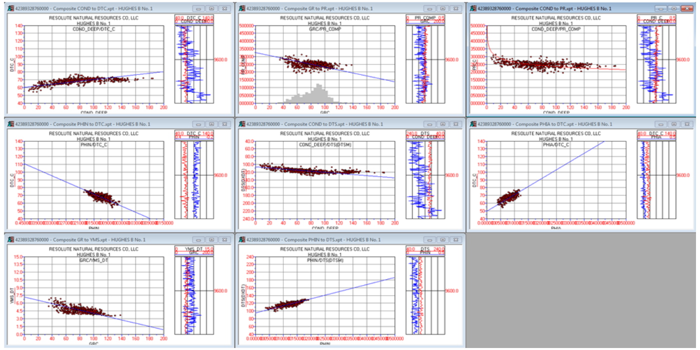


- Data Reconstruction for Missing PE and Sonic Measurements
  - Estimate the DTC and DTS slowness measurements using the Composite Mechanical Rock Properties Model (SPE 108139)
  - Estimate the PE for mineralogy determination using neural network

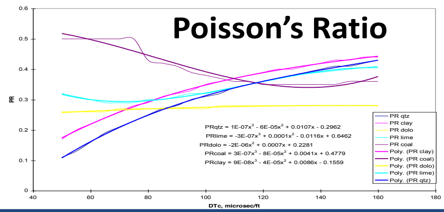
- Key Papers for Estimating Rock Properties from Logs
  - SPE 108039 – Composite Rock Model
  - SPE 115258 – Brittleness Index
  - Brittleness Index is also related to the Lame' parameters of Rigidity (μRHO) which helps tie seismic interpretation with log data. Goodway, 2001

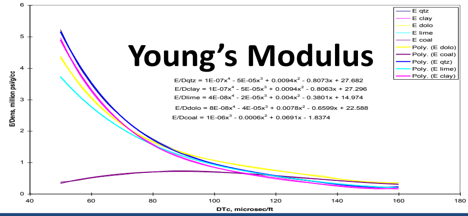
DATA ANALYSIS

Crossplots to Identify Petrophysical Relationships between common Log measurements and DTC, DTS, PR and YMS

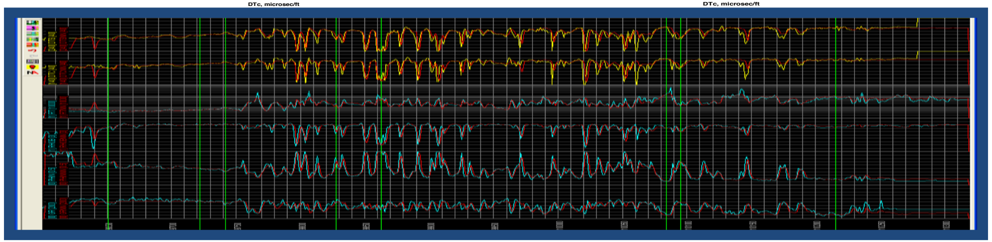


Multi-Mineral Lithology Determination of PR and YMS - Gohfer



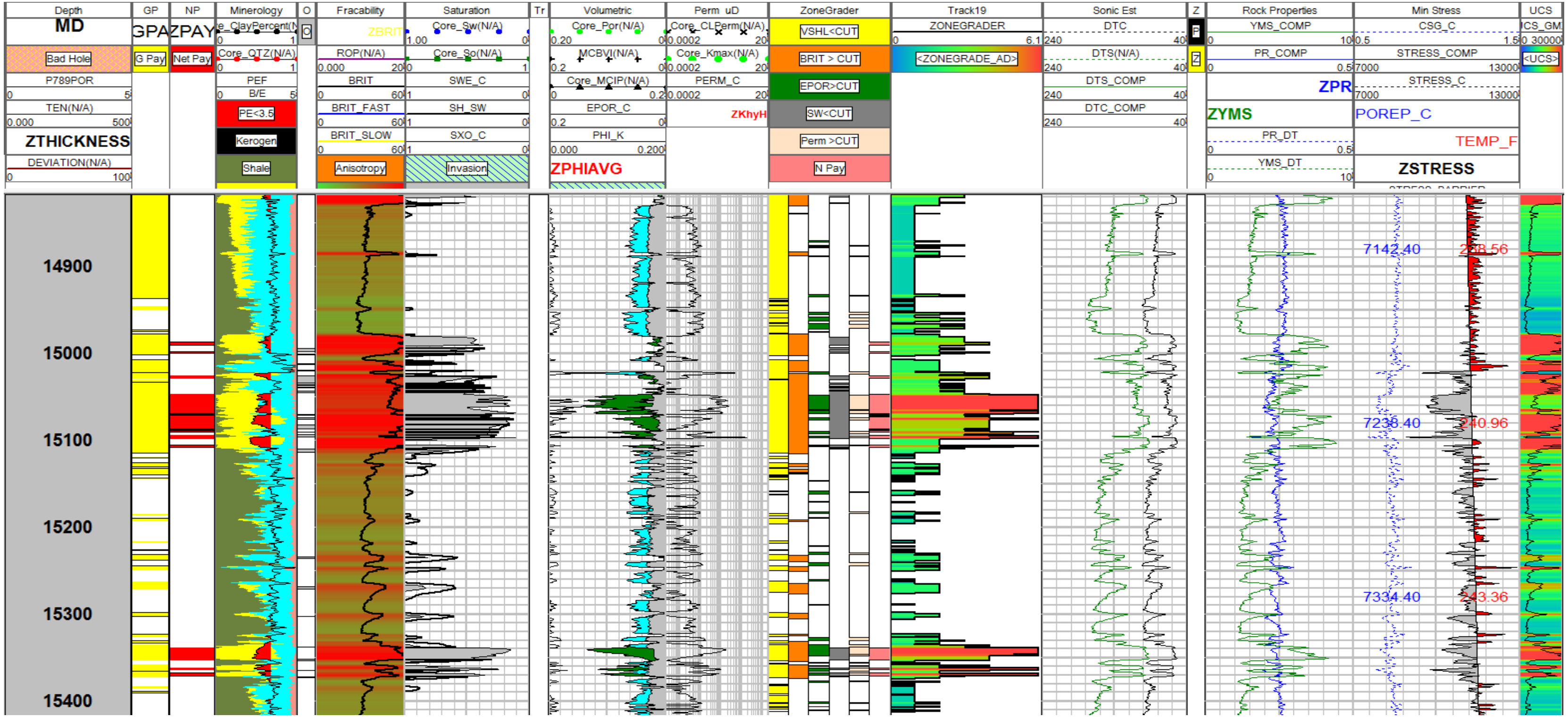


Neural Network Model For Determining DTC, DTS, PR and YMS (Optional)



DATA ANALYSIS

Advanced Geomechanical and Petrophysical interpretation



FEEDING THE FRAC MACHINE

HOW DO WE ACQUIRE THE NEEDED DATA COST EFFECTIVELY & WITH LOW LIH RISK ?

DATA CAPTURE

- In horizontal well challenge is to acquire needed formation evaluation data in a low risk and total cost effective way.
- There are various methods commercially available that will measure the minimum needed formation evaluation data:

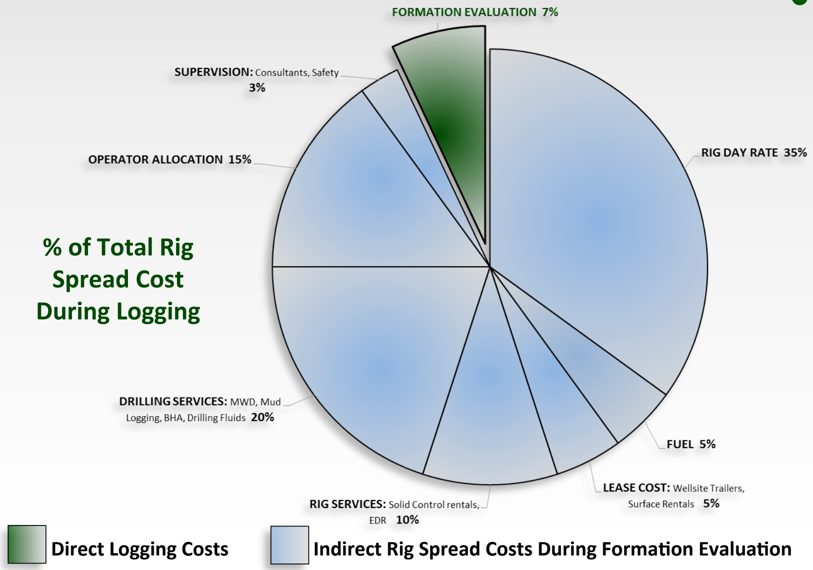
  - **Logging While Drilling (LWD)**
    - Most costly and high LIH risk profile.
  - **Wireline Pipe Conveyed or Thru − the - Bit Logging**
    - More cost effective than LWD but still total cost can be prohibitive (extra trip needed)
    - No total well control while logging and moderate LIH risk
  - **Logging While Tripping (LWT™)**
    - Most total cost effective
    - Full well control while logging and virtual no LIH risk

LWT™ FORMATION EVALUATION OPTIMIZATION

Objective:

LWT™ acquires quality formation evaluation data in vertical, highly deviated, unstable and horizontal well bores by replacing Wireline Logging, Thru-the-Bit Logging, Pipe Conveyed (PCL,TLC) and Logging While Drilling.

Main Cost of Formation Evaluation is Indirect Rig Expense



LWT™ Reduces Formation Evaluation Risk Exposure

Lost In Hole

- Eliminates LIH risk for tools & radioactive sources
- Inexpensive BHA

Well Control

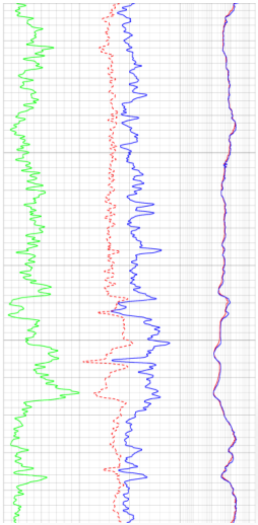
- Circulation during logging
- Pipe rotation during logging
- Logging tools retrievable at an time during LWT operations

Operational Risk

- Eliminates bridging
- Neutralizes most hostile hole conditions
- Reliable tool retrieval if BHA stuck
- Reduces risk of failure to acquire data

LWT™ MEASUREMENT OUTPUTS

- Gamma Ray
  - GR
- Spectral Gamma Ray
  - SGR, Thorium, Potassium, Uranium
- Neutron Porosity
  - Raw counts: Near, Far
  - NPOR
- Formation Density
  - Raw counts: Near, Medium, Far
  - RHOB, DCOR
  - Caliper
- Resistivity
  - Dual Induction (+Synthetic SP)
  - Propagation Resistivity
  - Laterolog Resistivity

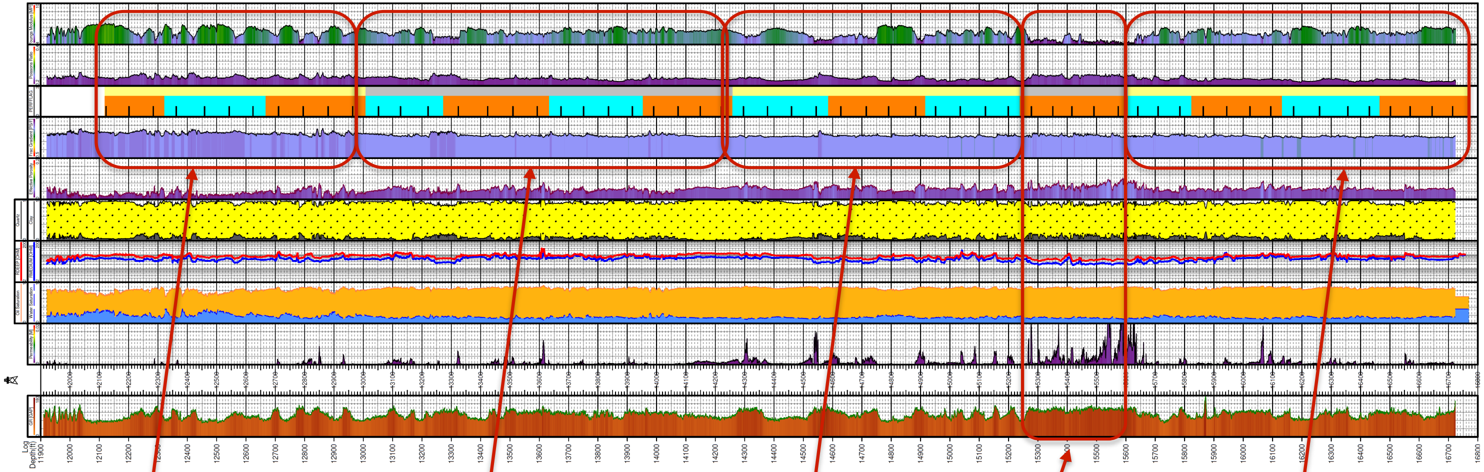


LWT™ Logging Tools Specifications:

LWT™ tool	Dual Induction (DUIN)	Triple Detector Density (DEN)	Compensated Neutron & Gamma Ray (CN-GR)	Spectral Gamma Ray (SGR)	Memory Logger (MEMBAT)
Weight (lbs)	17.6	38.4	58.4	22.7	14.6
Length (ft)	6.19	5.43	3.07	3.94	4.0
Outside Diameter (in)	$1\,^{11}/_{16}$	2.0	2.0	2.0	$1\,^{11}/_{16}$
Max Temp (F)	300	300	300	300	300
Max Pressure (PSI)	14,000	14,000	14,000	14,000	14,000

ENGINEERED COMPLETION METHODOLOGY

Using processed log data, group the lateral into “like” rock segments



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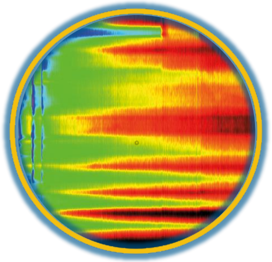
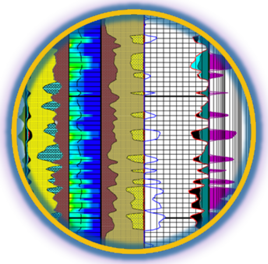


Monitoring

Data capture



Data analysis

High-efficiency field execution

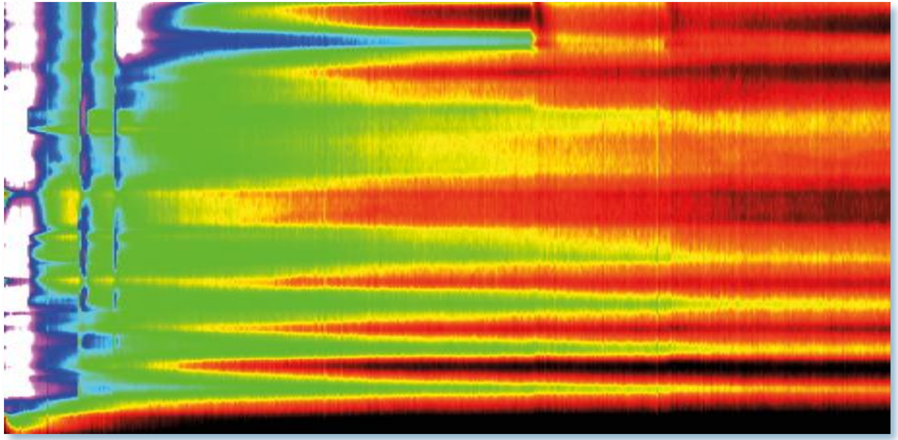
Completion / Perforating design

DATA CAPTURE – PRODUCTION MONITORING

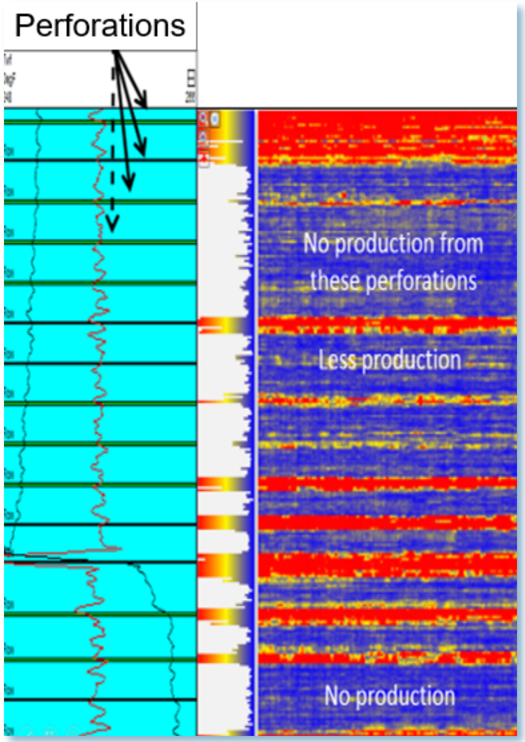
- In horizontal well challenge is to acquire needed stage production data contribution data in a low risk and total cost effective way.
- There are various methods commercially available that will measure the stage production data in a horizontal well:
  - **Full Permanent Production Monitoring**
    - Complex installation and cost prohibitive
  - **Permanent Fiber Optic Production Monitoring**
    - Less cost prohibitive than Full Permanent Monitoring installation
    - Complex installation specially with "plug and perf" completions
  - **Periodic Fiber Optic Production Monitoring**
    - Cost effective
    - Proven method with low operational risk.

PRODUCTION WELL MONITORING

- Well integrity monitoring
- Enhanced production logging
- Production and injection well profiling
- Artificial lift optimization
- Well interference



Post-injection DTS warmback survey used to establish a relative injectivity profile



DAS survey identifying contributing perforation clusters post stimulation

FEEDING THE "FRAC MACHINE"

- Drilling and completion cost efficiency gains have been mostly achieved.

- The next industry challenge is to increase the production per well while maintaining achieved drilling and completion efficiency.
  - Engineered Completion Design methodology has proven to optimize and increase the production per well.

- Cost effective and low LIH risk formation evaluation and production data capture in each well is needed.
  - The formation evaluation LWT^{TM} technology is a proven and cost effective method to acquire the needed formation evaluation in each well.
  - The periodic "tractor-wireline" conveyed fiber optic production monitoring is a proven and cost effective method to acquire the needed stage production data.

THANK YOU

Ricardo Quintero
Senior Vice President
Cordax Evaluation Technologies Inc.
Sugar Land, TX, United States
Mobile +1 (832) 520-8942
Email ricardo.quintero@cordax.com
www.cordax.com

Donald R. Herman
Business Development Manager
GR Energy Services | 2150 Town Square Place, Suite 410 |
Sugar Land, TX 77479
Direct: 281.201.6812 | Cell: 713.550.2595 |
don.herman@grenergyservices.com