# Exploration and Development Techniques for Unconventional Resources*

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## Abstract

The productivity of an organic shale is driven by its reservoir quality (RQ) and completion quality (CQ). RQ consists of parameters such as effective porosity, organic content, matrix and system permeability, fluid saturations, net thickness and hydrocarbons in place. We have little control over reservoir quality parameters other than well placement that accounts for their spatial variation. CQ parameters include closure stress magnitudes and profiles, structural setting, mechanical properties, productive fracture geometry dimensions, and their placement relative to each other. Some of these parameters can be addressed via well placement, completion designs and production management strategies. The exploration phase of a project is focused on defining the RQ and CQ and how they vary spatially within a basin. Existing seismic, log and core data are used to high grade acreage. Once the location(s) is selected the data acquisition program should focus on petrophysical and geomechanical assessment from logs and core acquired in a pilot hole. Unlike with conventional reservoirs, without stimulating and producing the well this cannot be truly confirmed. If no horizontal well is planned, then strong consideration should be given to completing and producing the vertical well. If a lateral is planned, then hydraulic fracture simulations can determine the best lateral landing point and predict frac geometries. Post-frac production management will insure fracture conductivity is not compromised, while assessing the peak production rate and subsequent rate of decline. Ideally six months to one year of production is acquired to accurately assess ultimate recovery. In the exploration phase completion and economic optimization is not the primary objective. The data acquired at this time will we used to design a field development strategy. Once the potential for commercial production has been indicated the key drivers become well completion optimization and development strategy. This is accomplished by field experimentation supported by design modeling. Different completion designs, well lengths and spacing, and production techniques are evaluated. At the same time the supply chain is developed to feed the rapid increase in well count so that

unnecessary costs are eliminated. Many procurement topics with be the same between basins, but each basin will have unique supply chain issues. This presentation will provide workflows to address the key technical and economic challenges for the exploration and field development phases for unconventional reservoirs. A case history from the Fayetteville Shale will show how one US operator achieved these objectives and ultimately developed a reservoir with tens of thousands of wells.

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# Exploration and Development Techniques for Unconventional Reservoirs

George Waters
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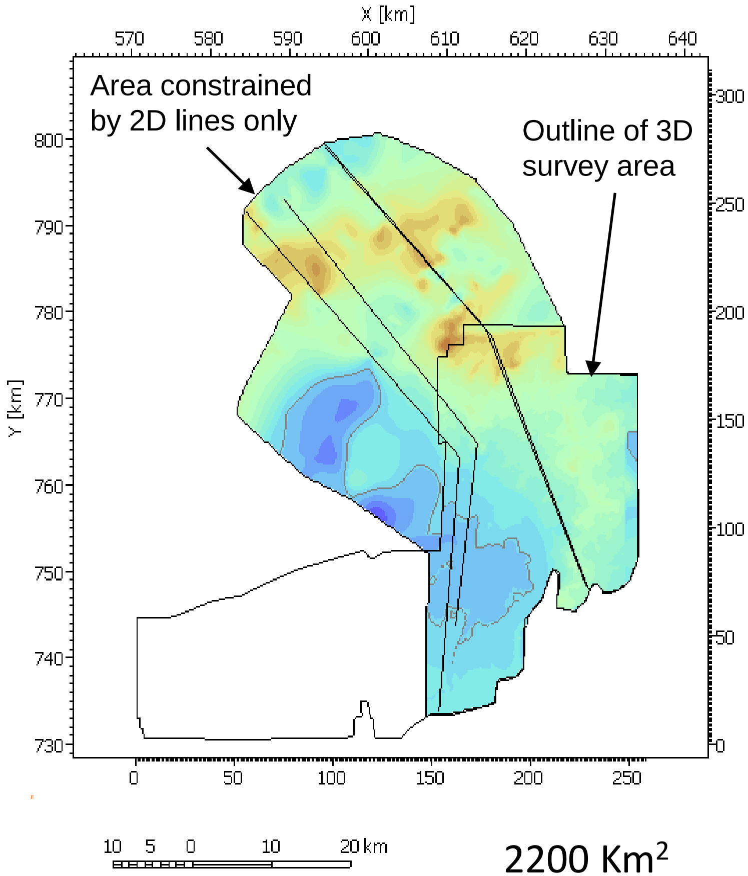
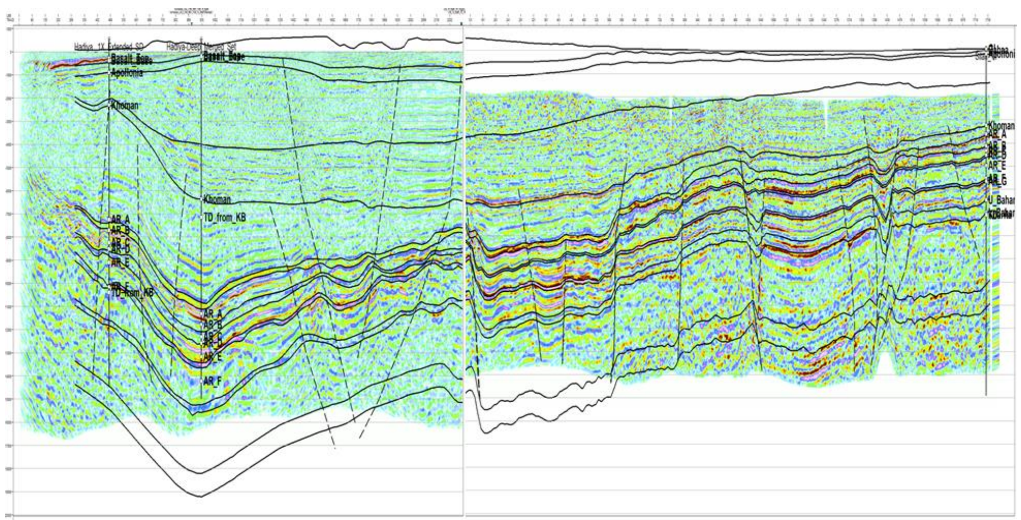
Schlumberger Stimulation Fellow

- Exploration Phase
  - High grading acreage for exploration well location
  - Data acquisition on initial wells
- What Makes A Good Unconventional Reservoir
  - Reservoir Quality (RQ)
  - Completion Quality (CQ)

## ➢ Seismic Data to Define Basin Structure




2200 Km$^2$

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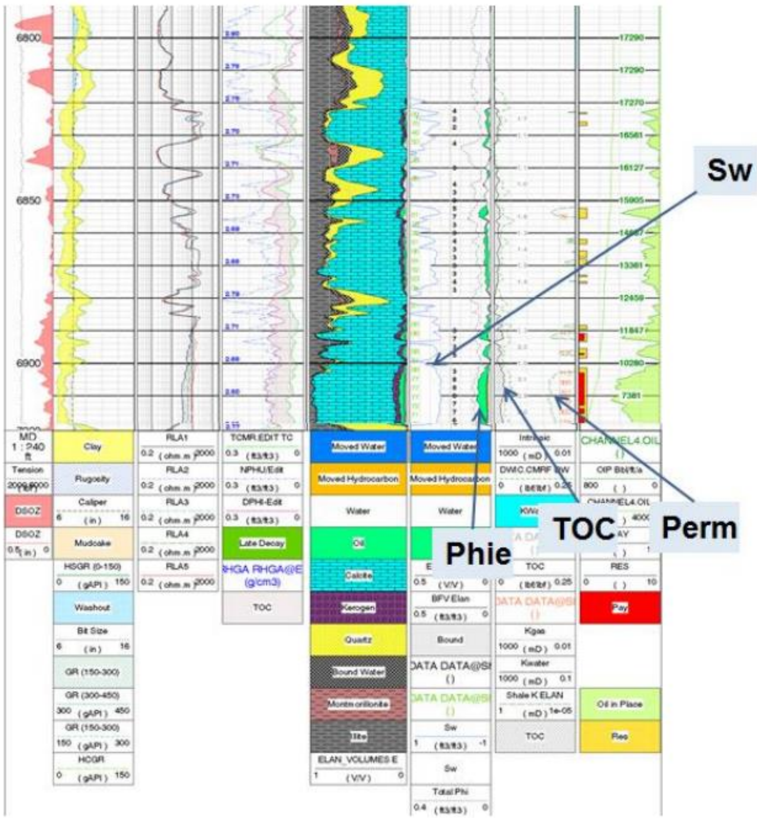
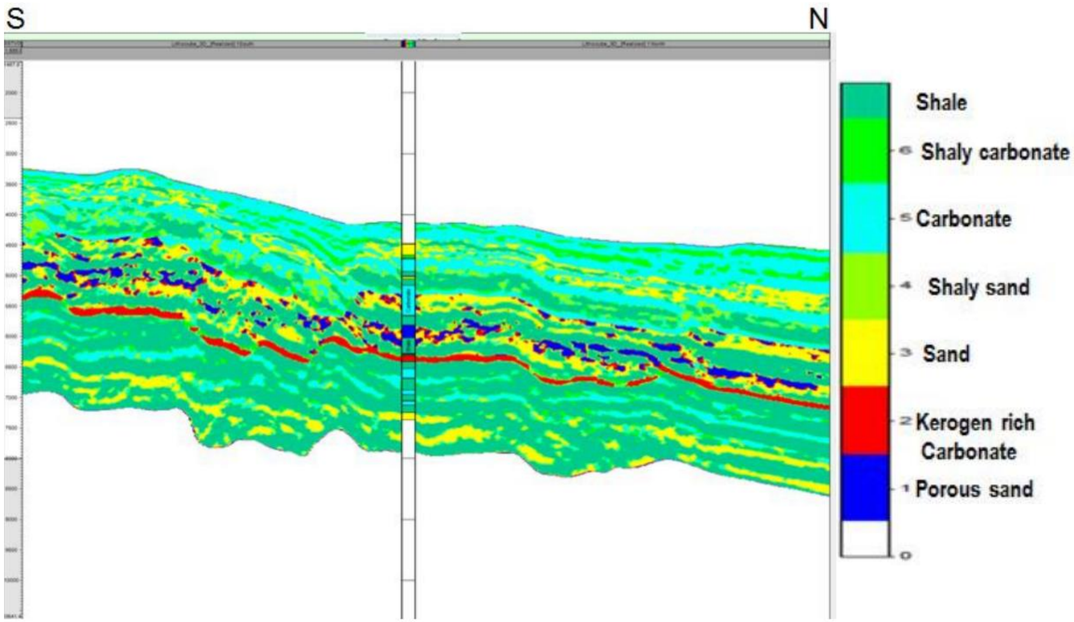
- Well Log / Core / Cuttings Petrophysics Integration with Seismic

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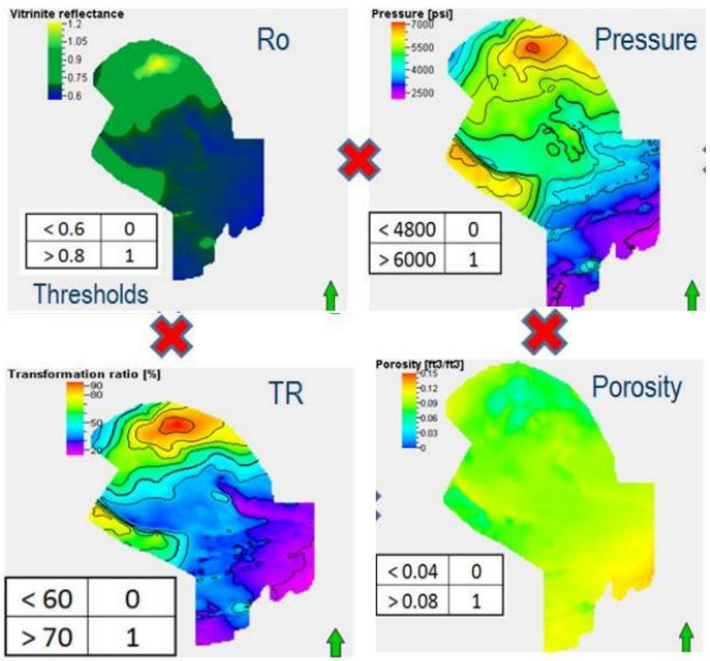
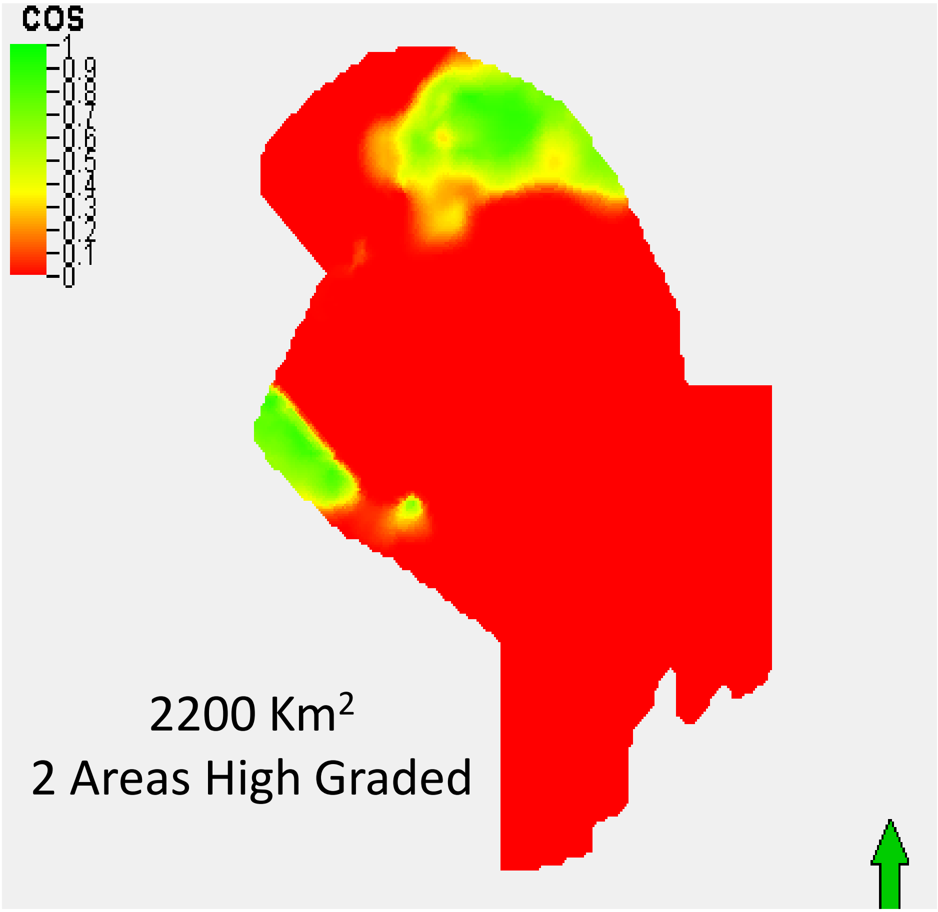
- Petroleum Systems Modeling




- Chance of Success (COS) Map

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- Data Acquisition on Initial Exploration Wells
  - Logging Data
    - Triple Combo
    - Geochemical Tool
    - Spectral GR
    - NMR Tool
    - Dielectric
    - Image Log
    - Advanced Dipole Sonic
    - In-Situ Stress Testing (where feasible)
      - Or Frac and Flow Test the Vertical
  - Core Analysis
    - Retort
    - Dean Stark
    - LECO TOC
    - Rock Eval
    - Tight NMR
    - MICP
    - XRD / FTIR
    - Petrography
    - Organic Petrology
    - Organic Geochemical Biomarkers
    - Inorganic Carbon Isotopes
    - VTI Rock Mechanics
    - Scratch / Thin Bed Analysis
    - Frac Fluid Compatibility: CST, RO

Reservoir Quality Parameter
Completion Quality Parameter

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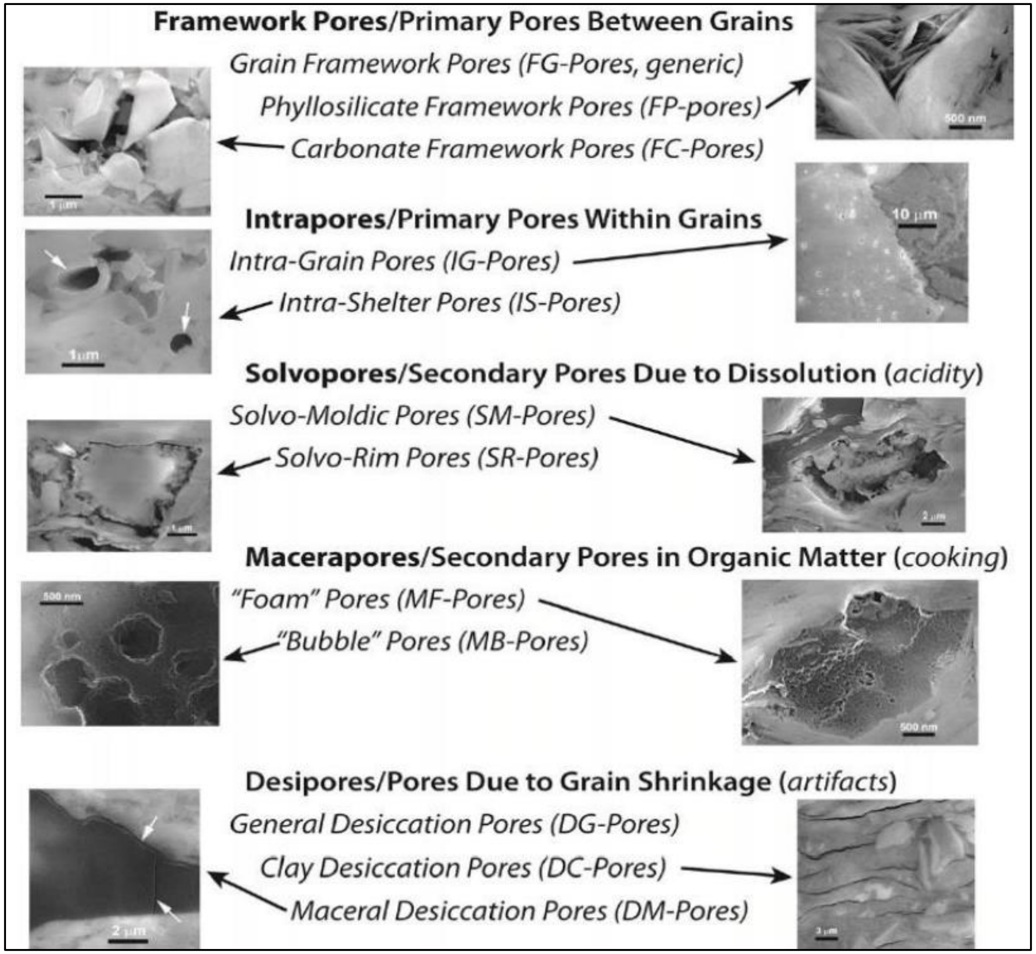
- A review of our reservoir
- Organic Hosted Pores
  - Cannot always be imaged with SEM (< 3 nm)
- Conventional Pores
  - Inter-Grain
  - Intra-Grain
  - Dissolution

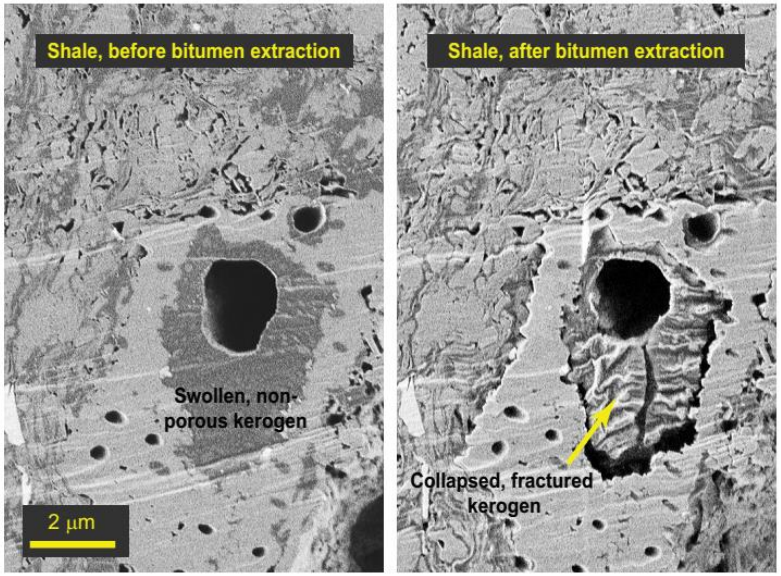
Common Pore Types In Shales




Schieber, 2011

## Tight Oil

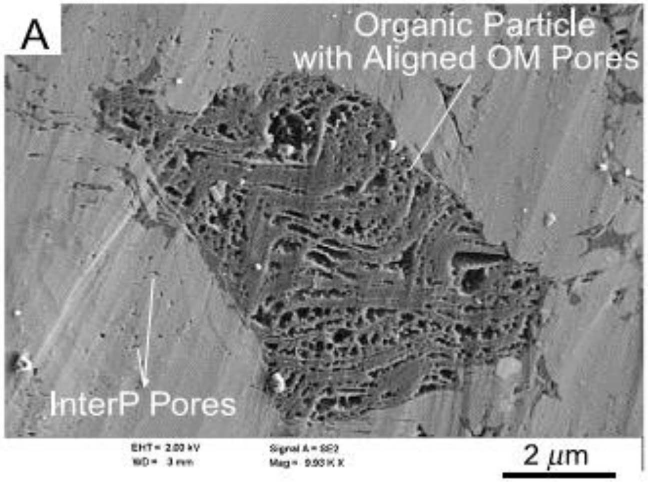
| Kerogen | Bitumen | Oil |
|---|---|---|
| Negative RQ | Negative RQ | Positive RQ |



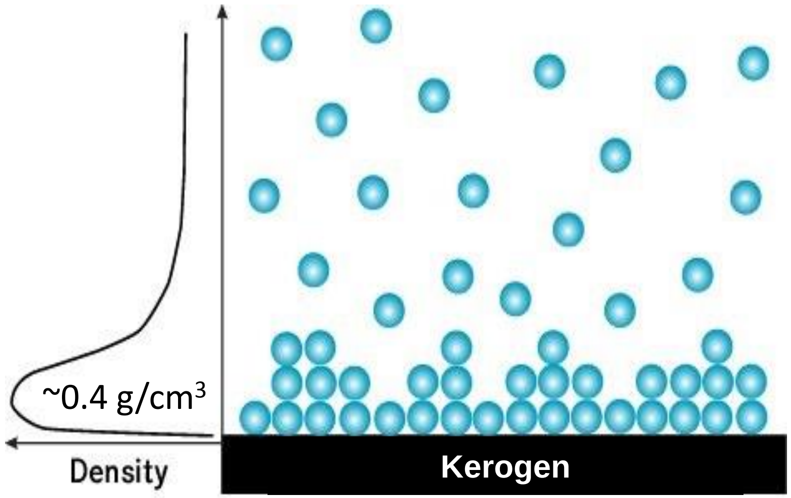

Reeder et al. (2016) Petrophysics

## Shale Gas

| Kerogen | Gas |
|---|---|
| Positive RQ | Positive RQ |

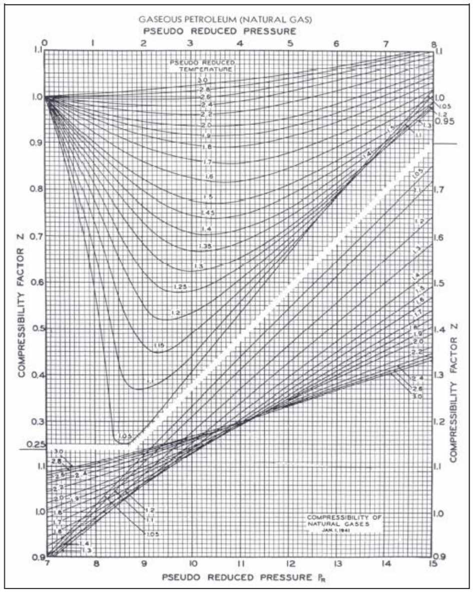


- Reservoir Quality: Gas
  - Traditional Gas In Place Calculation




SPE 131772

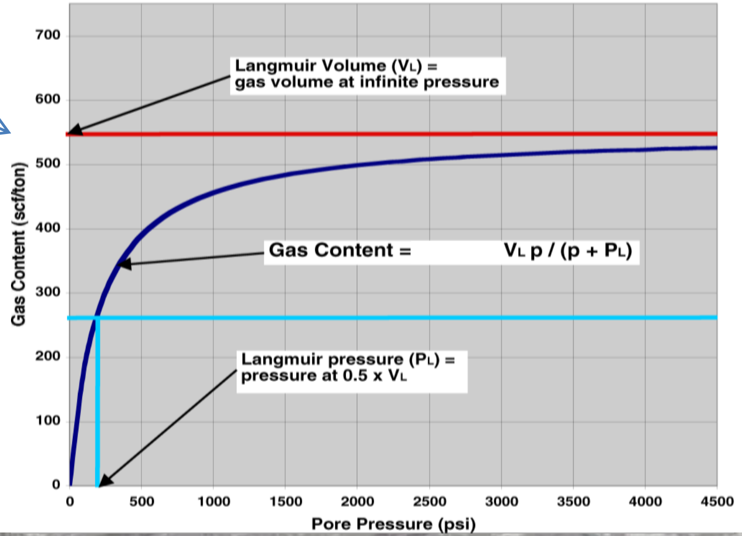
Free Gas




Natural Gas Tables

Adsorbed Gas

Isotherm




But gas injection into organic cores shows the Hydrogen Index is much higher (~75%) than for methane at a given pressure and temperature (SPE 147198), resulting in +-40% more gas.

- Pilot Hole Reservoir Quality: Dry Gas

Total NMR Porosity — Bulk Volume Water (ELAN Analysis)

$$\phi_{MR}(gas) = \phi_{TCMR} - BVW$$

Water parameters

$$TGAS_{Total} = 7.54 \text{x} 10^5 \frac{scf/m^3}{mole/cm^3} \bullet \phi_{MR}(gas) \bullet \frac{n_w \rho_w}{M_w} \bullet \frac{1}{\bar{n}_g}$$

Equivalent to Gas Gravity

$TGAS_{Total}$ = Total gas in place (scf/ton)

$\phi_{TCMR}$ = Total magnetic resonance porosity (v/v)

$BVW$ = Bulk volume water (v/v)

$\phi_{MR}$ = Magnetic resonance porosity (v/v)

$n_w$ = Number of hydrogen molecules per water molecule (2)

$\rho_w$ = Density of water molecule (1 g/cm$^3$)

$M_w$ = Atomic weight of water (18.02 g/mole)

$\bar{n}_g$ = Number of hydrogen atoms per gas molecule in natural gas mixture

- No input required for P/T
- No Langmuir isotherm
- No input for pore system or kerogen type

Kausik et al. 2015

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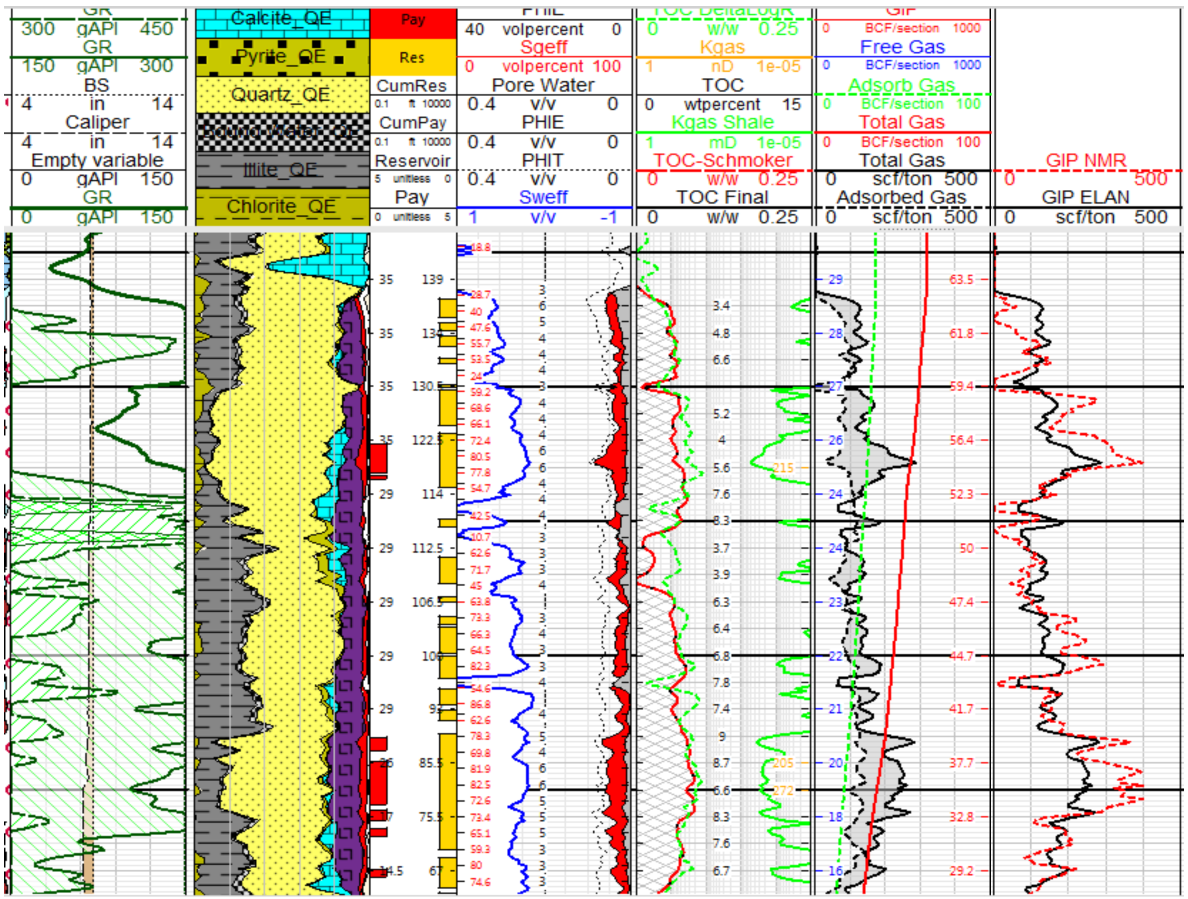
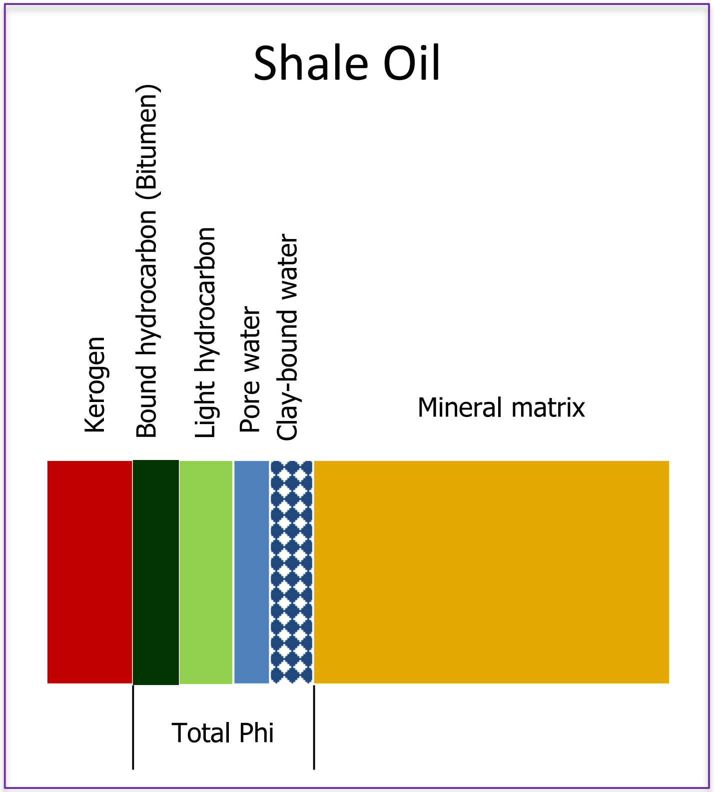
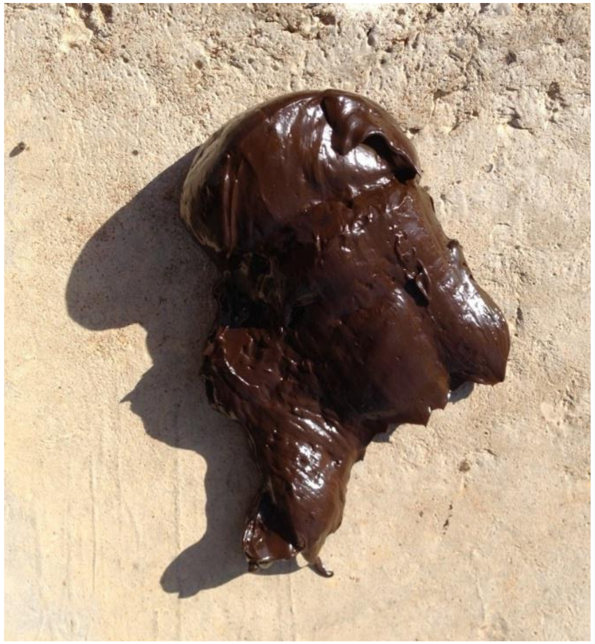
## ➢ Woodford Shale Example




30% Increase in GIP

- Reservoir Quality: Oil
  - Volume of Bitumen
  - Presence of inorganic pore system



| | Light Oil PV |
|---|---|
| Good | 5-9 % |
| Medium | 2-5 % |
| Poor | < 2 % |

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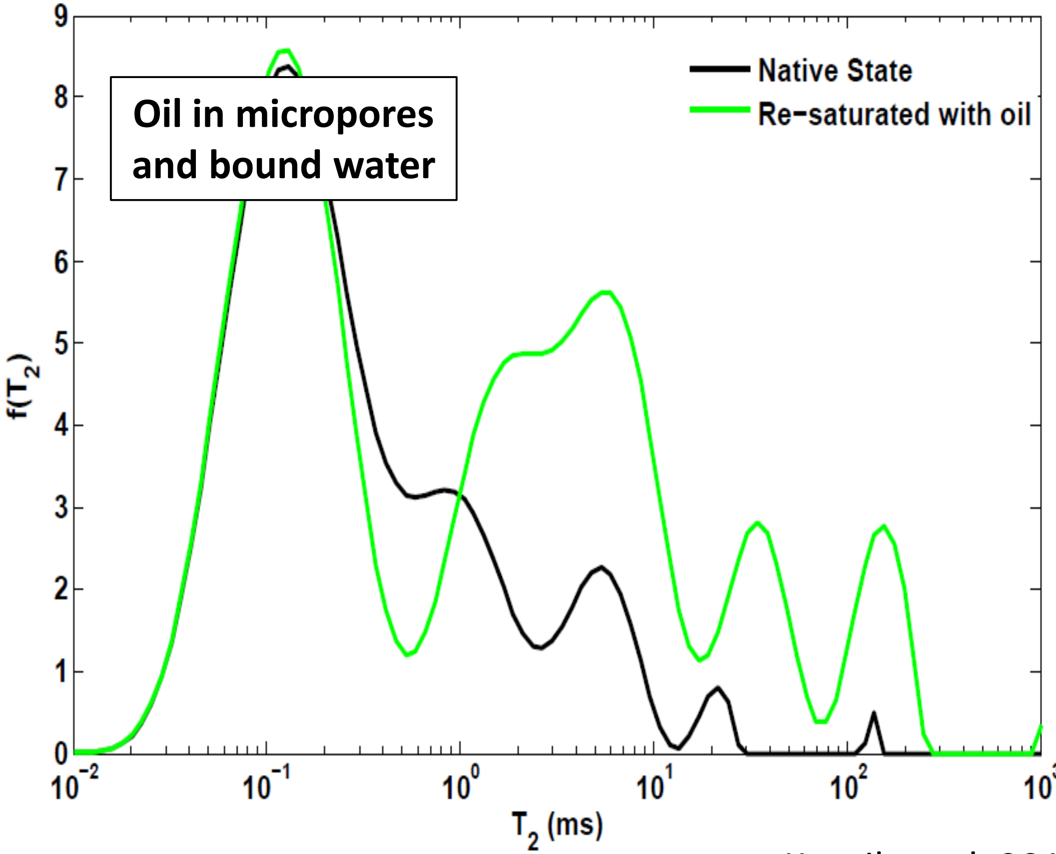
- Pilot Hole Reservoir Quality: Oil
  - T2 relaxation in native and resaturated shale




Kausik et al. 2015

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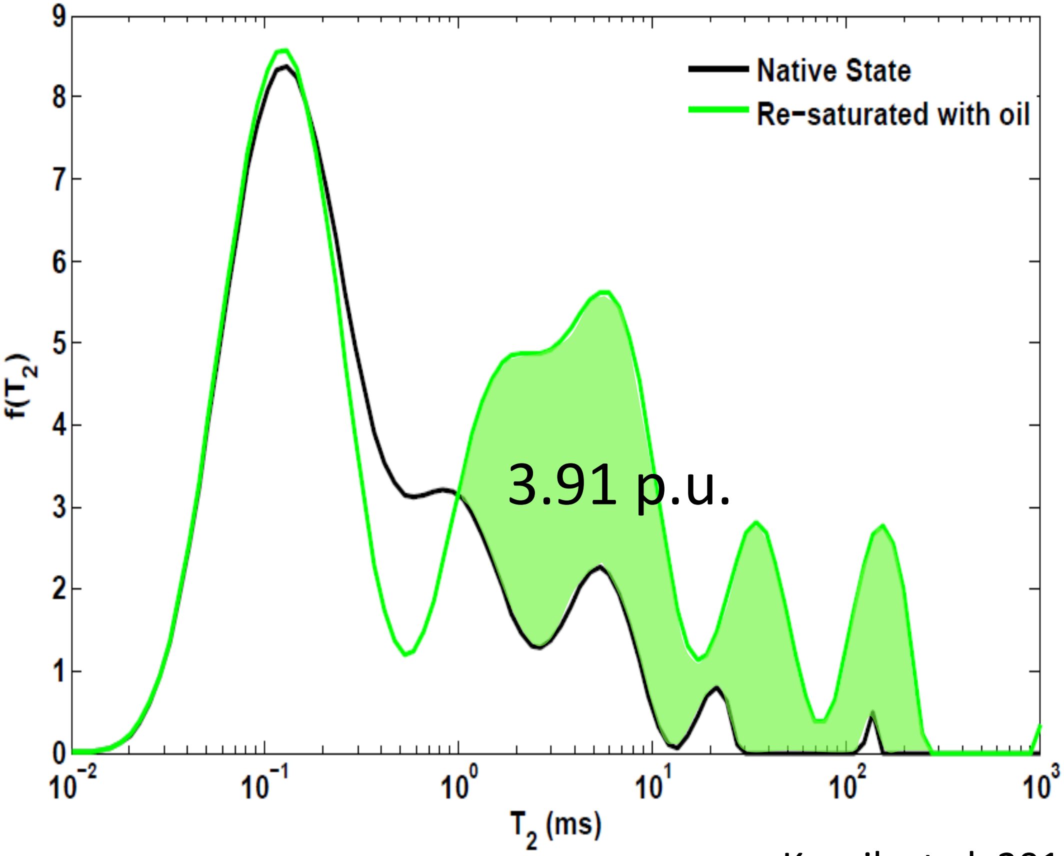


Kausik et al. 2015

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- Pilot Hole Reservoir Quality: Oil
  - Reservoir Producibility Index

Oil in Larger Pores: ~>3 ms

$$RPI = \frac{W_{c-oil} \bullet W_{c-oil}}{W_{c-organics}} \approx \frac{S1^2}{TOC}$$

- Log generated index
- Circumvents problems associated with recovery and analysis of hydrocarbons from cuttings and/or core
- OSI of 100 ~ RPI of 0.1 (fc of porosity)

$W_{c-oil}$ = Oil Weight fraction of carbon in light hydrocarbon, may require correction for bitumen (w/w)

$W_{c-organics}$ = Total organic carbon (TOCj) content, directly from Litho Scanner (w/w)

$TOC$ = Total organic carbon measured from RockEval (wt%)

$S1$ = Residual hydrocarbon from Rock Eval (mg HC/g rock)

Kausik et al. 2015

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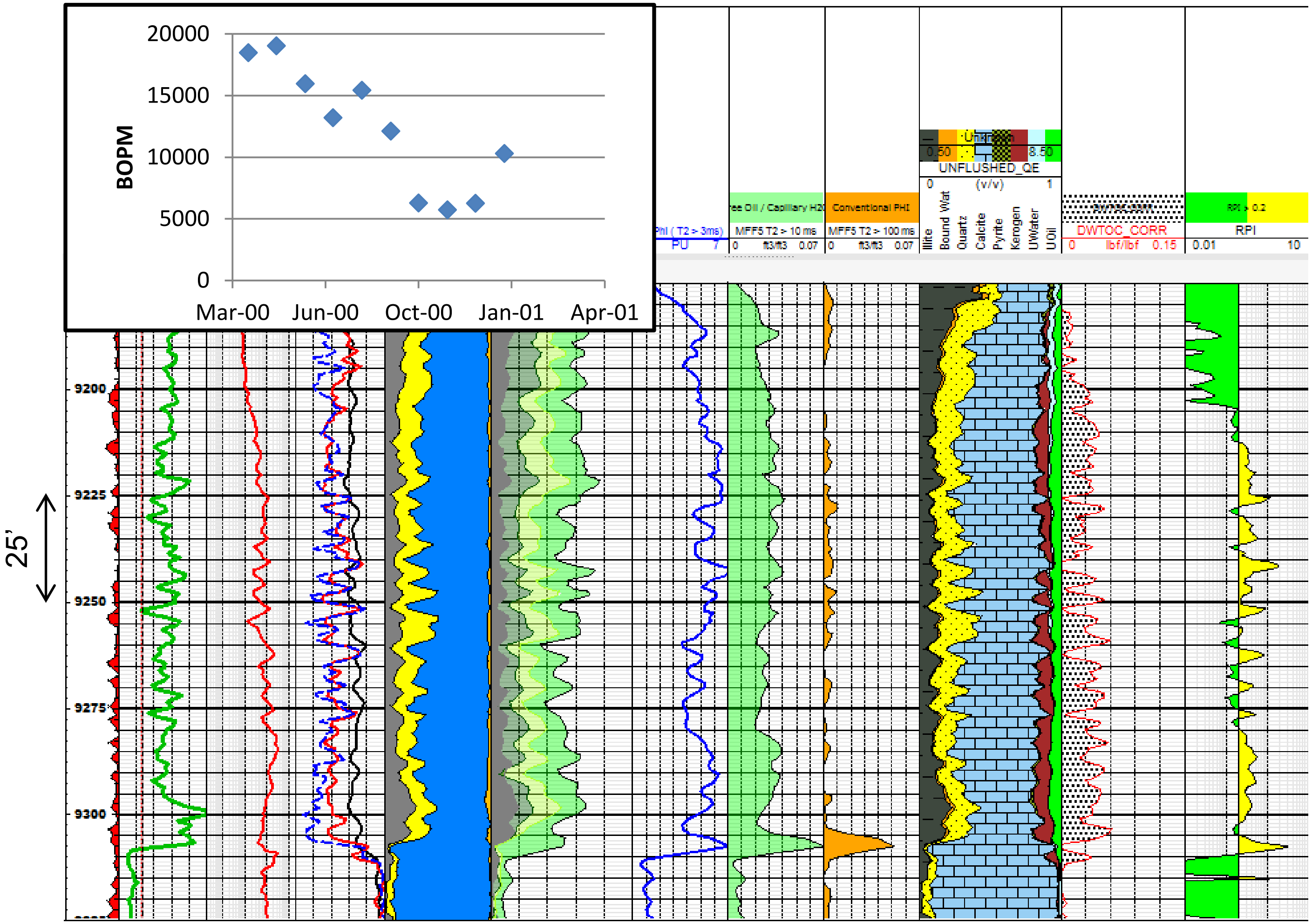
# ➢ RPI of a Good Well



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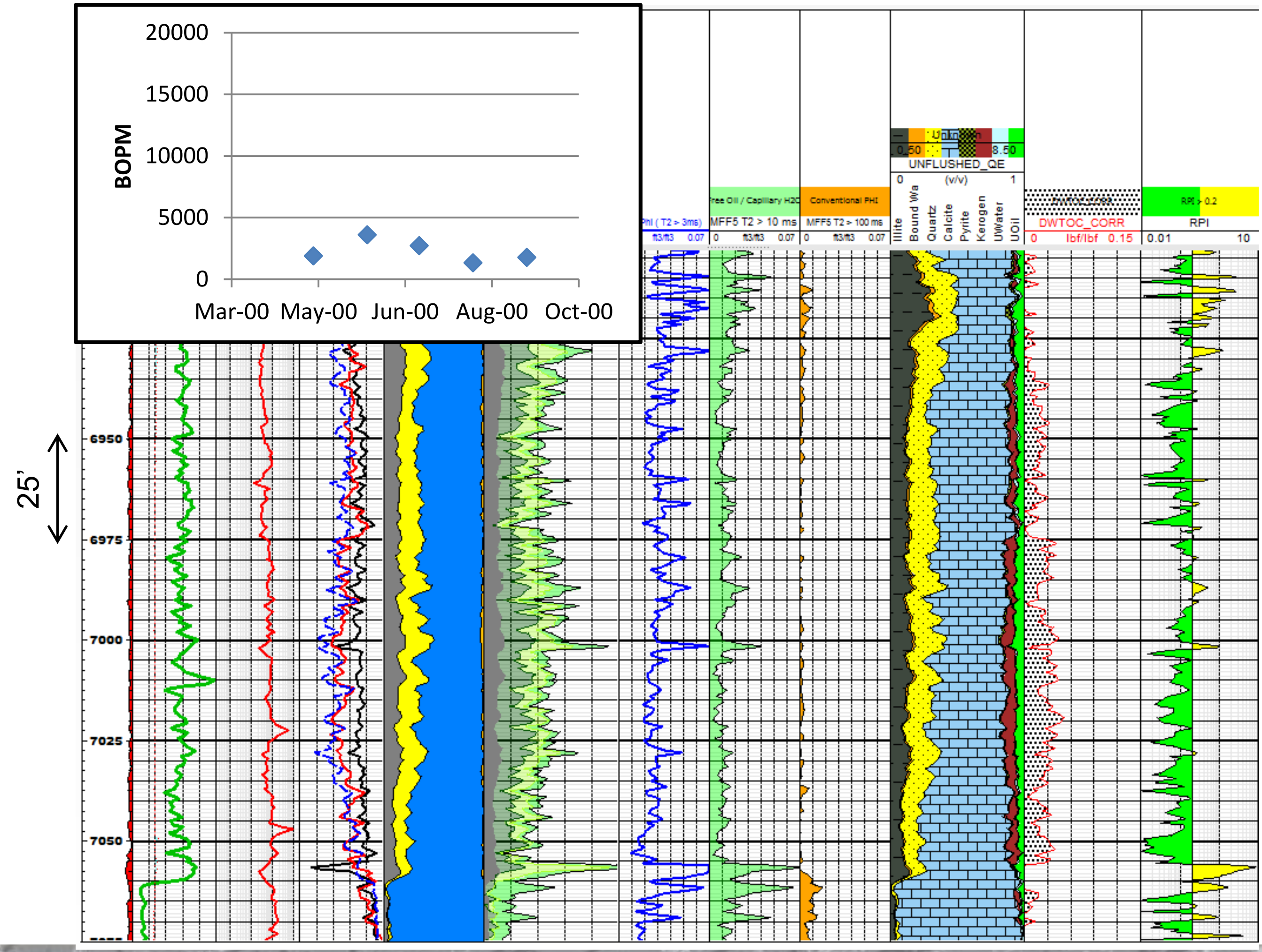
## ➢ RPI of a Poor Well



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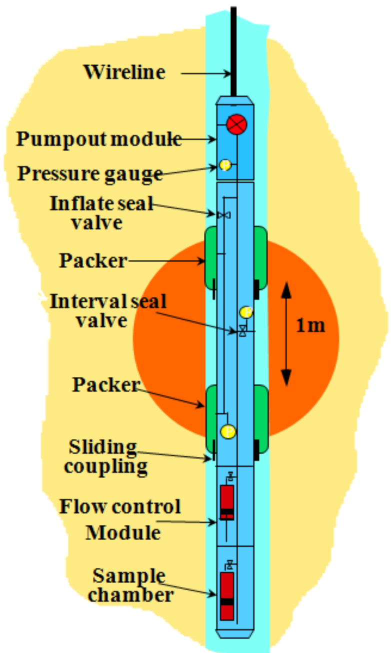
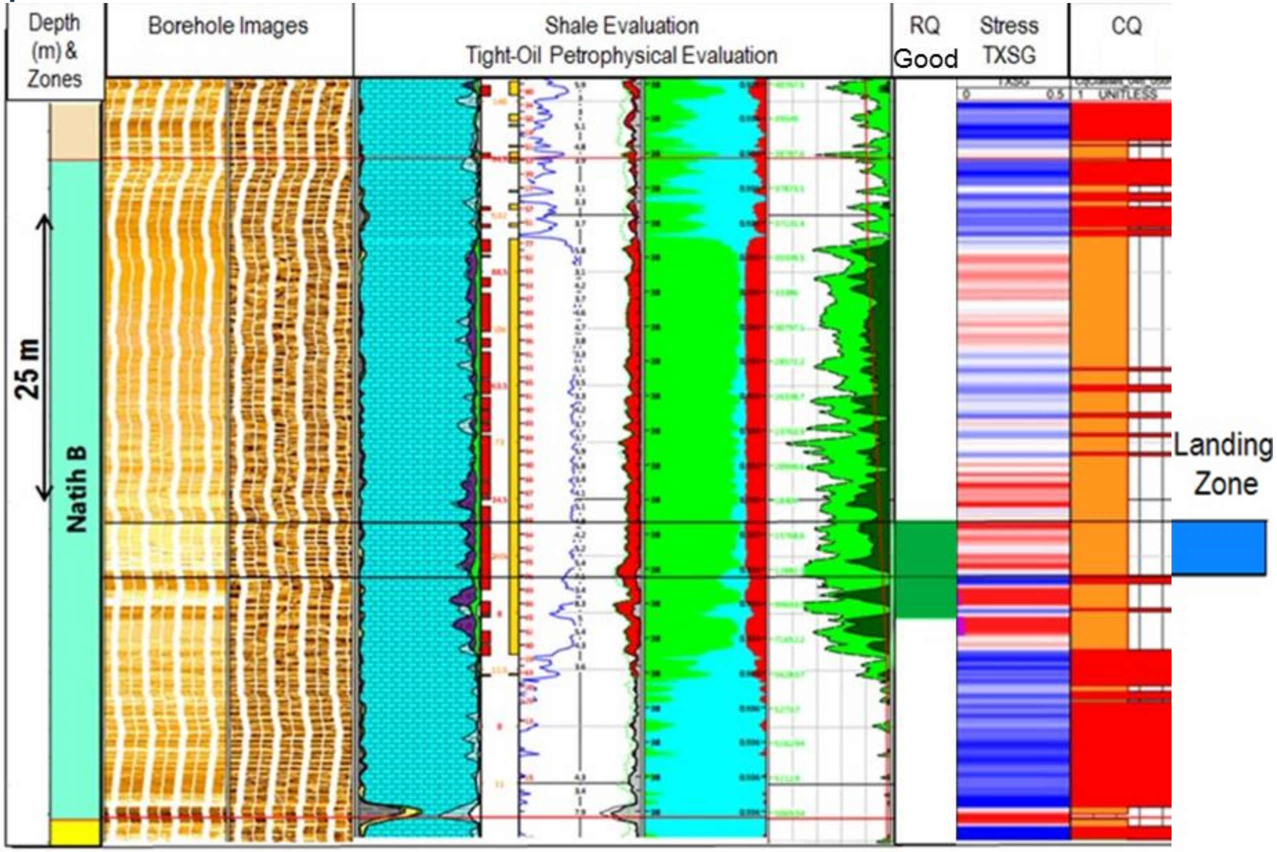
- Completion Quality: Place the Frac in the Desired Location
  - Stress profile / Tectonics
  - Lateral landing point

CQ Classification:
Extensional
Strike-Slip
Reverse



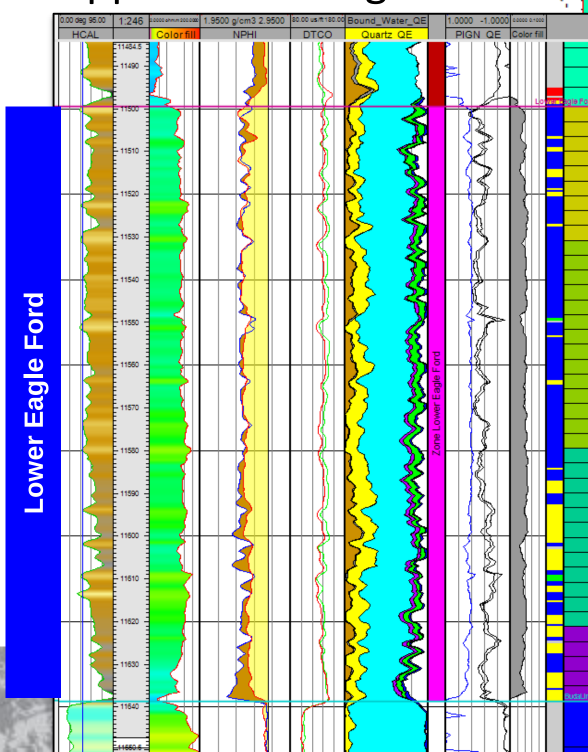

Modular Dynamic Tester

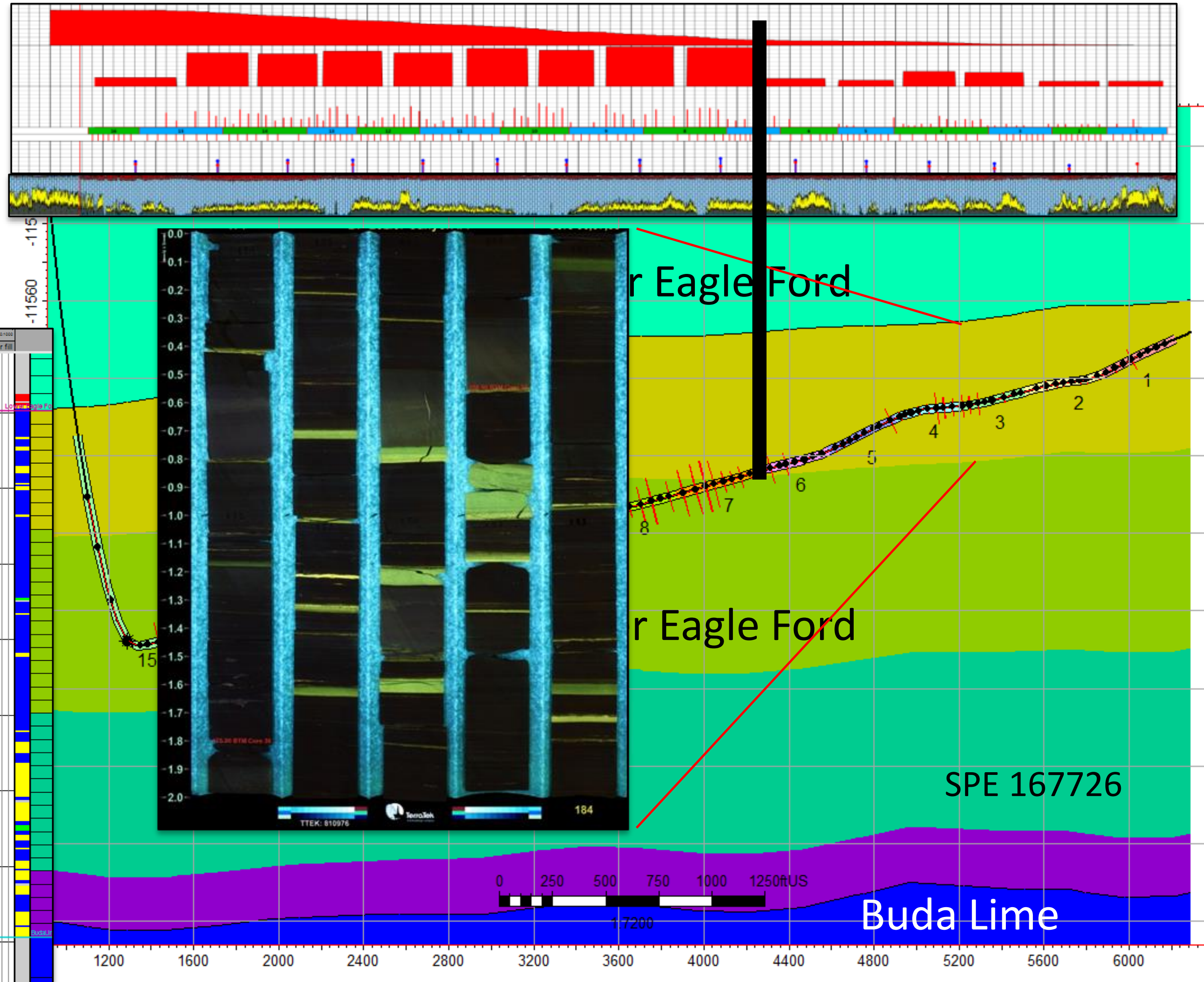



SPE 188474

- Completion Quality: Adequate Fracture Surface Area
  - Frac Design
  - Laminations

Well landed in target zone in Middle and Upper Lower Eagle Ford



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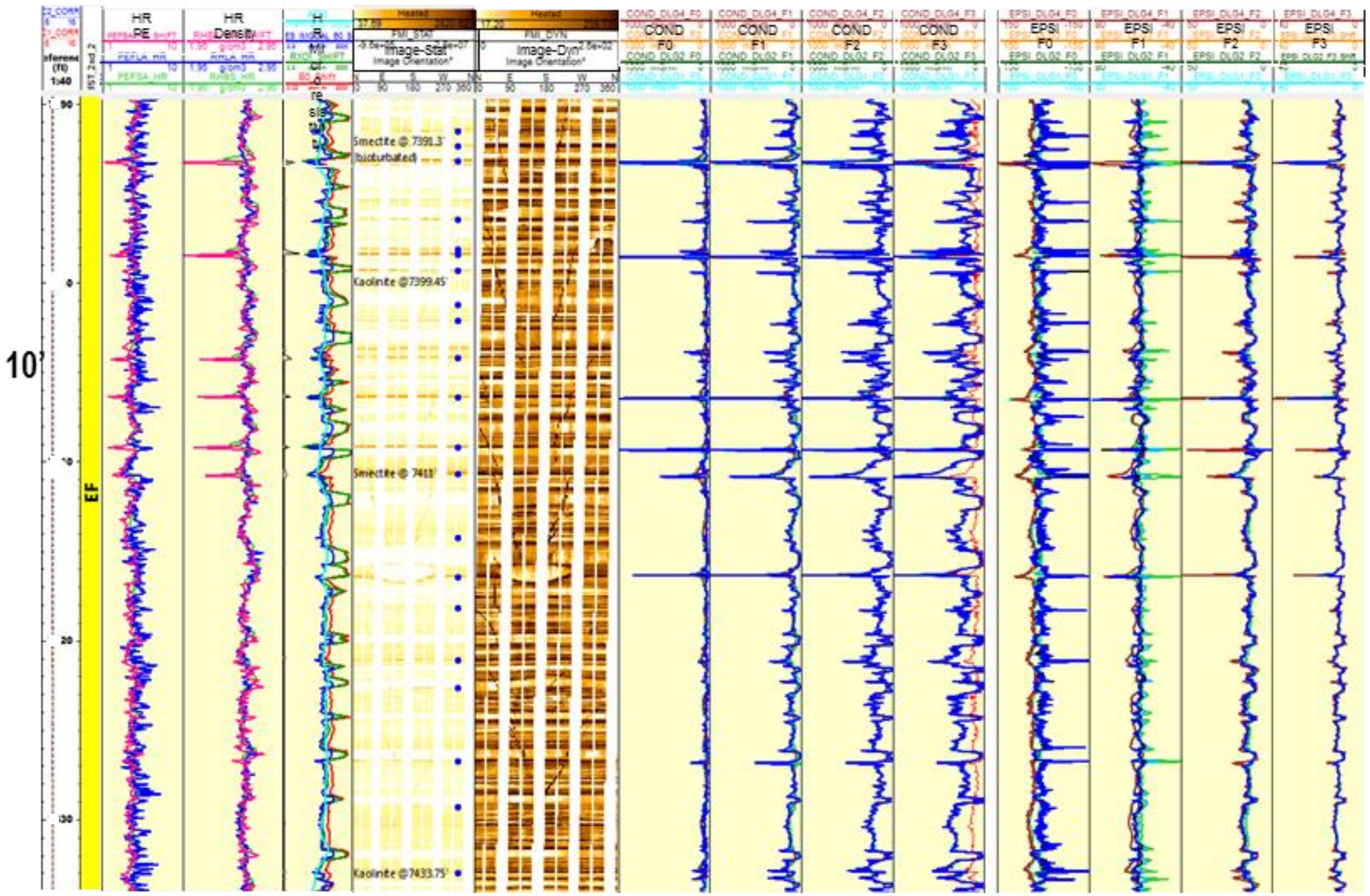
## ➢ Completion Quality: Laminations / Ash Beds




Blue dots represent ash beds identified in core

SPE 175961

- Completion Quality: Ability for Frac to Remain Conductive
  - Frac design
  - Lateral landing point
  - Production management