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# Optimized Shale Resource Development using proper placement of Wells and Hydraulic Fracture Stages

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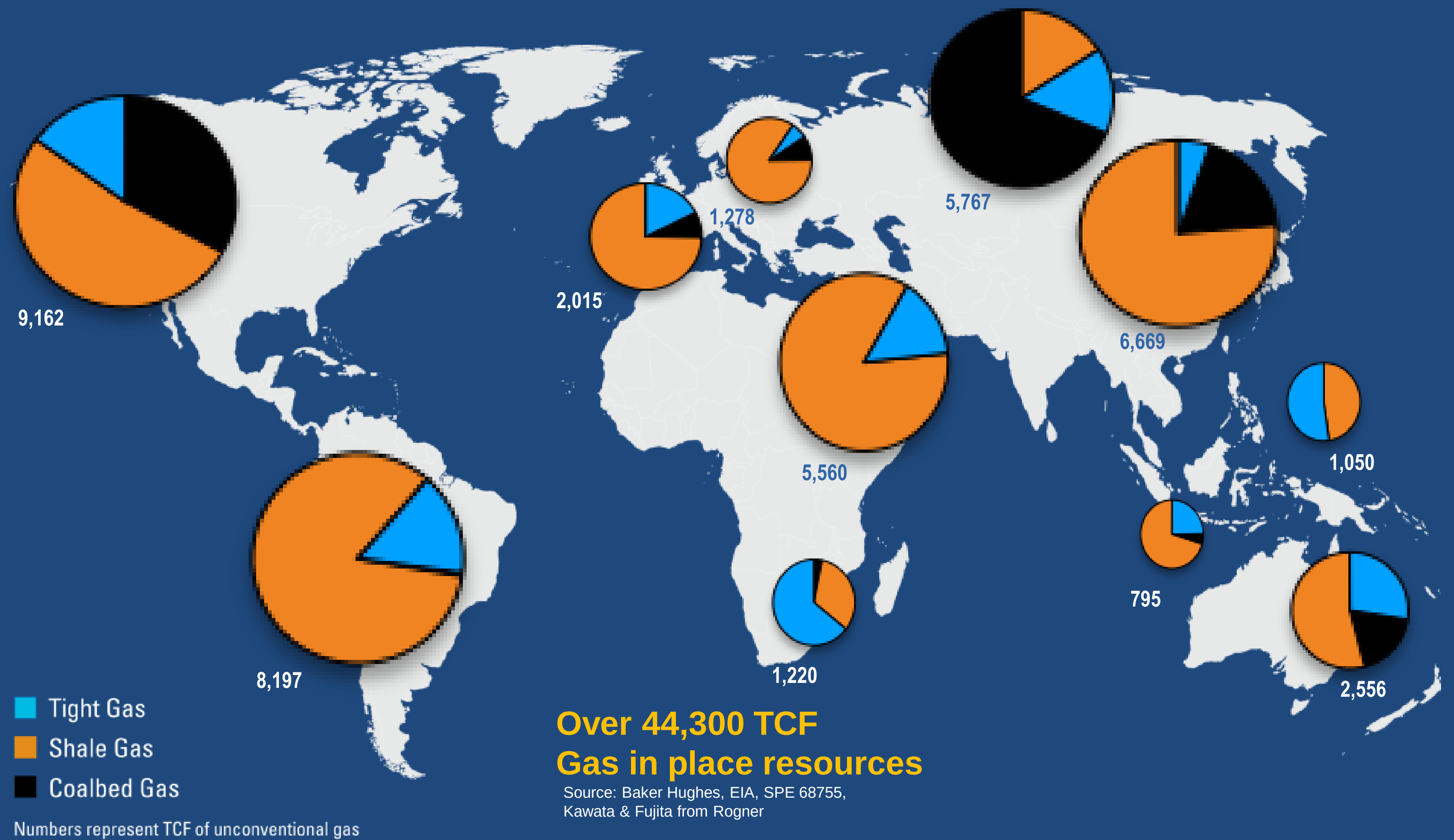
# Outline

- Illustration of the Prize
- Present trend in Unconventional Reservoir Modeling and it's impact on production
- Challenges the industry face to enhance recovery factor while reducing cost per unit of hydrocarbon recovered
- Where should the future engineers focus?
  - What technologies are there and what are needed in the near future to ***optimally place wells*** for the enhanced recovery
  - What technologies are there and what the industry needs in the near future to decide the ***optimum placement of the hydraulic fracture stages***
- Illustrative field examples and the recommended way forward

# Unconventional Gas Resource: A Global Phenomenon

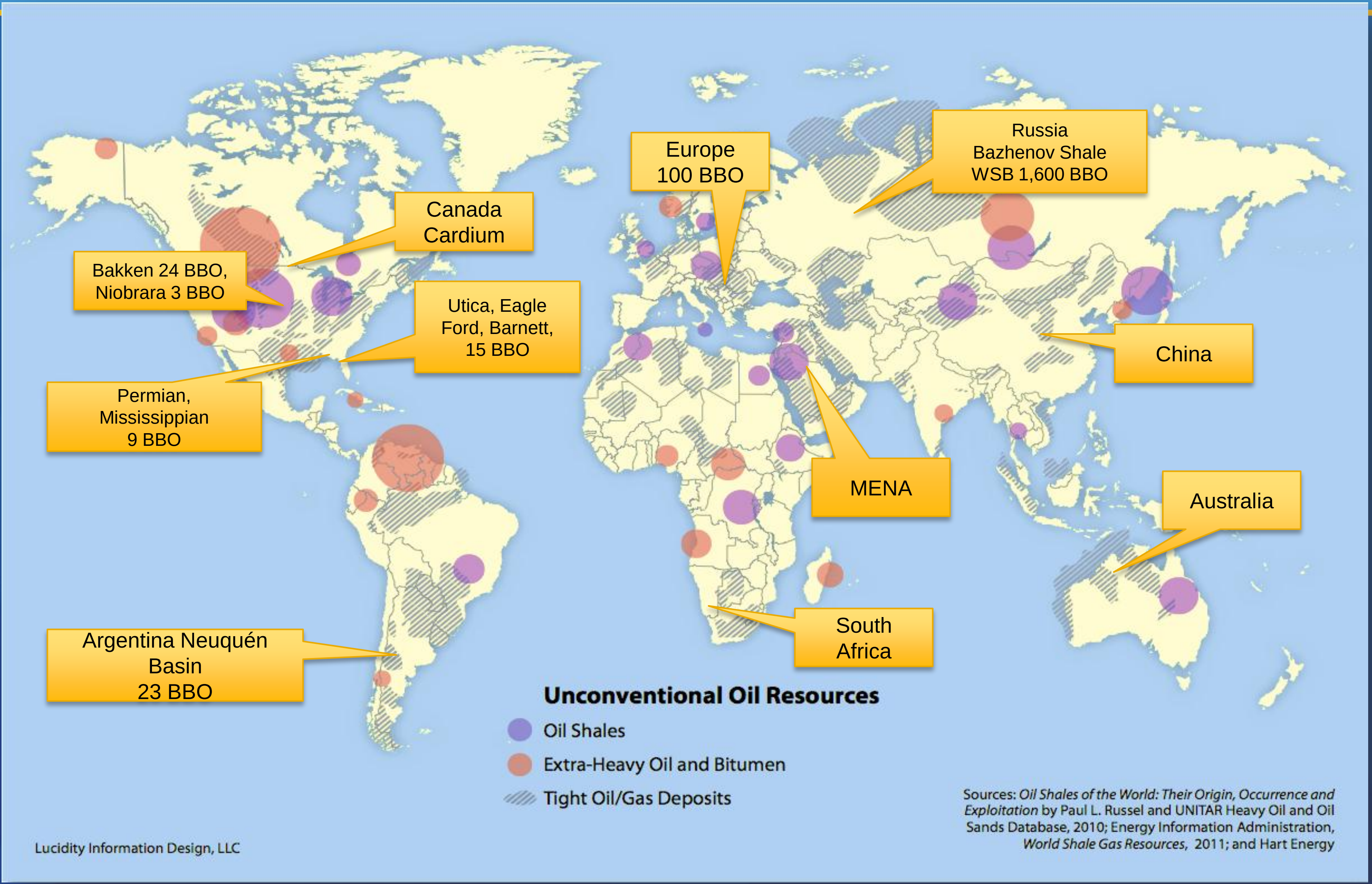



**Pie size to scale**

**Over 44,300 TCF**
**Gas in place resources**

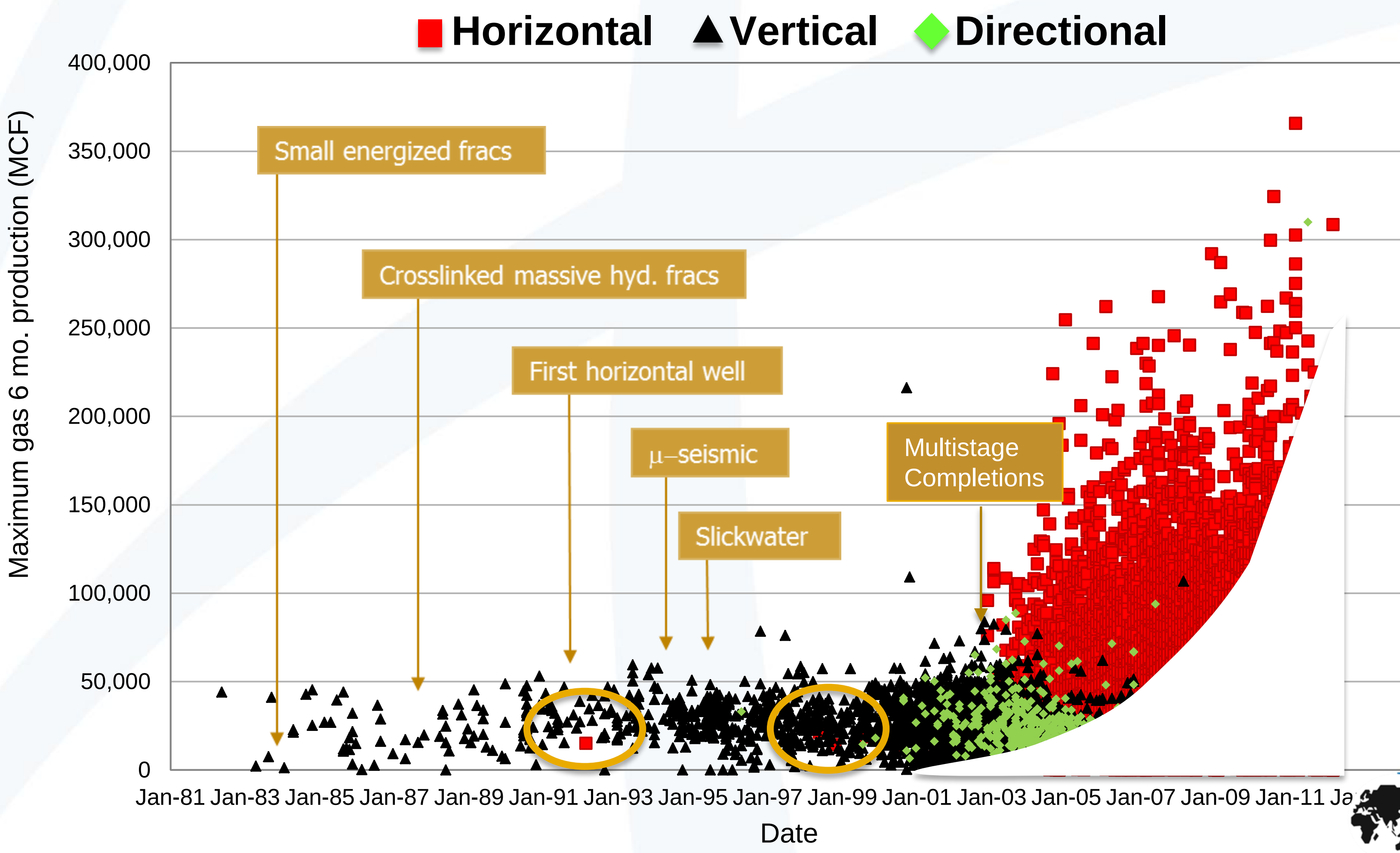
Source: Baker Hughes, EIA, SPE 68755, Kawata & Fujita from Rogner

# Unconventional Oil Resources 2-3 Trillion Barrels



# Unconventional Development – Learning Curve

## Barnett Shale Development



# A Closer Look at the "Shale Revolution"

**70%** of unconventional wells in the U.S. do not reach their production targets*

**60%** of all fracture stages are ineffective**

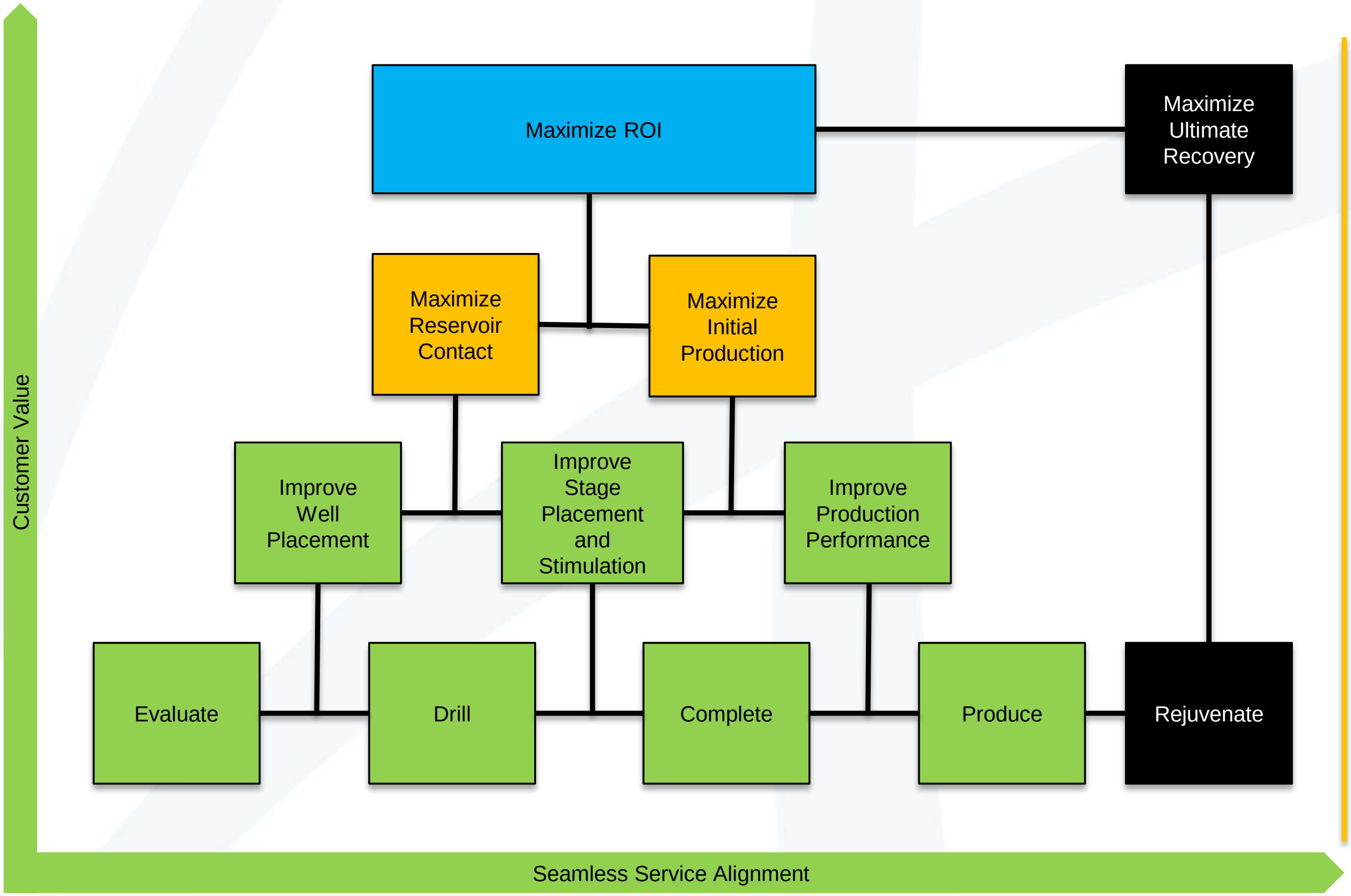
**73%** of operators say they do not know enough about the subsurface*

**Efficiency** and **Effectiveness are key for Proper Placement of Well and Frac Stage in Sweet Spots**

**Source: Welling & Company, 2012*
***Source: Hart's E&P, 2012*

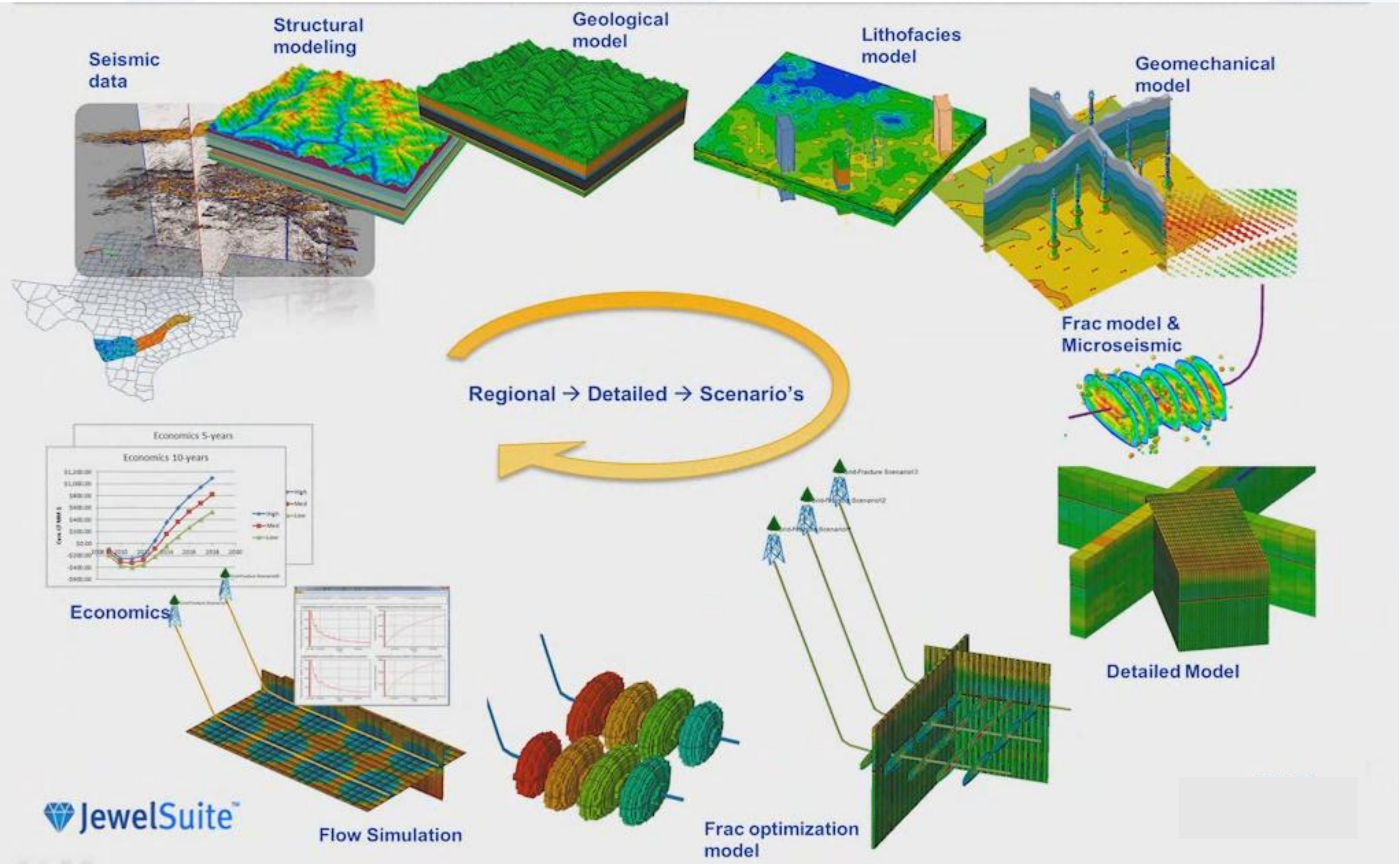
# From Discrete Components To An Integrated Solution

## Unconventional Market Segment




- **Identify sweet spots**
- **Predict performance /EUR**
- **Where to place wells:** Well placement, spacing, drainage area, lateral orientation, and length
- **Which Method of completion:** Open hole, cased hole,
- **Optimal Stimulation design:** Stage placement, number of stages, fluid, proppant, volume
- **Production management:** Flowback, managed rate of production

# Unconventional Workflow: How is it Different?

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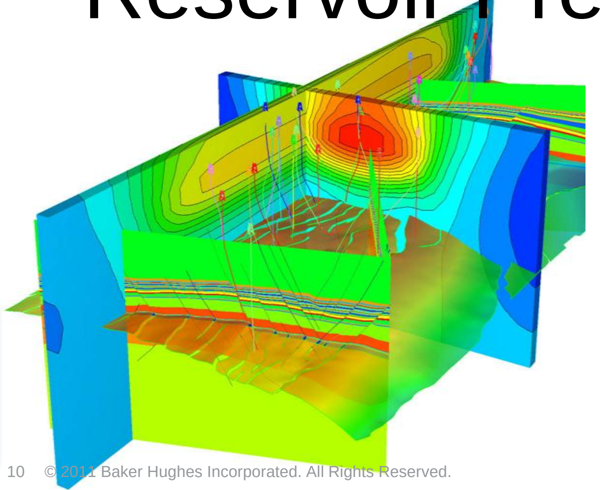
# Moving from Conventional To Shales

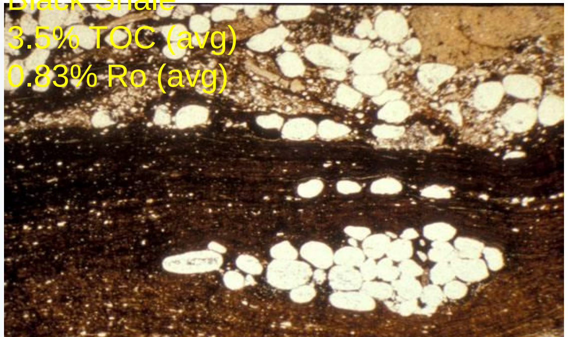
## Conventional

- Porosity
- Saturations
- Permeability
- Resource Base
- Reservoir Pressure



## Shales

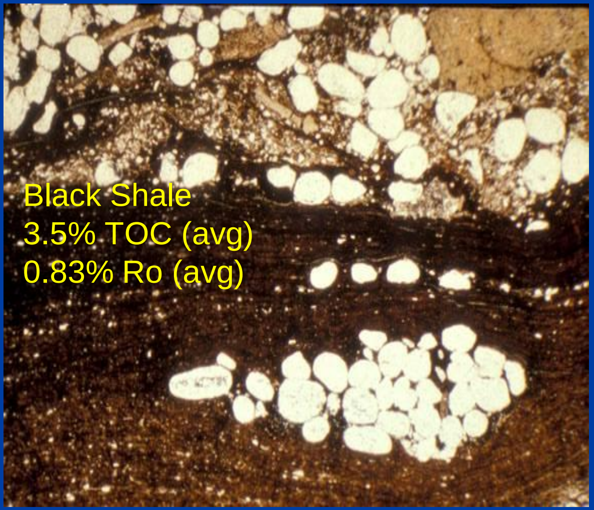
- Reservoir Pressure
- TOC
- Ro (Vitrinite Reflectance) / TM
- Natural Fracture / Km
- Brittleness

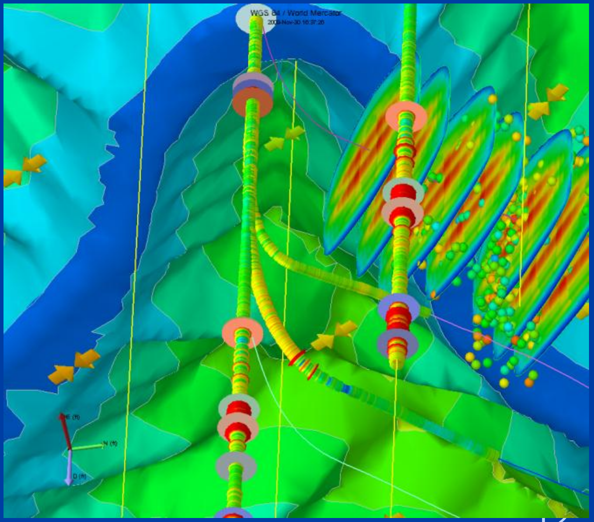


# Shale Reservoir Analysis

- Conventional **reservoir modeling & analyses** not effective for shale
- **Shale reservoirs require** new approaches to Analysis & Forecast
- **An integrated** “shale engineering” **approach is required to** plan wells, stimulate & forecast  long-term production **for economic evaluations**

- SWEET SPOTS: Well and Frac Stage Locations



# What is a “Sweet Spot”?

- The “Sweet Spot” is where the maximum power is generated with the least amount of effort and vibration .
- The Sweet Spot is important in these sports because we don’t all have perfect swings.
- What does this have to do with unconventional resources?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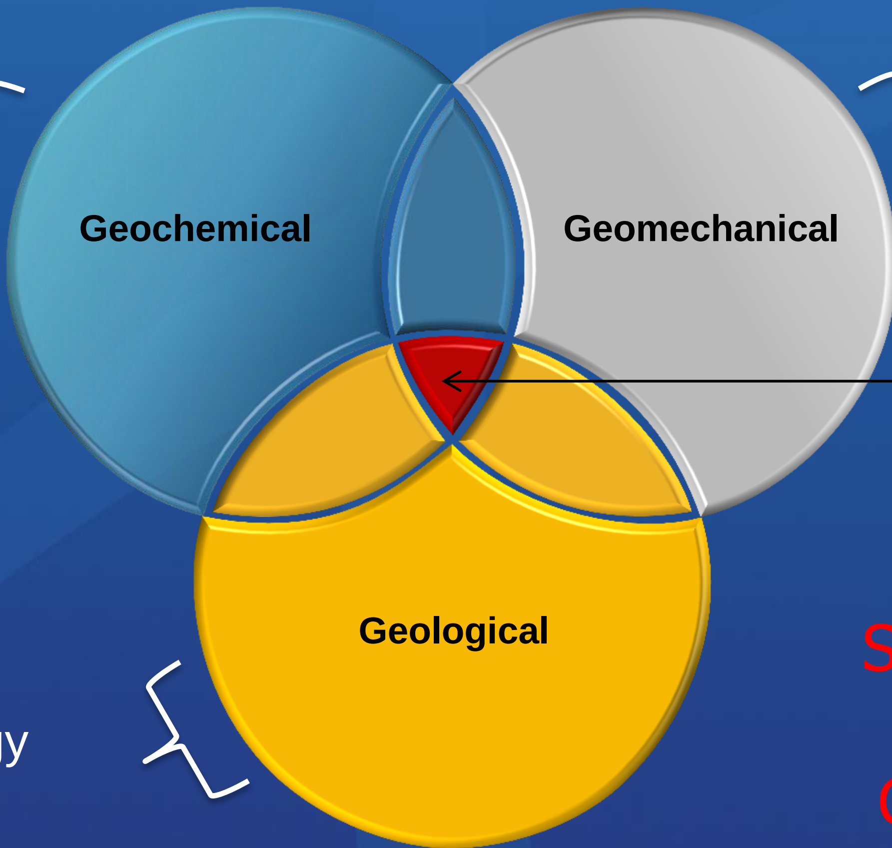
# Unconventional Resources Sweet Spot Characteristics

A "Sweet Spot" or "Core" represents the concurrence of several favorable parameters such as:

TOC
Kerogen Type
Fluid
Thermal Maturity
Depositional Environment
(Litho-facies)

Anisotropy
Stress Regime
Fractures
Faulting
Brittleness
(Fracturability)




Sweet Spot

Depth
Thickness
Lithology/Mineralogy
Porosity
Pressure
(Continued Producibility)

Sweet Spots are not Contiguous

BAKER HUGHES

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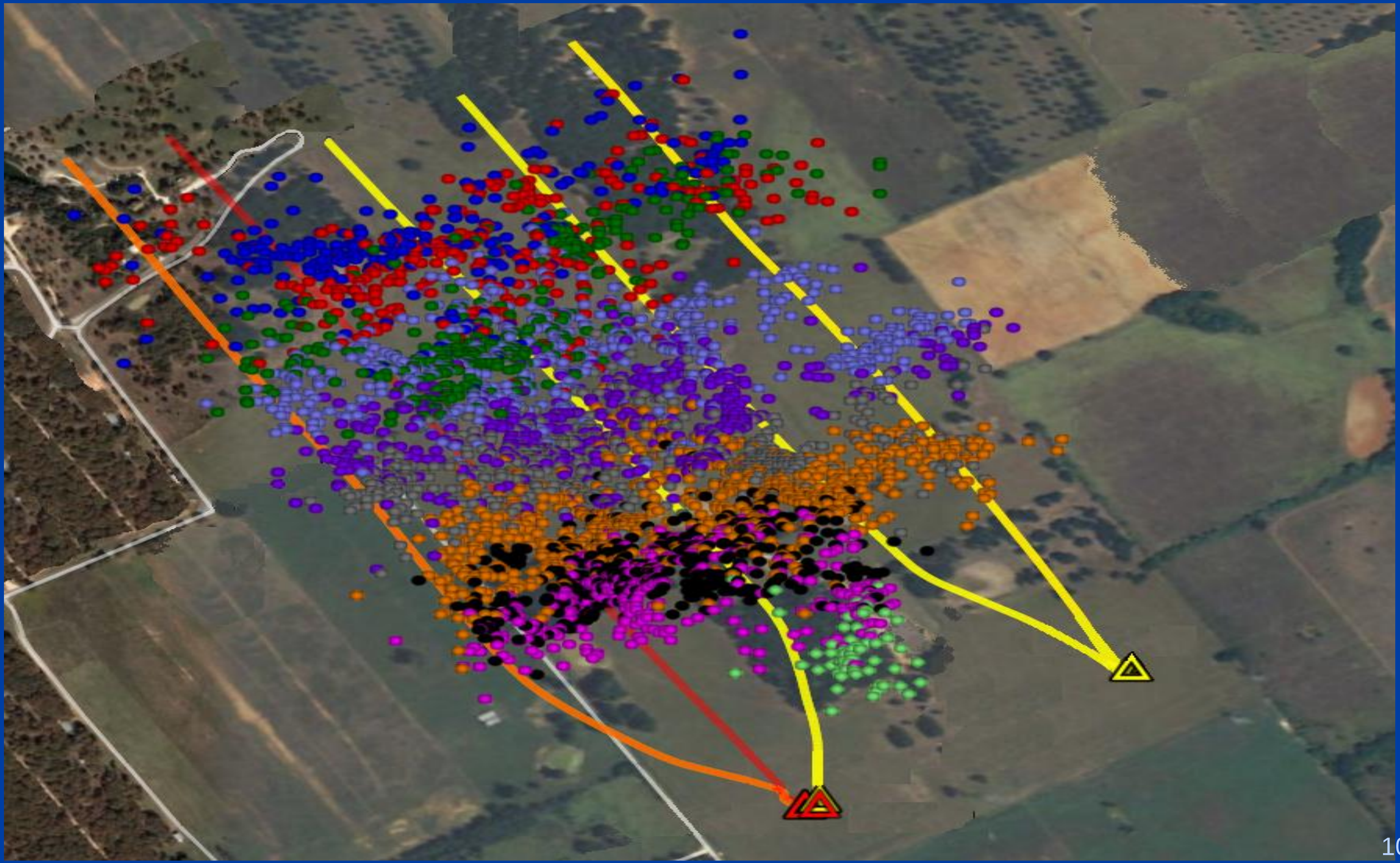
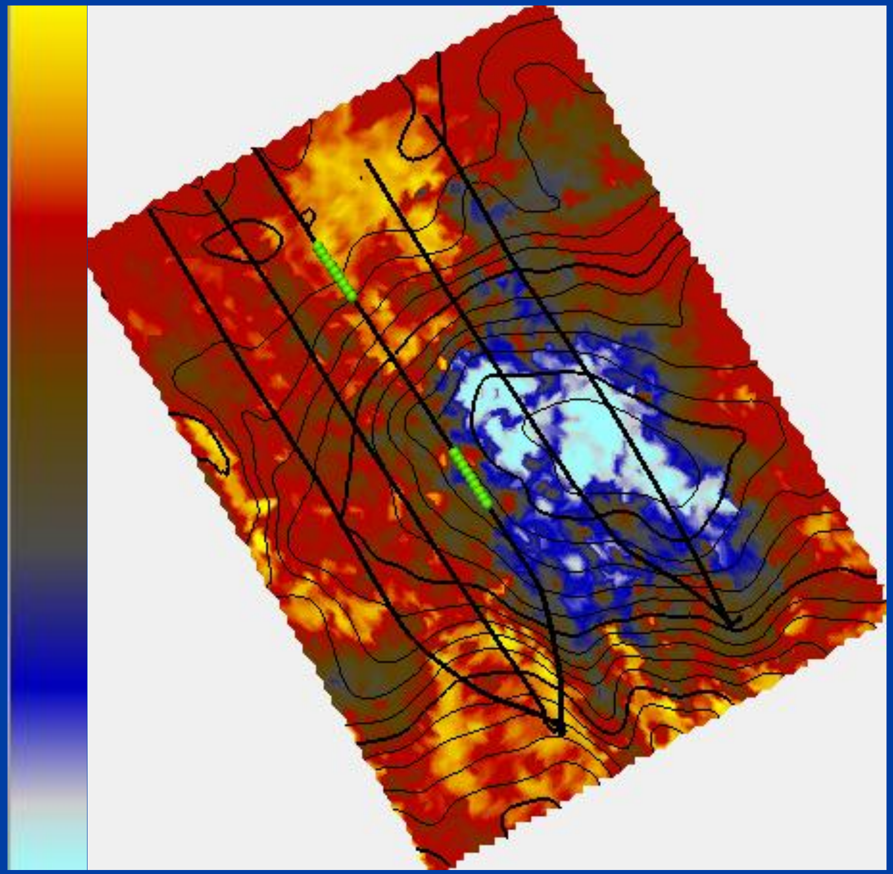
# Can we Identify Optimal Areas For Reservoir Stimulation Before Drilling and Frac'ing?

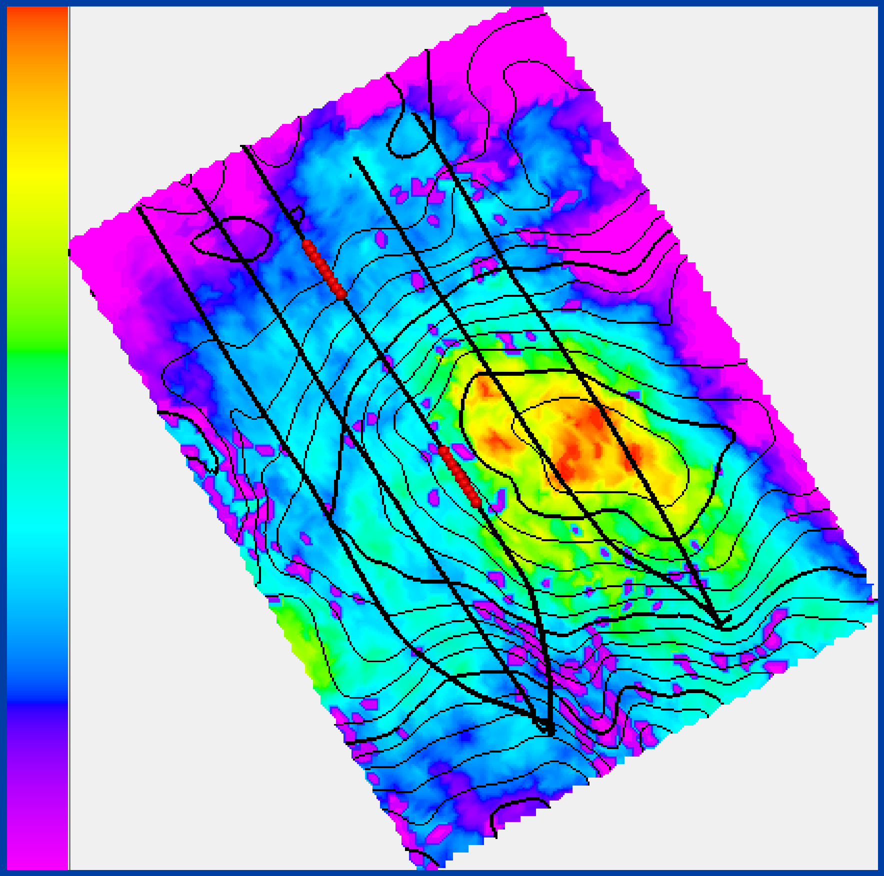


# Attribute Analysis + Lithofacies = Sweet Spot Identification

Actual Amplitude Formation Top



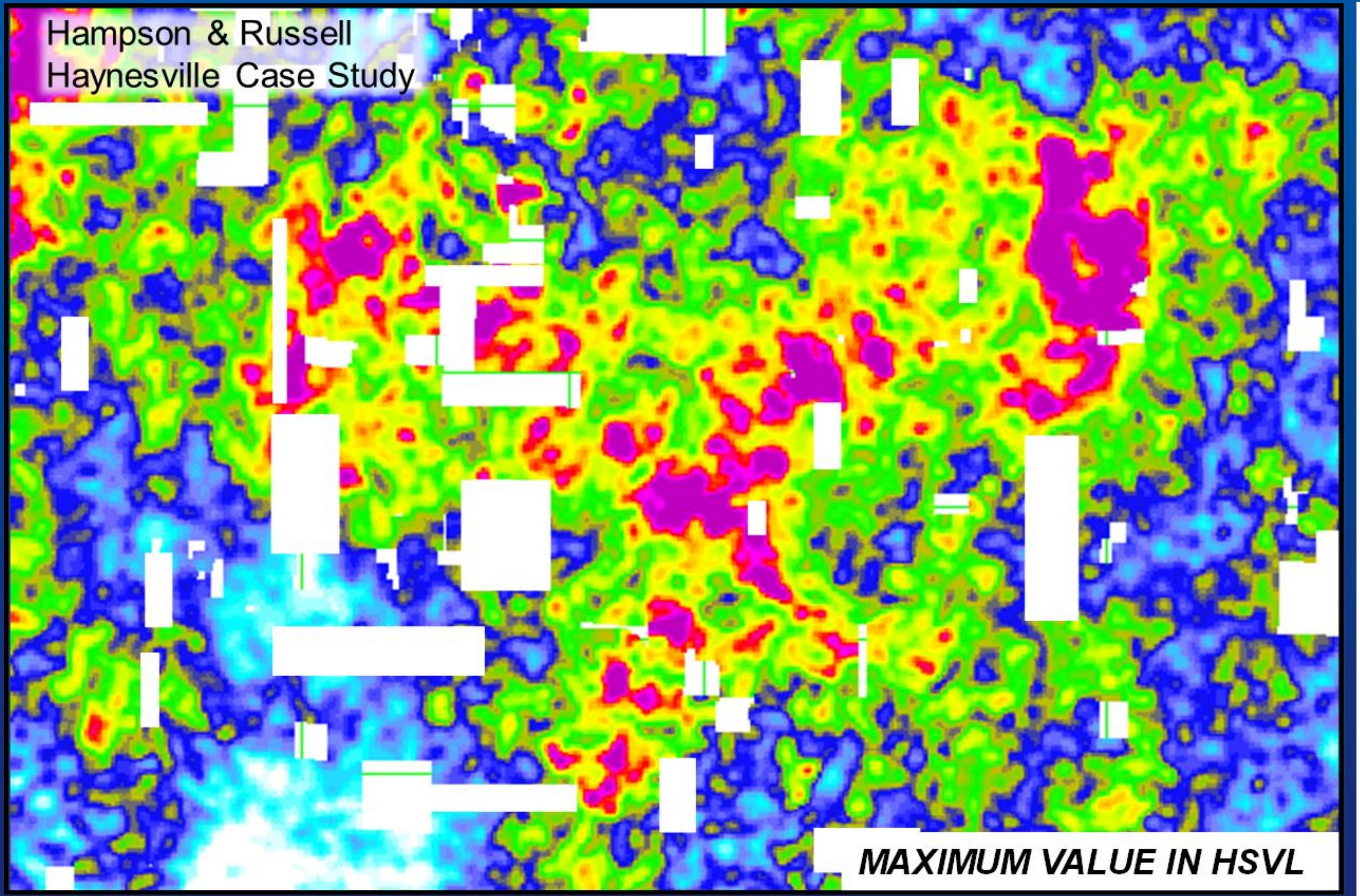

RMS Amplitude Formation Top

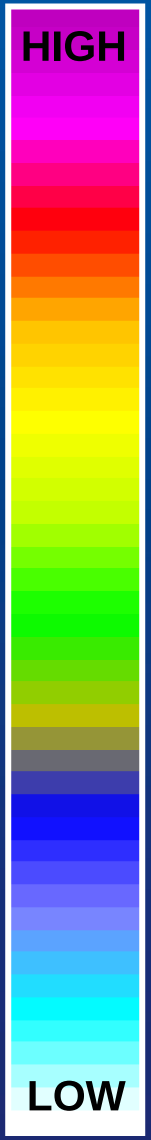



Location of LPLD events are correlative with amplitude anomalies

# Multi-Attribute Prediction of Key Parameters

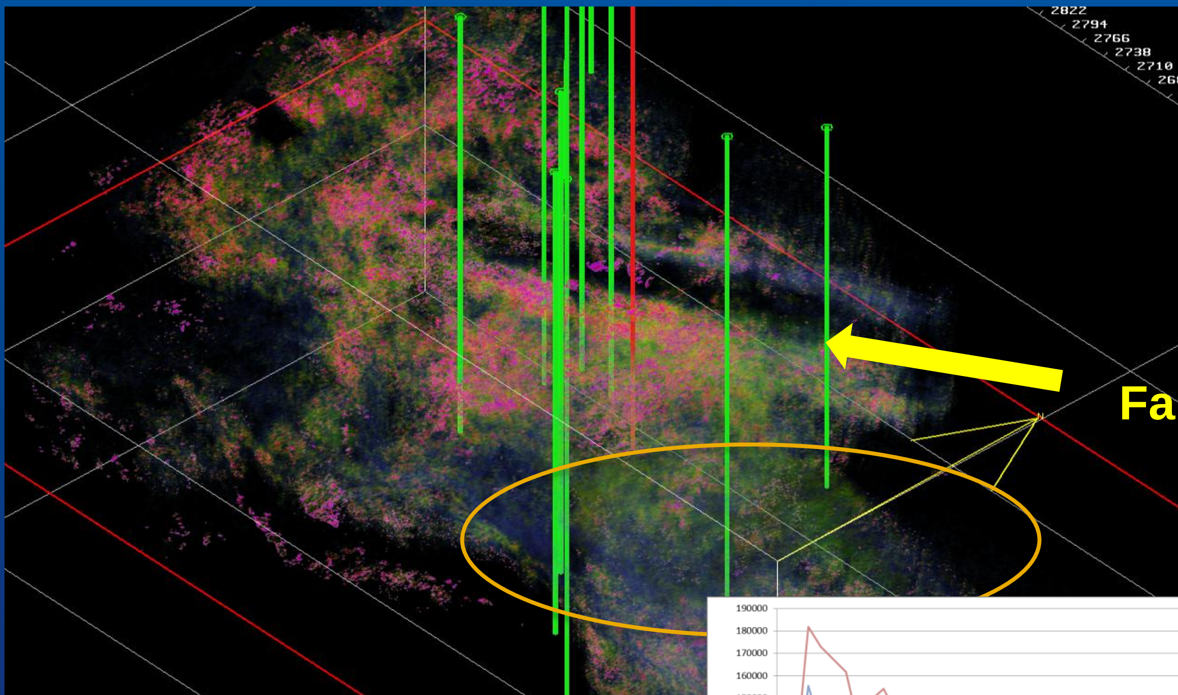
TOC – Reservoir Pressure – Ro –Brittleness – Thermal Maturity



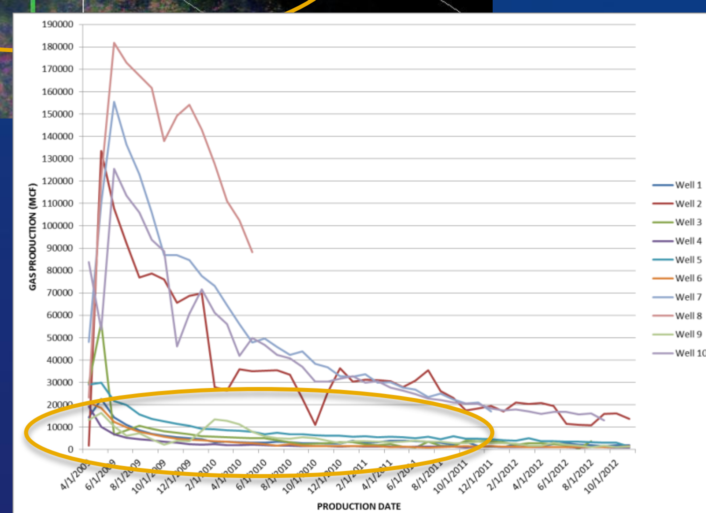

Courtesy of CGG and BHI Alliance

# Locating Areas of High Potential in Seismic Volume




High

Probability



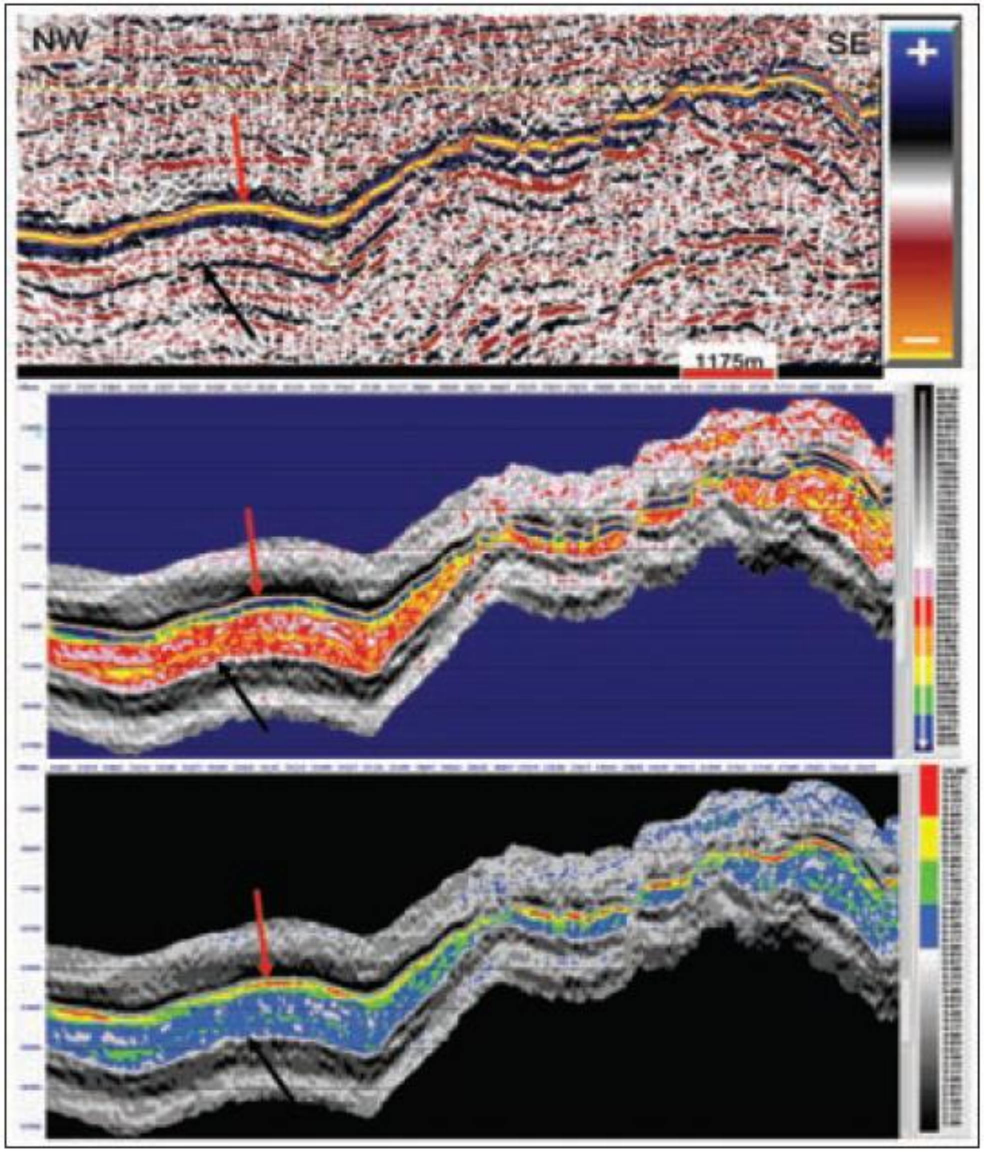

Volumetric View of TOC and other key parameters with well penetrations

Multiple uneconomic wells

Several rich areas yet to be exploited

Courtesy of CGG and BHI Alliance

# TOC (Total Organic Content) Vs. Acoustic Impedance



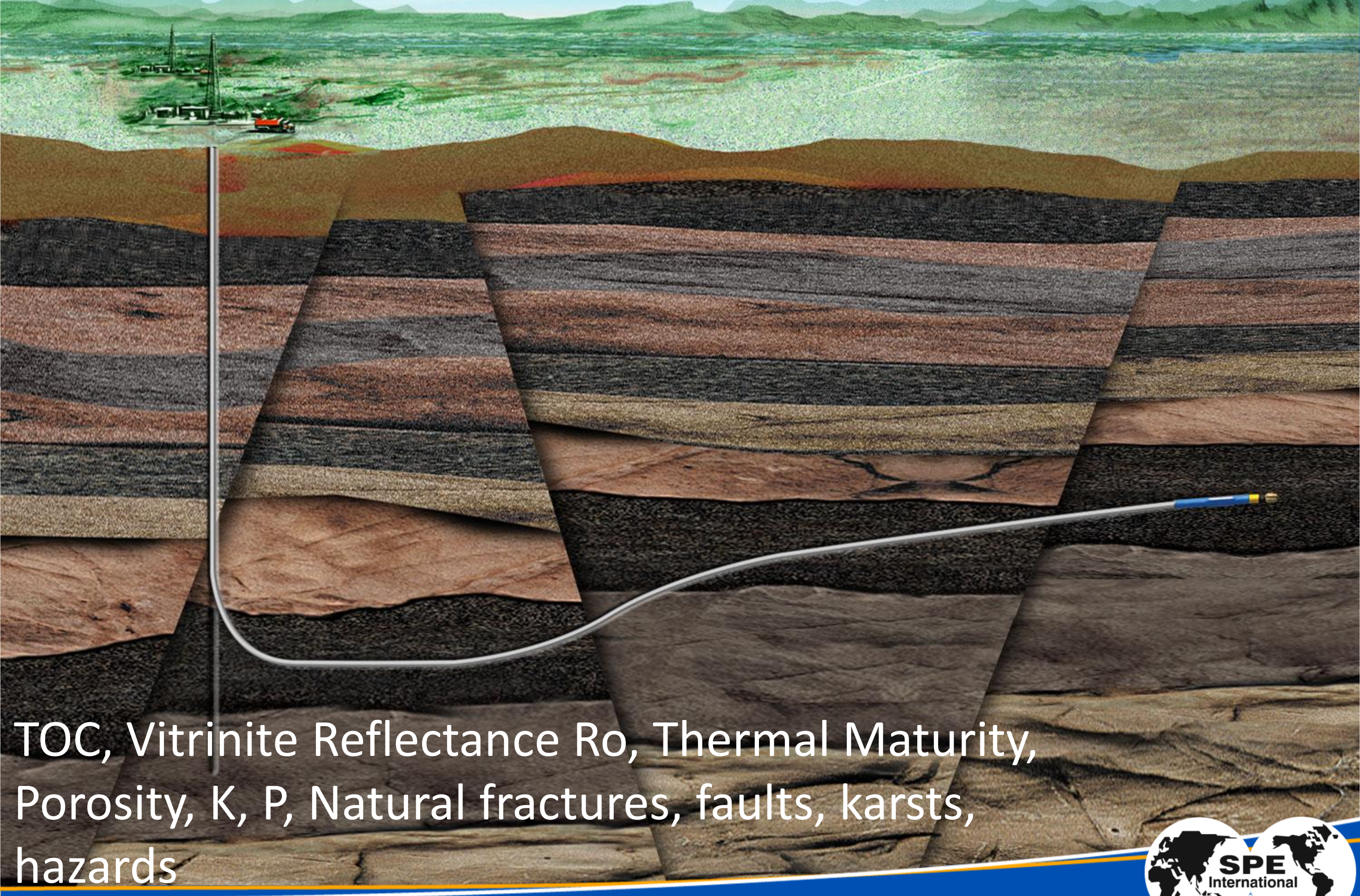

**Lower Acoustic Impedance = Higher TOC and Natural Fractures**

Pictured here (from top), near stack seismic section, Acoustic Impedance section and TOC section through the northern calibration well. The red arrows point at the top of the Spekk Formation and the black arrows point at the base. In the middle Acoustic Impedance section, the acoustic impedance is lower within the Spekk Formation than in adjacent strata, apart from in the shallowest part where the low impedances are due to the shallow depth and not due to organic content. A trend from very low acoustic impedances in the upper part (blue colors) to higher acoustic impedances further down (red and pink colors) is clearly seen within the Spekk Formation. TOC content greater than 6 percent TOC is highlighted in bright colors in the lower figure.

*Graphics courtesy of Statoil Research Center*

**Source: AAPG Explorer. Dec 2009**

# Vertical Pilot Well: The start

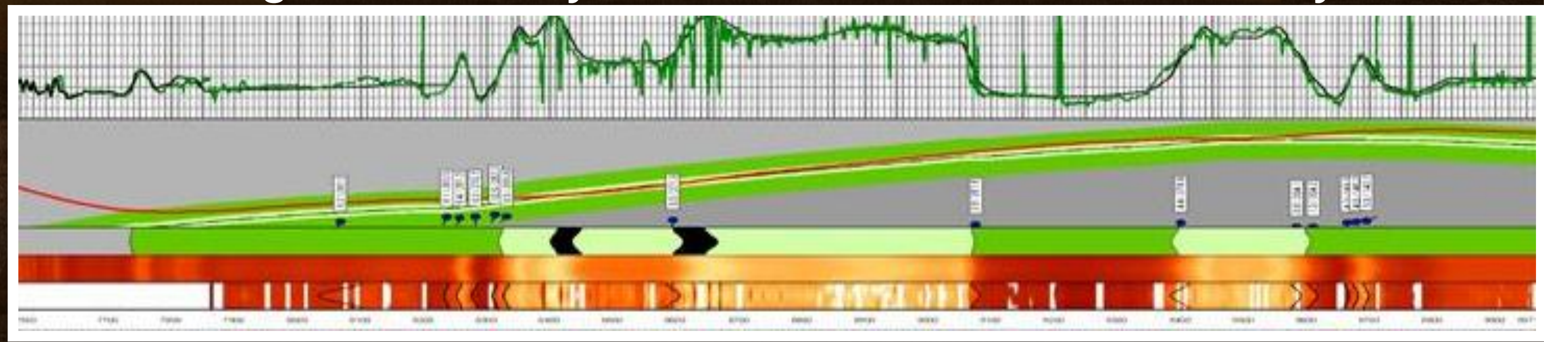


TOC, Vitrinite Reflectance Ro, Thermal Maturity, Porosity, K, P, Natural fractures, faults, karsts, hazards

# Moving from Pilot wells to development wells

## Reservoir Navigation Services - RNS (Azimuthal Resistivity & Gamma Images)

Armstrong Co., Pennsylvania – Marcellus Case History



Target for Lateral
High TOC = only 15ft Thick

**Well Trajectory Planned**

- Seismic
- Shale Analysis
- Offset Well Data

**Monitored LWD GR**

- Up and Down
- To determine if well approaching formation top or bottom / correct

## Follow the high TOC, Ro, BI and Pp path

# Evaluating the Resource and Production Potential

| Resistivity / Density /Neutron | | | | | | |
|---|---|---|---|---|---|---|
| 20<br>Formation Lithology | Spectroscopy | Micro-seismic | Imaging | Large Diameter Coring | Deep Reading Shear Acoustic | Nuclear Magnetic Resonance |
| • *Geochemistry*<br>• Lithology<br>• Mineralogy<br>• Total organic carbon | • *Lithology*<br>• Mineralogy<br>• Th/U for Carbon classification | Image correlation with lithology and *facies* | *Fracture detection* | *Core analyses* | • Geomechanical properties from Wellbore and *away from wellbore* | • Porosity<br>• Indepen-dent measure of *total organic carbon* |

## Logging and Core analyses can identify:

- Fomation with producible source rock hydrocarbon
- Optimum formations to drill horizontal laterals
- Optimall placement of frac stages
- Potential barriers for frac containment
- Mineralogy key component integrated with Geomechanics

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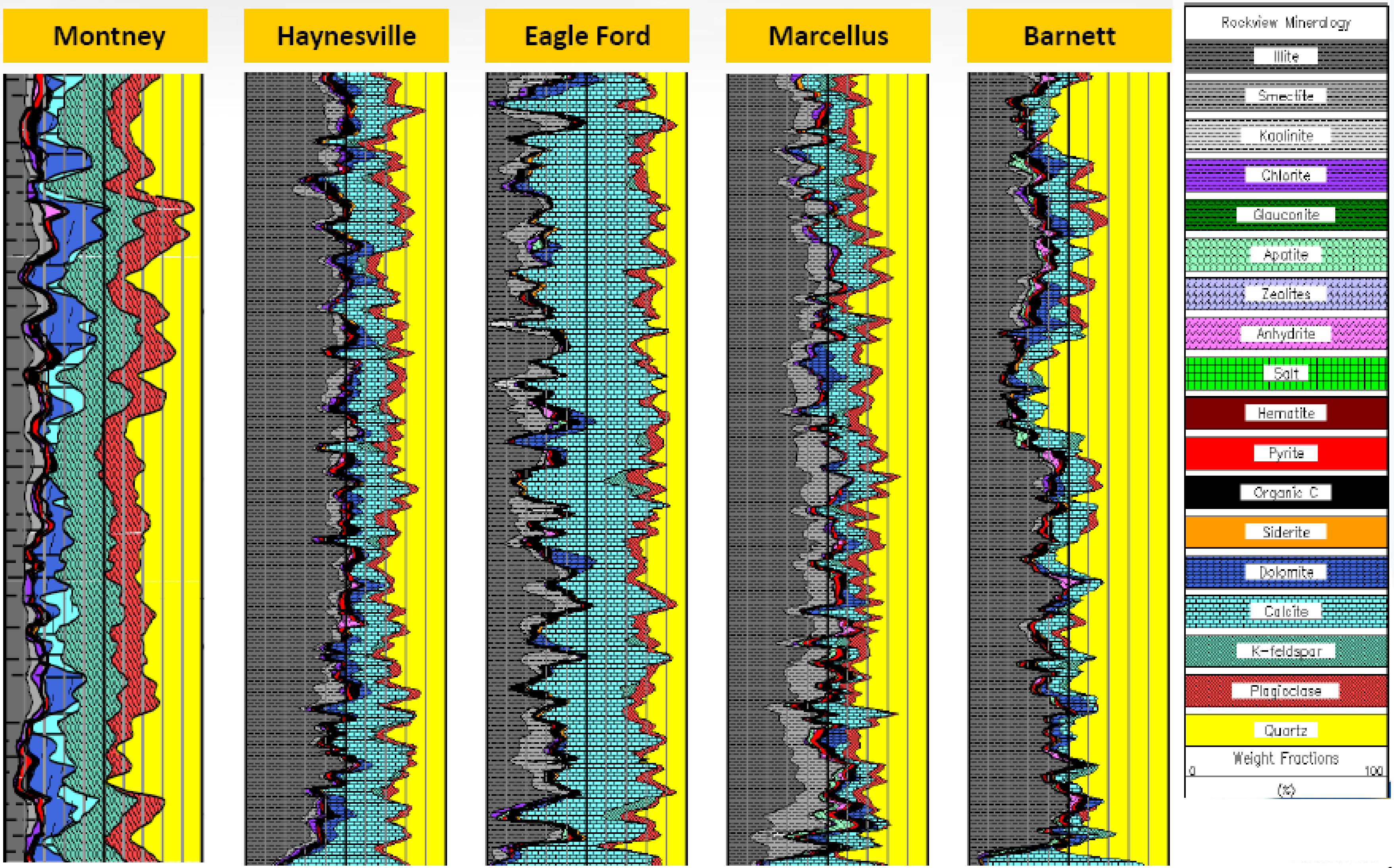
# Mineralogy Varies in Shale Reservoirs

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# Wellbore Imaging: Fractures, Faults & Geohazards

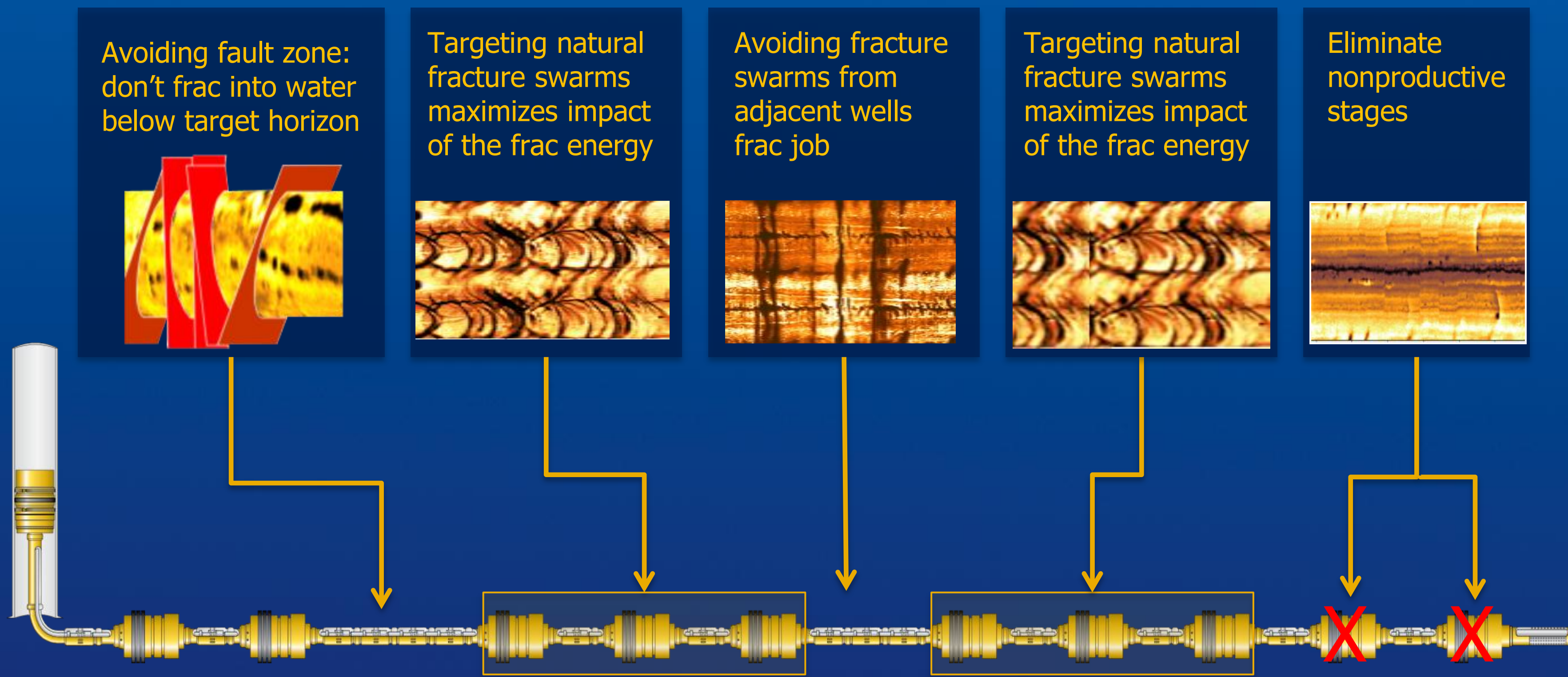
**WBM Imager**

Acquire high-resolution resistivity formation i

**OBM Imager**

Acquire high-resolution microresistivity images in oil-based mud system

# High-definition LWD Imaging to Optimize Completions



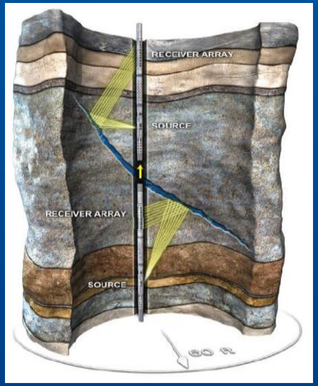

**Case Histories Show Production Increases above 20 % and above 10% in EUR**

# Deep Shear Wave Imaging (up to 70m away)

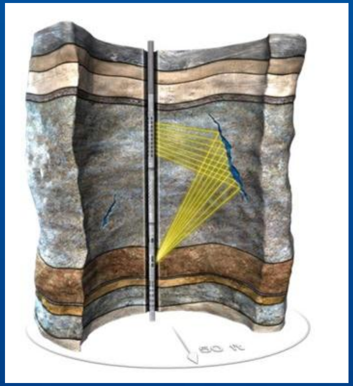
- Methodology
  - Filtering direct waves
  - Reflected wave stacking
  - Reflector strike inversion
  - Fullwave data migration

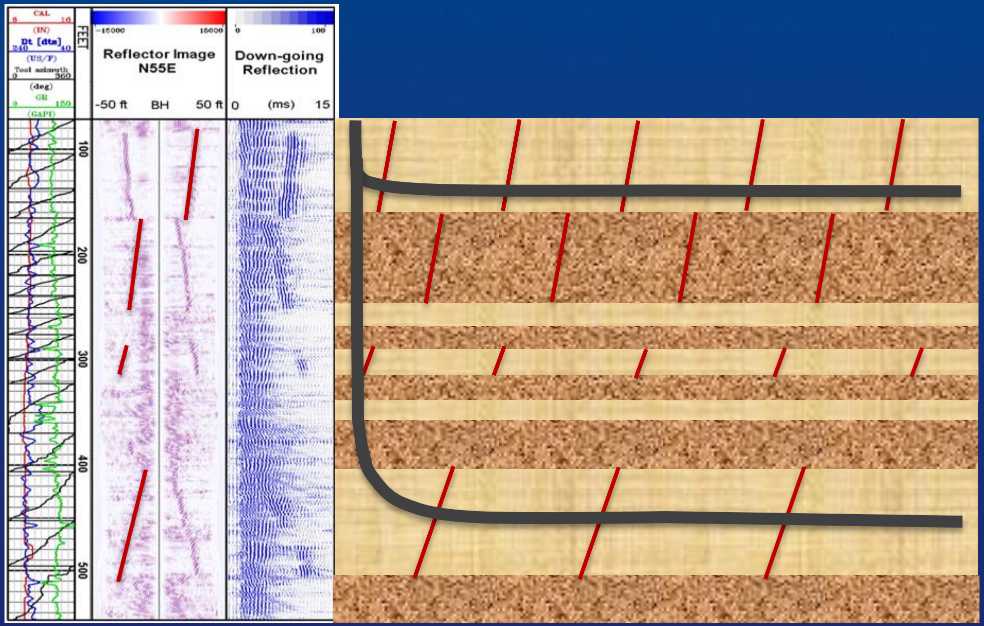
- Benefits
  - Illuminate natural fractures up to 70 m away.
  - Identify mechanical strata
  - Placing laterals

Imaging fractures that intersect the well

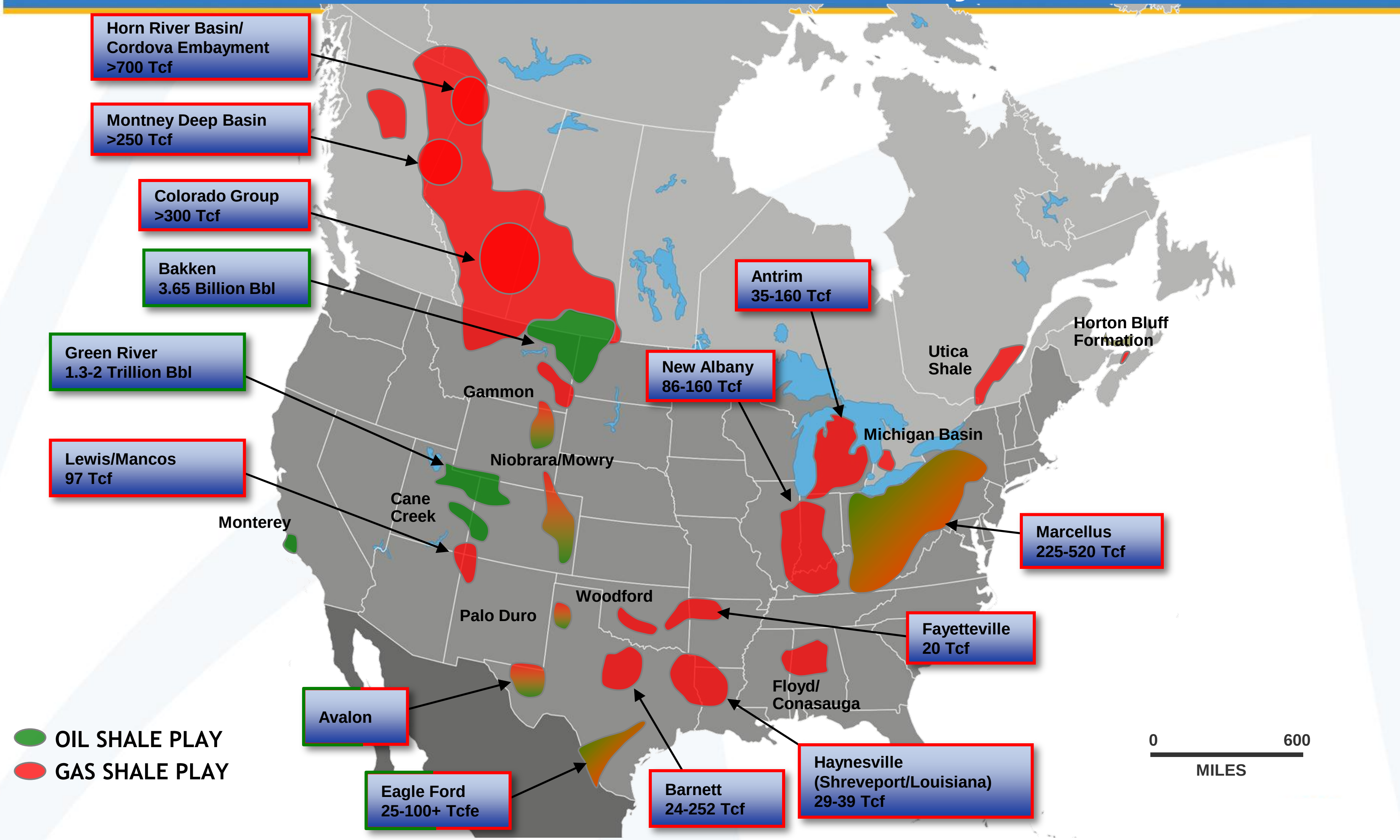



Imaging fractures that do not intersect the well





# The Next 5-10 Years
# ~100,000 Wells, 1-2 Million Hydrofracs




## How Do We Optimize Resource Development?

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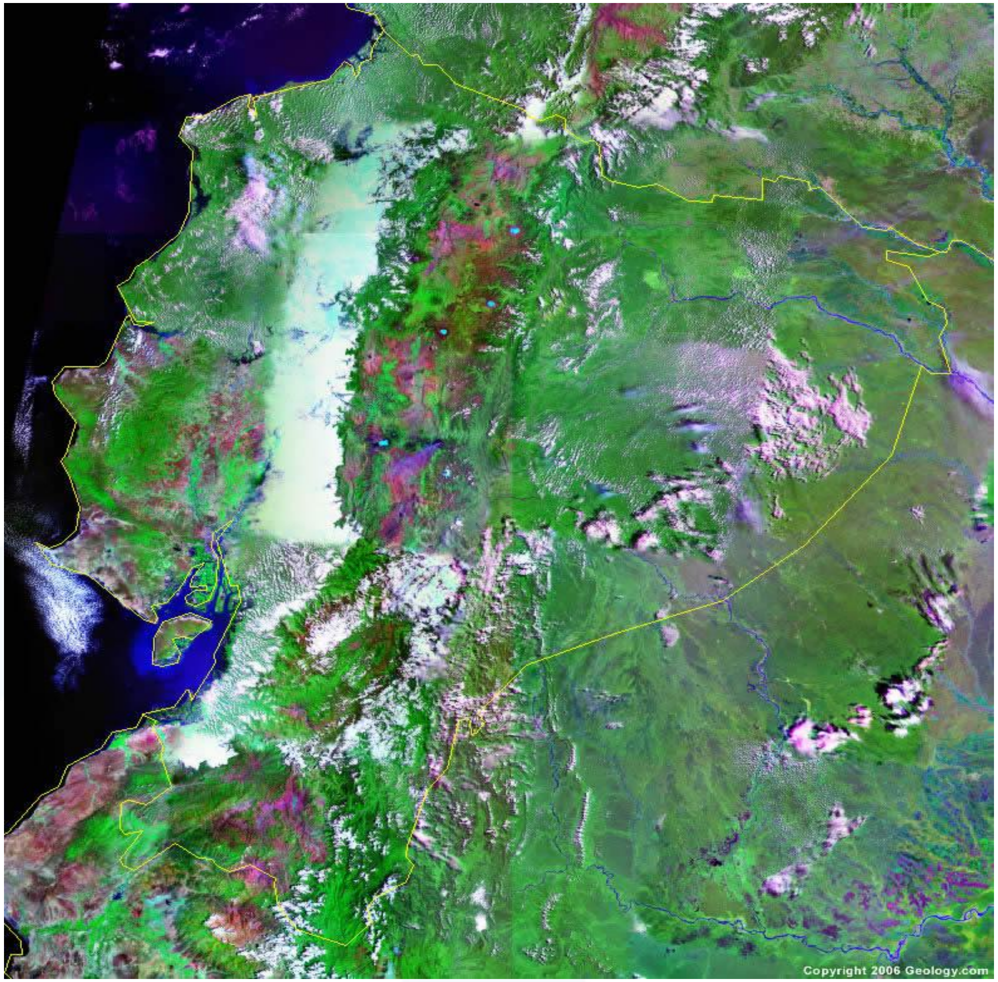
# Outside North America?: The Next 5-10 Years? Wells, ? Hydraulic fracs

**Eastern Hm**
UK
Poland
Russia
Turkey
Saudi Arabia
Kuwait
India
China
Indonesia
Australia
Croatia

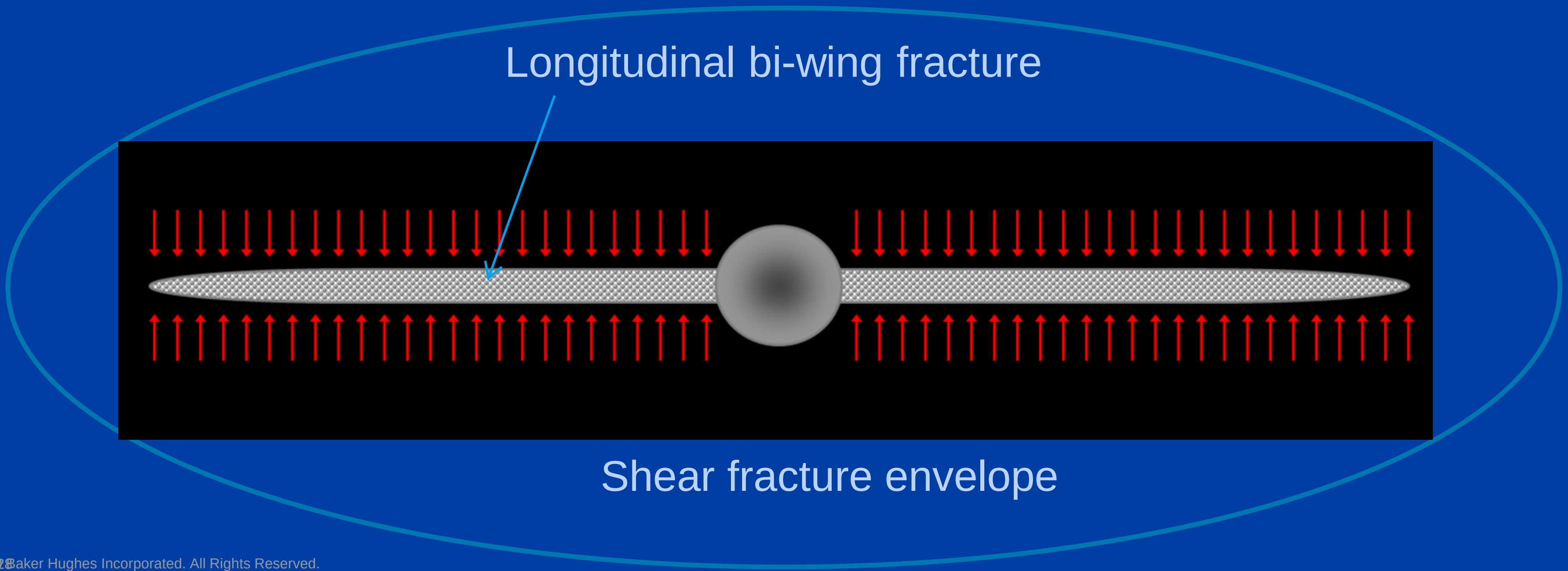



**Western Hm**
Argentina
Mexico,
Colombia
Venezuela
Ecuador
Brazil

**How Do We Optimize Resource Development?**

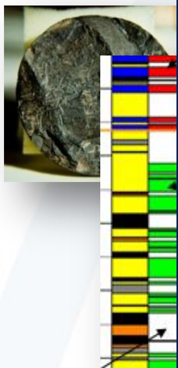
# Production from Nano-Darcy Rocks?

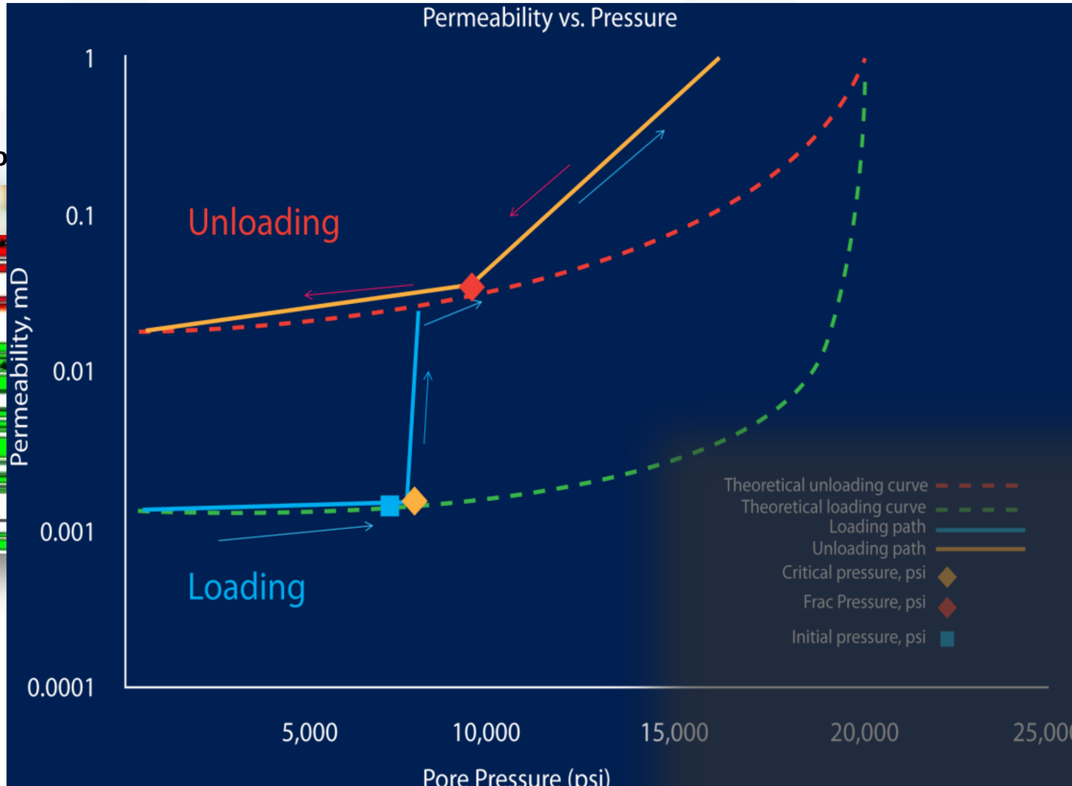
- Shale Resource has typically permeability in the nano-Darcy range
- Gas / hydrocarbon may move in order of few feet in a year!!
- What mechanism is there then to produce hydrocarbon from such low permeability rocks?
- Creation of a stimulated reservoir volume that has both longitudinal and shear fractures



# From Natural Shale to the Artificial Reservoir

Logs and co



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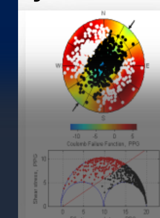
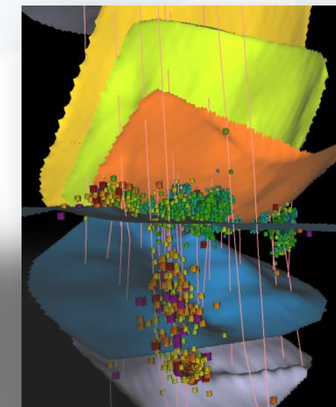


Microseismic Re-processing



## Benefits

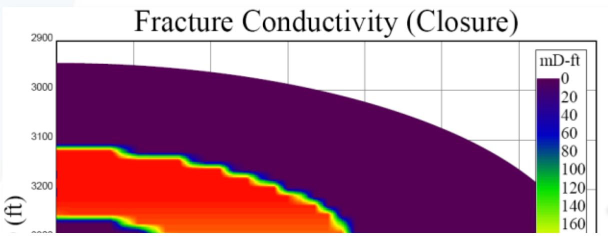
- Enhancing reservoir understanding
- Exploiting modern technology

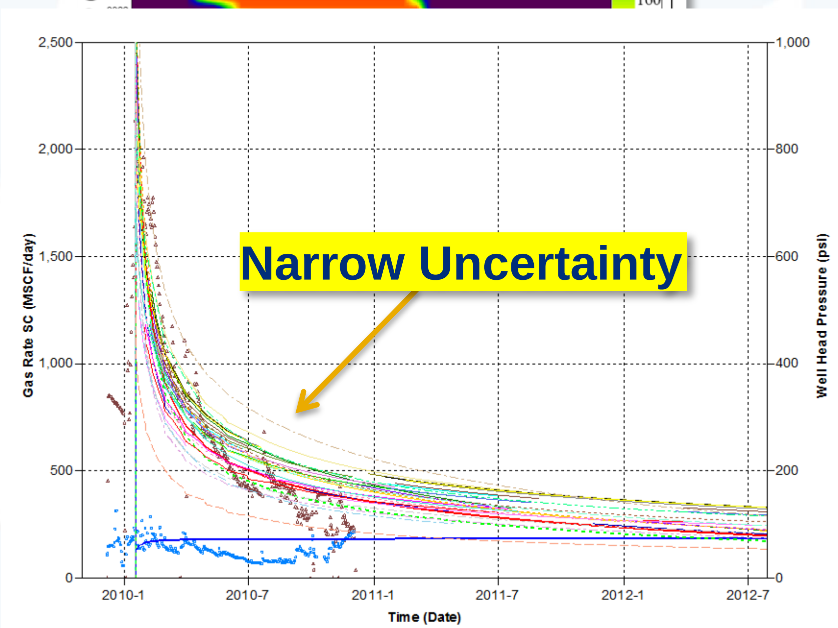
# Shale Engineering Predictive Model

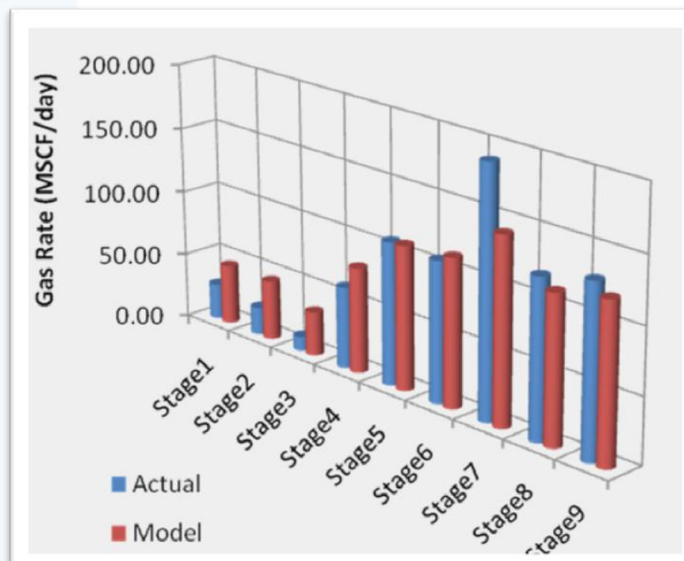
Matched production history and production logging

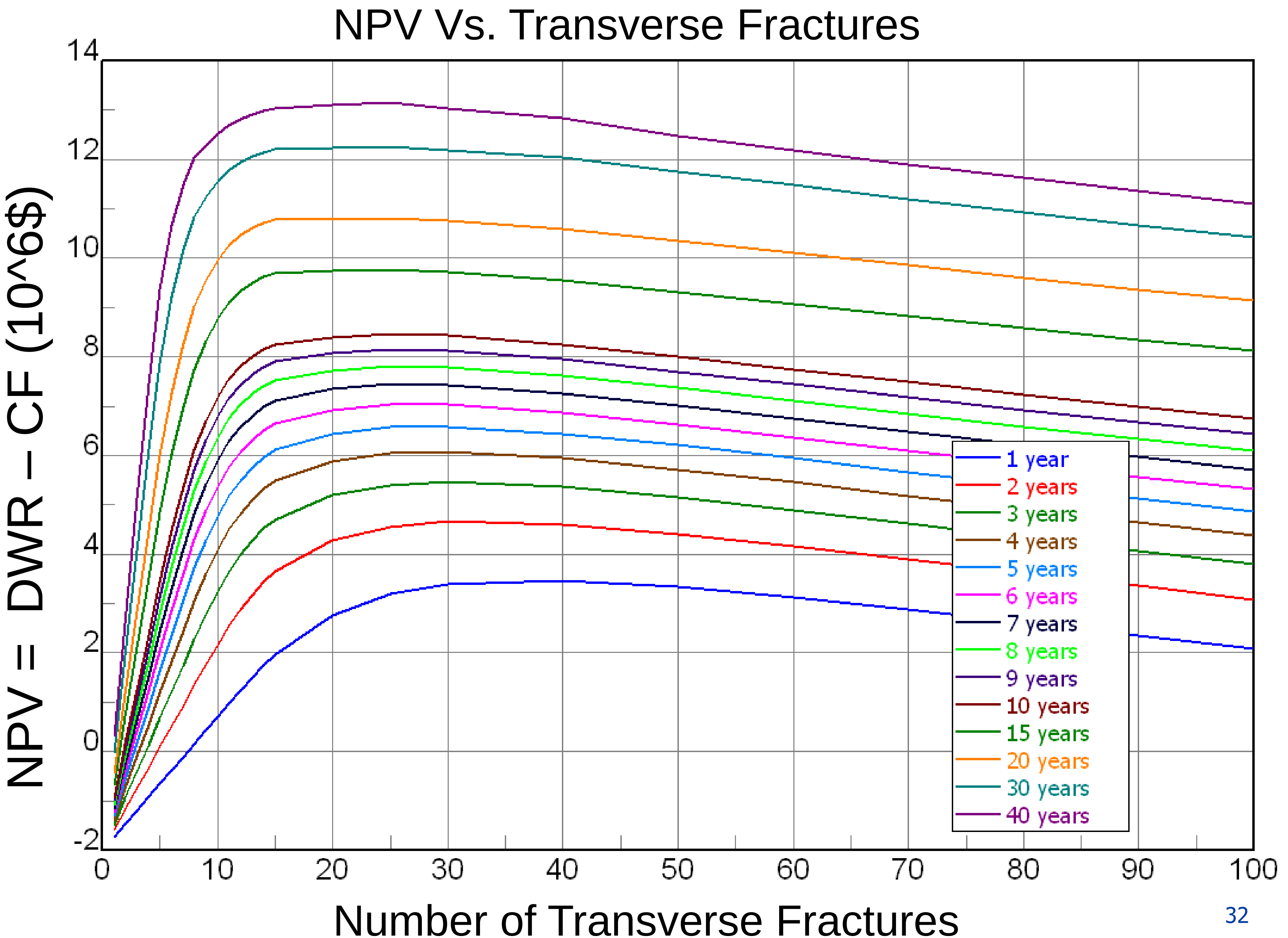
- ✓ **Frac stage contribution match**
- ✓ **Proppant placement match**
- ✓ **Well History match**

Pressure Drop, psi

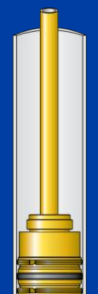
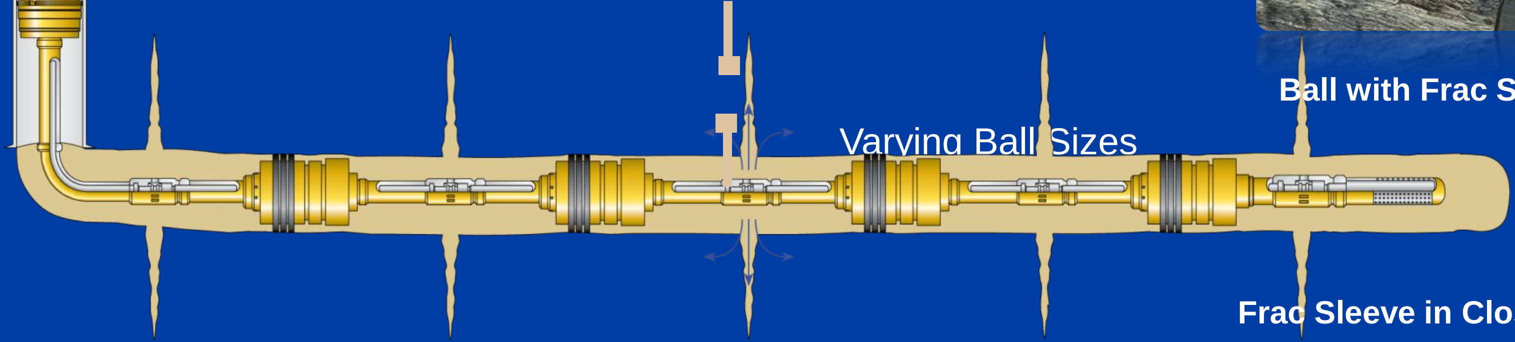


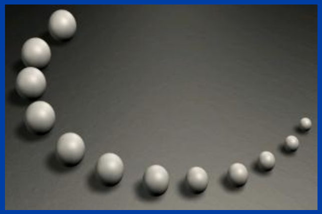




NPV Vs. Transverse Fractures
NPV = DWR – CF (10^6$)
Number of Transverse Fractures
14
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90
100
1 year
2 years
3 years
4 years
5 years
6 years
7 years
8 years
9 years
10 years
15 years
20 years
30 years
40 years

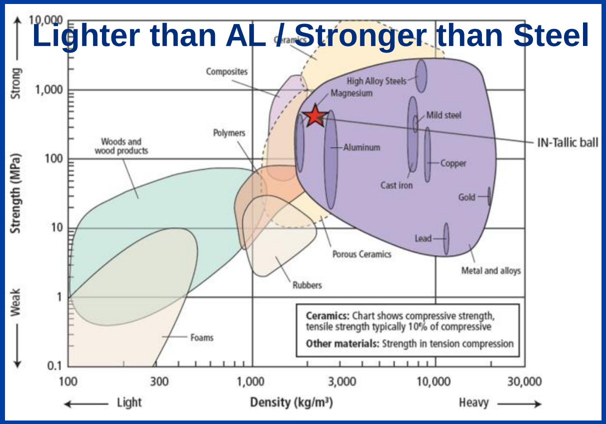
# Ball Activated Sleeve Open / Close Completion System

Ball with Frac Sleeve Open

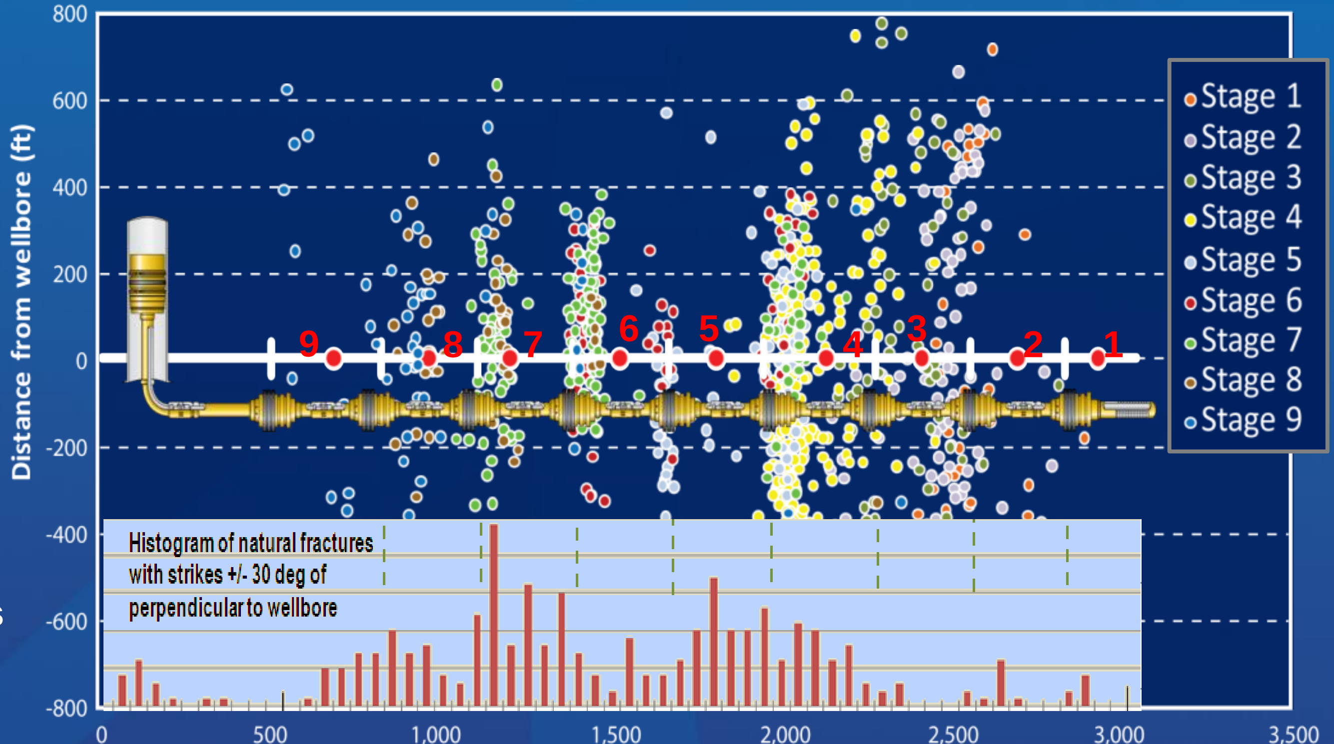
Frac Sleeve in Closed Position



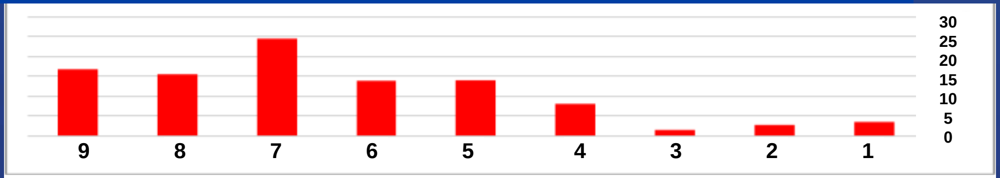
# Relating stage contributions to production:
## Impact on Field Development Plan

Events

Natural fractures



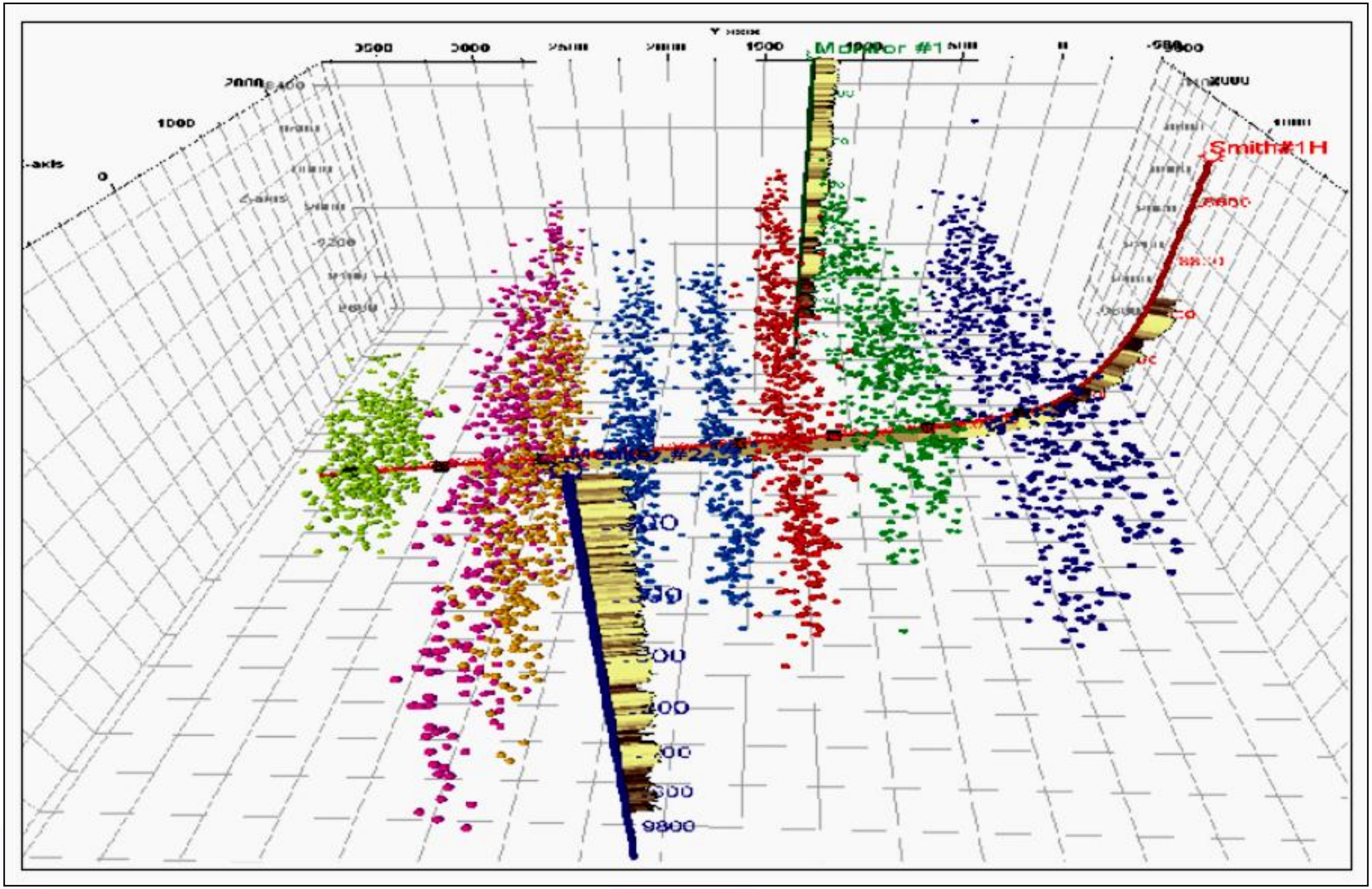

| B-values | - | 0.98 | - | 1.01 | - | 1.92 | 2.27 | 1.92 | - |
|---|---|---|---|---|---|---|---|---|---|




Rates measured by PLT 5 months later

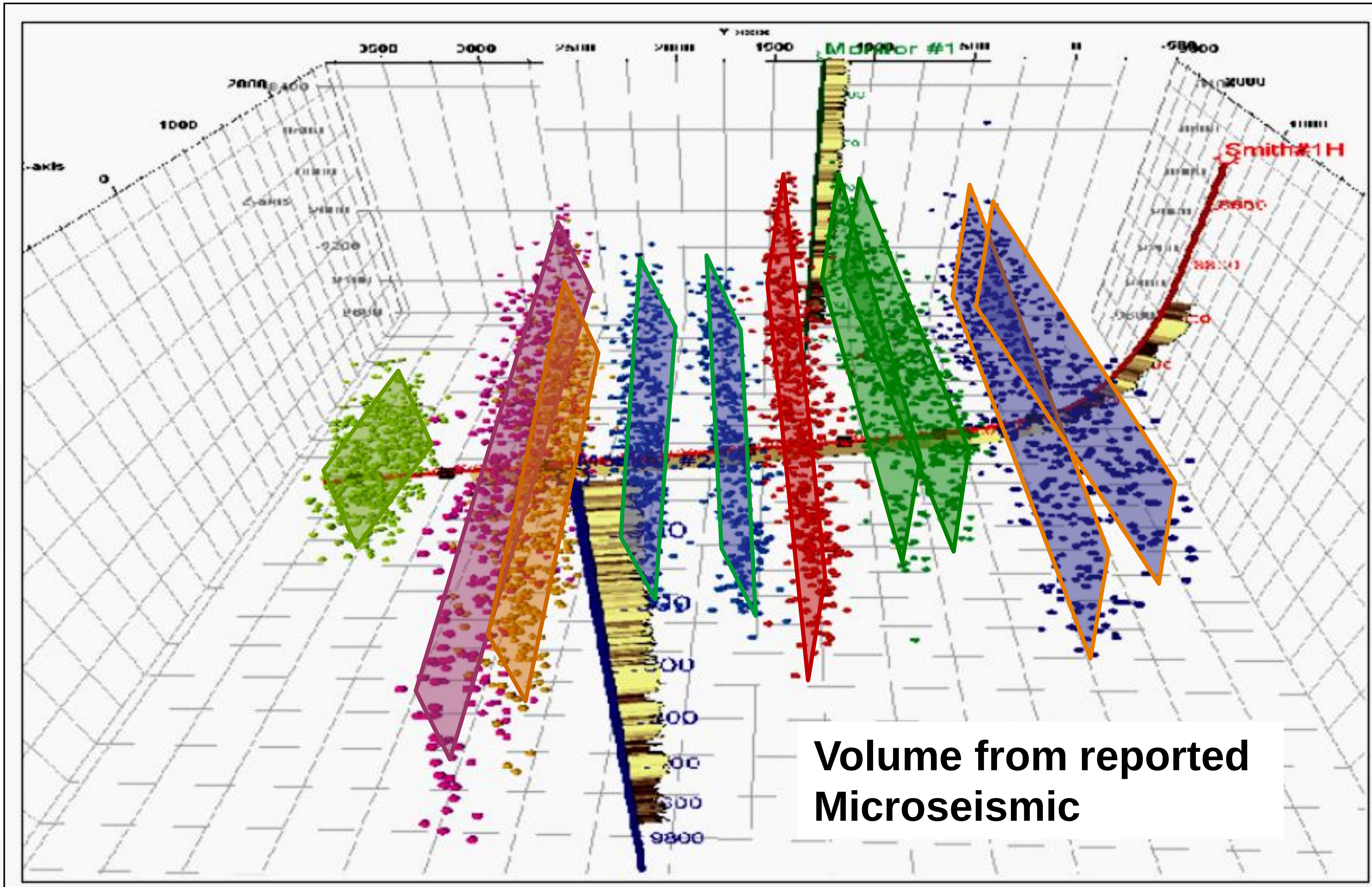
 

# Stimulated Shale Volume (SSV)



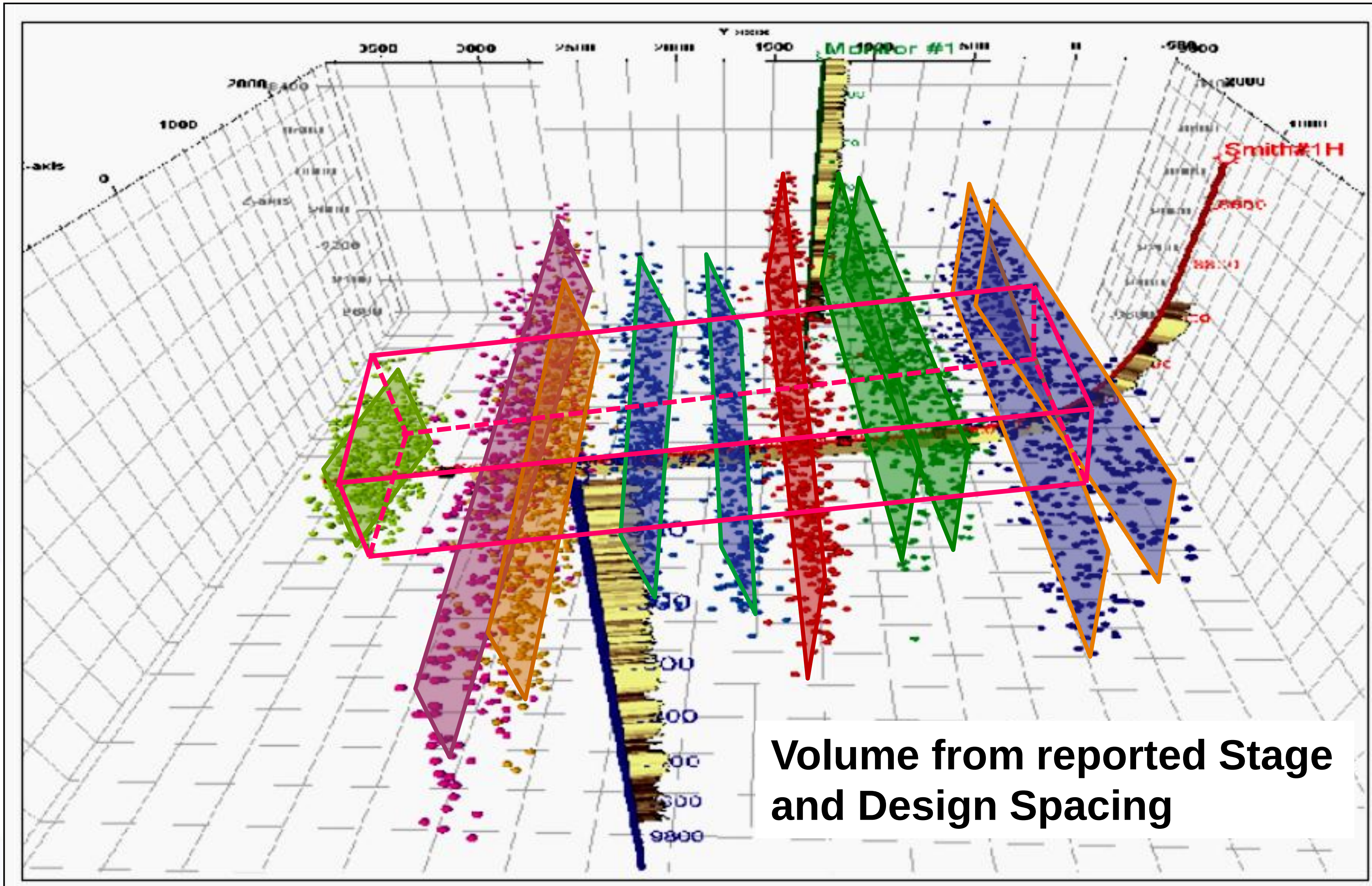

Modified from Baihly et al. (SPE 110067, 2007)

# Microseismic SSV



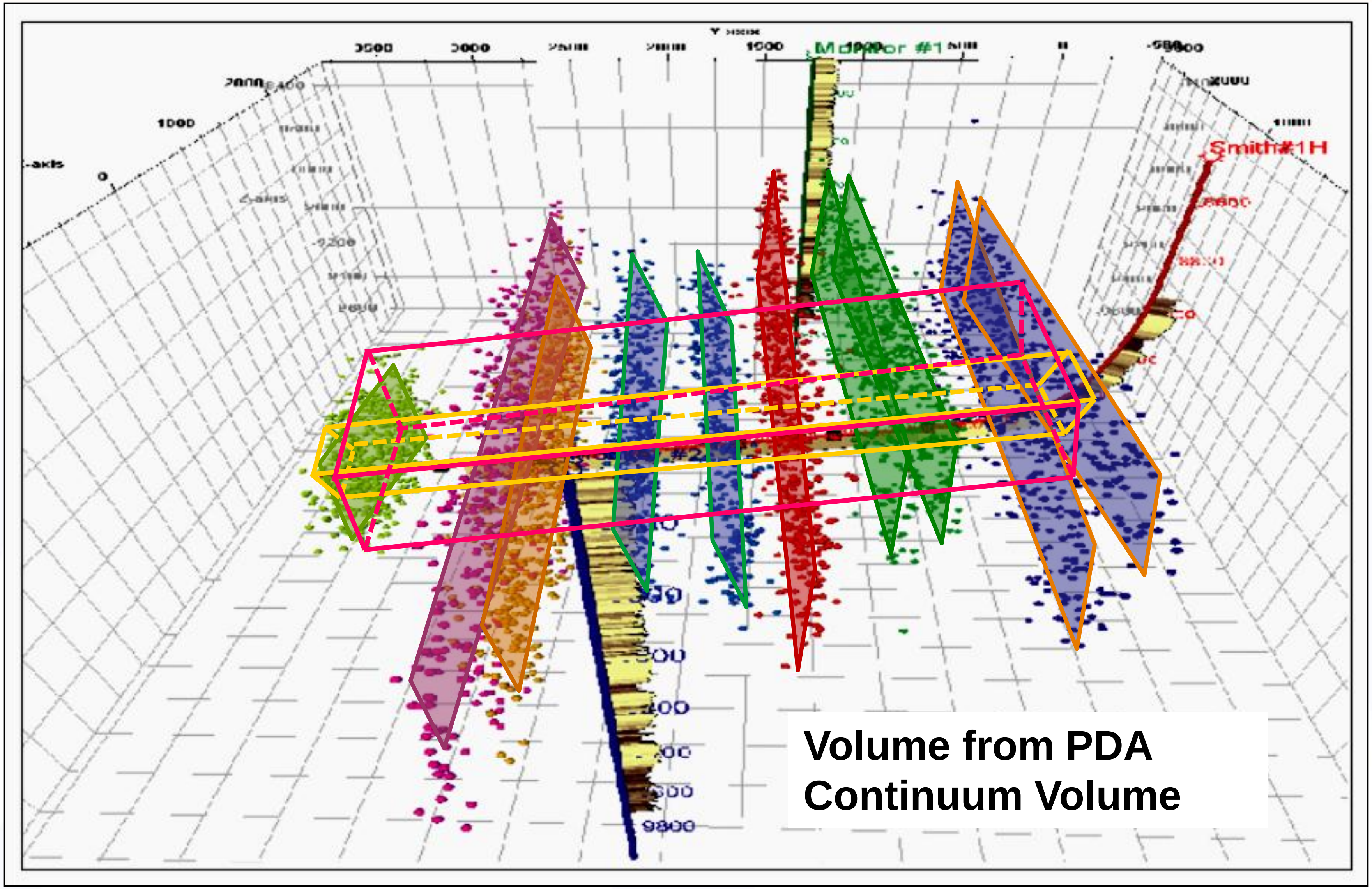

Modified from Baihly et al. (SPE 110067, 2007)

# Propped SSV




Modified from Baihly et al. (SPE 110067, 2007)

# Productive SSV



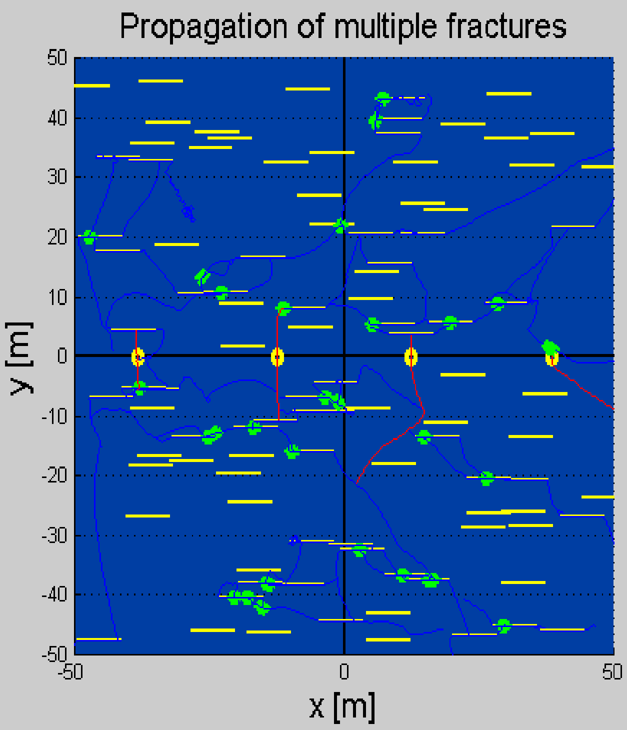

Modified from Baihly et al. (SPE 110067, 2007)

# Stimulated Shale Volume Comparison

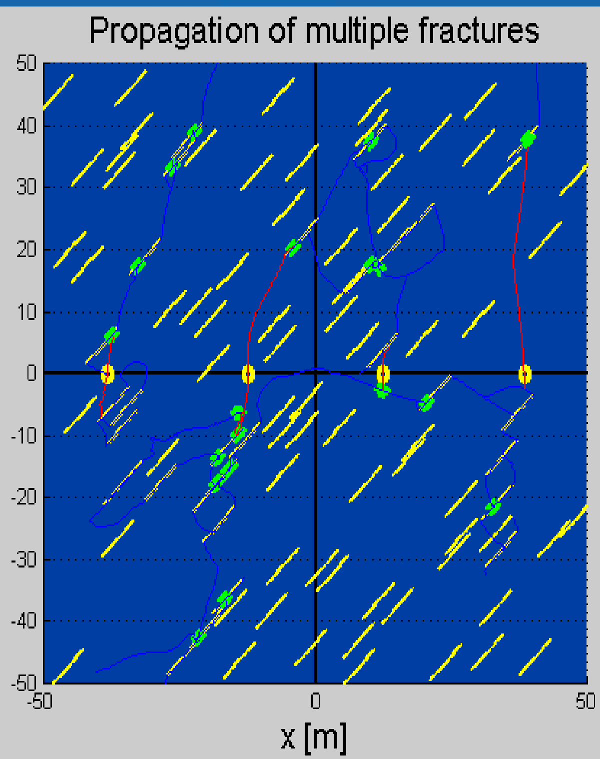
| Micro-seismic Monitoring | Fracture Model | Transient Performance |
|---|---|---|
| 6.58 B $ft^3$ | 1.69 B $ft^3$ | 0.85 B $ft^3$ |
| Difference Ratio | 0.7432 | 0.8708 |

**25.68% of MS** **12.92% of MS**

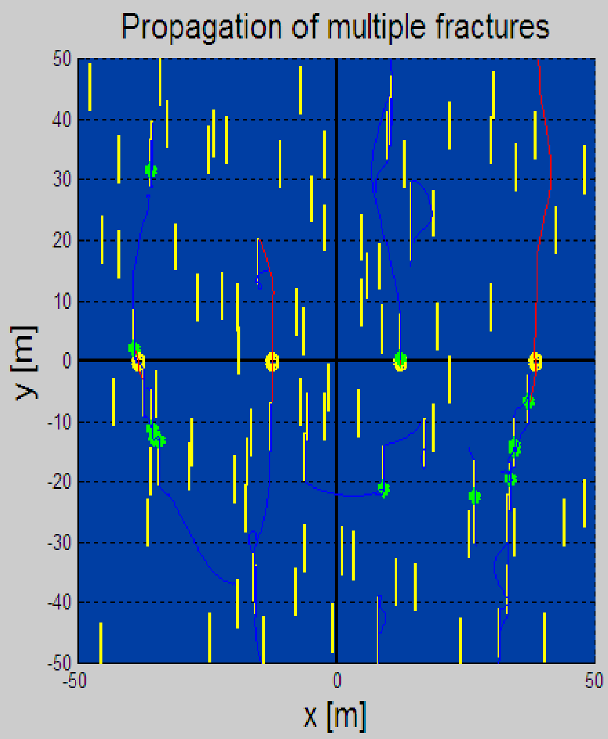
# Fracture Mechanics Based Model




σh = σH, NF 100 EW (90º)

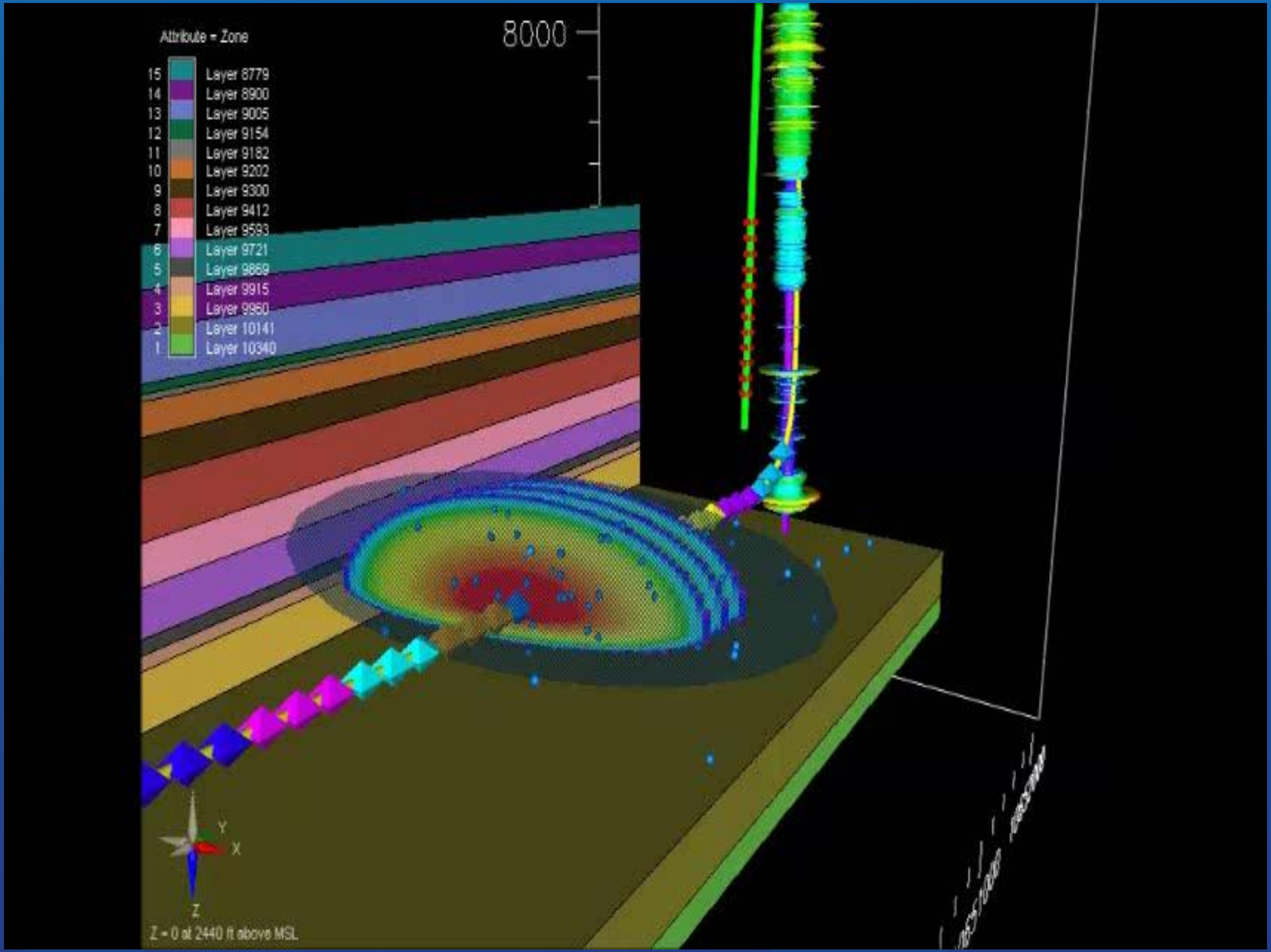



σh = σH, NF 100 NS (45º)




σh = σH, NF 100 NS (0º)

# Integrated Display




- Well Logs
- Layers
- Fracture Model
- Events
- Real-Time "SRV"

# Concluding Remarks

- Shale resource is not contiguous and no two Shale basins are the same
  - Sweet spot identification is going to be critical (seismic attribute + Lithofacies) for well placement
  - Different shales will require different set of attributes and the associated lithofacies
- Geometric placement of hydraulic fracture stages needs to be replaced by shale productivity based parameters
  - Capitalize on the presence of natural fractures at the well bore as well as away from the wellbore
  - Avoid faults and geohazards

# Distinguished Lecturer Program

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