Unconventional Multi-Variate Analysis: A Non-Linear Review of the Most Relevant Unconventional Plays in the U.S.*

Roderick Perez[1]

Search and Discovery Article #80428 (2014)**
Posted December 8, 2014

*Adapted from oral presentation given at Geoscience Technology Workshop, Unconventionals Update, Austin, Texas, November 4-5, 2014

[1]DrillingInfo Inc., Houston, TX, USA (roderickperezaltamar@gmail.com)

Abstract

Data is a powerful tool. It can be both overwhelming to the point of being ignored, and addictive, creating tendencies to overanalyze. In the fast-paced business world, successful leaders know the ability to make quick adjustments to workflows can make a huge difference to bottom lines. Data analysis is what identifies trends that seem to be working and that need to be changed.

It is no different in the oil and gas business, and many different industry specific software packages have been developed to try to handle the huge amounts of data that come in from daily operations. However, the key to success is in full scope integration of data from different fields of study. The use of the use multidisciplinary analytical methodologies has become a necessity in order to provide descriptive and predictive models to complement conventional geological, geophysical, and engineering analysis in unconventional resources plays.

The challenge is to unveil relationships and opportunities buried in mountains of geological, geophysical, and engineering data, collated at various scales: in depth as well as in time. This presentation will cover methodologies that can be used to integrate data collected in these various aspects, and review lessons learned from some of the most important unconventional shale plays in the U.S. such as: the Barnett Shale, Eagle Ford Shale, Haynesville Shale, and Utica Shale, in order to discover connections between the available input variables without explicit knowledge of the physical behaviors of the system.

References Cited

Browning, D.B., 2006, Investigating corrections between microseismic event data, seismic curvature, velocity anisotropy, and well production in the Barnett Shale, Fort Worth Basin, Texas: M.S. Thesis, University of Oklahoma, Norman, Oklahoma, 105 p.

Goodway, B., J. Varsek, C. Abaco, 2007, Anistropic 3D amplitude variation with azimuth (AVAZ) methods to detect fracture prone zones in tight gas resource plays: CSPG, CSEG, CWLS Conference, p. 590-596.

Perez, R., 2013, Brittleness Estimation from Seismic Measurements in Unconventional Reservoirs: Application to the Barnett Shale: Ph.D. Dissertation, ConocoPhillips School of Geology and Geophysics: The University of Oklahoma.

Perez, R., and K. Marfurt, 2014, Mineralogy-Based Brittleness Prediction from Surface Seismic Data: Application to the Barnett Shale: (in press).

Roth, M., 2013, An Analytic Approach to Sweetspot Mapping in the Eagle Ford Unconventional Play: Web Accessed November 11, 2014. https://www.transformsw.com/wp-content/uploads/2013/05/An-Analytic-Approach-to-Sweetspot-Mapping-in-the-Eagle-Ford-Unconventional-Play-2013-Geoconvention-Roth-Roth-Peebles.pdf

Thompson, A., 2010, Induced fracture detection in the Barnett Shale, Ft. Worth Basin, Texas: M.S. Thesis, The University of Oklahoma, Norman, Oklahoma, 69 p.

Verma, S., A. Roy, R. Perez, R., and K.J. Marfurt, 2012, Mapping High Frackability and High TOC Zones in The Barnett Shale: Supervised Probabilistic Neural Network vs. Unsupervised Multi-Attribute Kohonen SOM: 2012 SEG Annual Meeting, 4-9 November, Las Vegas, Nevada.

UNCONVENTIONAL MULTI-VARIATE ANALYSIS:

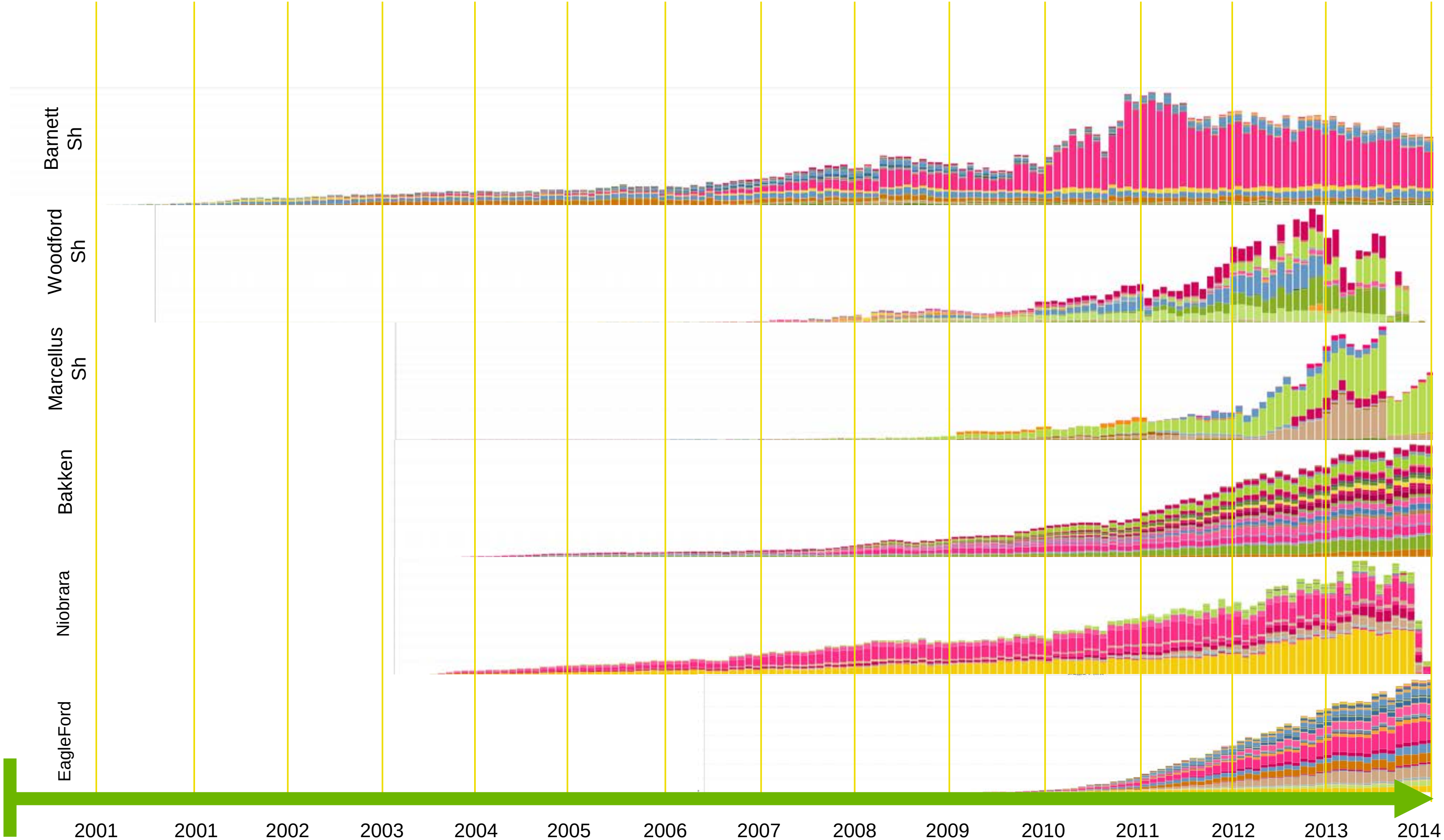
A non-linear review of the most relevant unconventional plays in the U.S.

drillinginfo
better, faster decisions

Roderick Perez Altamar, Ph.D.

November, 5th, 2014

PRODUCTION HISTORY
Timeline



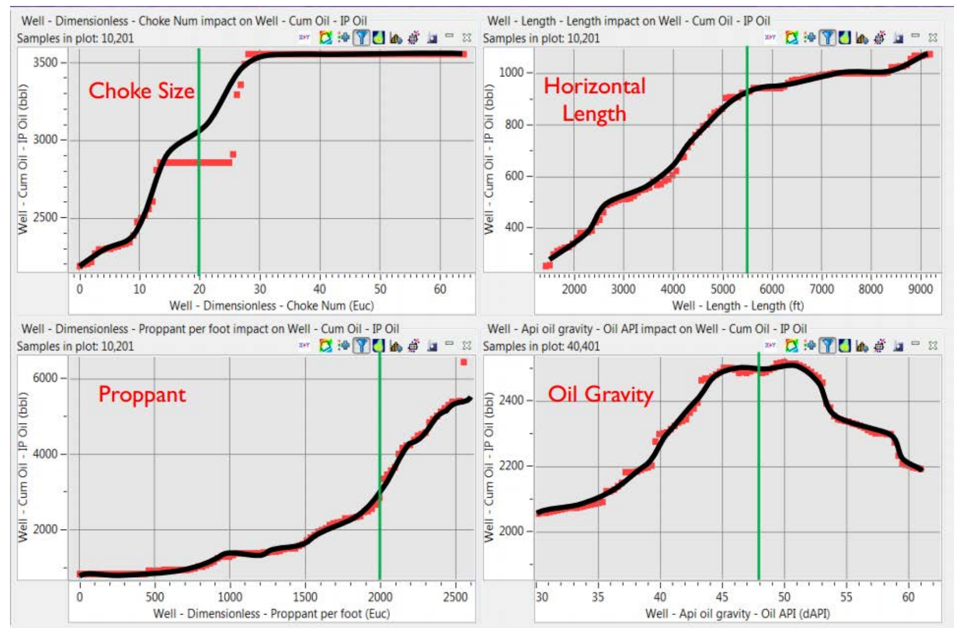
drillinginfo
better, faster decisions

ANALYTICS

ANALYTICS

"The amount of data gathered from production activity has also increased due to placement of downhome sensors that relay information to the operator on a real-time basis."

The Big Challenges of Big Data for Oil, Gas by Karen Boman



From Murray Roth - An Analytic Approach to Sweetspot Mapping in the Eagle Ford Unconventional Play

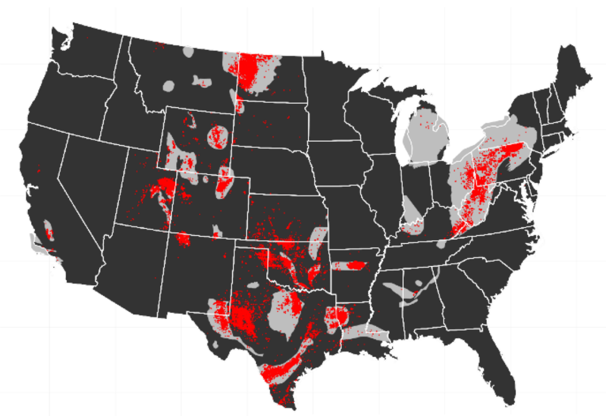
https://www.transformsw.com/wp-content/uploads/2013/05/An-Analytic-Approach-to-Sweetspot-Mapping-in-the-Eagle-Ford-Unconventional-Play-2013-Geoconvention-Roth-Roth-Peebles.pdf

Analytics is the discovery of meaningful patterns in data.

drillinginfo better, faster decisions

(Unconventional) APPLICATION OF ANALYTICS

The data suggests that proximity to a natural gas well is correlated with lower housing prices.



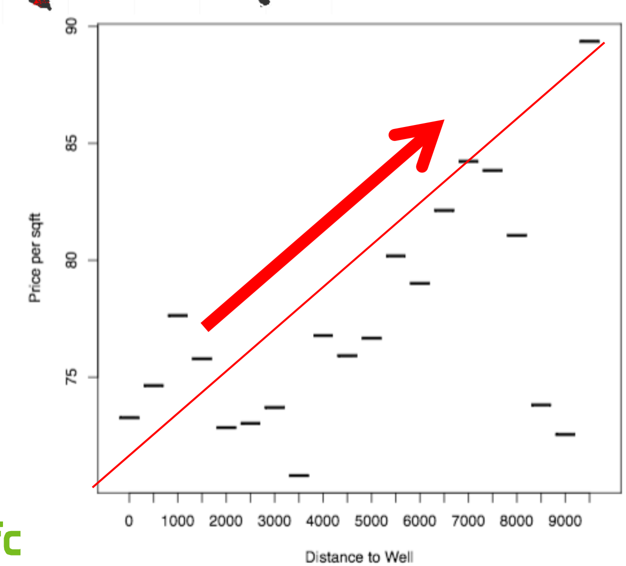


Table 1: Distance to Well and Property Price per Square Foot

	(1)	(2)	(3)	(4)
10 km threshold				
Distance to Well	0.014*	0.014*	0.014*	0.012
	(0.008)	(0.008)	(0.008)	(0.009)
bedrooms	−0.092***	−0.091***	−0.091***	−0.109***
	(0.014)	(0.015)	(0.015)	(0.012)
baths	0.185***	0.181***	0.180***	0.098***
	(0.021)	(0.020)	(0.020)	(0.020)
age	−0.012***	−0.012***	−0.012***	−0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	29,207	29,207	29,207	29,207
Adjusted R^2	0.250	0.251	0.257	0.357
20 km threshold				
Distance to Well	0.009**	0.009**	0.009**	0.010**
	(0.004)	(0.004)	(0.004)	(0.005)
bedrooms	−0.107***	−0.106***	−0.106***	−0.116***
	(0.015)	(0.015)	(0.015)	(0.013)
baths	0.146***	0.143***	0.142***	0.085***
	(0.034)	(0.033)	(0.033)	(0.021)
age	−0.012***	−0.012***	−0.012***	−0.009***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	44,423	44,423	44,423	44,423
Adjusted R^2	0.228	0.229	0.235	0.353
Fixed Effects	County	County & Year	County x Year	Census Tract & Year

Note: The dependent variable is the log of average price per square foot. Standard errors are clustered at the county level with stars indicating *** 0.01, ** 0.05, * 0.1.

http://freigeist.devmag.net/economics/808-fracking-and-house-prices-on-the-marcellus-shale.html

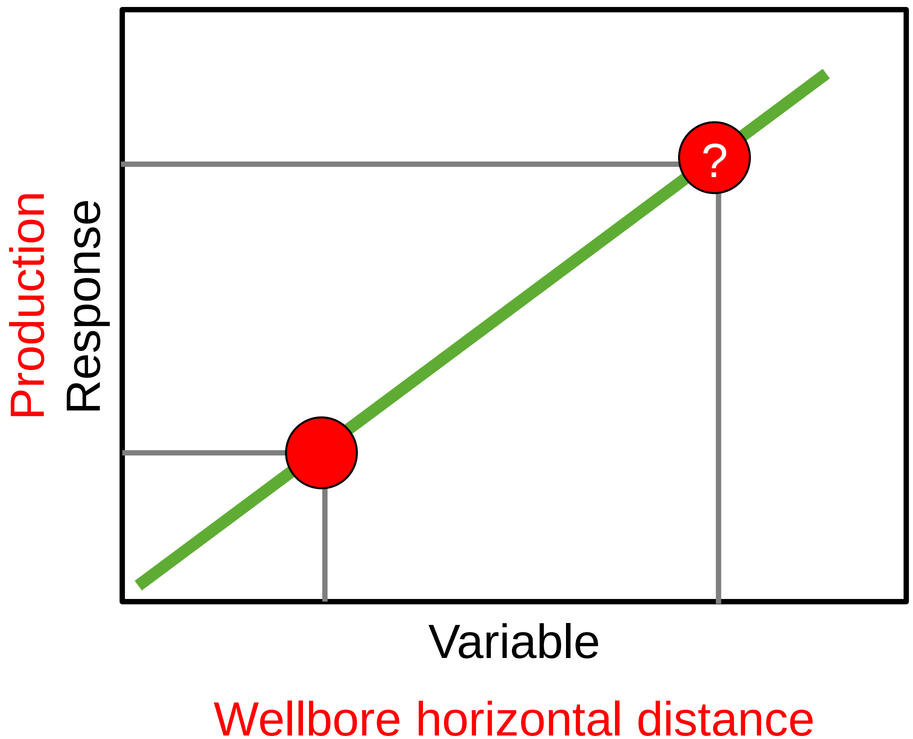
drillinginfo
better, faster decisions

CLUSTERING ANALYSIS ALGORITHMS & TECHNIQUES

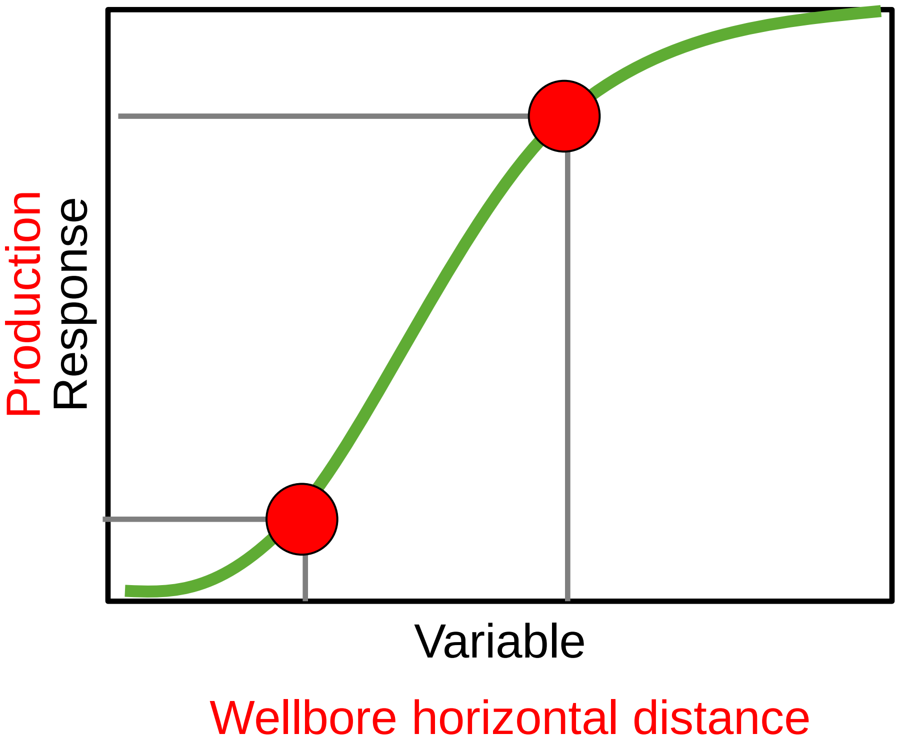
- Classification
  - Fuzzy Logic
  - Supervised
  - Unsupervised
    - K-means
    - SOM
  - Hierarchical
- Regression
  - Linear
    - Principal Component Analysis
  - Non-Linear
  - Neural Networks

LINEAR vs. NON-LINEAR CORRELATION

LINEAR

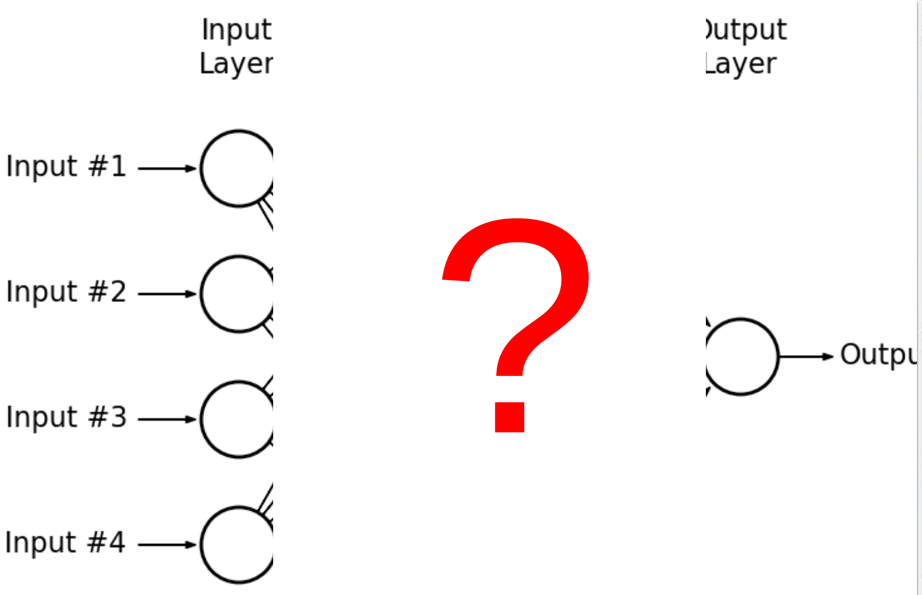


NON-LINEAR

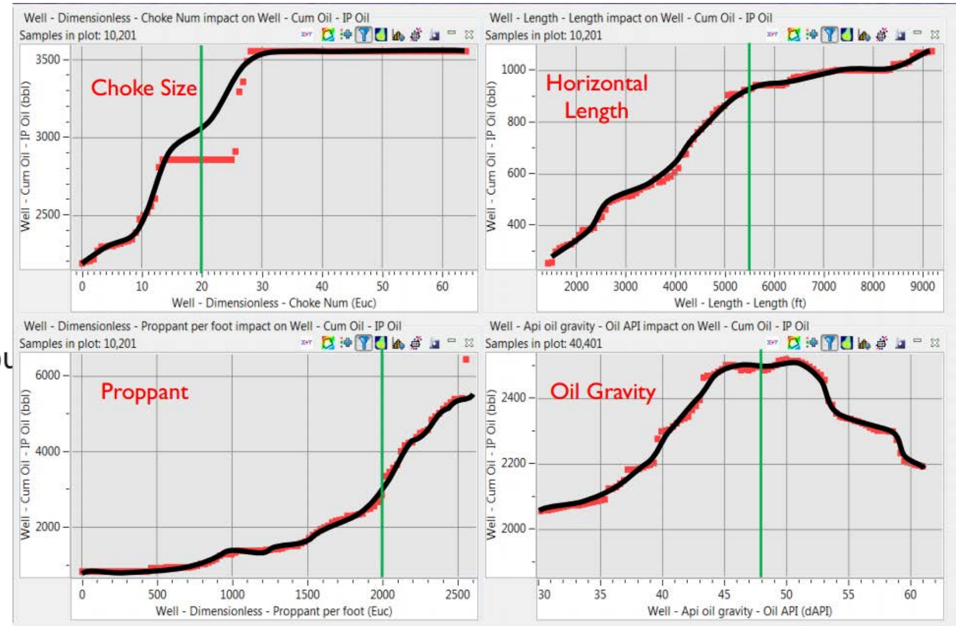


ANN vs. Non-Linear Regressions

ANN



Non-Linear Regression Modeling



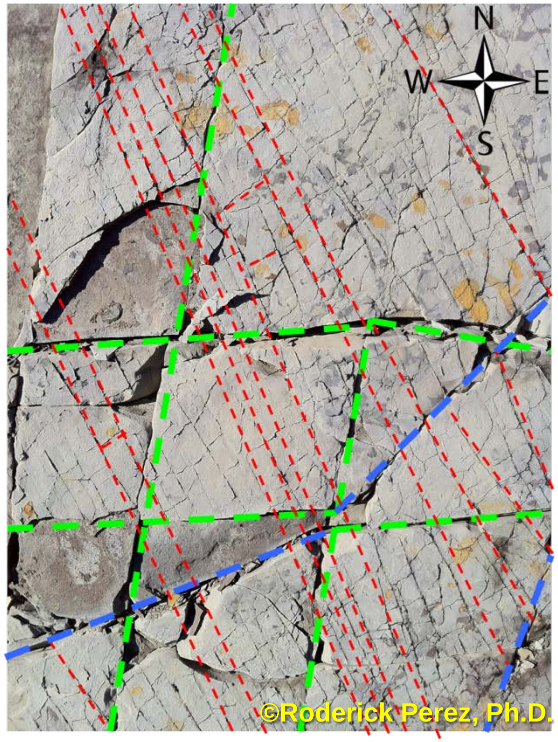
From Murray Roth - An Analytic Approach to Sweetspot Mapping in the Eagle Ford Unconventional Play

https://www.transformsw.com/wp-content/uploads/2013/05/An-Analytic-Approach-to-Sweetspot-Mapping-in-the-Eagle-Ford-Unconventional-Play-2013-Geoconvention-Roth-Roth-Peebles.pdf

drillinginfo
better, faster decisions

BRITTLENESS

OBJECTIVE



The figure shows the low permeability oil-saturated Woodford Shale, and relates the fracture size and length with a road speed limit, indicating that the higher the fracture size (the wider the road), the greater the permeability (or speed limit).

WOODFORD SHALE

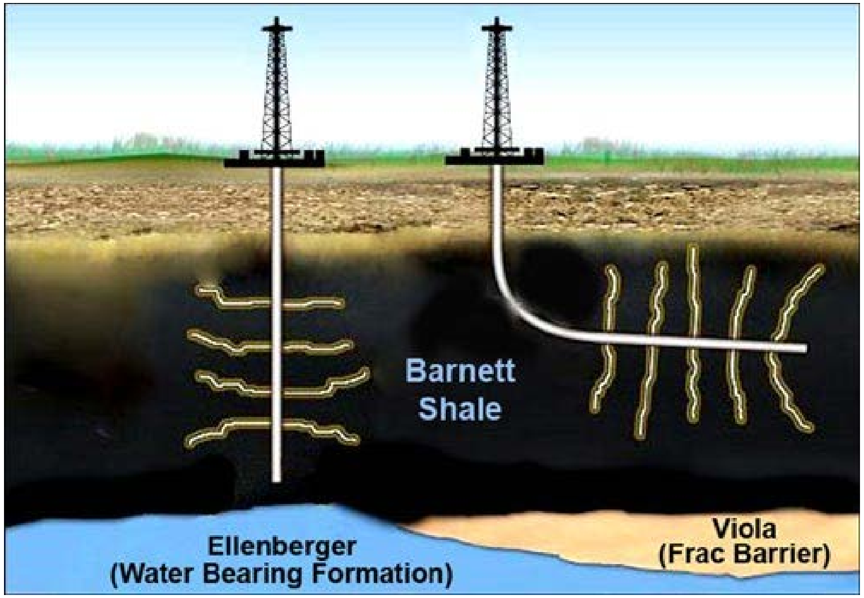
Location: Ardmore, OK

Fracture set A

Fracture set B

Fracture set C

0 1 2 3 4 inches



Due to the low permeability, it is necessary apply enhanced recovery techniques, such as hydraulic fracture stimulation or steam injection to extract the gas molecules from the rock matrix and achieve gas production.

Finding areas in the shale play that are "**brittle**" is important in the development of a fracture fairway large enough to connect the highest amount of "**rock volume**" during the **hydraulic – fracturing process**.

drillinginfo
better, faster decisions

WHAT IS BRITTLENESS?

BRITTLE

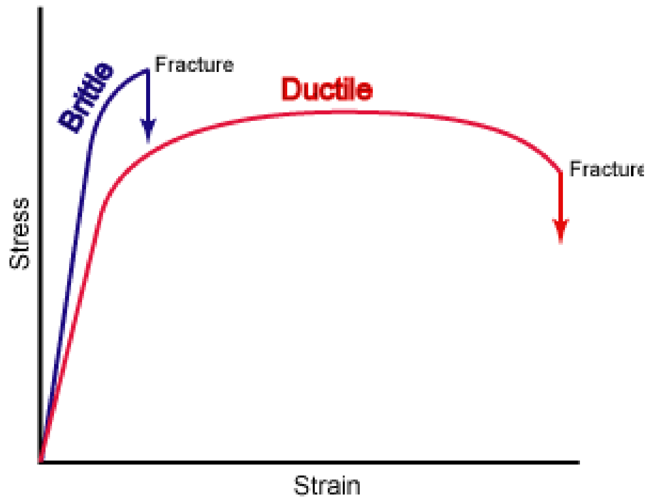
BRITTLENESS is the measurement of stored energy before failure, and is function of:

- Rock strength
- lithology
- texture
- effective stress
- temperature
- fluid type
- diagenesis
- TOC

BRITTLENESS INDEX (BI) is the most widely used parameter for the quantification of rock brittleness.

$$BI = \frac{\sigma_c}{\sigma_t}.$$

σ_c = Compressive strength
σ_t = Tensile strength



Higher the magnitude of the BI, the more brittle the rock is

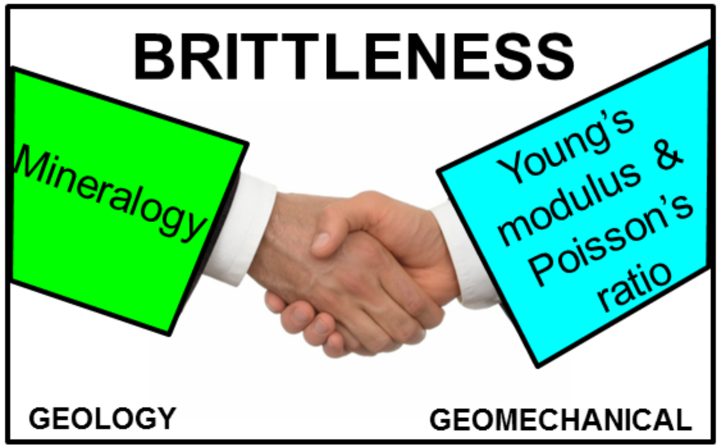
DUCTILE

HOW DO TO QUANTIFY BRITTLENESS???

MINERALOGY

$$BI_{Jarvie(2007)} = \frac{Qz}{Qz + Ca + Cly}$$

$$BI_{Wang(2009)} = \frac{Qz + Dol}{Qz + Dol + Ca + Cly + TOC}$$



ELASTIC PARAMETERS

$$E_{brittleness} = \frac{E - E_{min}}{E_{max} - E_{min}},$$

$$\nu_{brittleness} = \frac{\nu - \nu_{max}}{\nu_{min} - \nu_{max}},$$

$$Brittleness_{average} = \frac{(E_{brittleness} + \nu_{brittleness})}{2}.$$

BARNETT SHALE

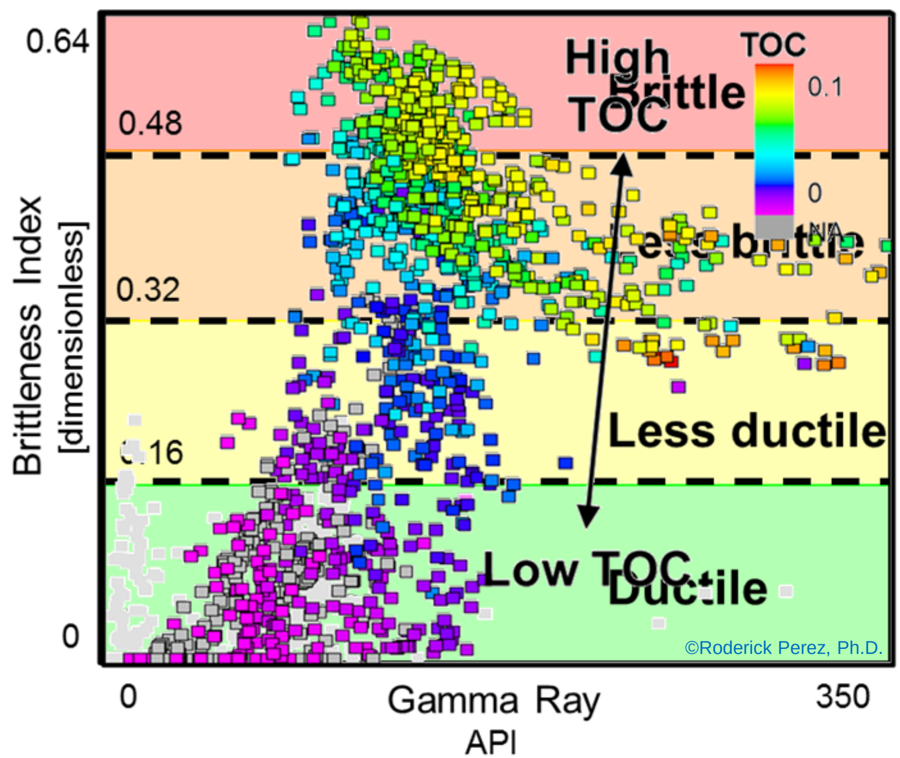
BRITTLENESS INDEX (Mineralogy)

LITHOFACIES	Average TOC (wt%)	Average silica (SiO_2) %
In situ phosphatic deposit	6	10 - 15
Siliceous, non calcareous mudstone	4.5	30
Siliceous, calcareous mudstone	3.5	-
Calcareous laminae	3.5	-
Micritic / limy mudstone	1.2	10
Reworked shelly deposit	2.6	2 - 10
Silty shelly (wavy) interlaminated deposit	-	20

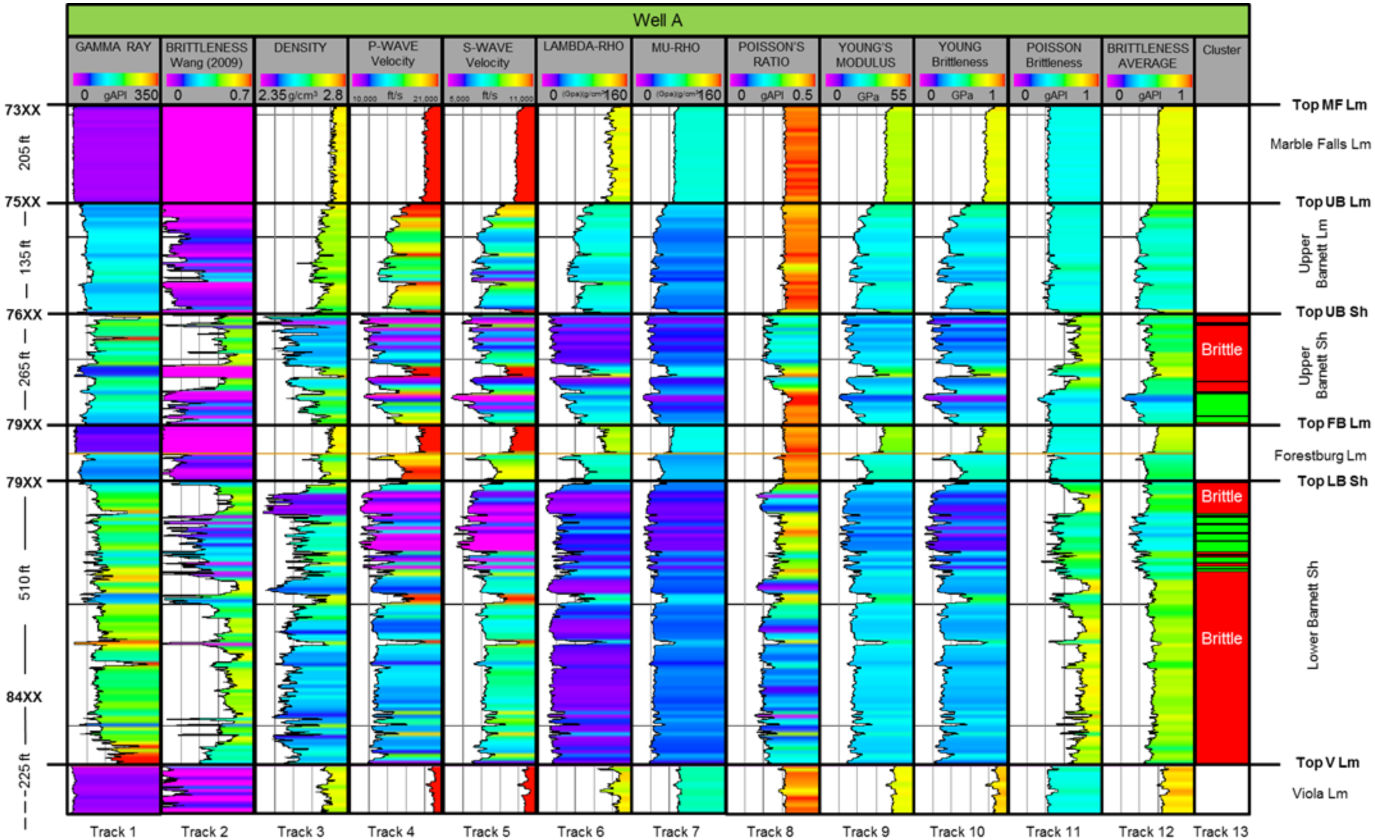
Increase in organic richness

Decrease in bottom water oxygen

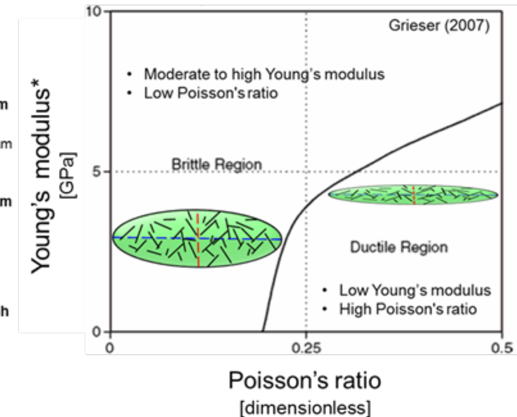
Singh (2008)



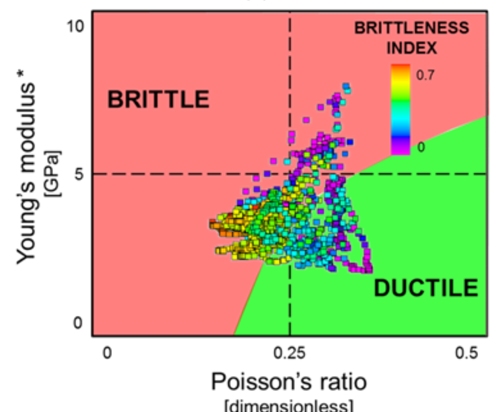
BRITTLENESS AVERAGE (Elastic parameters)



(a)



(b)

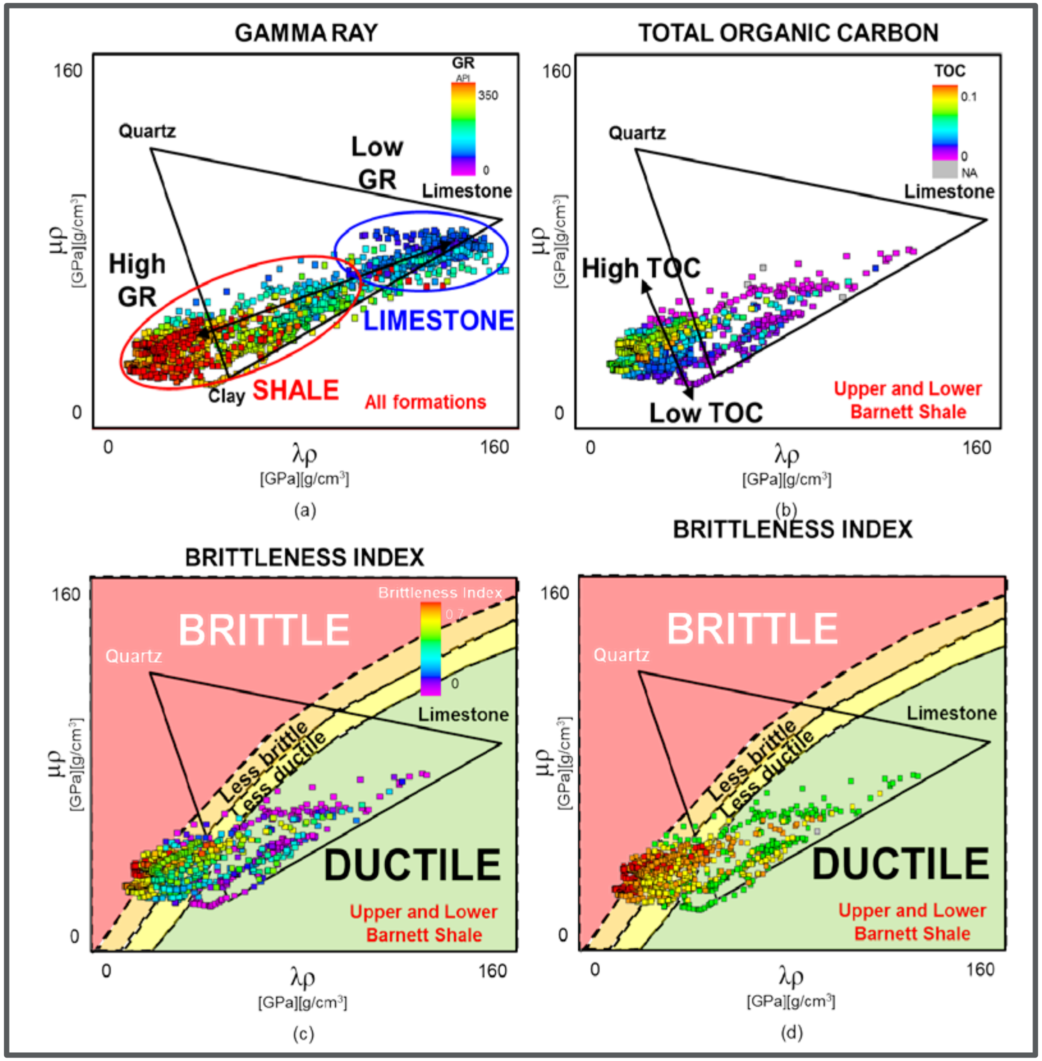


(c)

$$E_{brittleness} = \frac{E - E_{min}}{E_{max} - E_{min}}, \qquad \nu_{brittleness} = \frac{\nu - \nu_{max}}{\nu_{min} - \nu_{max}}, \qquad Brittleness_{average} = \frac{(E_{brittleness} + \nu_{brittleness})}{2}.$$

drillinginfo
better, faster decisions

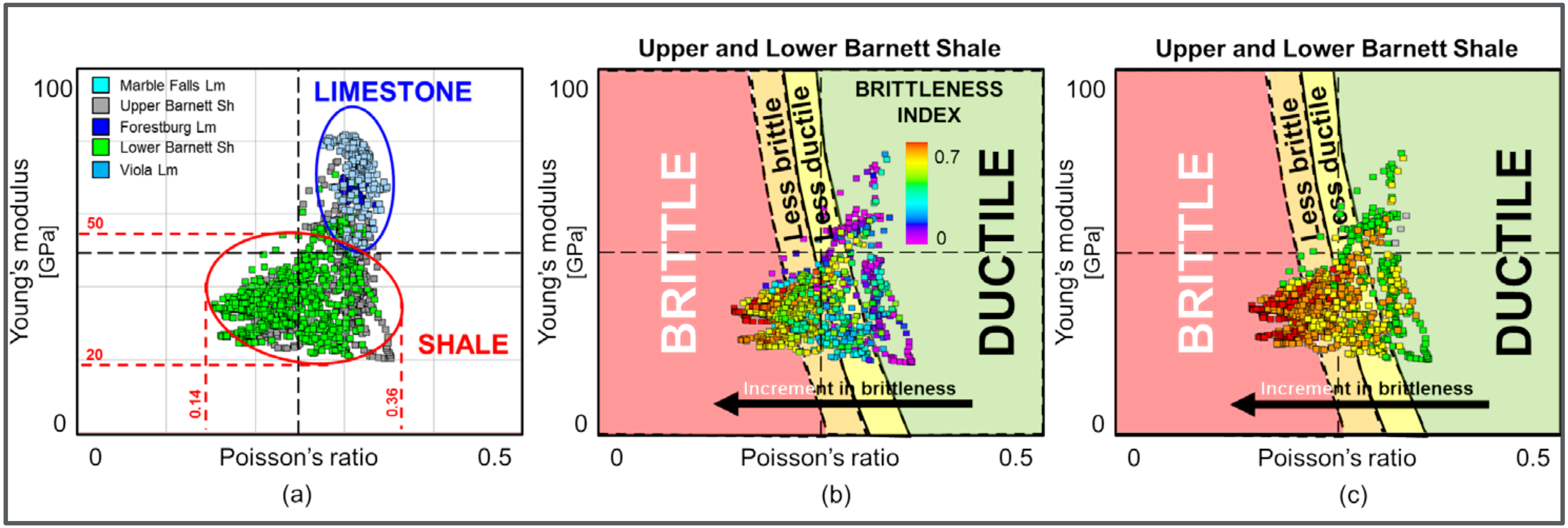
CALIBRATION GEOLOGIC AND GEOMECHANICAL PARAMTERS



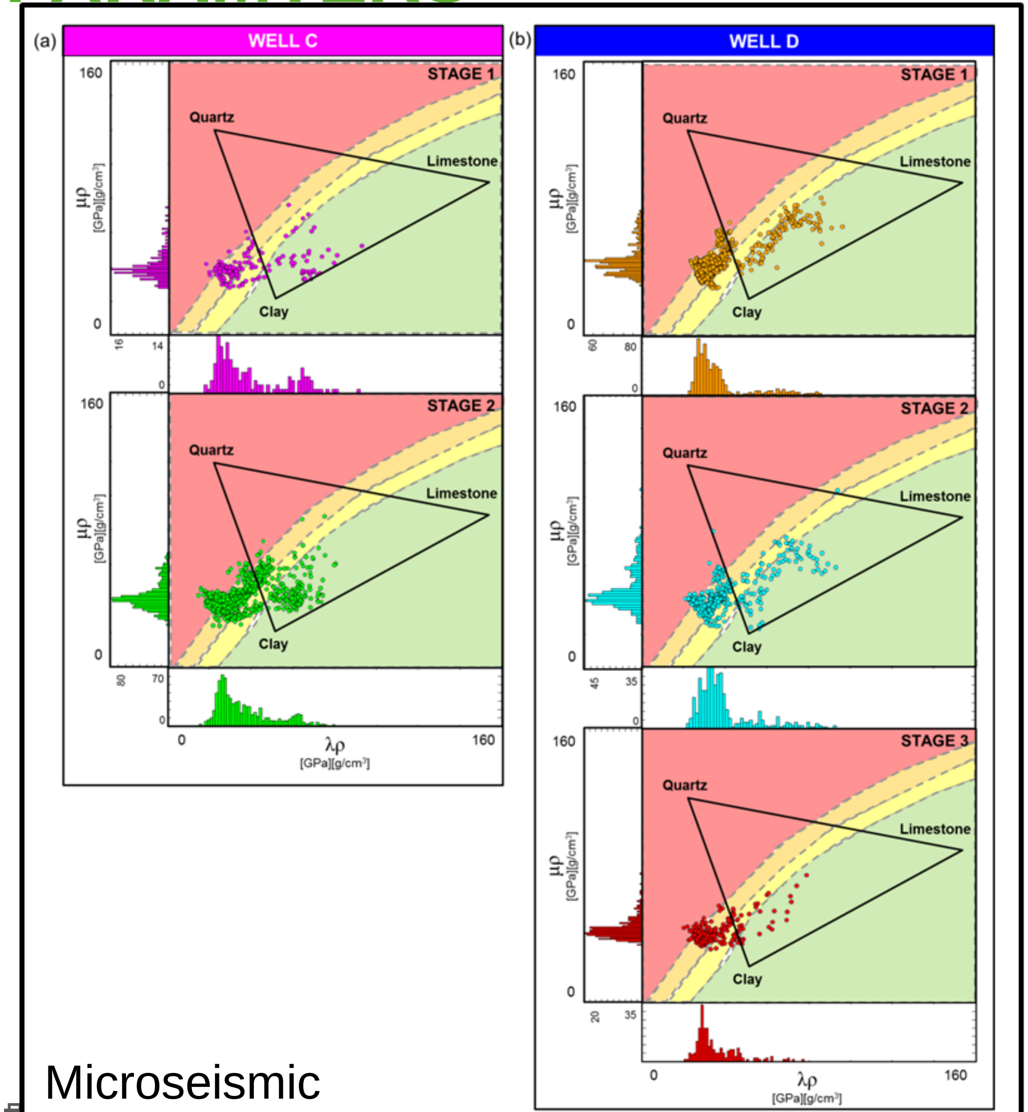
Well log

- Perez, 2013, Brittleness estimation from seismic measurements in Unconventional reservoirs: Application to the Barnett Shale: Ph.D. Dissertation, The University of Oklahoma.
- Perez, R. and K. Marfurt, 2014, Mineralogy-Based Brittleness Prediction from Surface Seismic Data: Application to the Barnett Shale (Manuscript ID: INT-2013-0161)

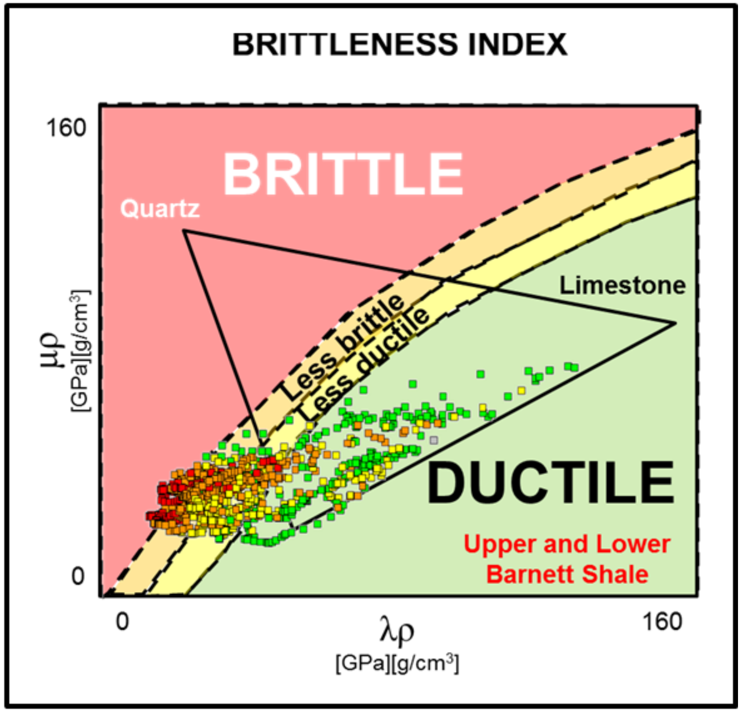
CALIBRATION OF BRITTLENESS TO ELASTIC ROCK PROPERTIES VIA MINERALOGY LOGS



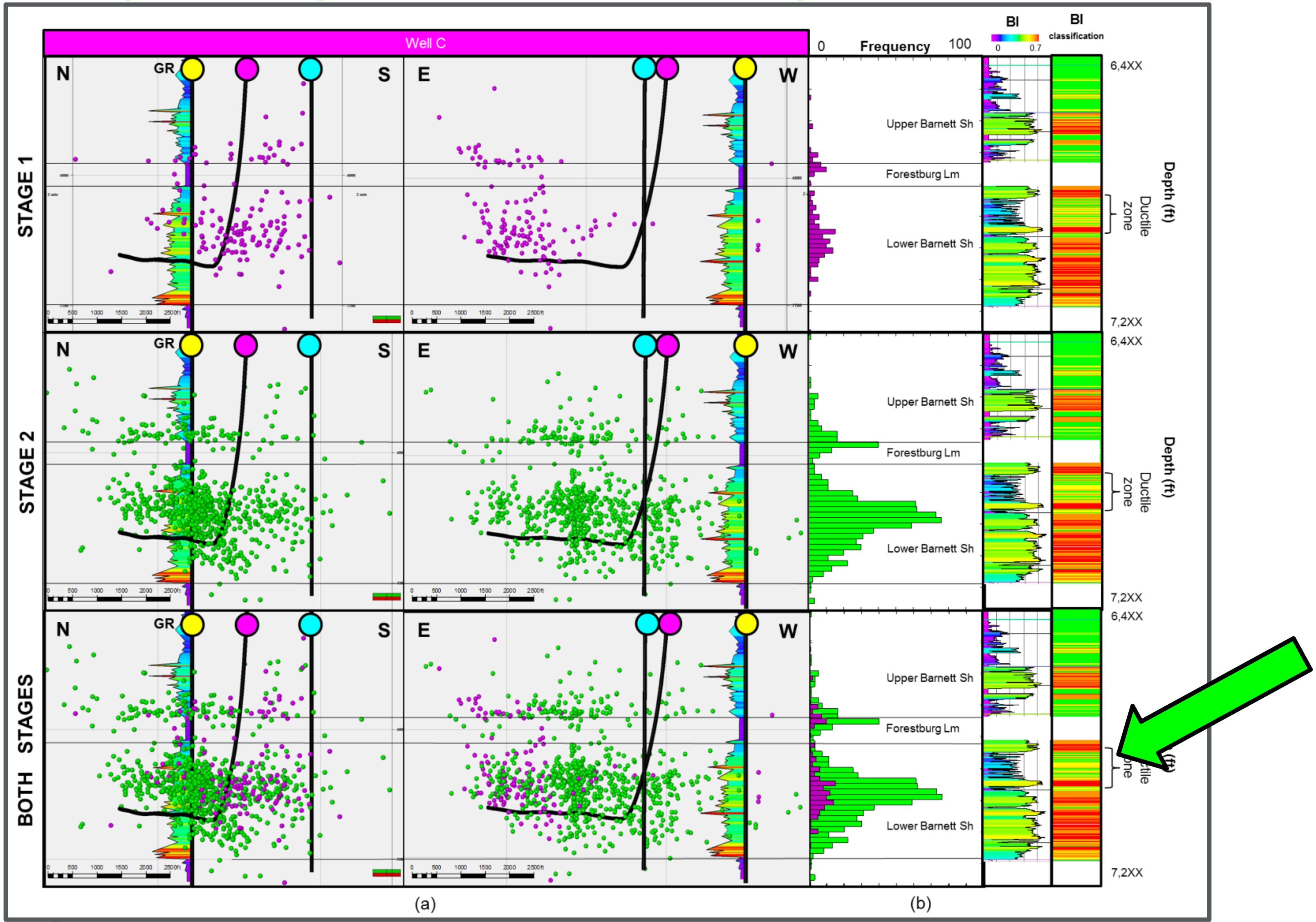
CALIBRATION GEOLOGIC AND GEOMECHANICAL PARAMTERS



Microseismic

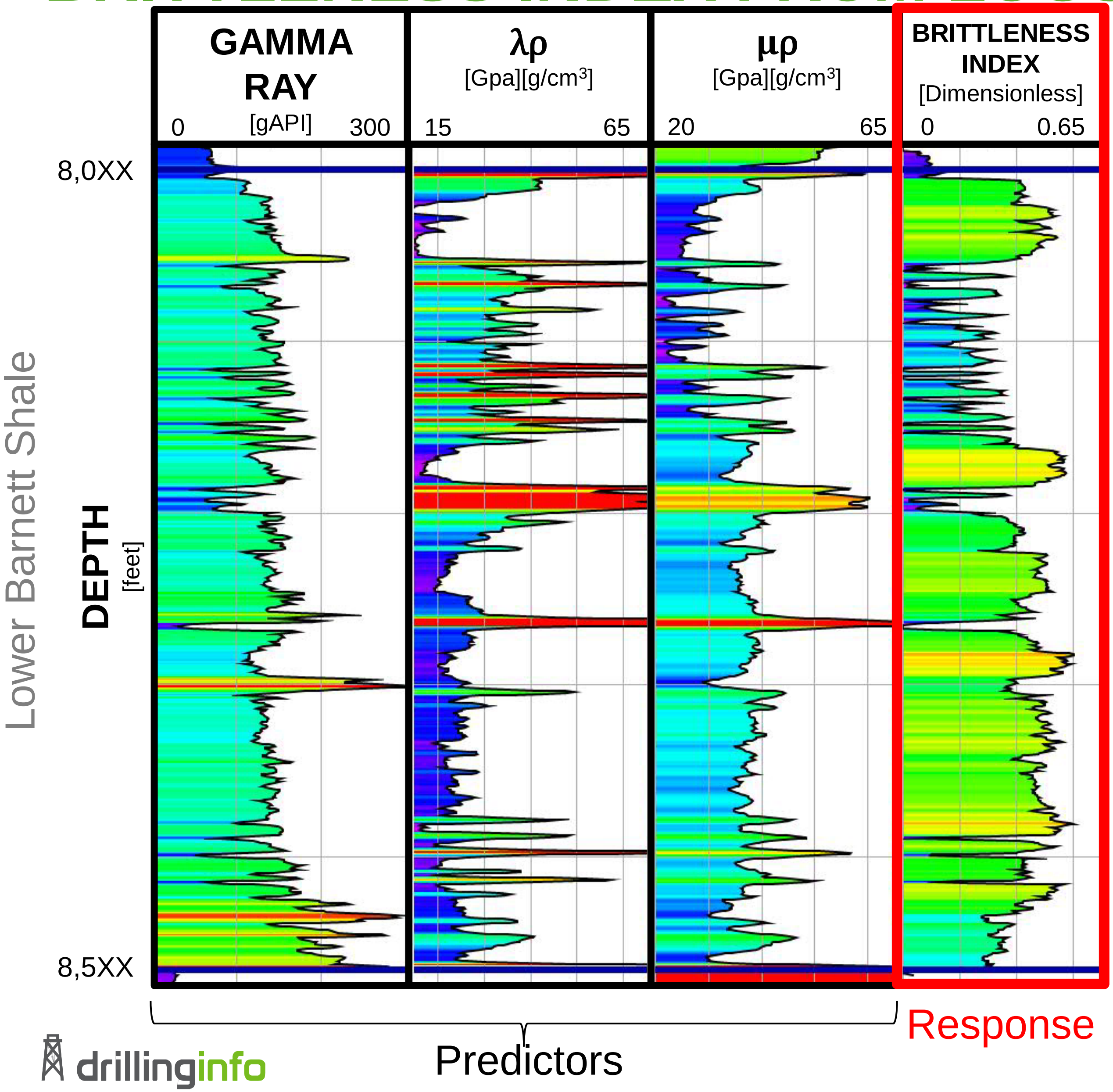


CALIBRATION GEOLOGIC AND GEOMECHANICAL PARAMTERS



STATISTICAL ANALYSIS

BRITTLENESS INDEX FROM LOGS



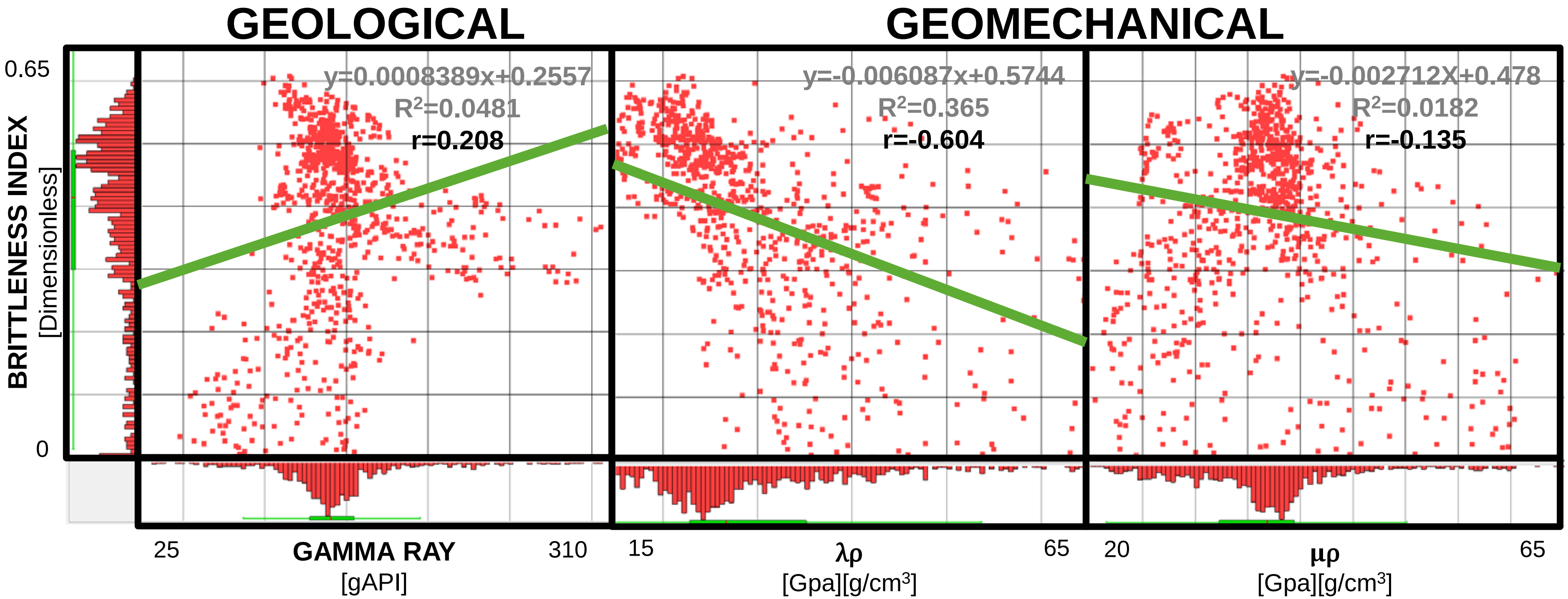
$$f_{BI}(\lambda\rho, \mu\rho, GR)$$

Brittleness Index:

$$BI_{Wang(2009)} = \frac{Qz + Dol}{Qz + Dol + Ca + Cly + TOC}$$

drillinginfo
better, faster decisions

LINEAR CORRELATION



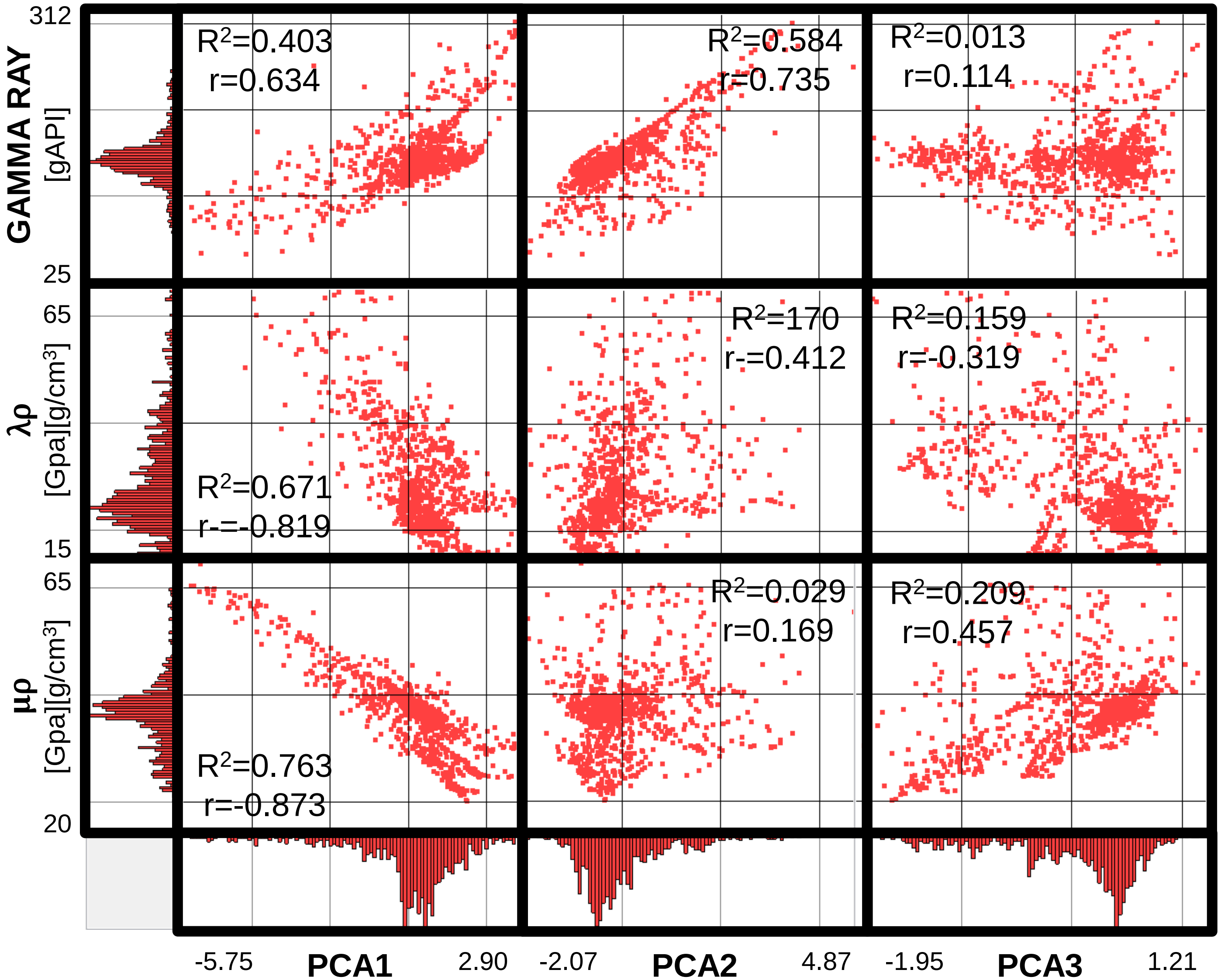
	Brittlene...	GR (Gam...	Lambda_...	Mu_Rho ...
Brittleness_...	1.0	0.208	-0.604	-0.135
GR (Gamm...	0.208	1.0	-0.259	-0.343
Lambda_R...	-0.604	-0.259	1.0	0.603
Mu_Rho (P...	-0.135	-0.343	0.603	1.0

Correlation coefficient

	Brittlene...	GR (Gam...	Lambda_...	Mu_Rho ...
Brittleness_...	1.0	0.015	-0.732	-0.036
GR (Gamm...	0.015	1.0	-0.142	-0.34
Lambda_R...	-0.732	-0.142	1.0	0.419
Mu_Rho (P...	-0.036	-0.34	0.419	1.0

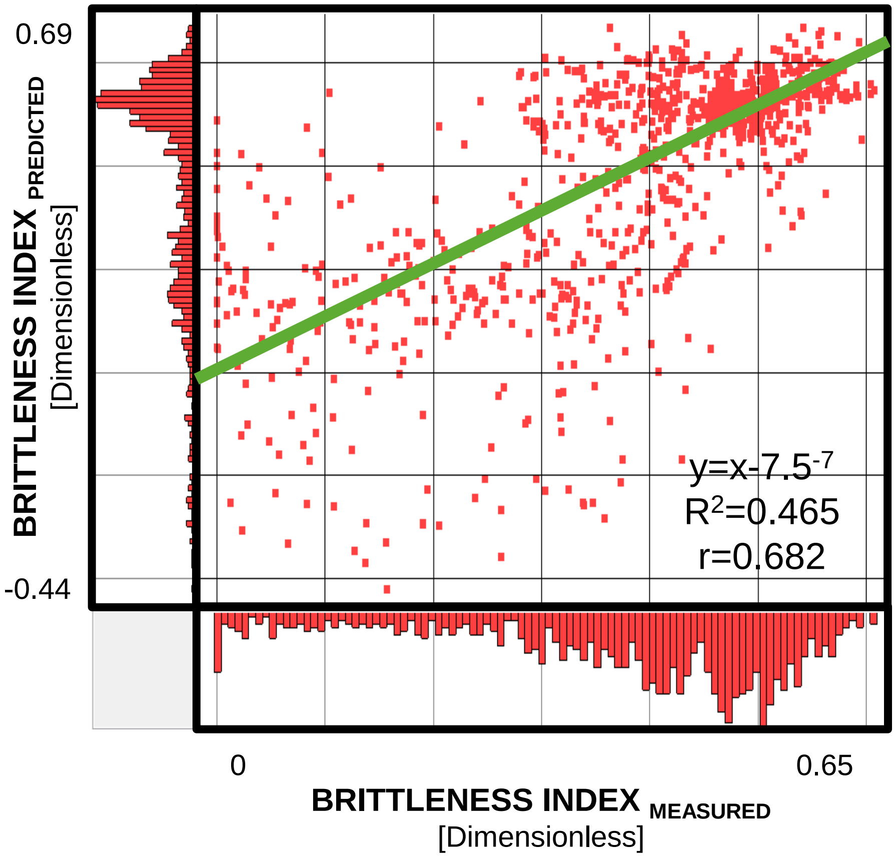
Rank

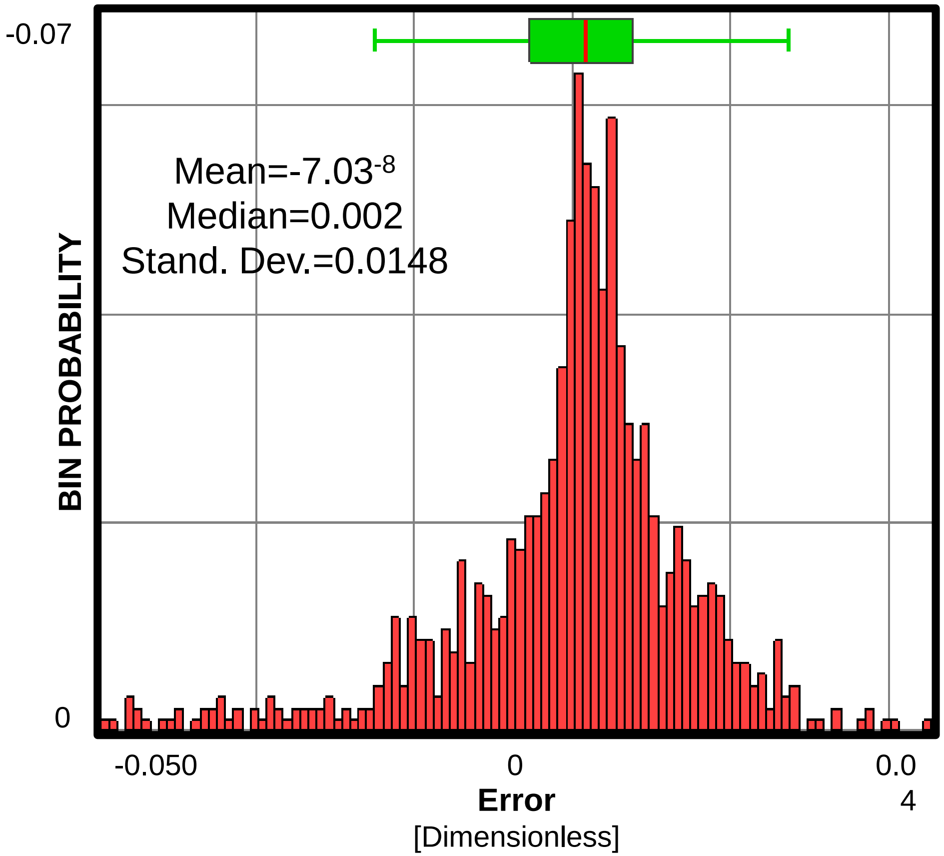
PRINCIPAL COMPONENT ANALYSIS



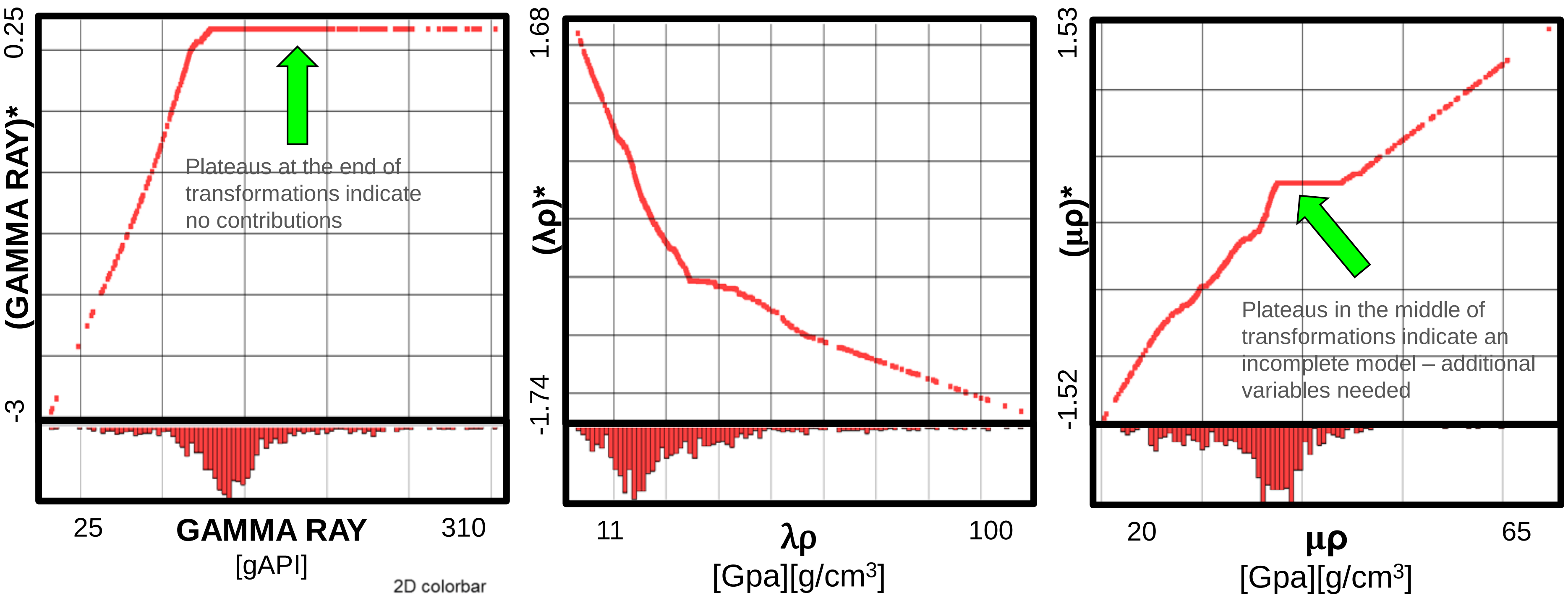
drillinginfo
better, faster decisions

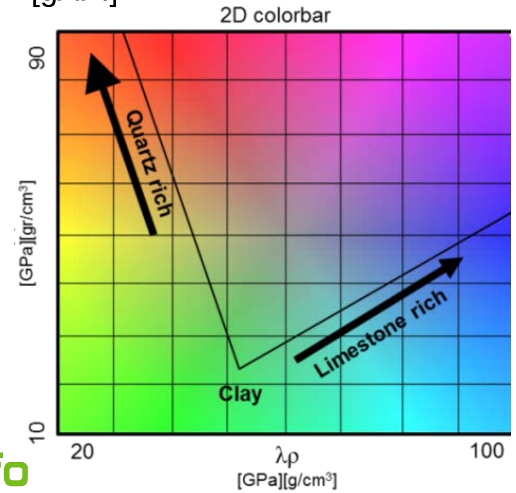
LINEAR REGRESSION RESULTS





NON-LINEAR REGRESSION RESULTS

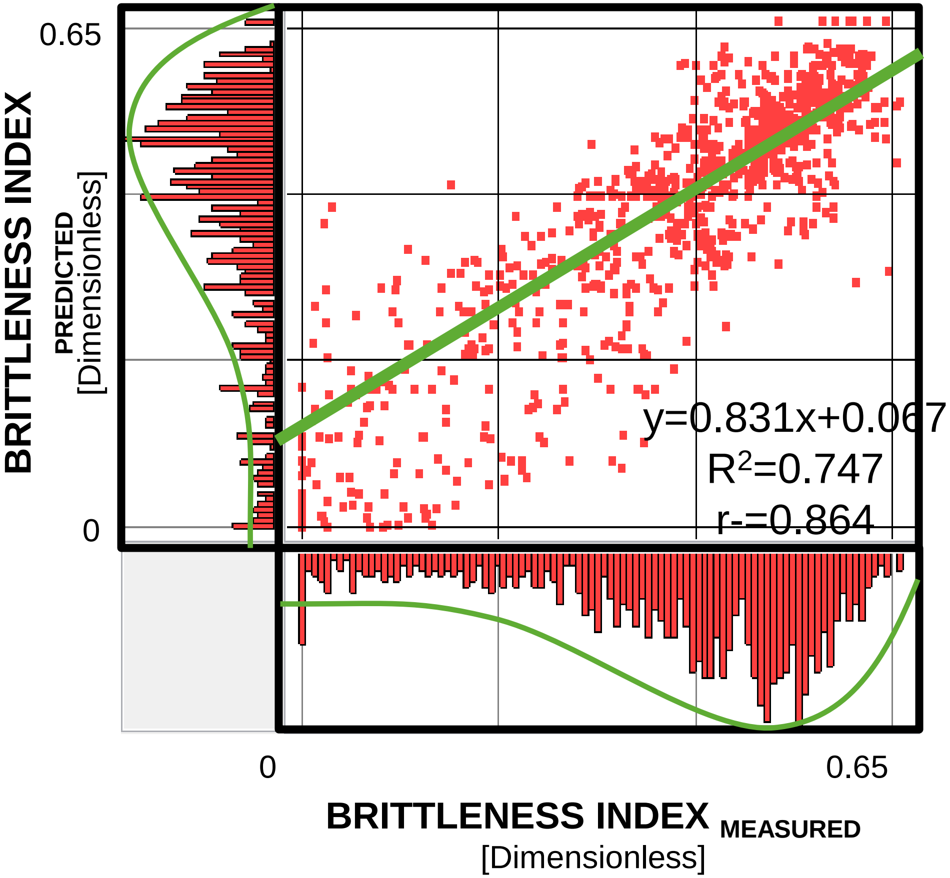


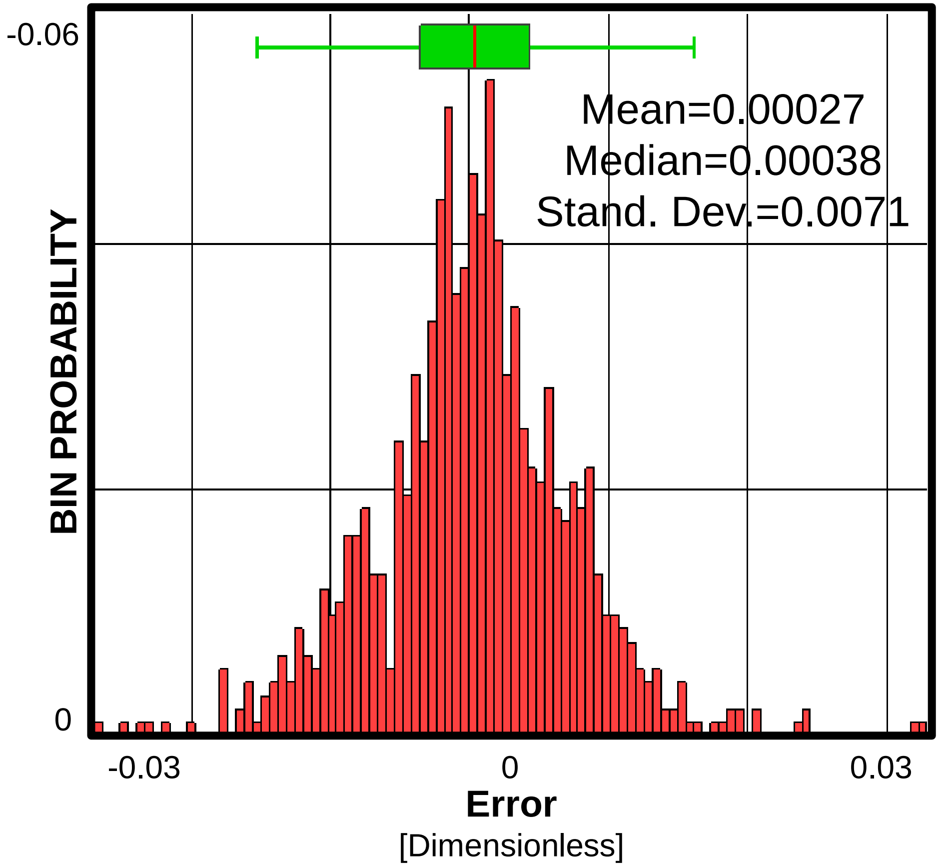


- Perez, R., 2013, Brittleness estimation from seismic measurements in unconventional reservoirs: Application to the Barnett Shale: Ph.D. Dissertation, The University of Oklahoma
- Perez. R., and K. Marfurt, 2014, Mineralogy-Based Brittleness Prediction from Surface Seismic Data: Application to the Barnett Shale: Interpretation (in press)

drillinginfo
better, faster decisions

NON-LINEAR REGRESSION RESULTS





SEISMIC PROCESSING

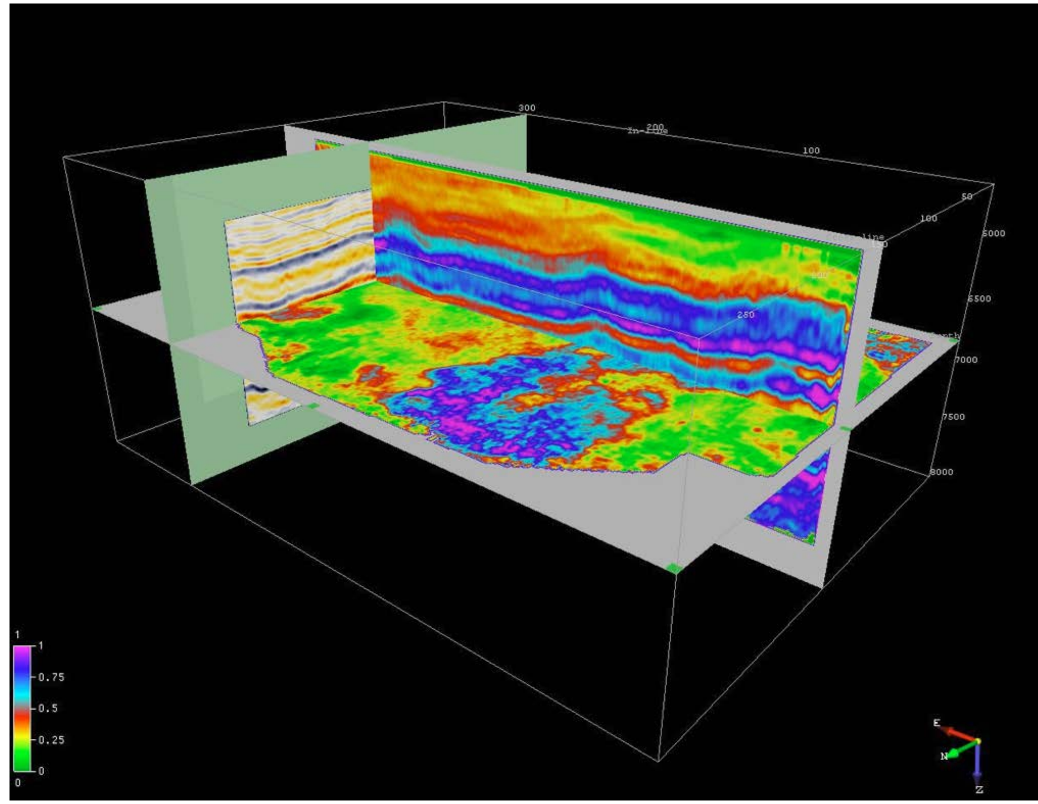
Angle Gathers

R_P reflectivity | R_S reflectivity

Z_P impedance | Z_S impedance

$\lambda\rho$ | $\mu\rho$

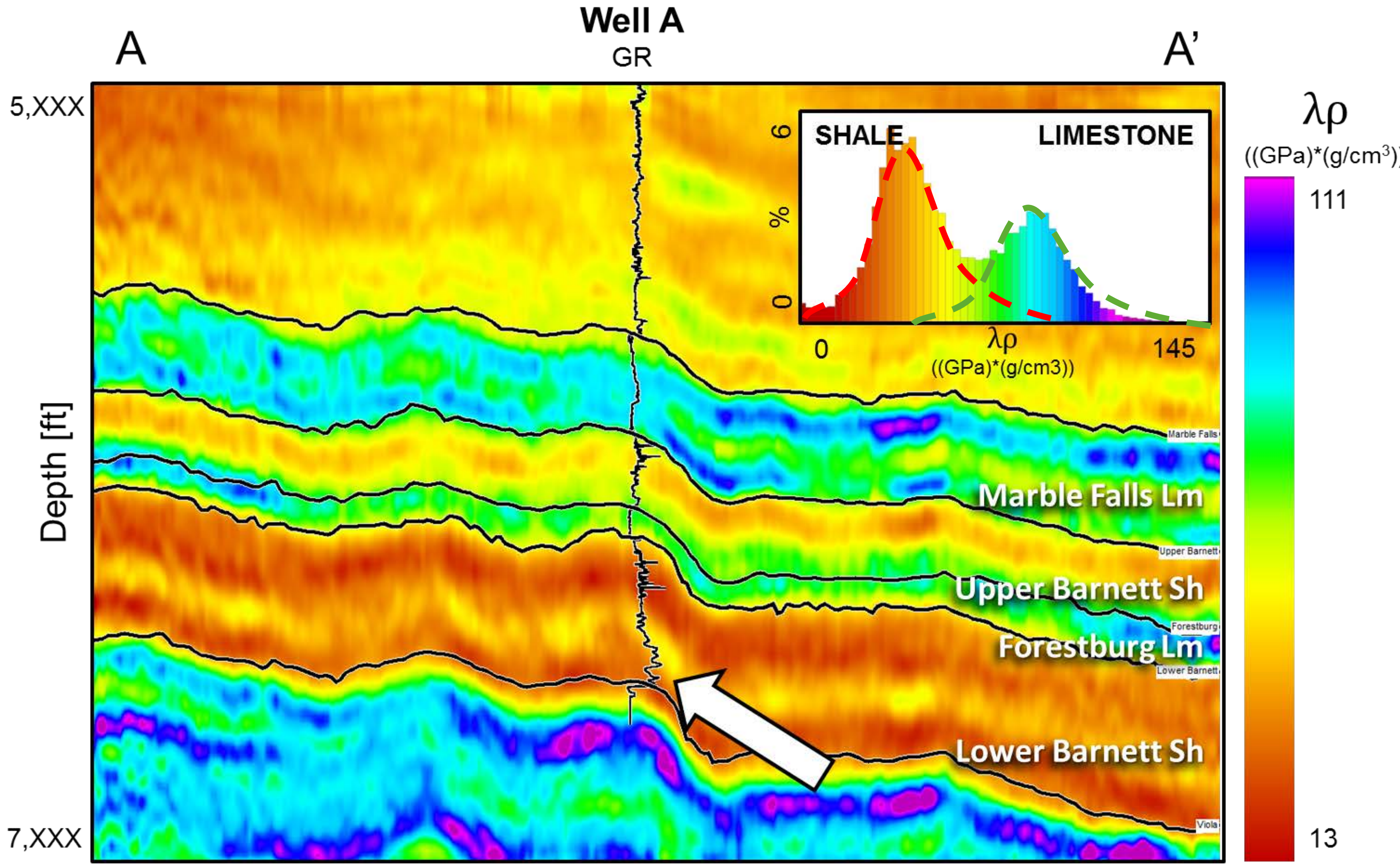
$\lambda\rho$ vs. $\mu\rho$ *crossplot*



$$\lambda\rho = (\rho V_P)^2 - 2(\rho V_S)^2. \qquad \mu\rho = (\rho V_S)^2$$

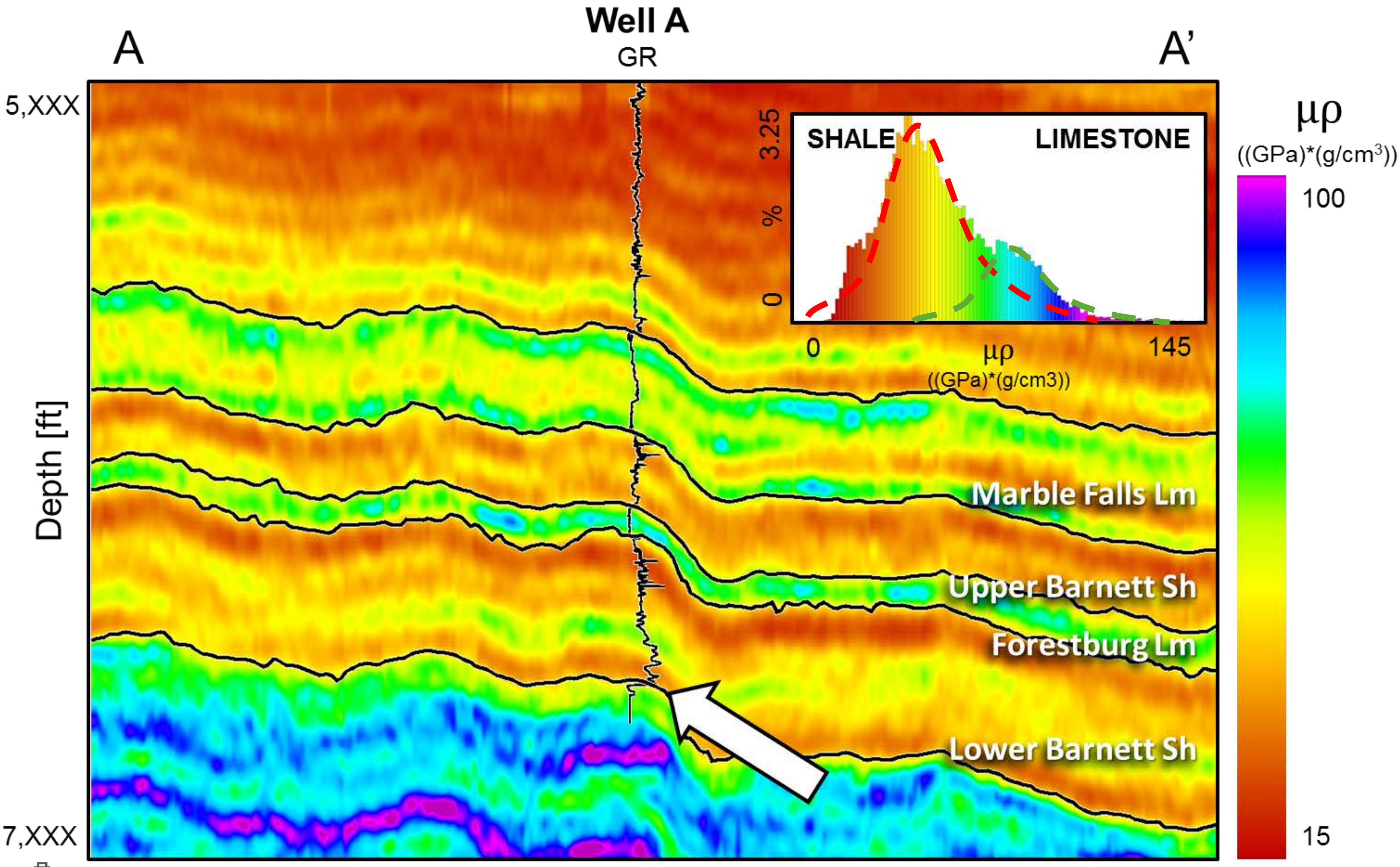
Goodway (2007)

SEISMIC ATTRIBUTES

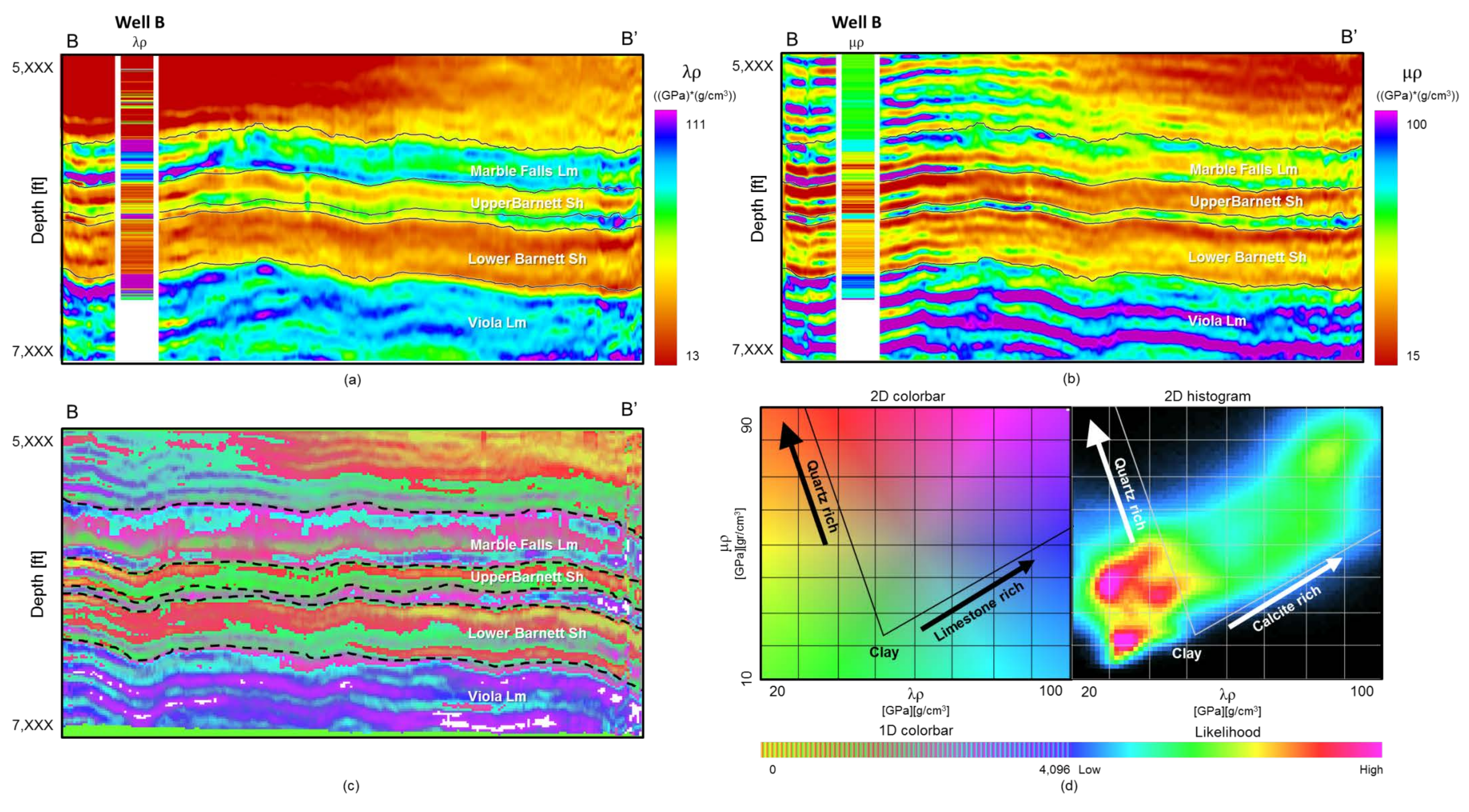


drillinginfo
better, faster decisions

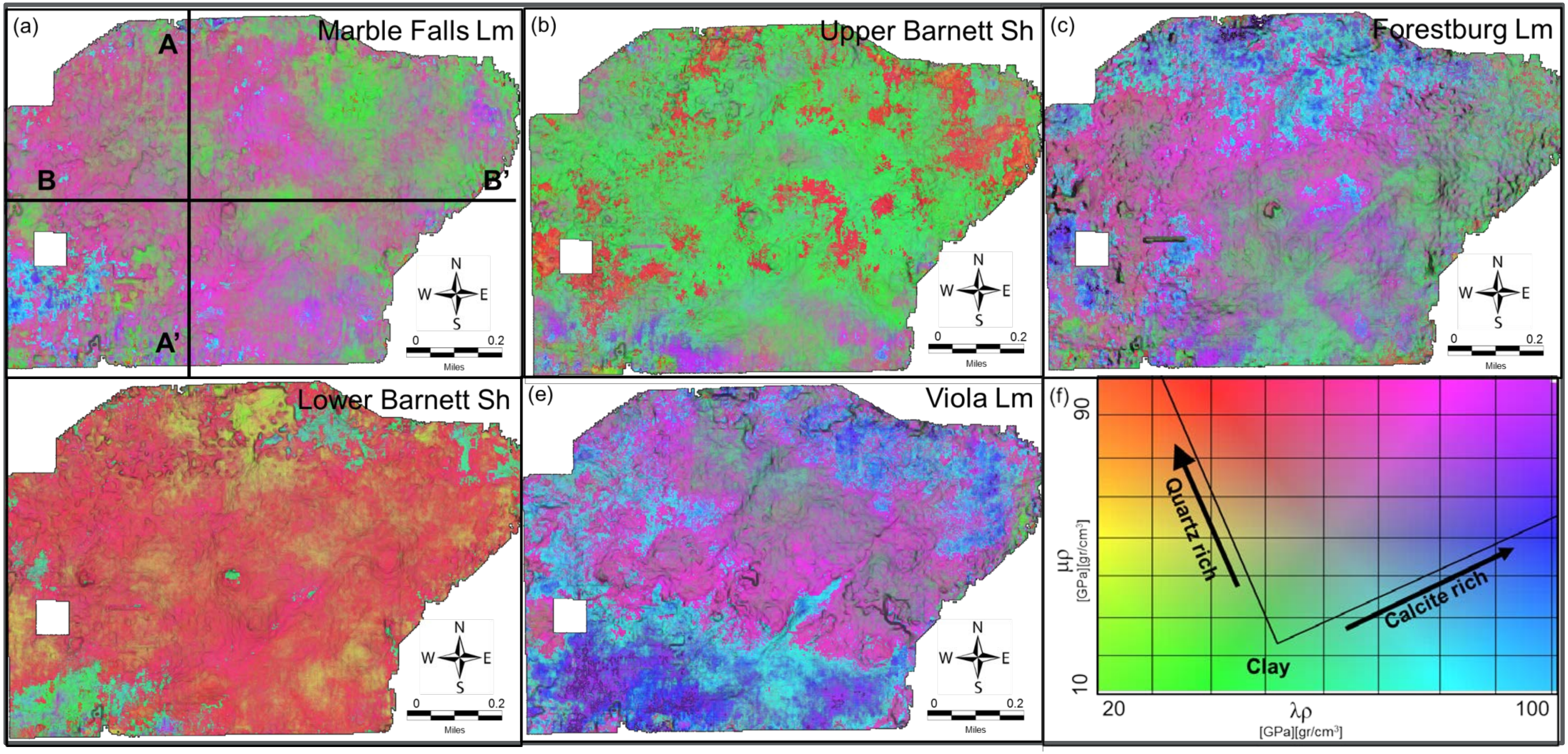
SEISMIC ATTRIBUTES



SEISMIC ATTRIBUTES – 2D colorbar visualization

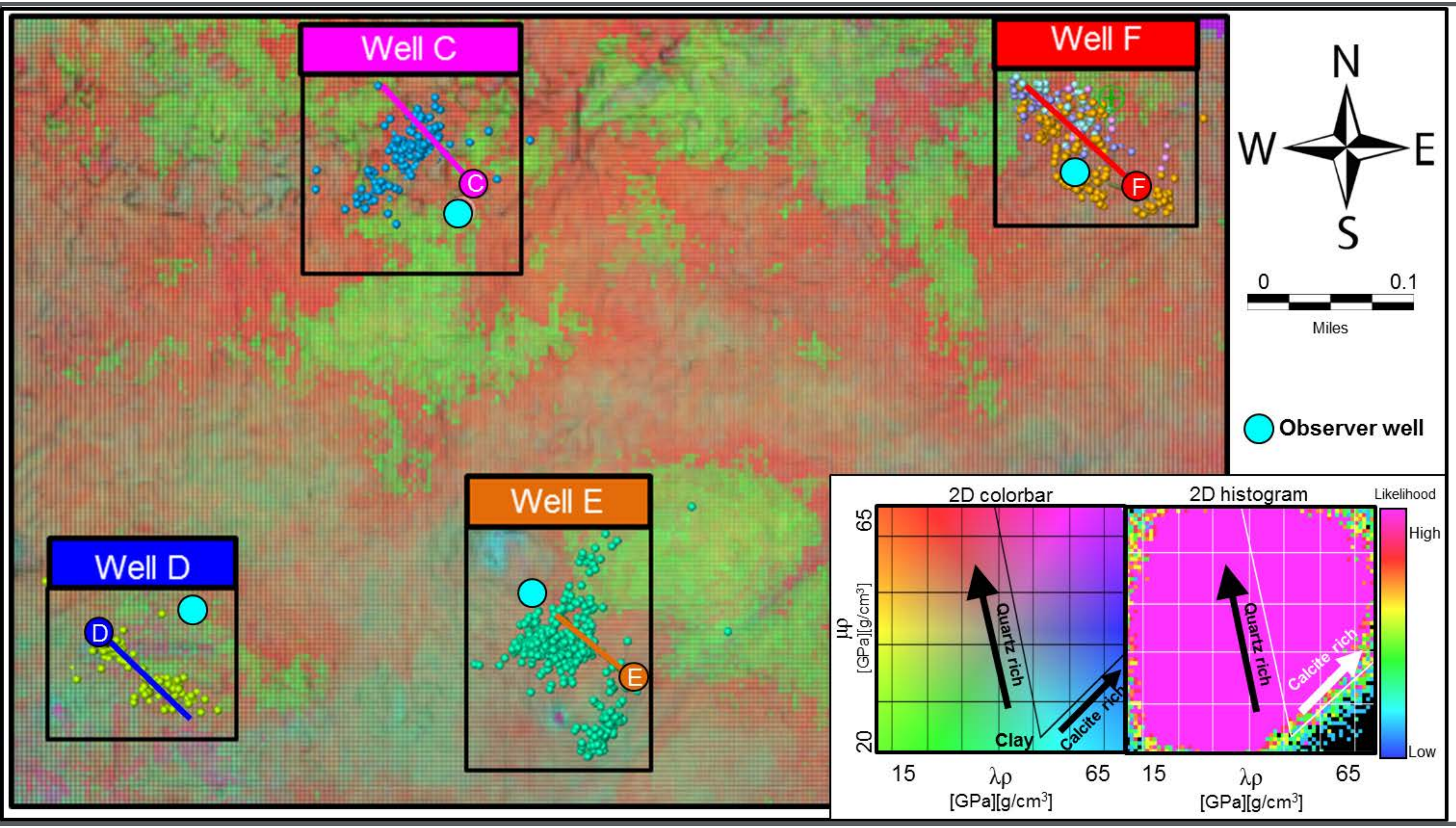


SEISMIC ATTRIBUTES – 2D colorbar visualization



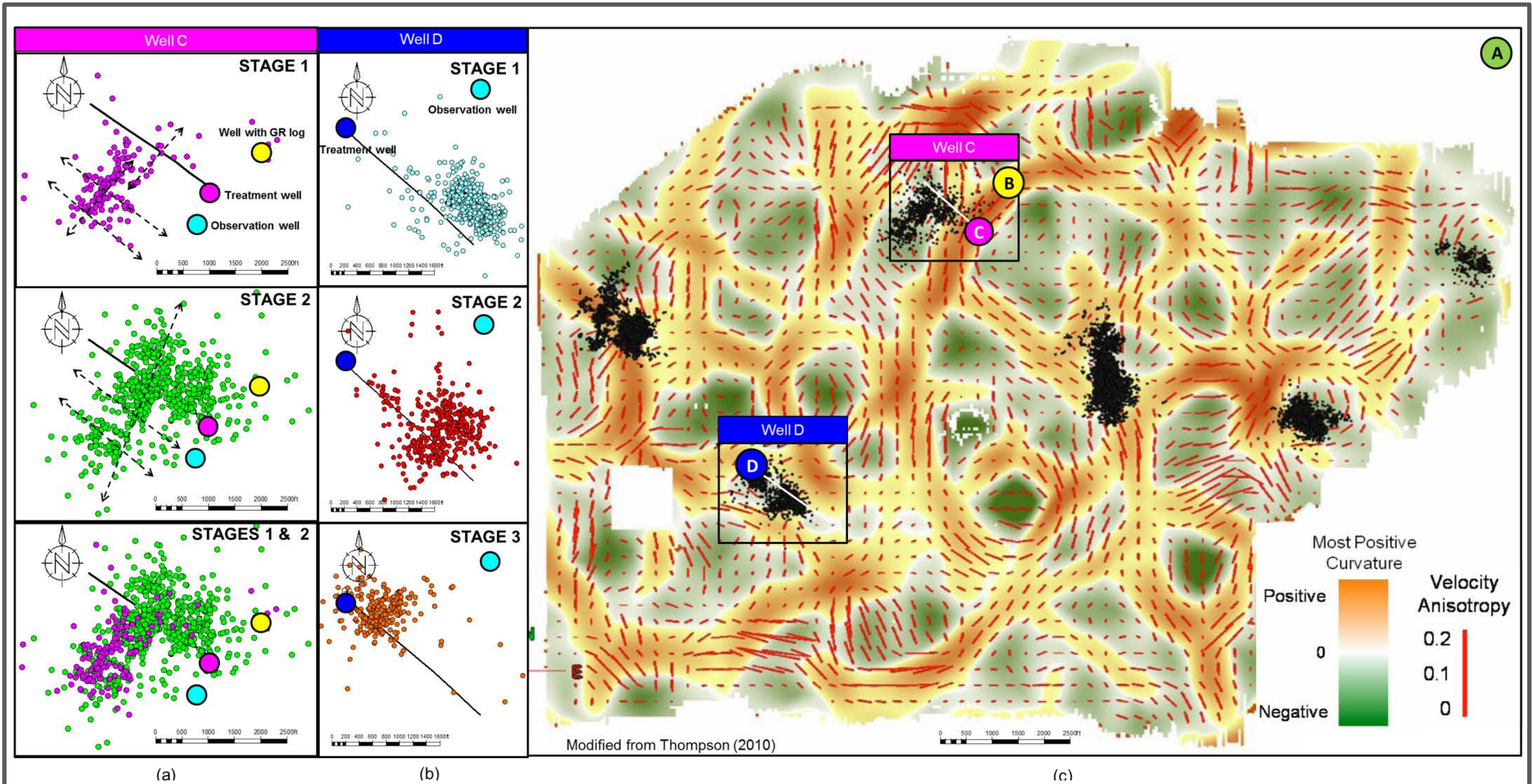
drillinginfo
better, faster decisions

SEISMIC ATTRIBUTES + Microseismic

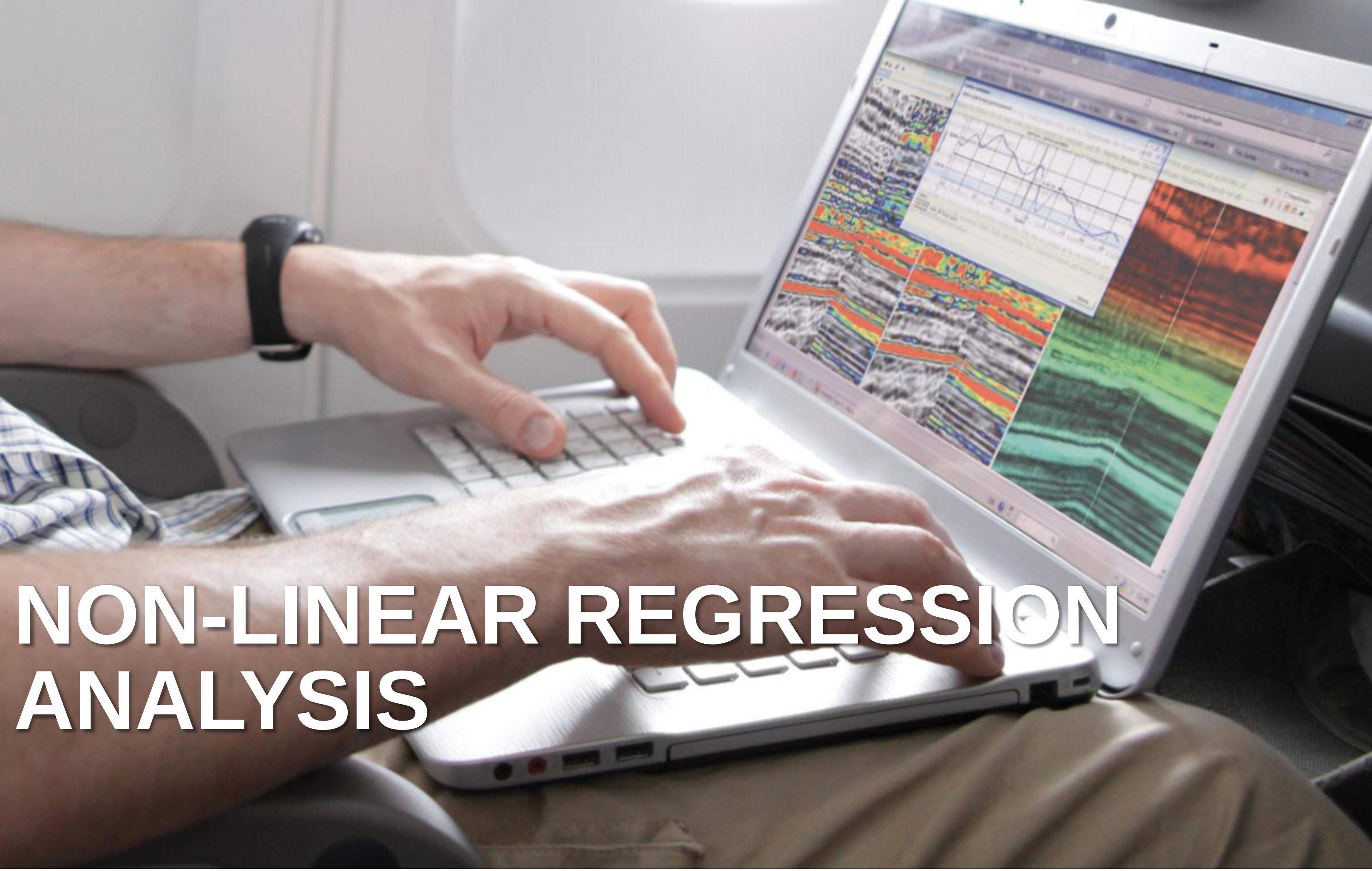


Microseismic events trend towards quartz rich areas, avoiding clay rich zones (green).

SEISMIC ATTRIBUTES + Microseismic

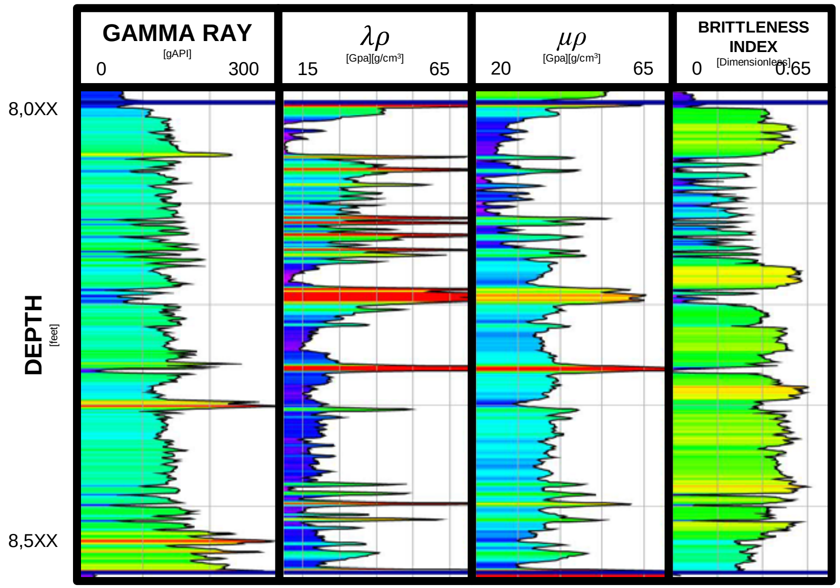


Microseismic events trend towards negative curvature values (green) avoiding the most positive curvature zones (orange) and follow the velocity anisotropy trend, previously described by Thompson (2010) and Browning (2006).

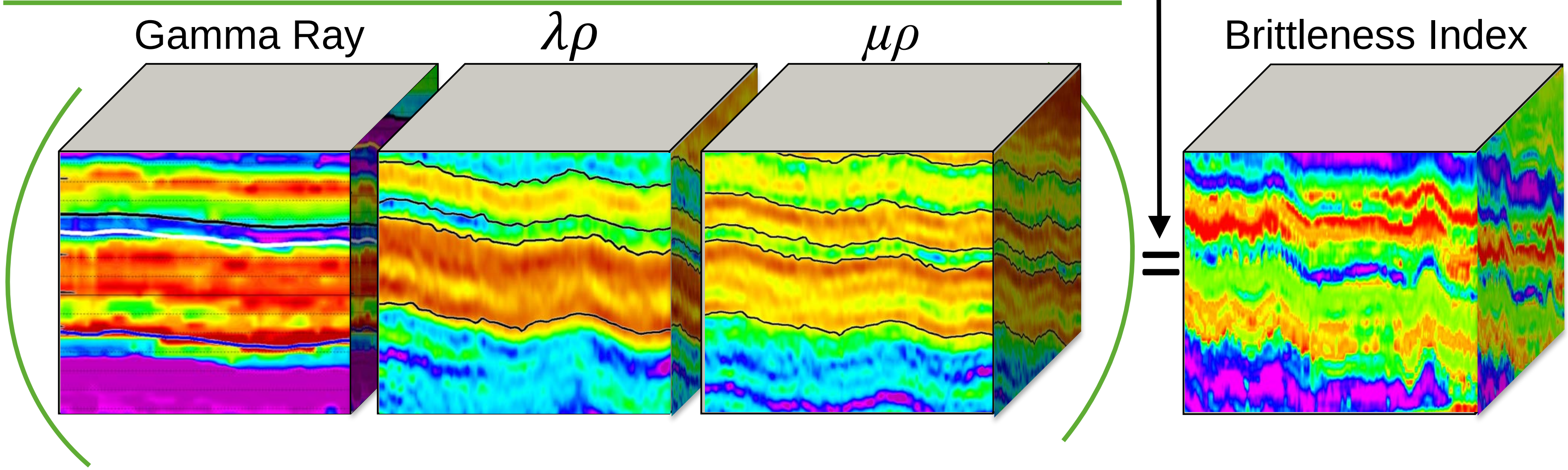


NON-LINEAR REGRESSION ANALYSIS

WORKFLOW SUMMARY

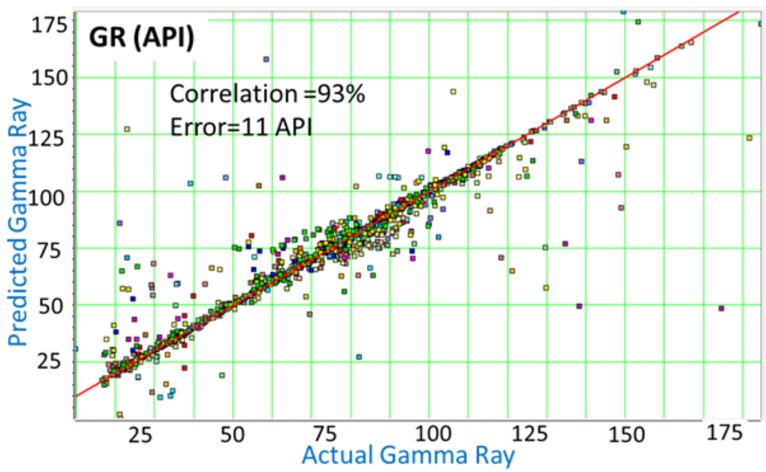


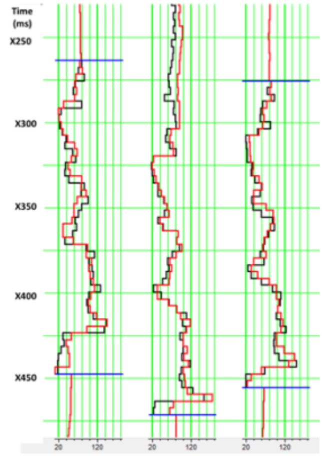
$$f_{BI}(\lambda\rho, \mu\rho, GR)$$



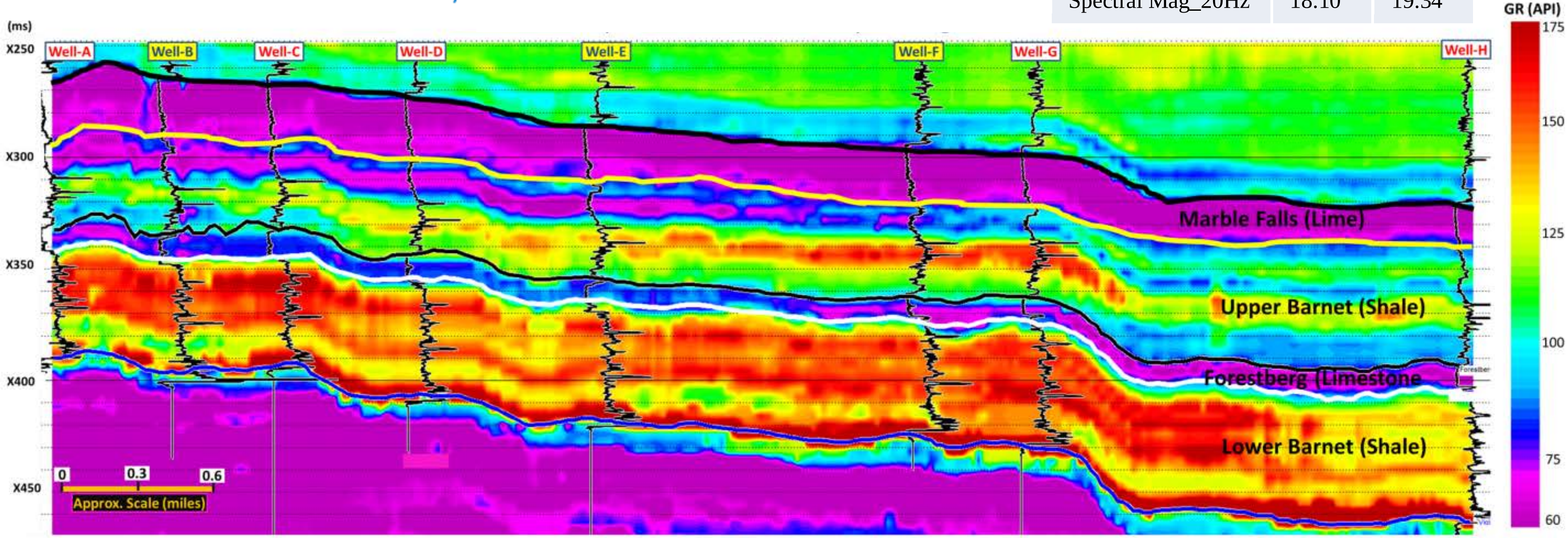
drillinginfo
better, faster decisions

GR SEISMIC VOLUME





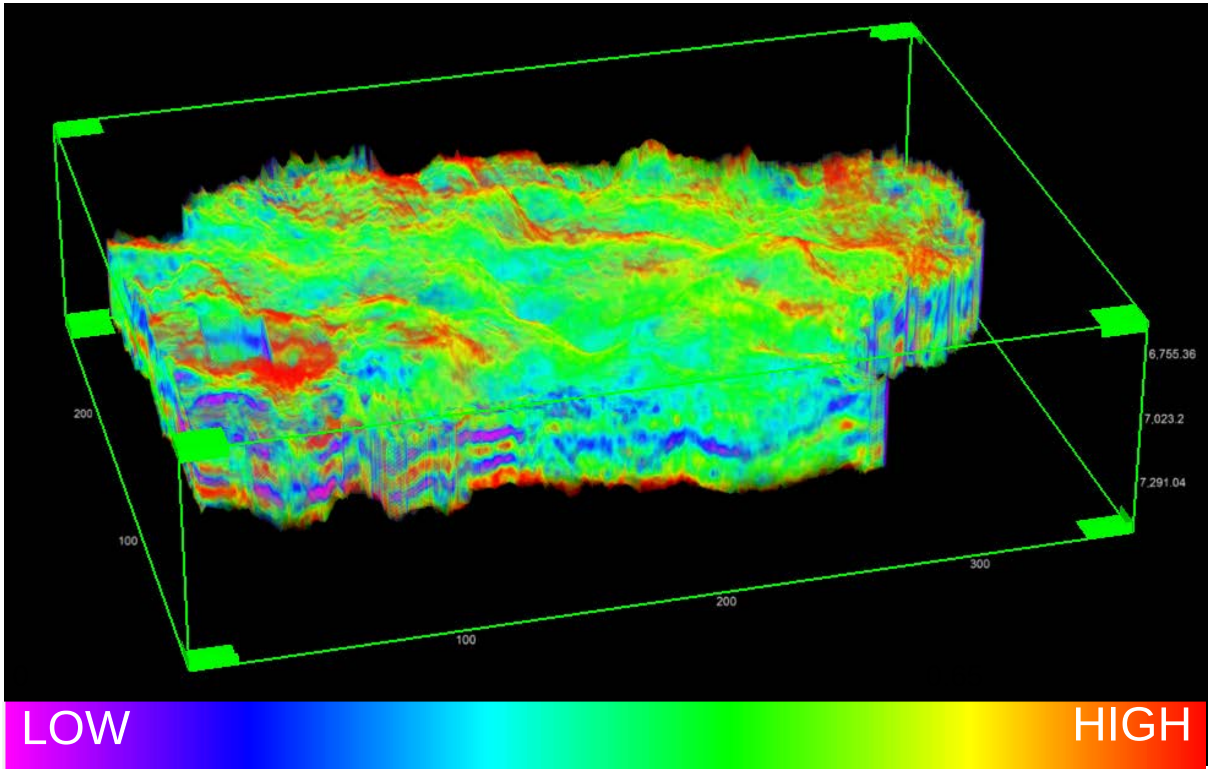
Final Attribute Operat. length: 9	Train. Error	Valid. Error
(Zp)**2	22.15	22.48
RAI	20.57	21.00
Sweetness	19.98	22.55
(Quadrature)**2	19.47	20.20
1/Zs	19.16	20.10
Vs/Vp	18.51	19.46
Coherent Energy	18.20	19.27
Spectral Mag_20Hz	18.10	19.34



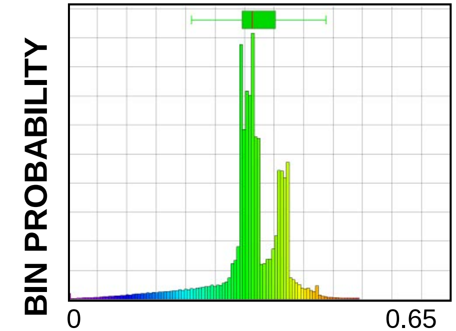
Verma, S., Roy, A., Perez, R., and Marfurt, Finding high frackability and high TOC zones in Barnet shale with supervised: Probabilistic Neural Network and unsupervised: multi-attribute Kohonen SOM, SEG Abstract, 2012.

drillinginfo
better, faster decisions

BRITTLENESS INDEX VOLUME

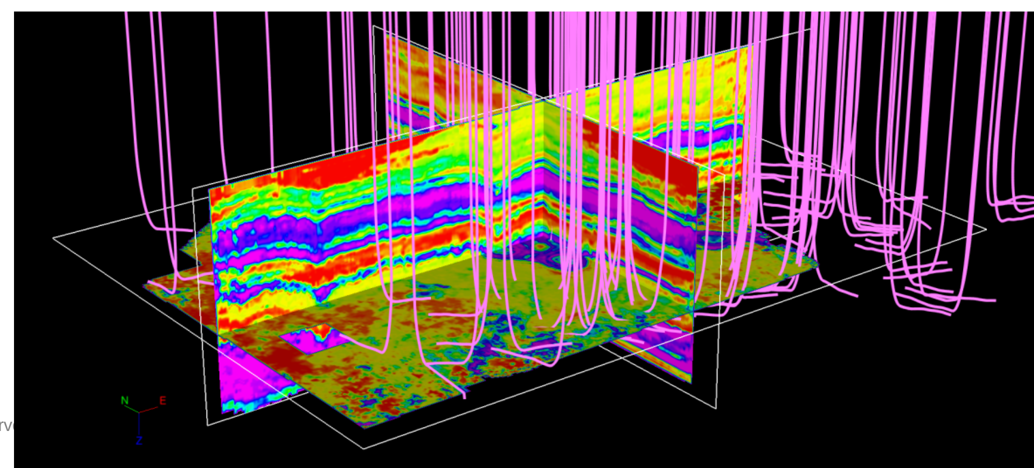


BRITTLENESS INDEX
[Dimensionless]



BRITTLENESS INDEX
[Dimensionless]

Num Points	1823034
Minimum	0.00
Maximum	0.494
Mean	0.310
Mean Absolute	0.310
Median	0.313
Std Deviation	0.0636
Skewness	-1.67
Kurtosis	4.67
25th %	0.296
75th %	0.353



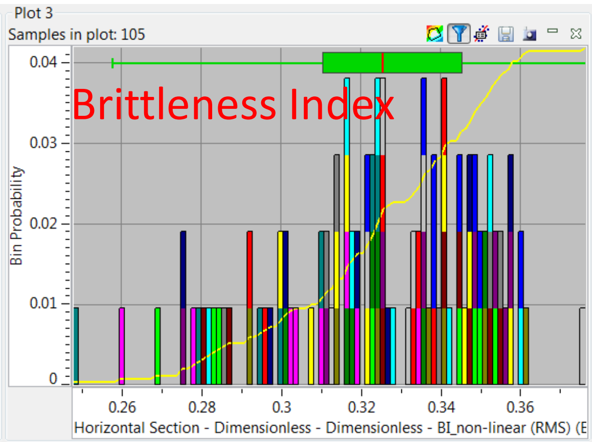
drillinginfo
better, faster decisions

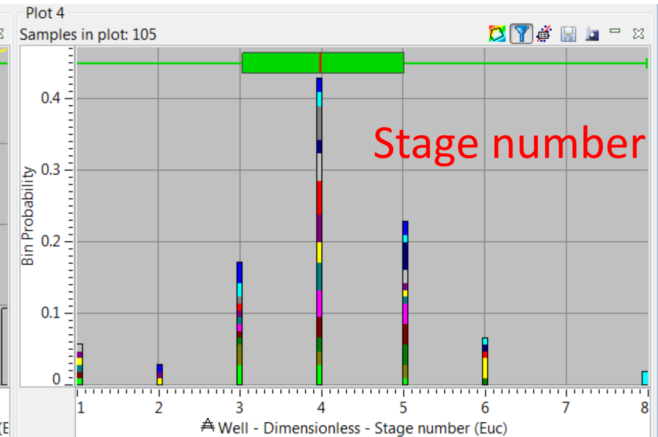
BRITTLENESS INDEX VOLUME + ENGINEERING VARIABLES

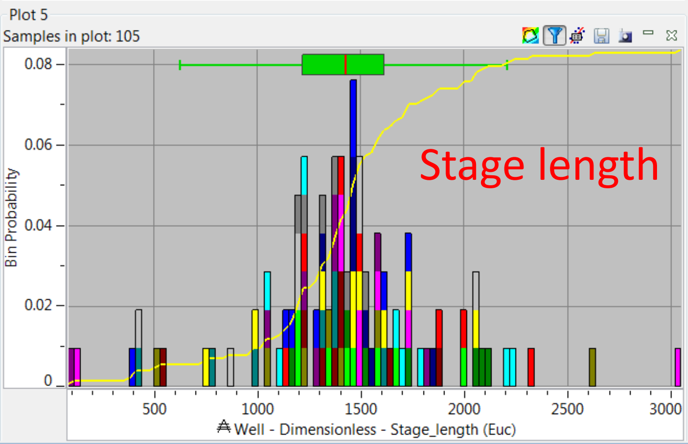
Plot 2

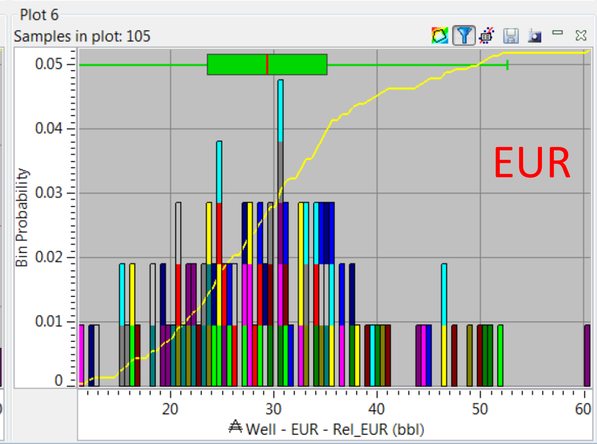
Data Correlations (44)

	Well - Dim...	Well - Dim...	Well - Dim...	Well - EUR...	Horizontal ...
Well - Dimen...	1.0	0.297	-0.7	-0.001	-0.02
Well - Dimen...	0.297	1.0	0.394	0.281	-0.389
Well - Dimen...	-0.7	0.394	1.0	0.145	-0.207
Well - EUR - ...	-0.001	0.281	0.145	1.0	0.06
Horizontal Se...	-0.02	-0.389	-0.207	0.06	1.0



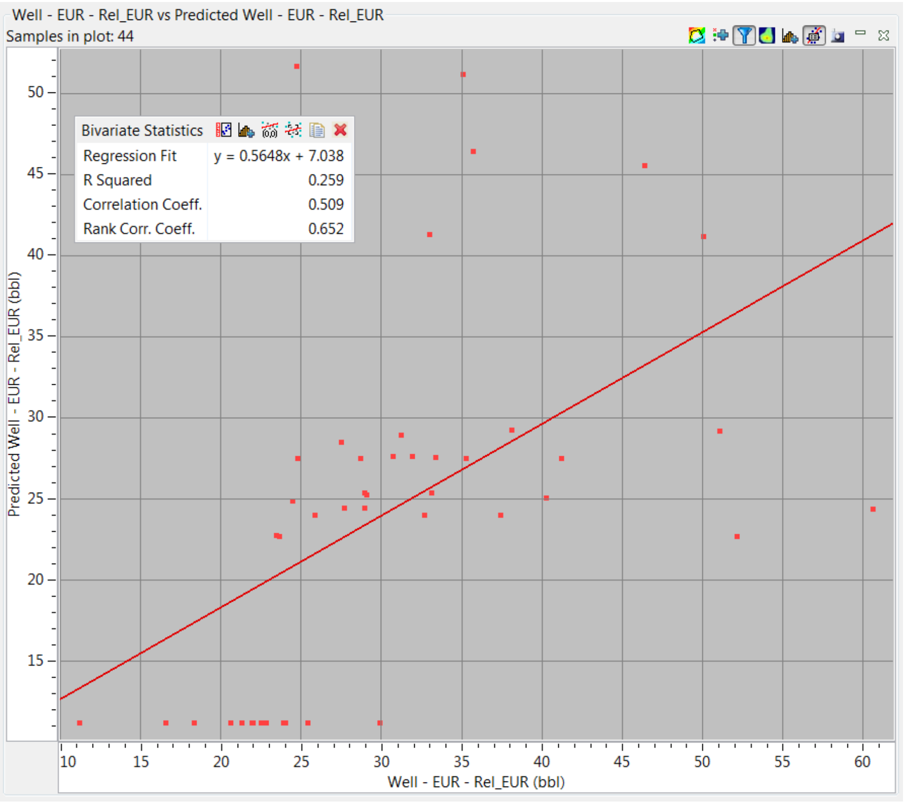




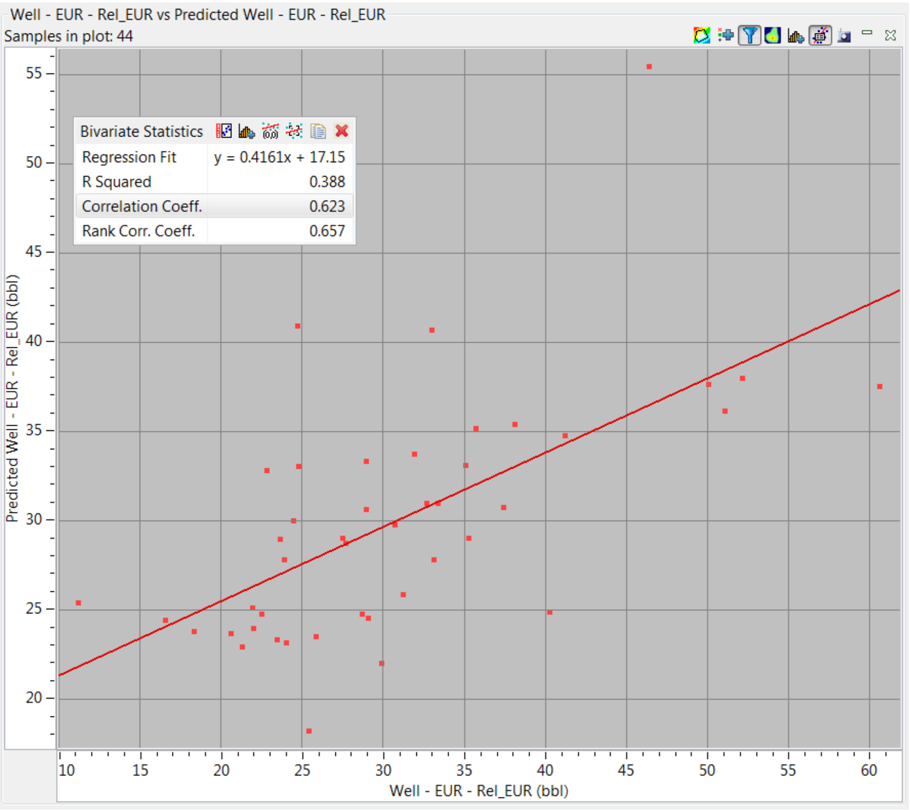


drillinginfo
better, faster decisions

BRITTLENESS INDEX VOLUME + ENGINEERING VARIABLES



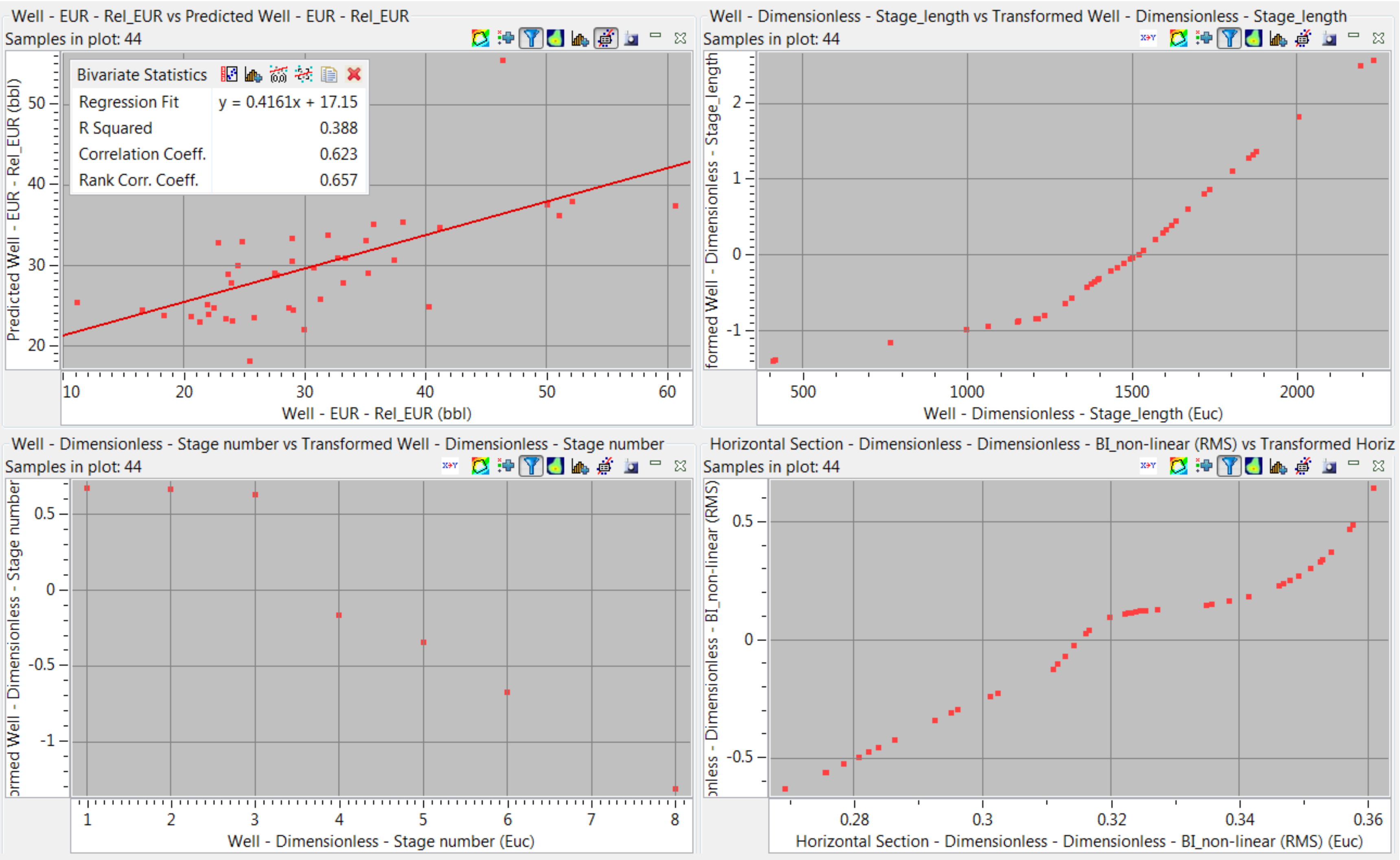
Engineering variables



Engineering variables + BI

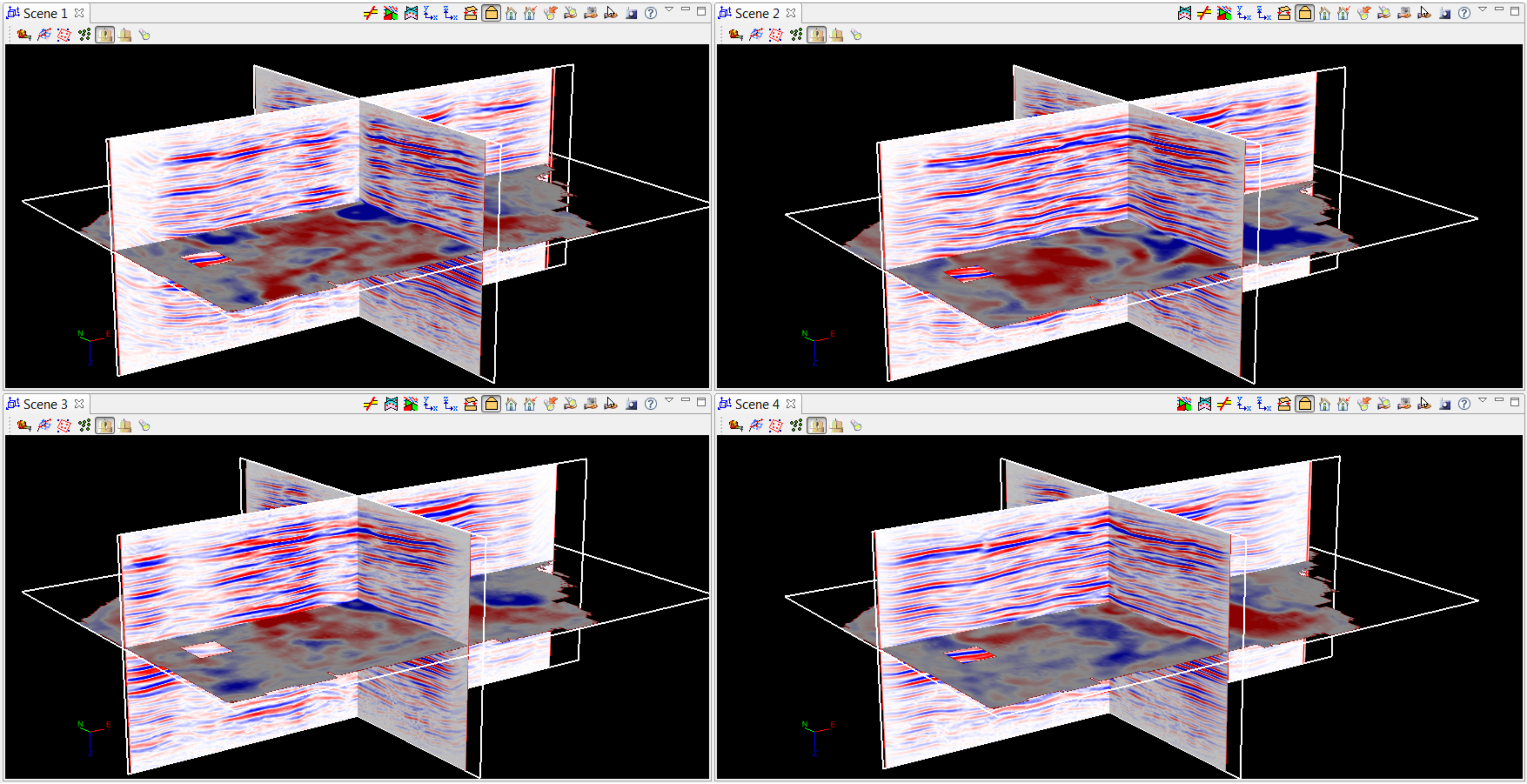
drillinginfo
better, faster decisions

BRITTLENESS INDEX VOLUME + ENGINEERING VARIABLES

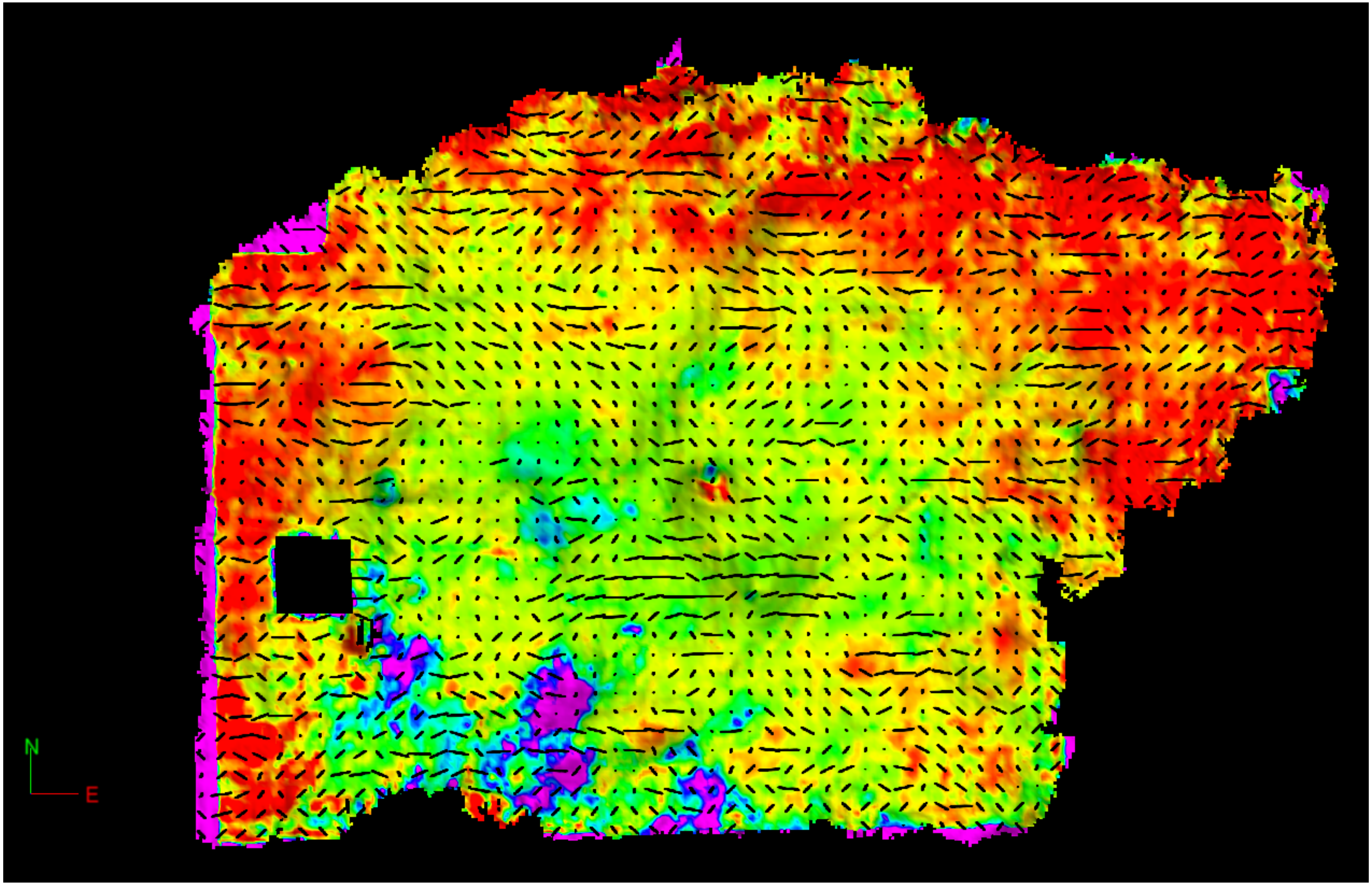


drillinginfo
better, faster decisions

AZIMUTHAL VOLUMES

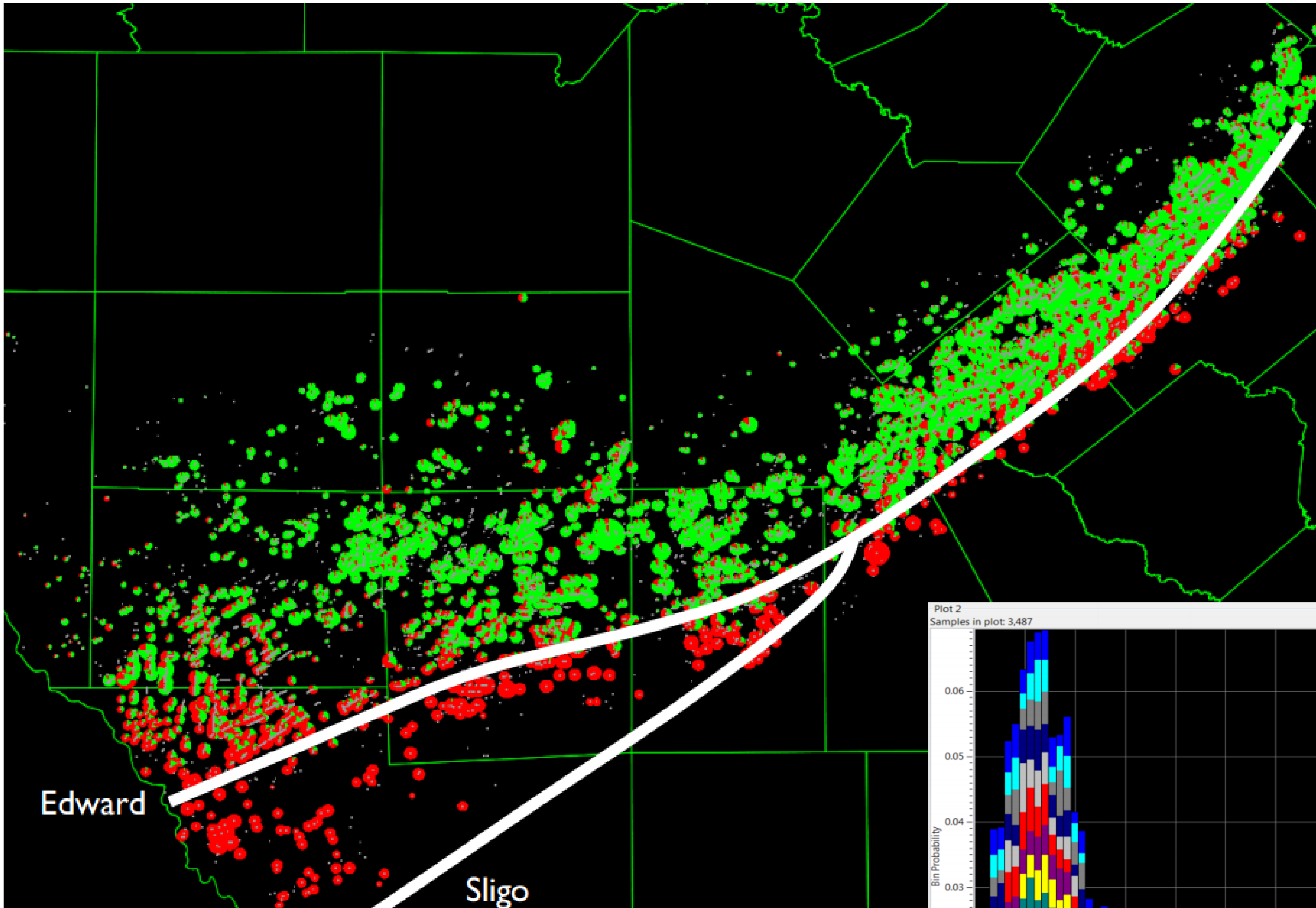


ANISOTROPY DIRECTION & INTENSITY + BI

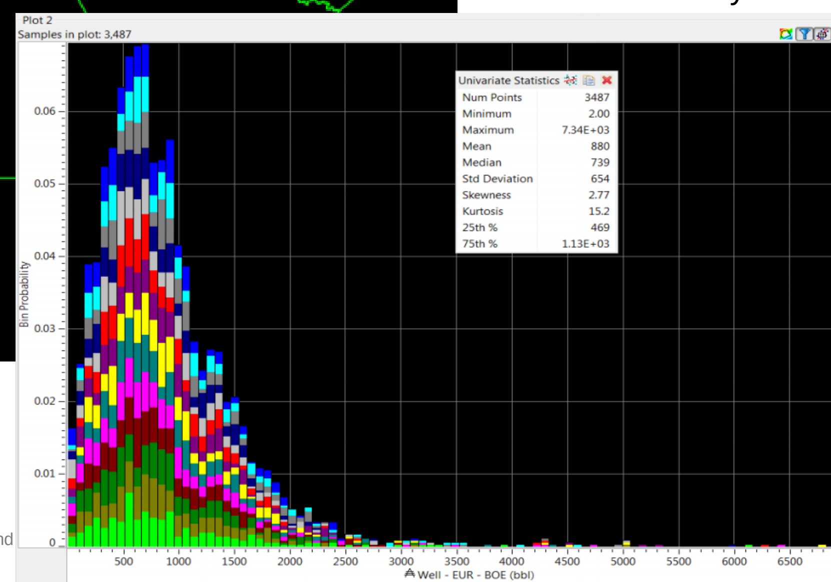


EAGLEFORD

EF OIL/GAS/CONDENSATE PRODUCTION

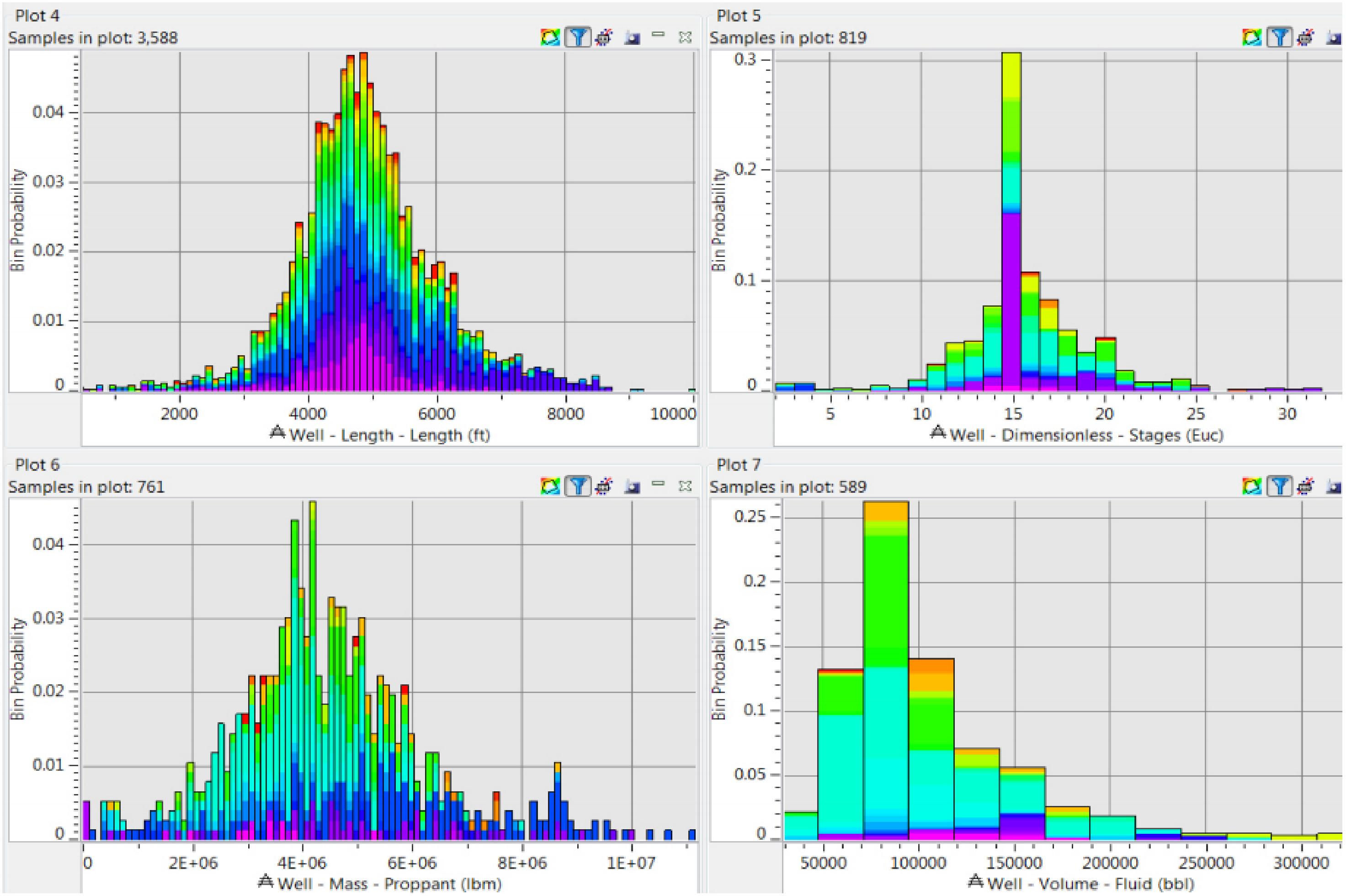


From Murray Roth



drillinginfo
better, faster decisions

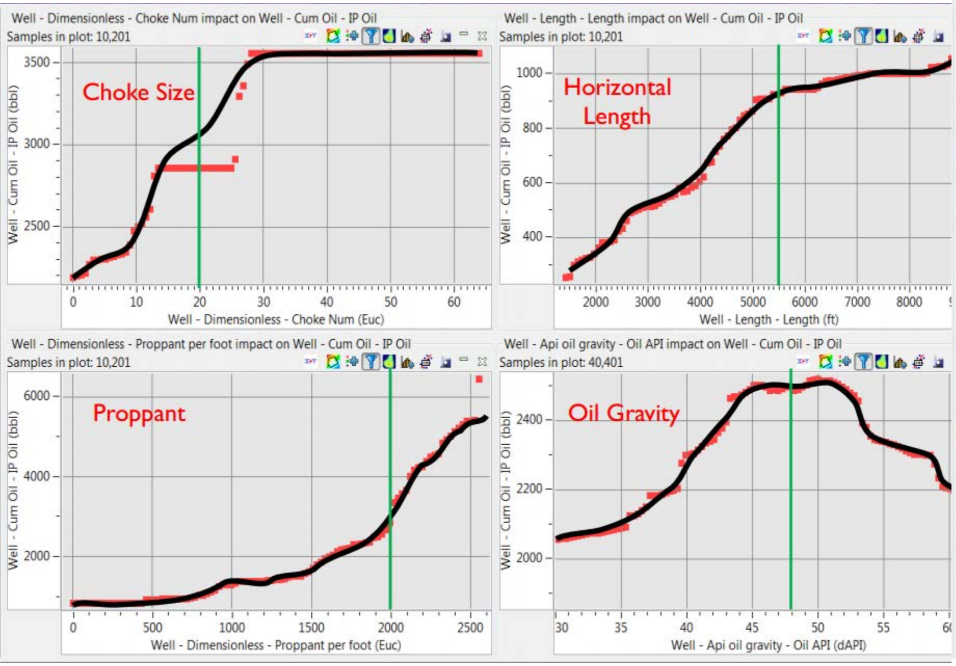
EF DRILLING AND COMPLETION DATA



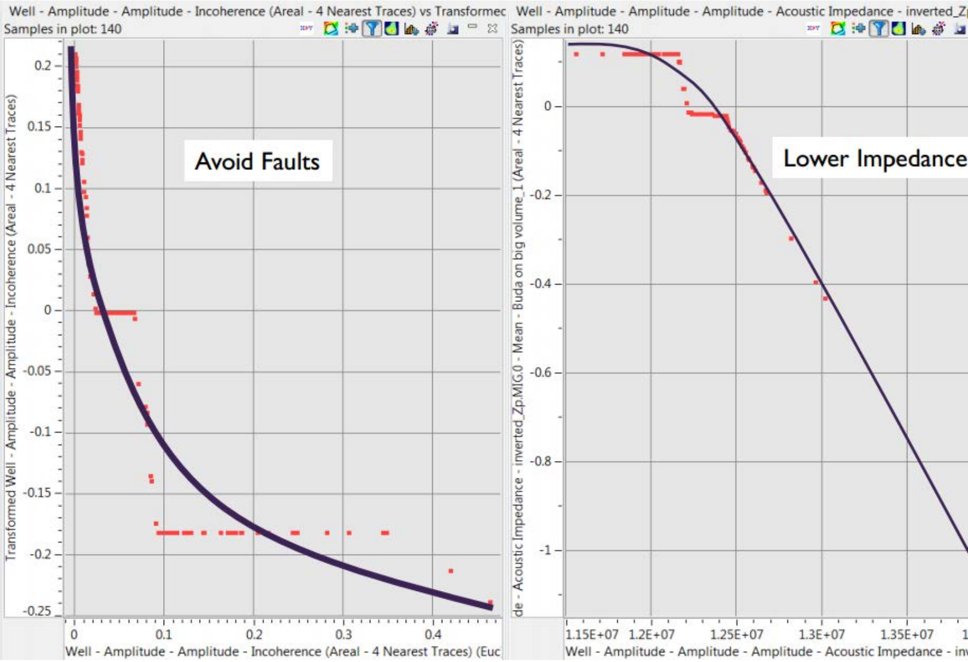
From Murray Roth

EF DRILLING AND COMPLETION DATA

From Murray Roth



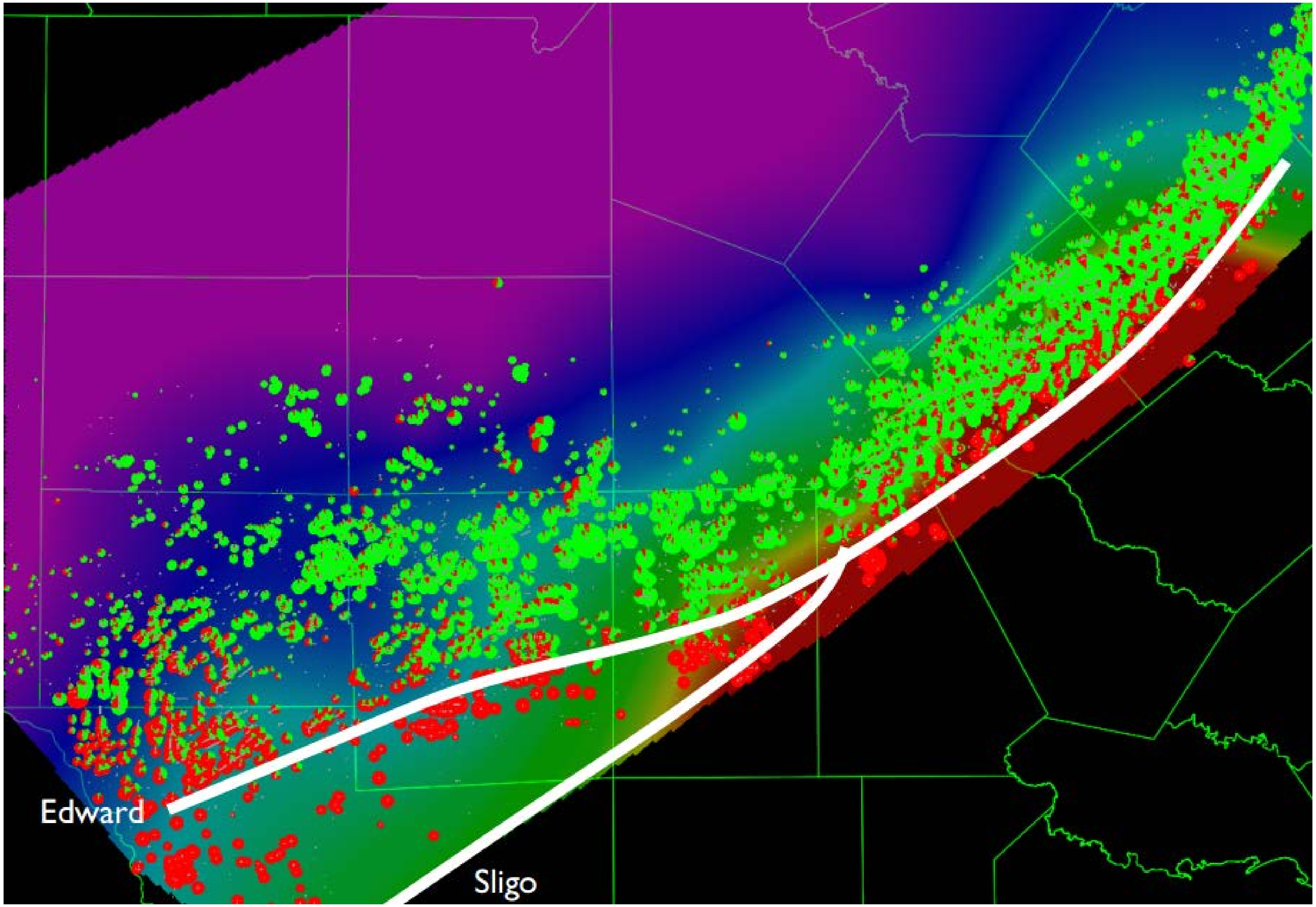
Engineering variables



G&G variables

drillinginfo
better, faster decisions

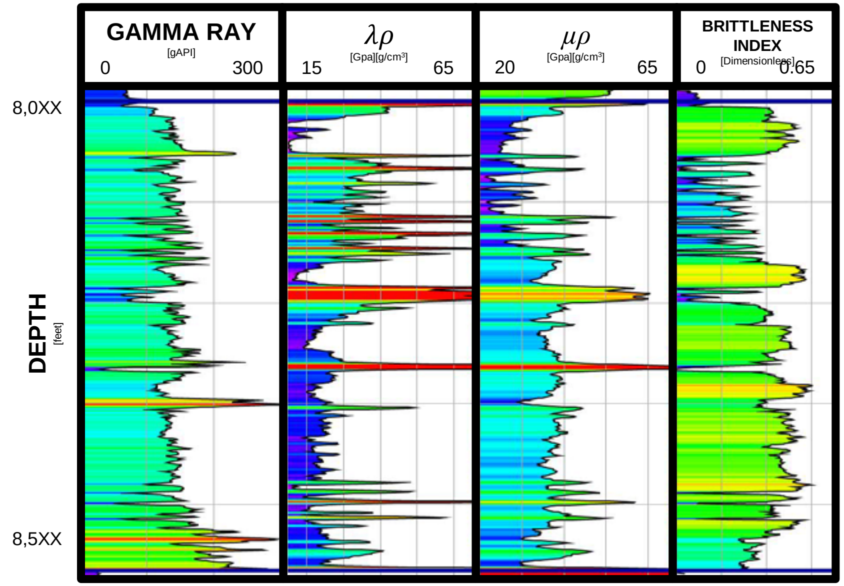
SWEEPSPOT MAP



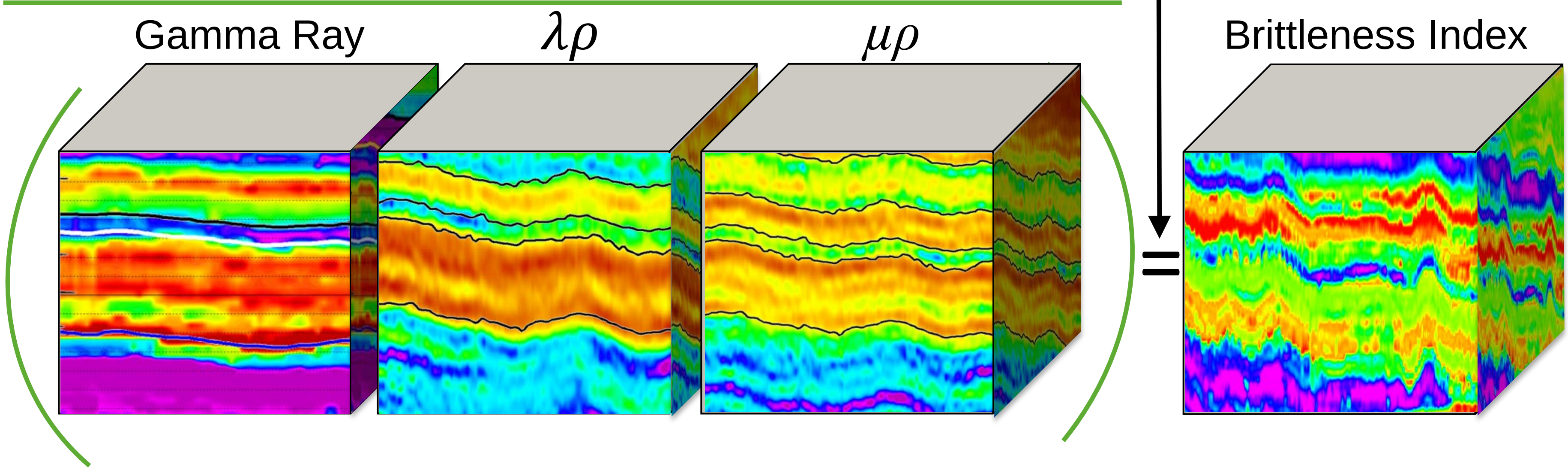
SUMMARY

drillinginfo
better, faster decisions

WORKFLOW SUMMARY

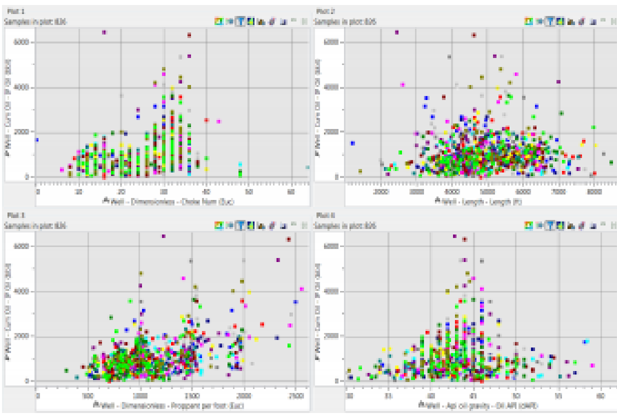


$$f_{BI}(\lambda\rho, \mu\rho, GR)$$

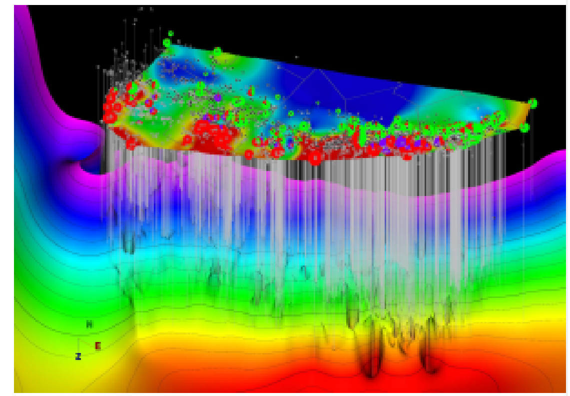


ANALYTIC WORKFLOW

Wellbore Paths, Perfs, Stages, Pressures, Slurry Flow, Proppant



Logs, Tops
Lithology/Facies logs
Geochemical data
Stress/strain data



Assign Properties To Wellbore Zones

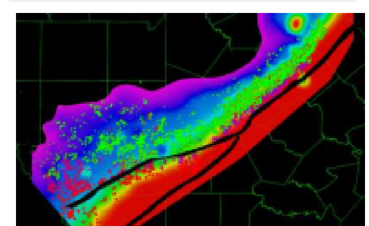
1) Multi-Variate Statistical Analysis

Correlation of Engineering Parameters with Production, Correcting for Spatial Geo Data Effects

Correlation of Geo Data with Production, Correcting for Variability in Engineering Parameters

2) Engineering "Best Practices"

3) Prospectivity Maps



Optimize Well Placement and Completions

From Murray Roth - An Analytic Approach to Sweetspot Mapping in the Eagle Ford Unconventional Play

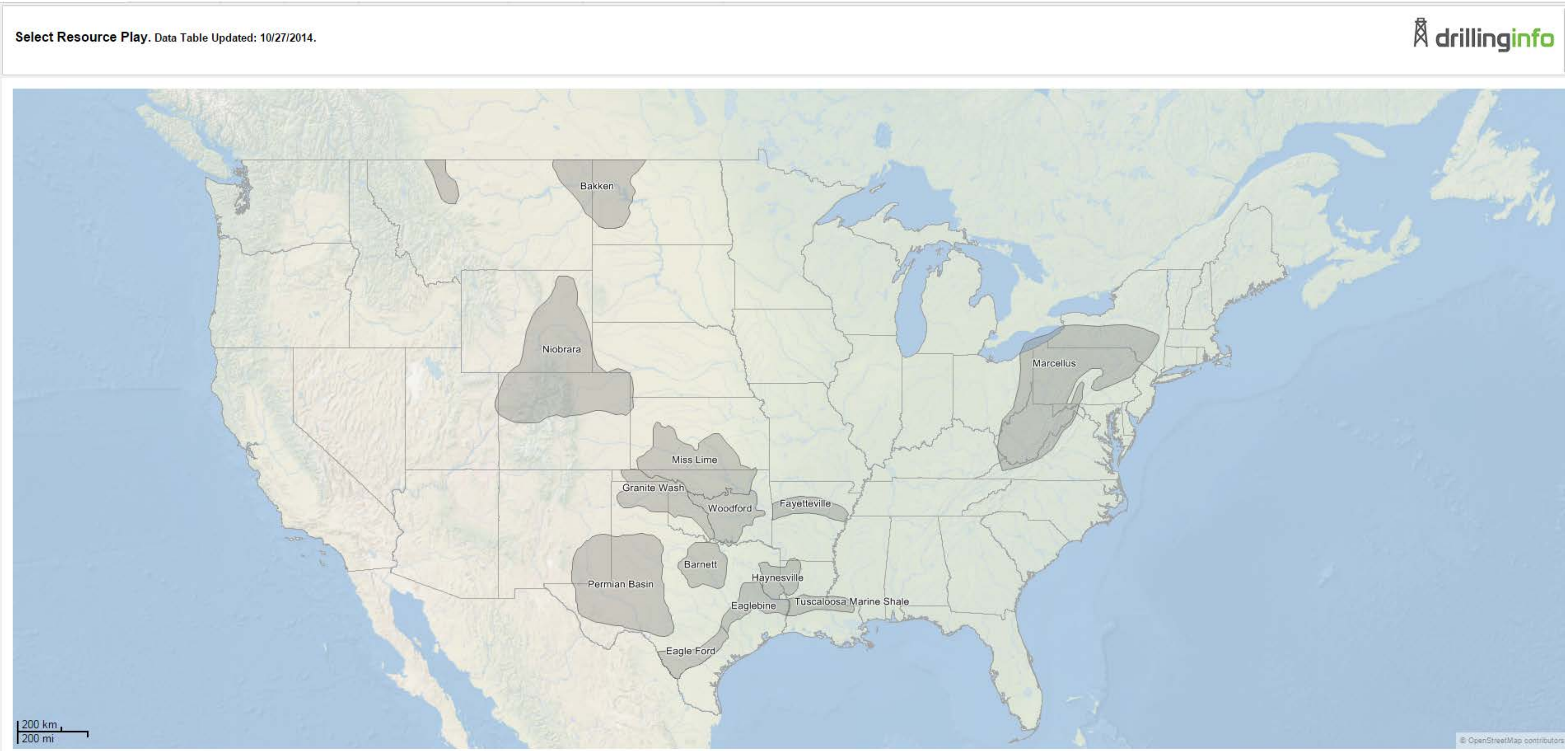
drillinginfo
better, faster decisions

THANK YOU

Questions & Open Discussion

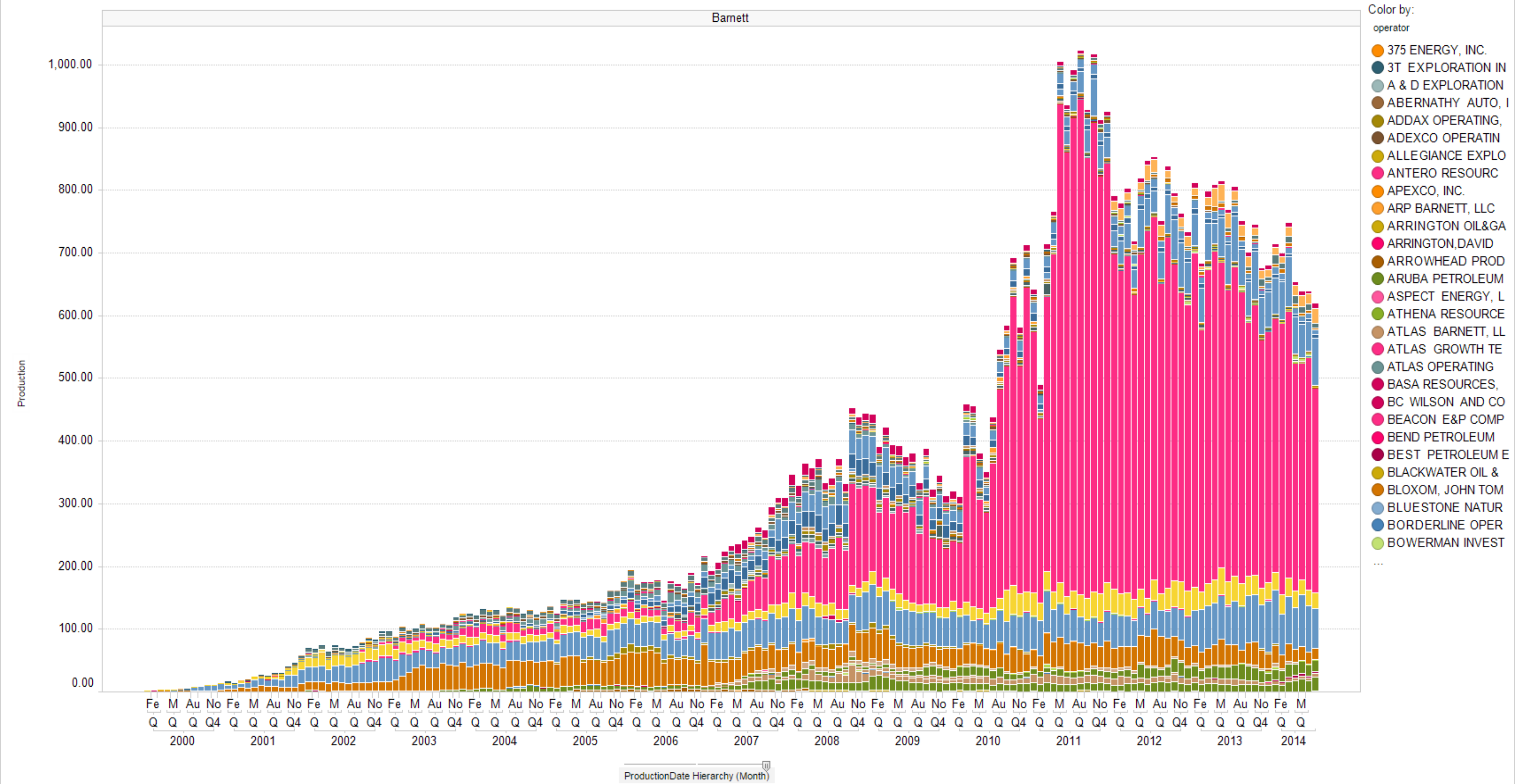
drillinginfo
better, faster decisions

MAJOR UNCONVENTIONAL U.S. BASINS



PRODUCTION HISTORY

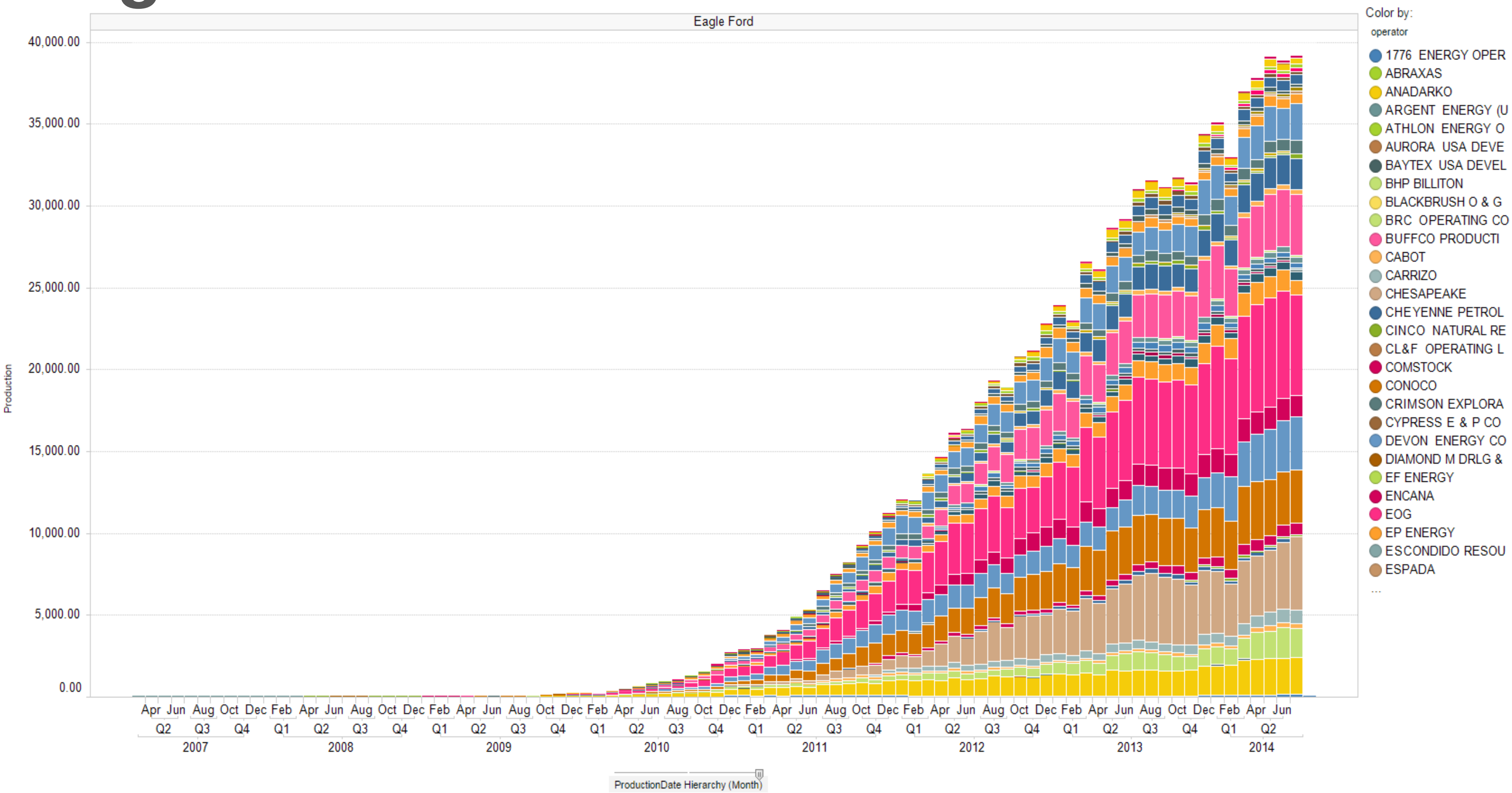
Barnett Shale



drillinginfo
better, faster decisions

PRODUCTION HISTORY

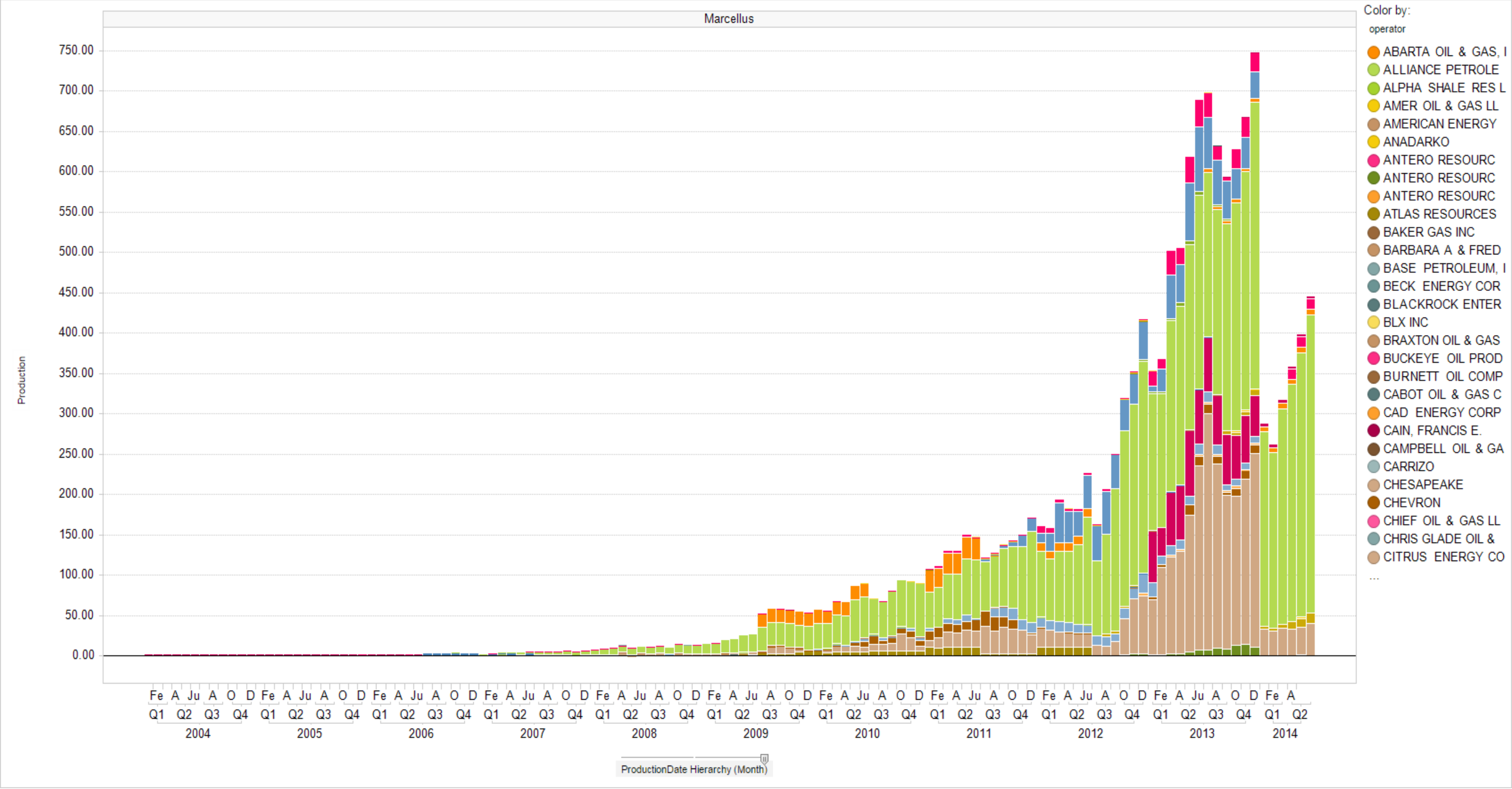
EagleFord



drillinginfo
better, faster decisions

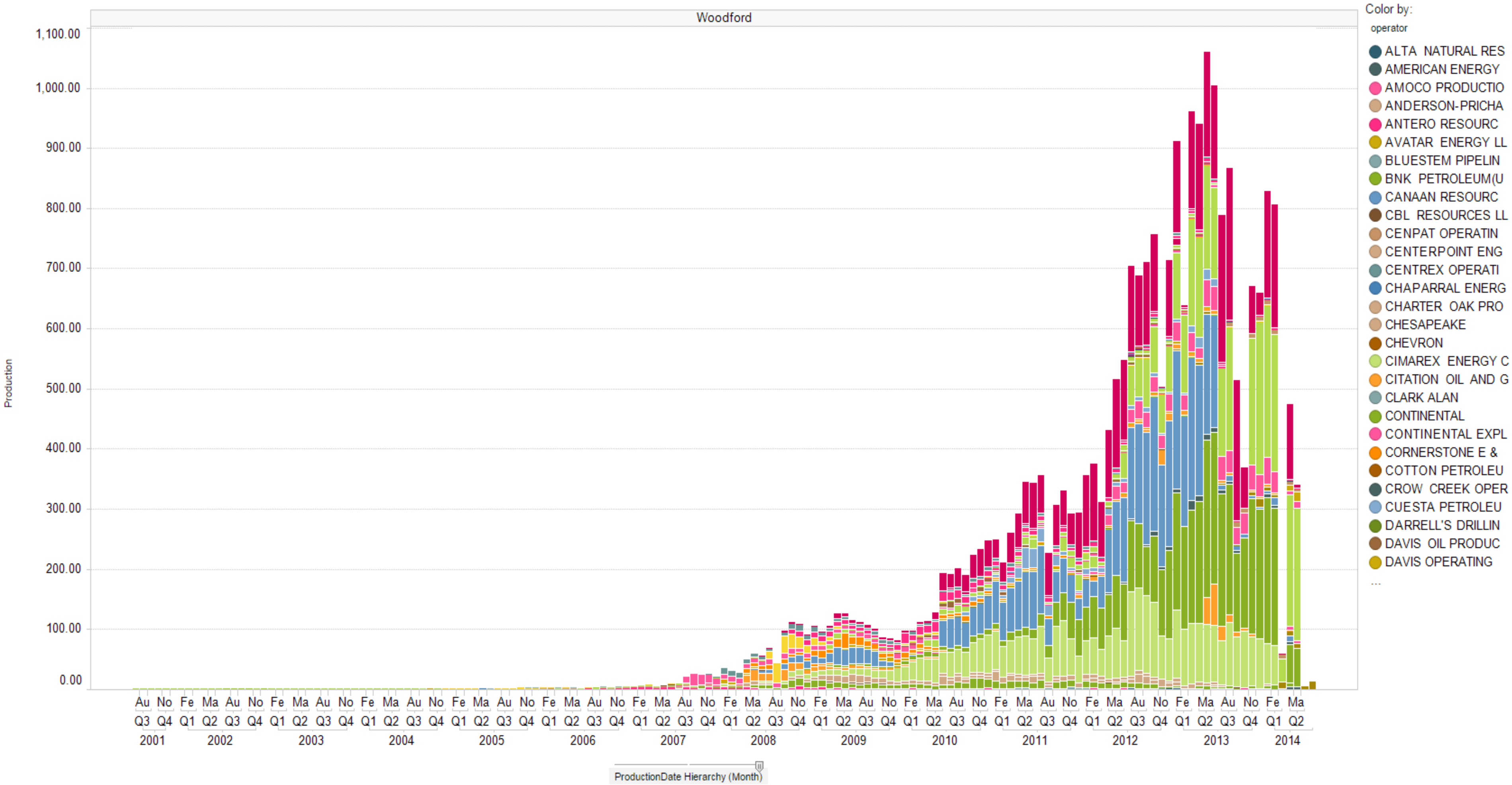
PRODUCTION HISTORY

Marcellus



drillinginfo
better, faster decisions

PRODUCTION HISTORY
Woodford



drillinginfo
better, faster decisions

PRODUCTION SCENARIO ANALYSIS

drillinginfo
better, faster decisions

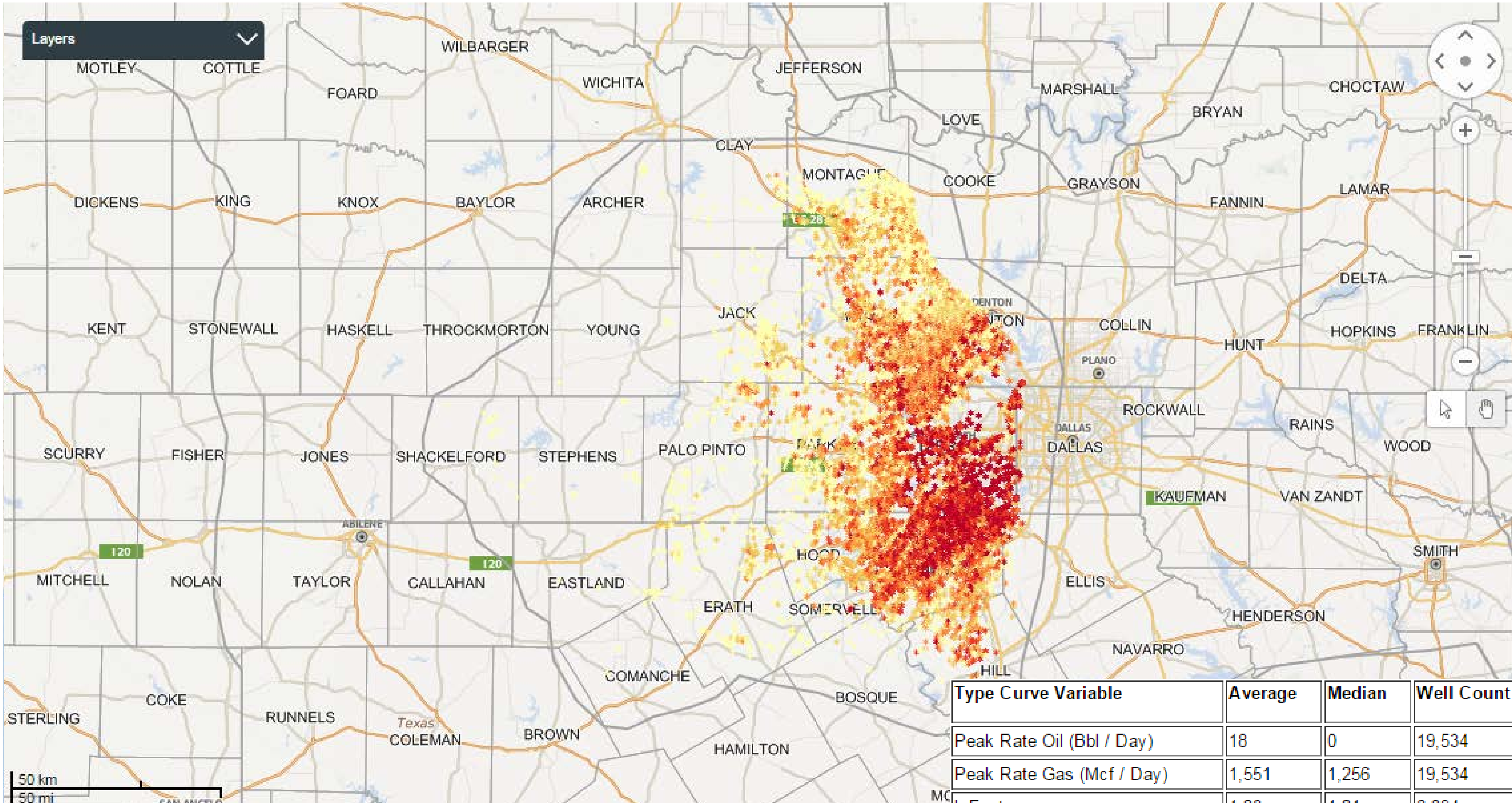
PRODUCTION SCENARIO ANALYSIS
Workflow

drillinginfo
better, faster decisions

PRODUCTION SCENARIO ANALYSIS

Barnett Shale

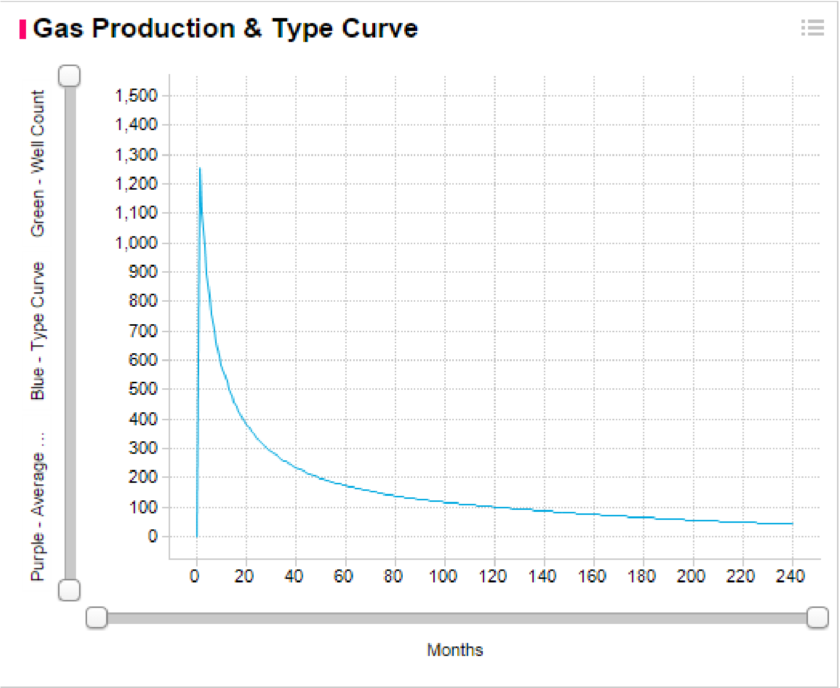
Peak Monthly Rate Gas (Mcf)



Type Curve Variable	Average	Median	Well Count
Peak Rate Oil (Bbl / Day)	18	0	19,534
Peak Rate Gas (Mcf / Day)	1,551	1,256	19,534
b-Factor	1.28	1.21	6,294
Effective Annual Secant Decline (Desi) (%)	60 %	61 %	6,294

drillinginfo
better, faster decisions

PRODUCTION SCENARIO ANALYSIS
Barnett Shale



Type Curve Variable	Average	Median	Well Count	Value
Peak Rate Oil (Bbl / Day)	18	0	19,534	0
Peak Rate Gas (Mcf / Day)	1,551	1,256	19,534	1,256
b-Factor	1.28	1.21	6,294	1.21
Effective Annual Secant Decline (Desi) (%)	60 %	61 %	6,294	60 %