QI Petrophysics

Quantitative Interpretation for a Strategic Competitive Edge:

Critical Integration of Geology, Petrophysics, and Geophysics
or

Rock Physics…Why I Should Care

DHI Consortium Meeting 5/18/2011

QI Petrophysics

WHAT IS PETROPHYSICS?

- **Ask a "Log Analyst" for the 3 Most Important Curves from a Given Well, what will you get?**
  - **Volume Shale**
  - **"Effective Porosity"**
  - **Water Saturation**
- **Geophysicists are interested in Density, Compressional Velocity and Shear Velocity**

- **SEISMIC PETROPHYSICS ADDRESSES THIS ISSUE**

KEY POINT: "PETROPHYSICS" MEANS DIFFERENT THINGS TO DIFFERENT PEOPLE

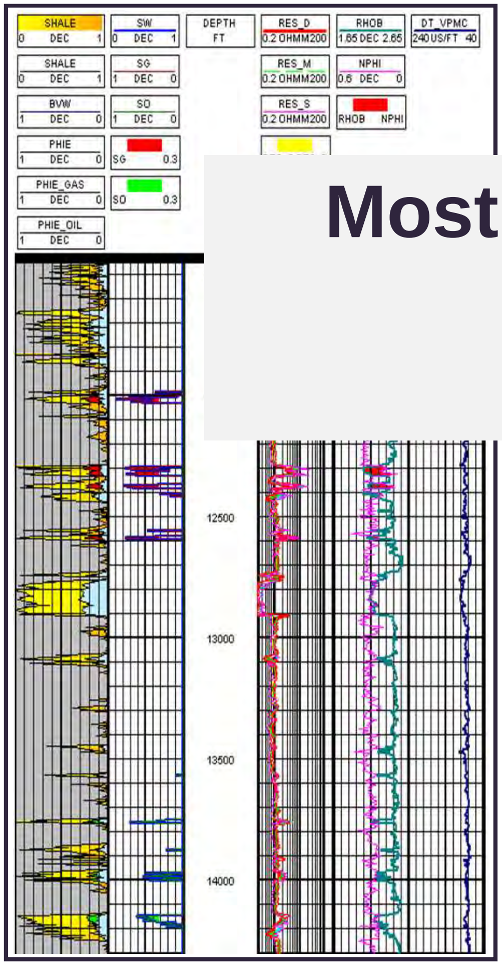
QI Petrophysics

Quantitative Interpretation for a Strategic Competitive Edge:

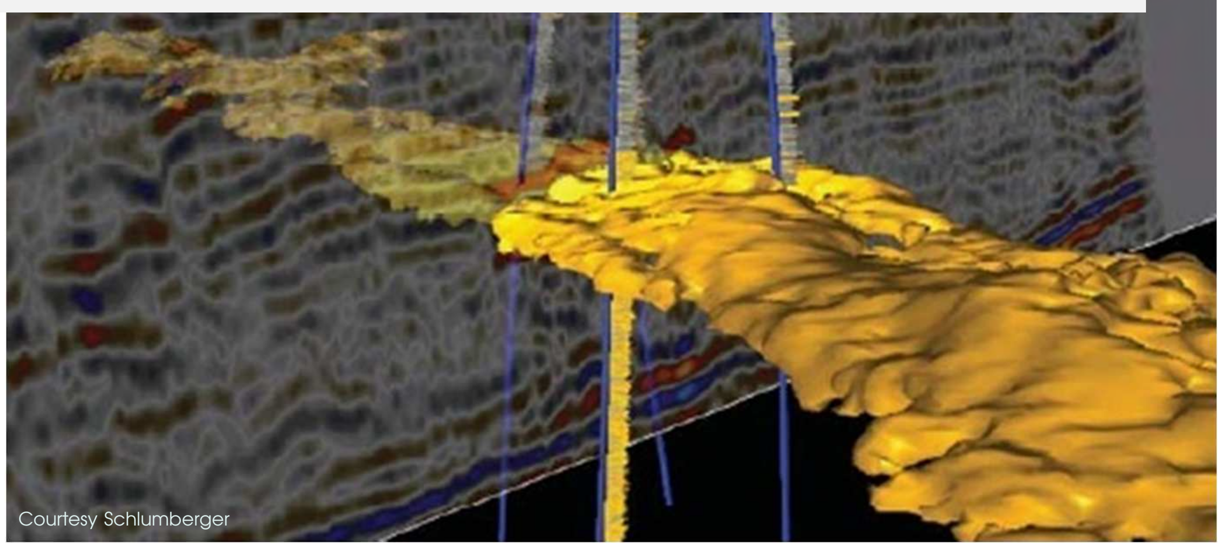
Critical Integration of Geology, Petrophysics, and Geophysics

2011

Fundamental Data in Exploration and Production are Wells and Seismic Volumes



Most of the data is available to most everyone in the industry



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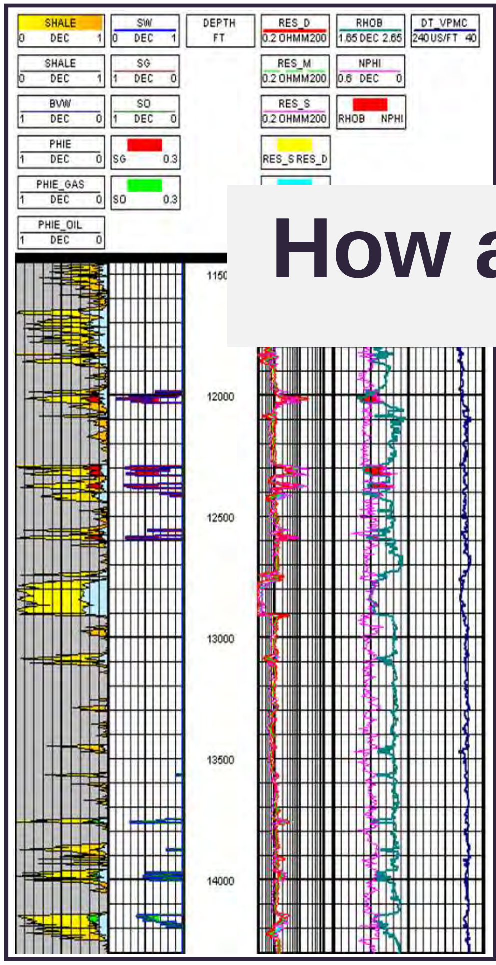
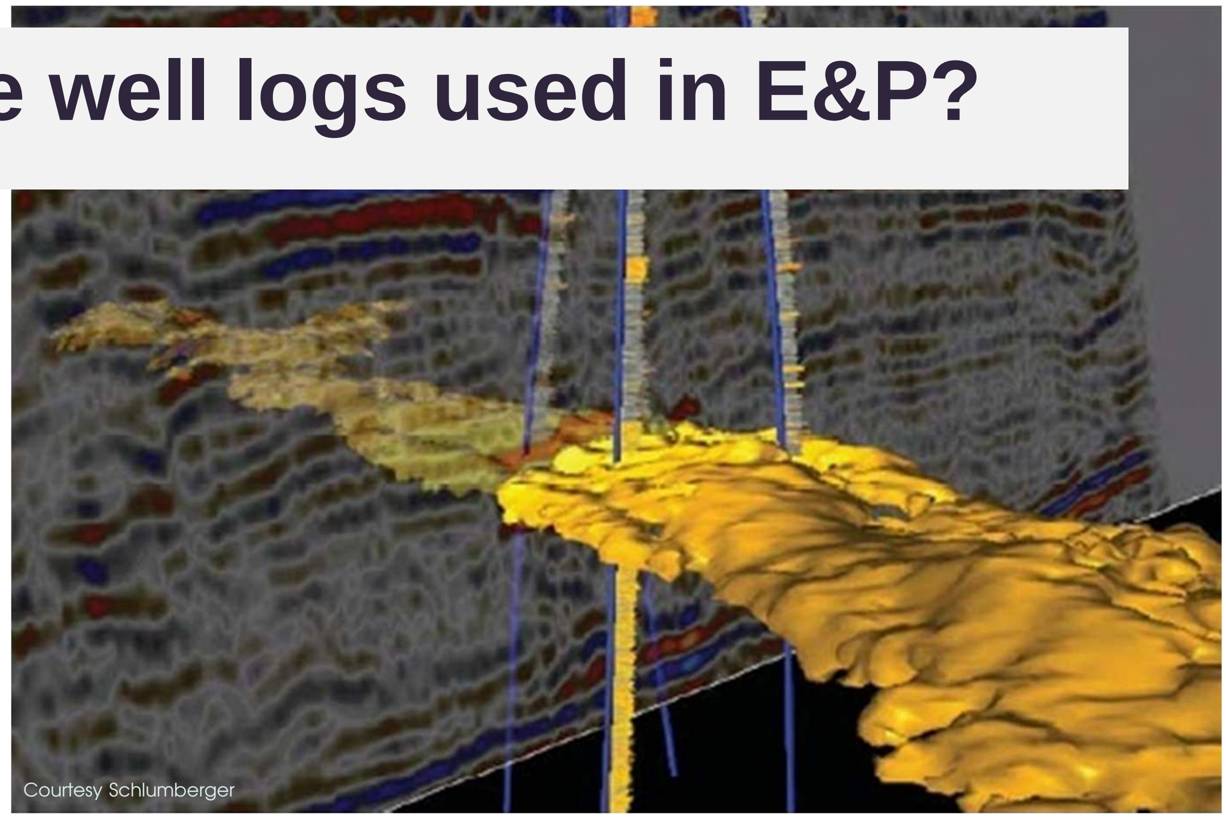
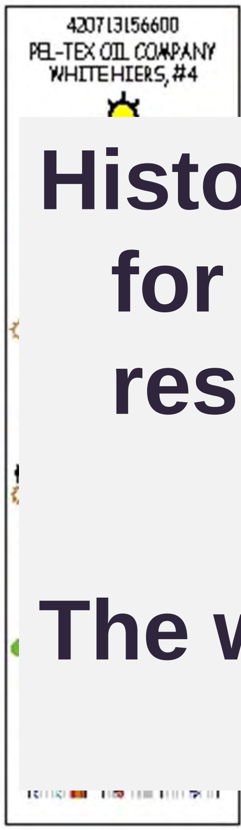
Fundamental Data in Exploration and Production are Wells and Seismic Volumes

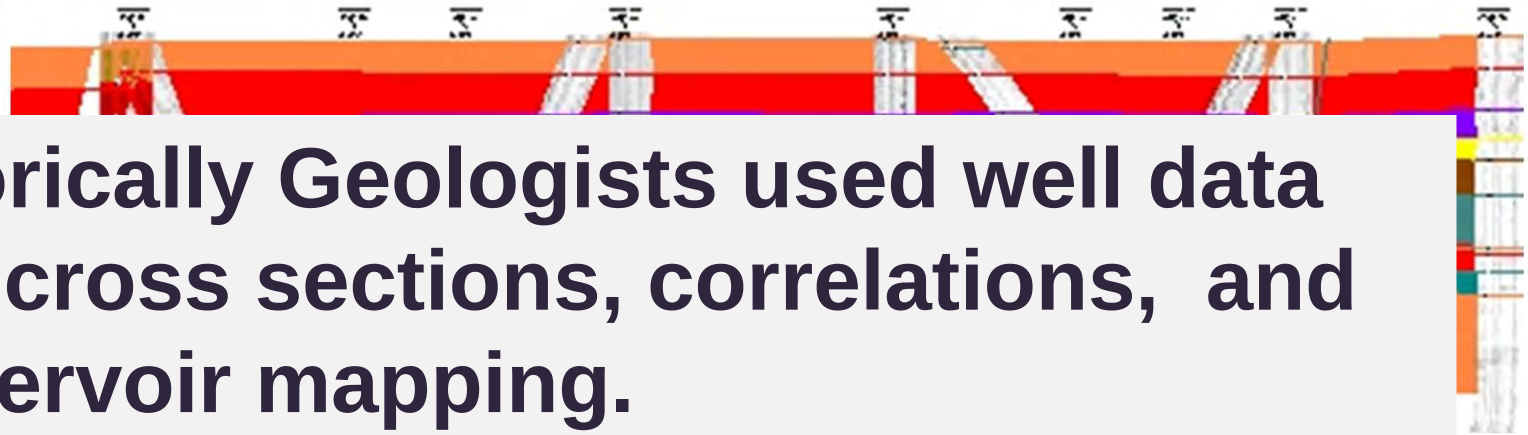


How are well logs used in E&P?



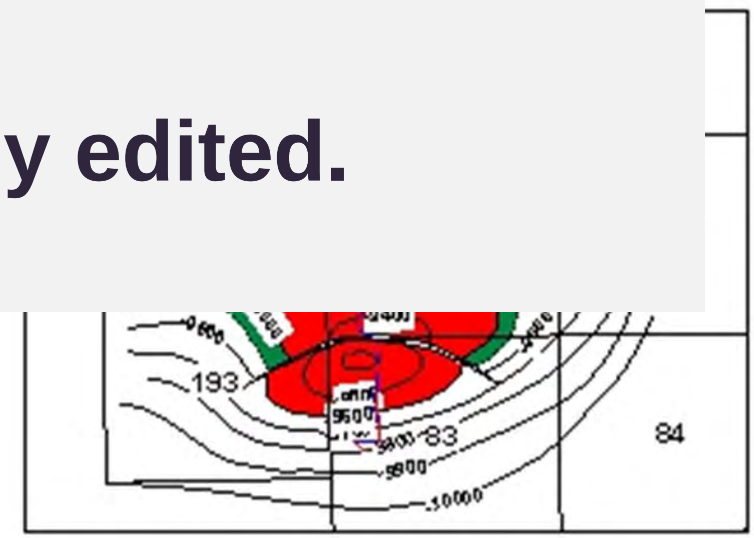
Seismic Volume Image Courtesy of Schlumberger



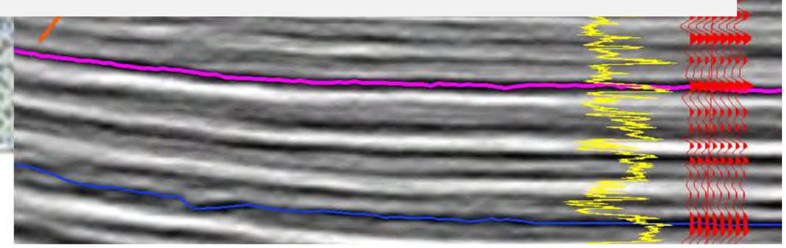


Historically Geologists used well data for cross sections, correlations, and reservoir mapping.

The well logs were rarely edited.



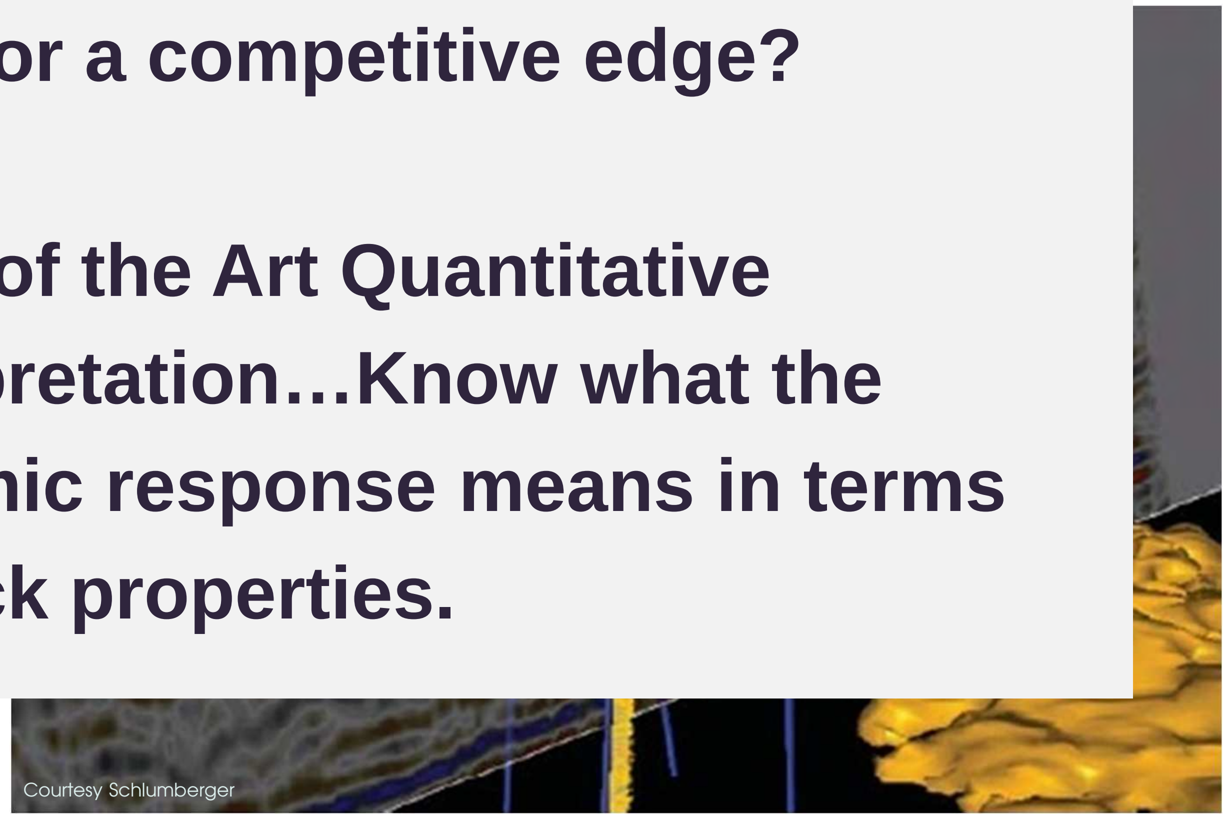
- **Historically Geophysicicists used well data for a synthetic to seismic tie.**
- **The rise of inversion techniques has made the synthetic critical for quantitative analysis**
- **For best results well logs must be properly analyzed for geophysical integration**



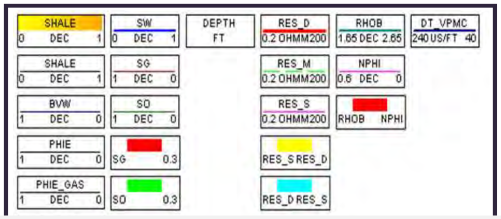
Fundamental Data in Exploration and Production are Wells and Seismic Volumes

Q: How can any E&P leverage data for a competitive edge?

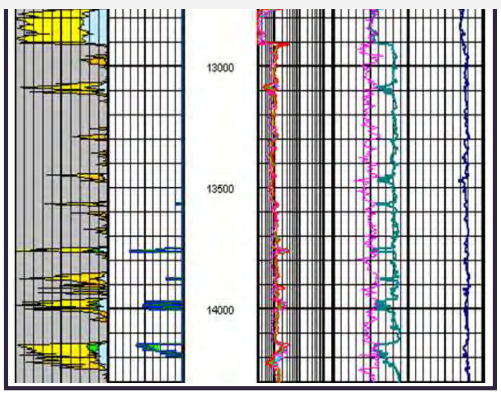
A: State of the Art Quantitative Interpretation…Know what the seismic response means in terms of rock properties.

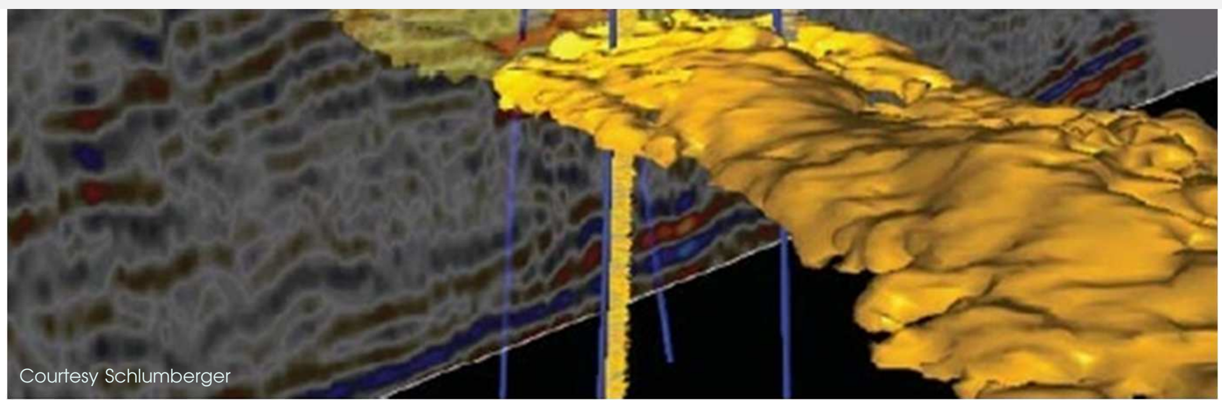

Courtesy Schlumberger

Fundamental Data in Exploration and Production are Wells and Seismic Volumes



Rock physics is the key to Quantified Integrated Interpretation by linking petrophysical properties to elastic response.





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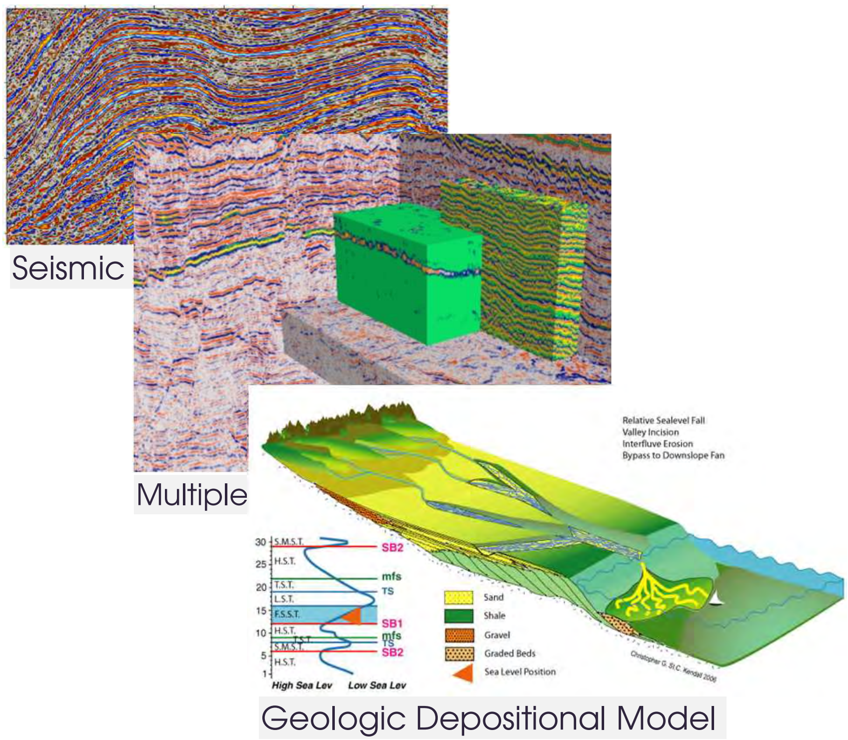
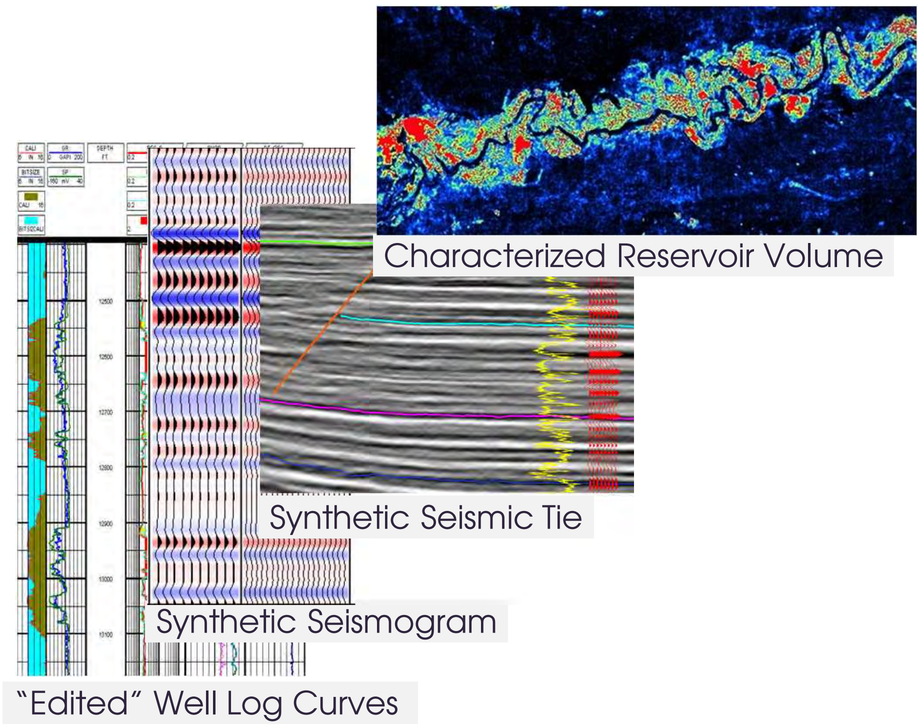
Integrated Interpretation or Quantitative Interpretation is the State of the Art in Exploration and Production





Relative Side of the Interpretation
Reservoir Morphology,
Structure and Stratigraphic Framework Defined

Quantitative Side of the Interpretation
Reservoir Defined in Terms of Lithology and
Pore Filling Fluids

Seismic Volume Images Courtesy of Schlumberger, and Paradigm,
Geologic Model Image Courtesy of C.G.St.C. Kendall, U. of S. Carolina

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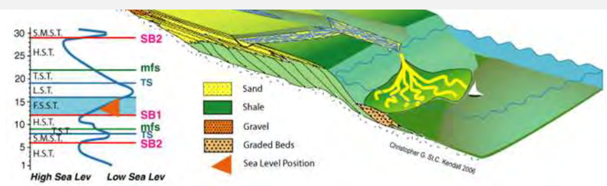
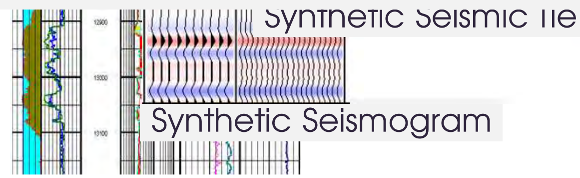
The purpose of quantitative interpretation is to rigorously integrate *Seismic Data* and *Well Data* for a better prediction of the spatial variation of the rock properties in an area of interest, to mitigate exploration risk.

Risk mitigation is accomplished through a set of best practices, specifically crucial is well log interpretation guided by rock physics, that provides insight into the natural variation of petrophysical properties, as well as their correlative acoustic and elastic behavior of the entire rock column in the area of interest.



Geologic Depositional Model



“Edited” Well Log Curves

Relative Side of the Interpretation

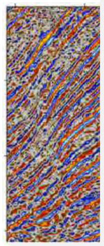
Reservoir Morphology,
Structure and Stratigraphic Framework Defined

Quantitative Side of the Interpretation

Reservoir Defined in Terms of Lithology and Pore Filling Fluids

Seismic Volume Images Courtesy of Schlumberger, and Paradigm,
Geologic Model Image Courtesy of C.G.St.C. Kendall, U. of S. Carolina

Competitive advantage can be achieved through Quantitative Interpretation.



Seismi

Key aspects of the Quantitative Interpretation include

1. Seismic Petrophysical Analysis
2. Rock Physics Characterization
3. Abnormal Pore-Pressure Evaluation
4. Perturbational Rock Modeling
5. AVO Analysis
6. Seismic Forward Modeling

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Geologic Depositional Model

"Edited" Well Log Curves

Relative Side of the Interpretation
Reservoir Morphology,
Structure and Stratigraphic Framework Defined

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Reservoir Defined in Terms of Lithology and
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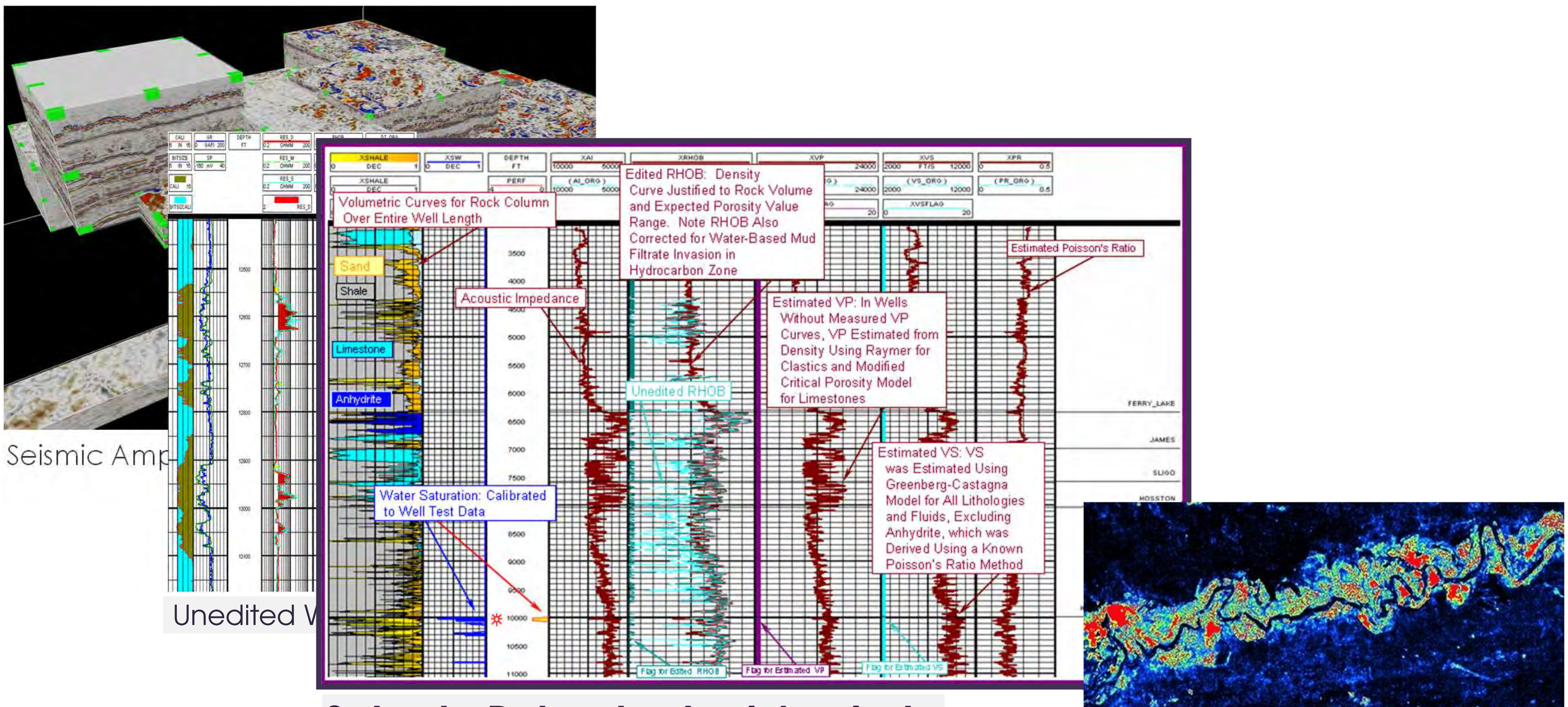
Quantitative Interpretation requires rigorous consistent well log analysis that is grounded in rock physics to provide competitive advantage.

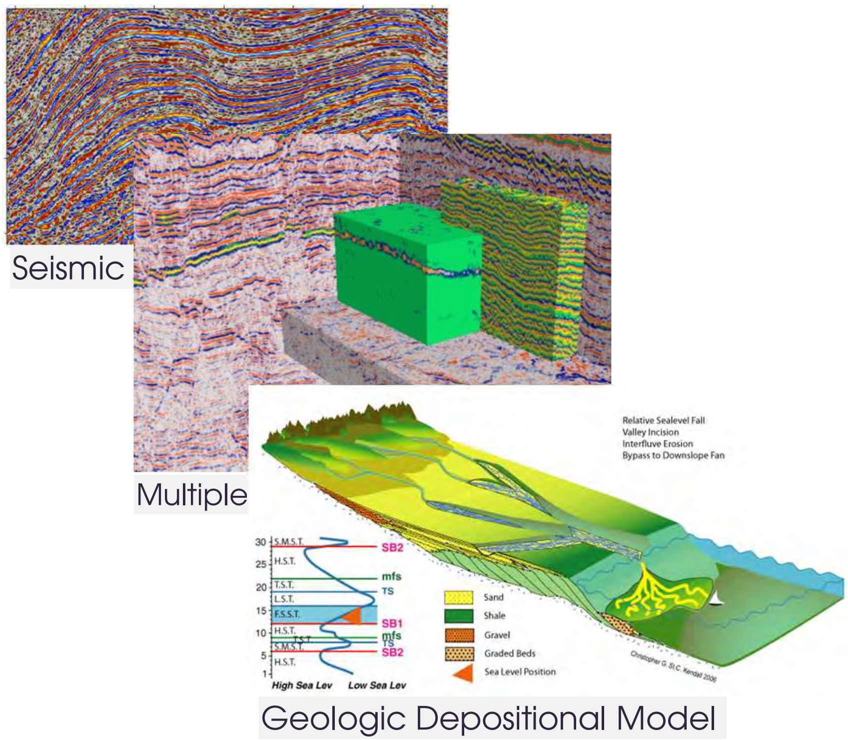


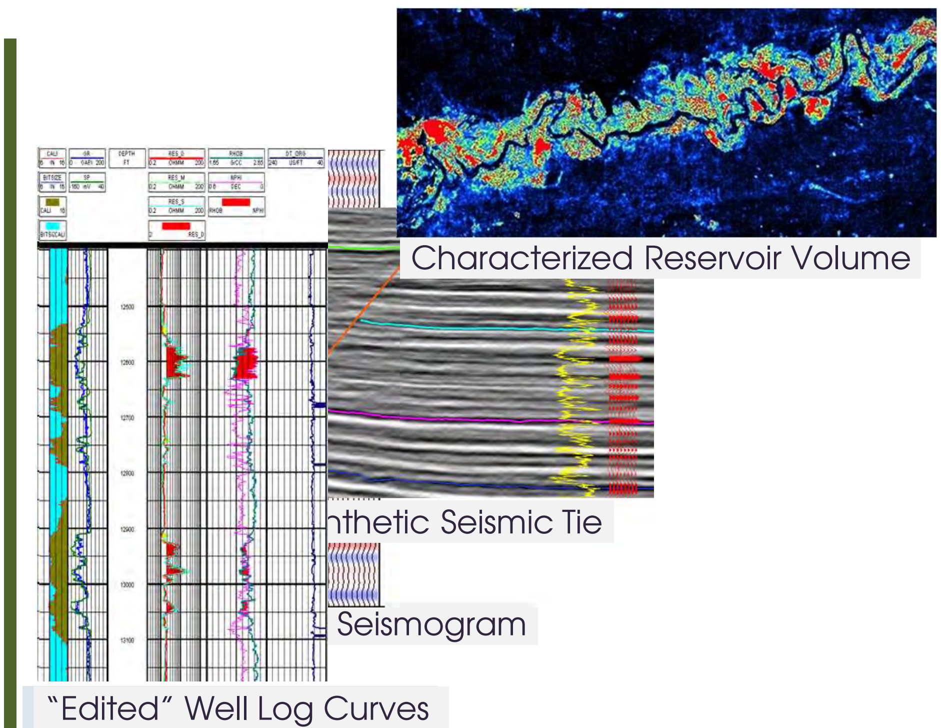
Seismic Petrophysical Analysis

Characterized Reservoir Volume

Seismic Volume Images Courtesy of Schlumberger, and Paradigm

Integrated Interpretation or Quantitative Interpretation is the State of the Art in Exploration and Production





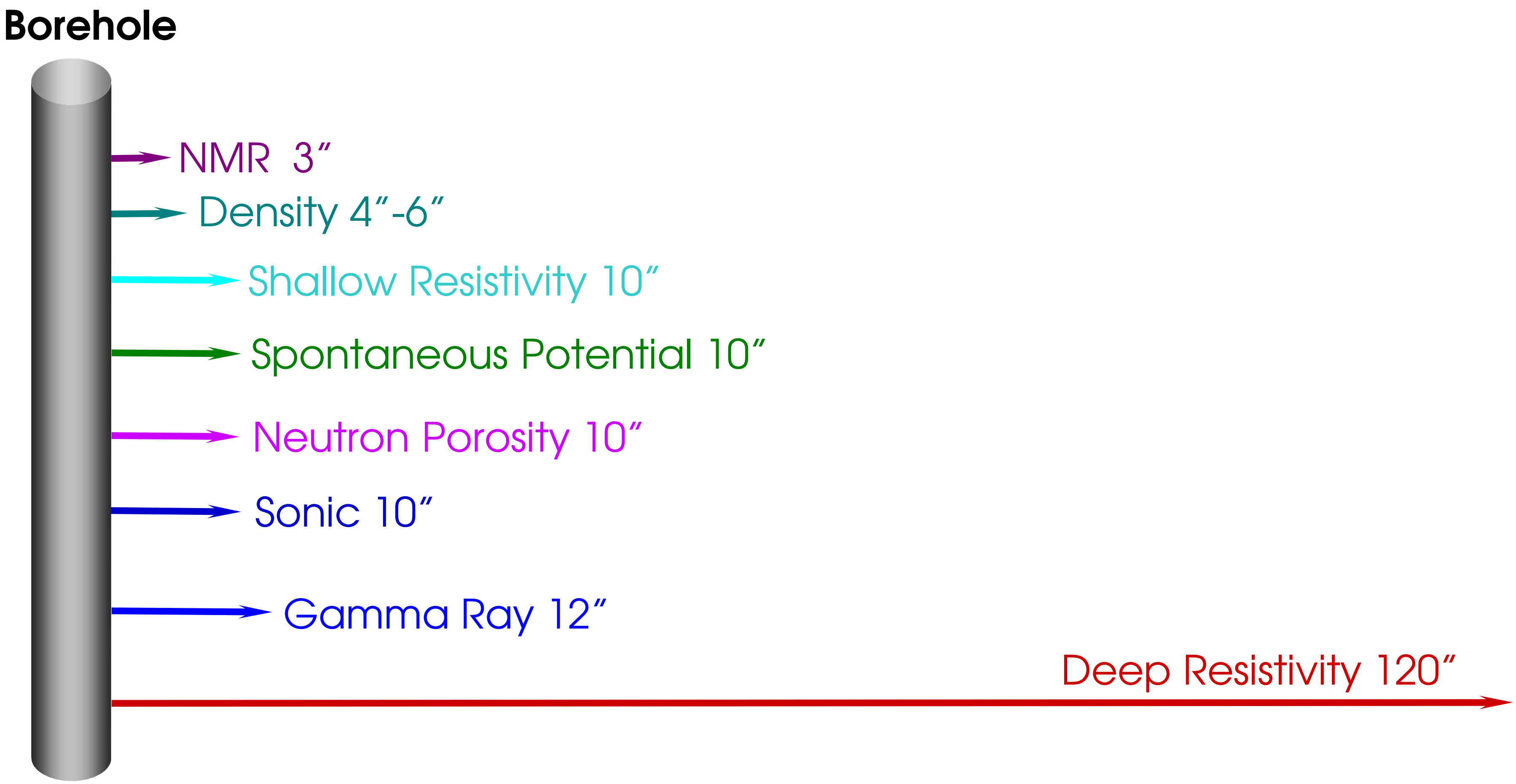
Relative Side of the Interpretation

Reservoir Morphology,
Structure and Stratigraphic Framework Defined

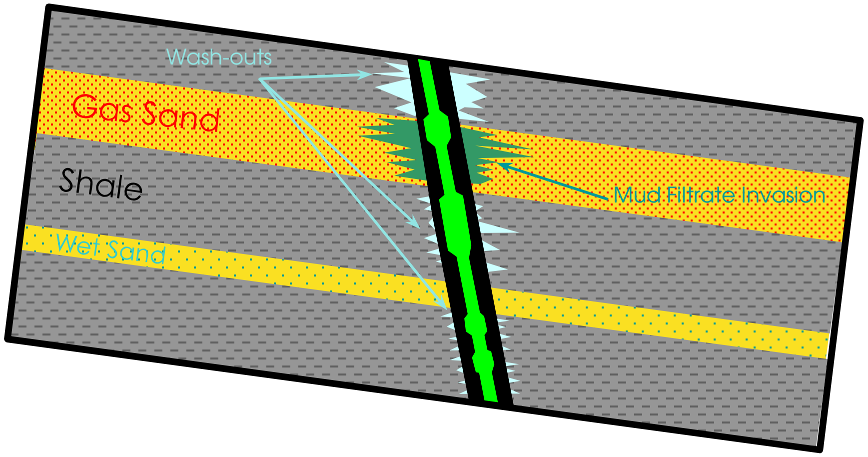
Quantitative Side of the Interpretation

Reservoir Defined in Terms of Lithology and Pore Filling Fluids

Depth of Investigation of Selected Tools



QI Petrophysics



Any of these factors can result in erroneous values in the well log data, this is particularly problematic when using well log data for geophysical applications and quantitative interpretation.

The wellbore is a very hostile environment to acquire remotely sensed data.

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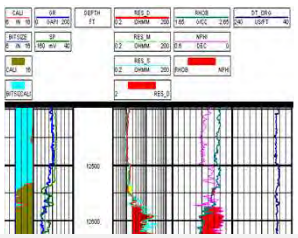
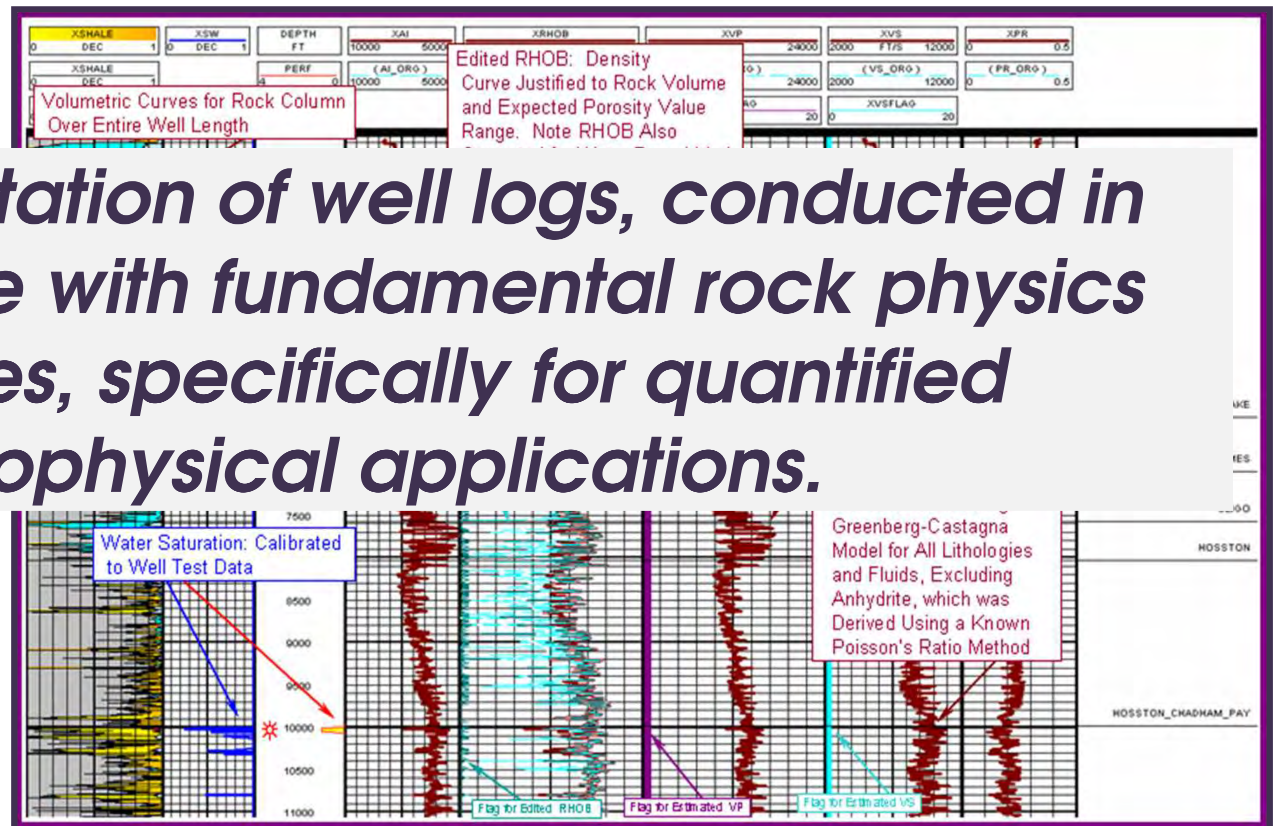
Seismic Petrophysical Analysis



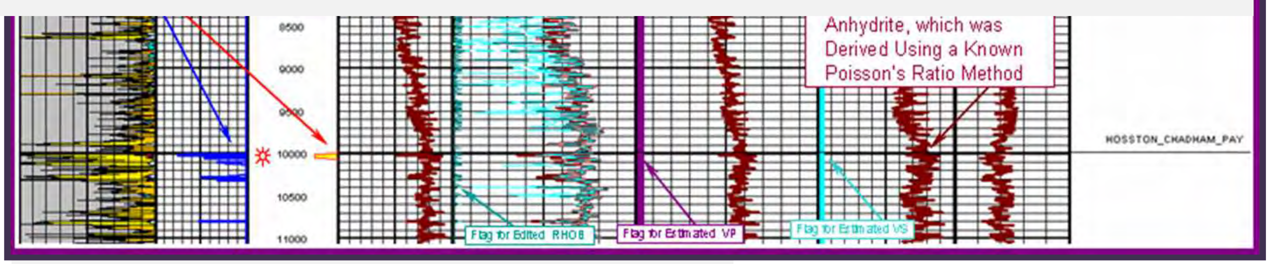


The interpretation of well logs, conducted in accordance with fundamental rock physics principles, specifically for quantified geophysical applications.

Seismic Petrophysical Analysis

Seismic Petrophysical Analysis

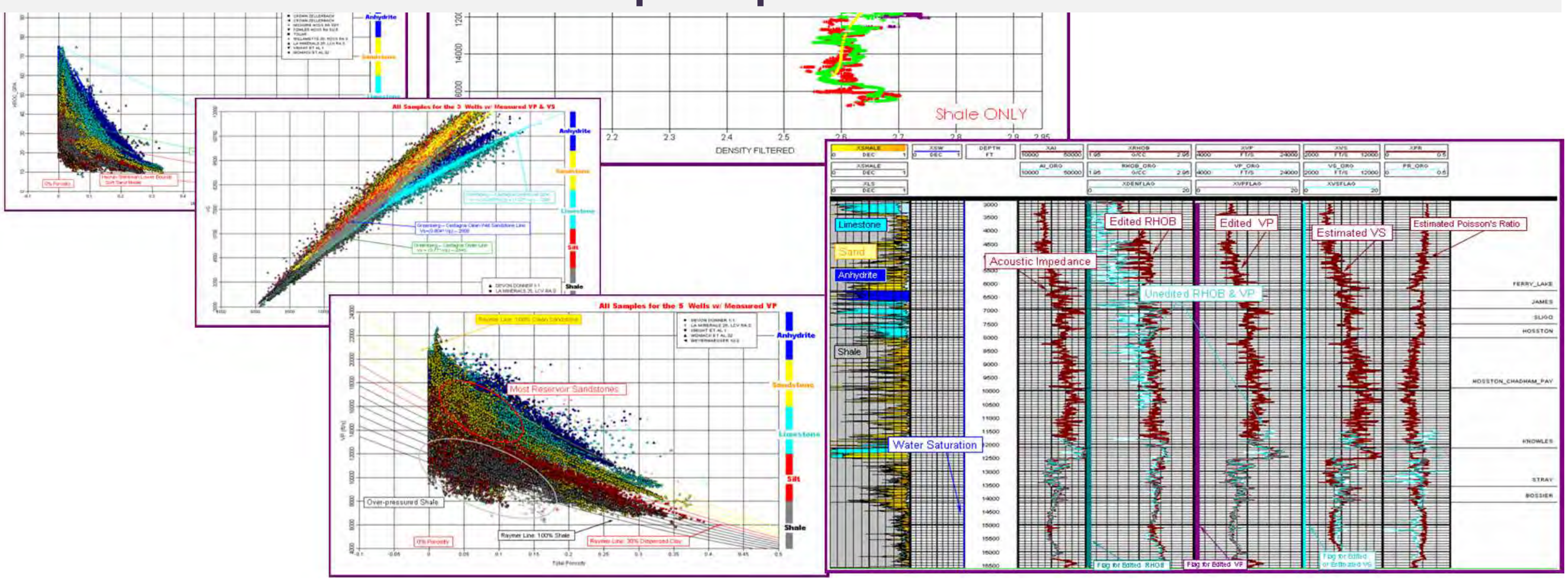
Fundamental Constraint: Interpret the well data, to describe the stratigraphic column in terms of dominant lithology from surface to TD. This results in a prediction of lithology (dominant minerals and their relative abundances), total fluid presence, and saturation values, temperature and pressure. Under this framework the range of values for VP, VS and Density becomes limited.



Seismic Petrophysical Analysis

Rock Physics Characterization

Rock Physics Characterization (RPC) **procedures, which allow for the definition and derivation of Effective Medium Models that best describe a given facies.** ***RPC*** **is a method of investigating the link between measured petrophysical properties of reservoir as well as non-reservoir rocks, and the correlative elastic response in the context of fundamental rock physics principles.**



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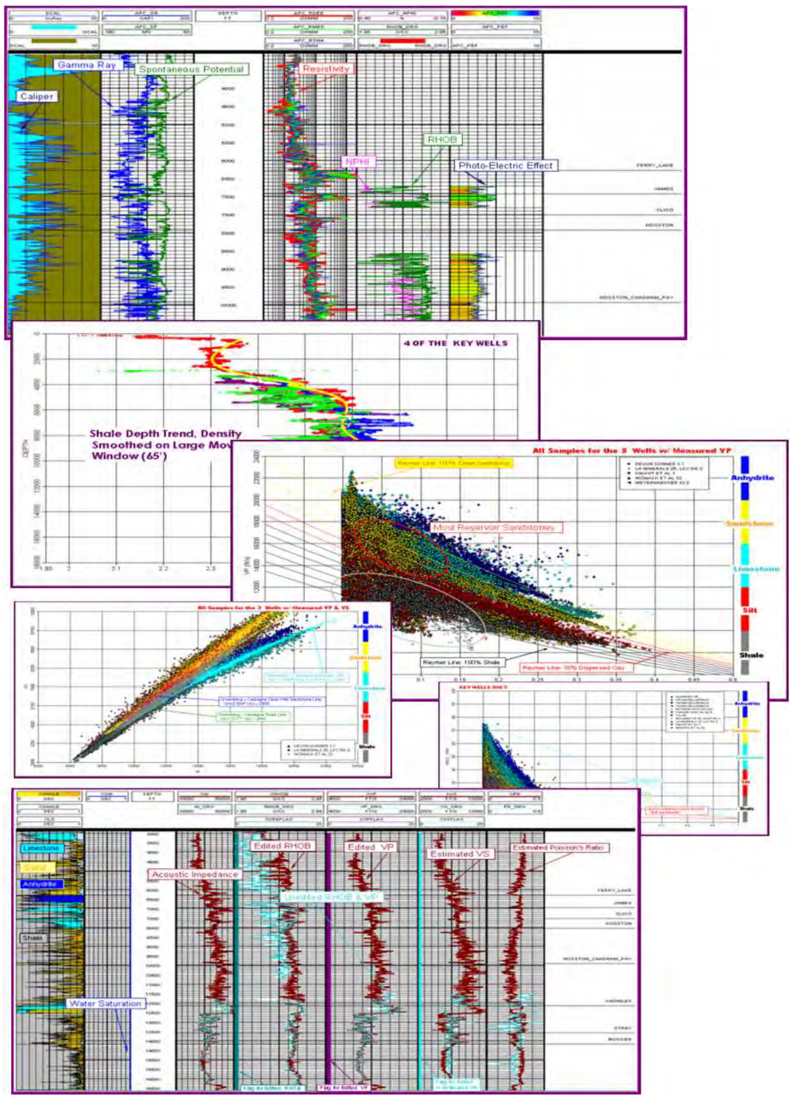


Rock Physics & Effective Medium Models

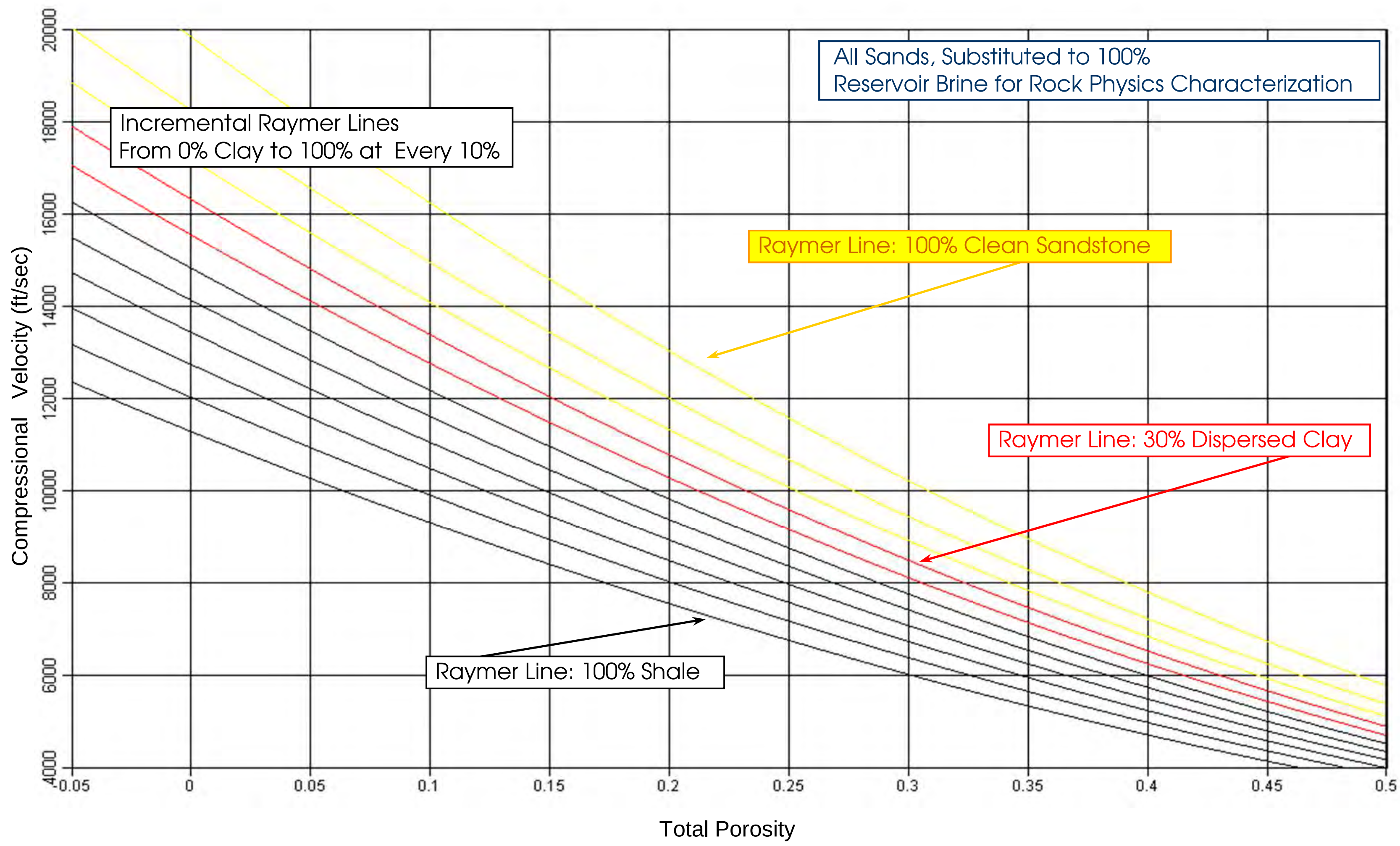
"All Models Are Wrong…"

"Some Are Useful"

Jack Dvorkin, Stanford University

QI Petrophysics

Total Porosity versus Compressional Velocity: “Raymer Plot”



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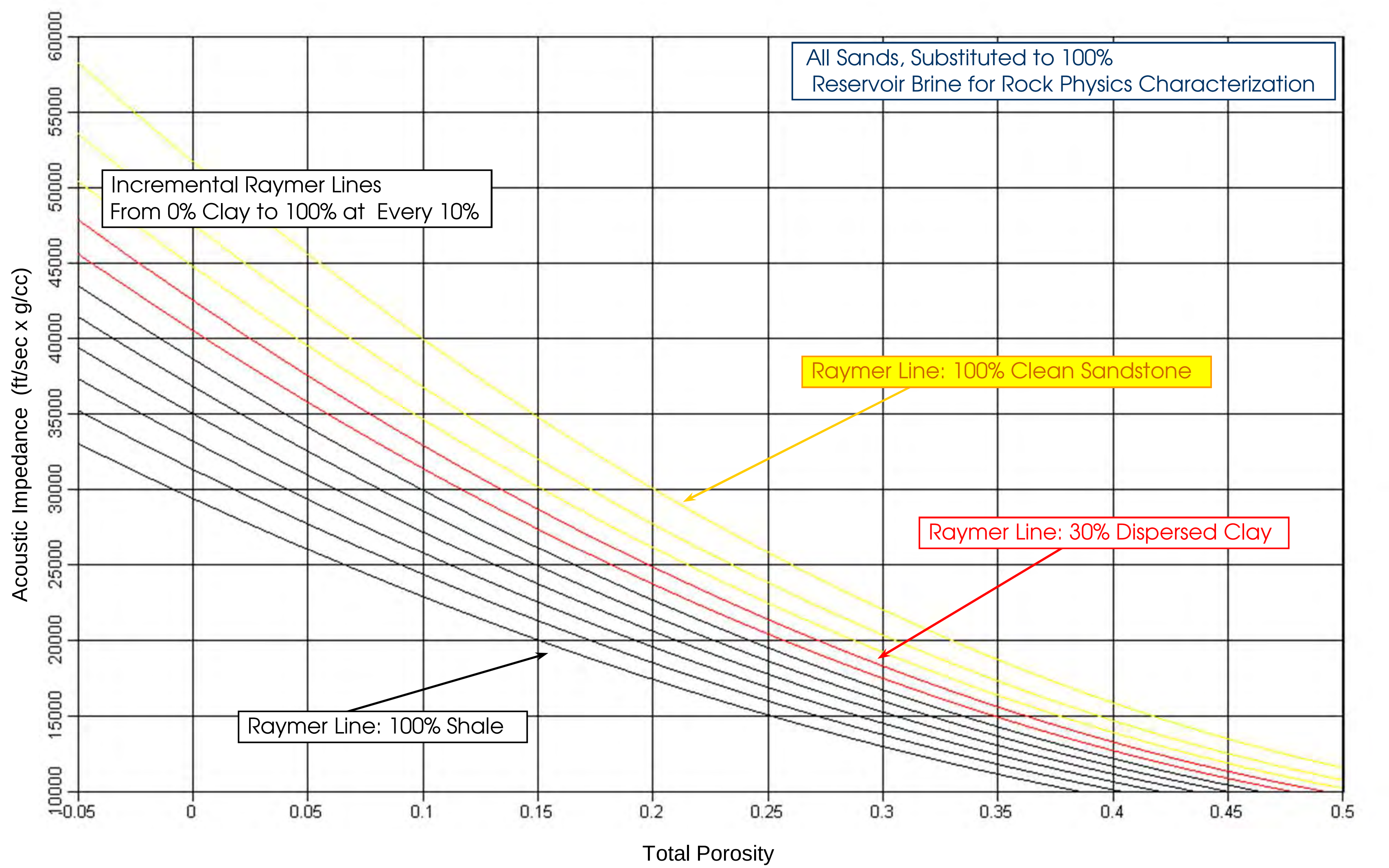
Total Porosity versus Acoustic Impedance: “Raymer Plot”



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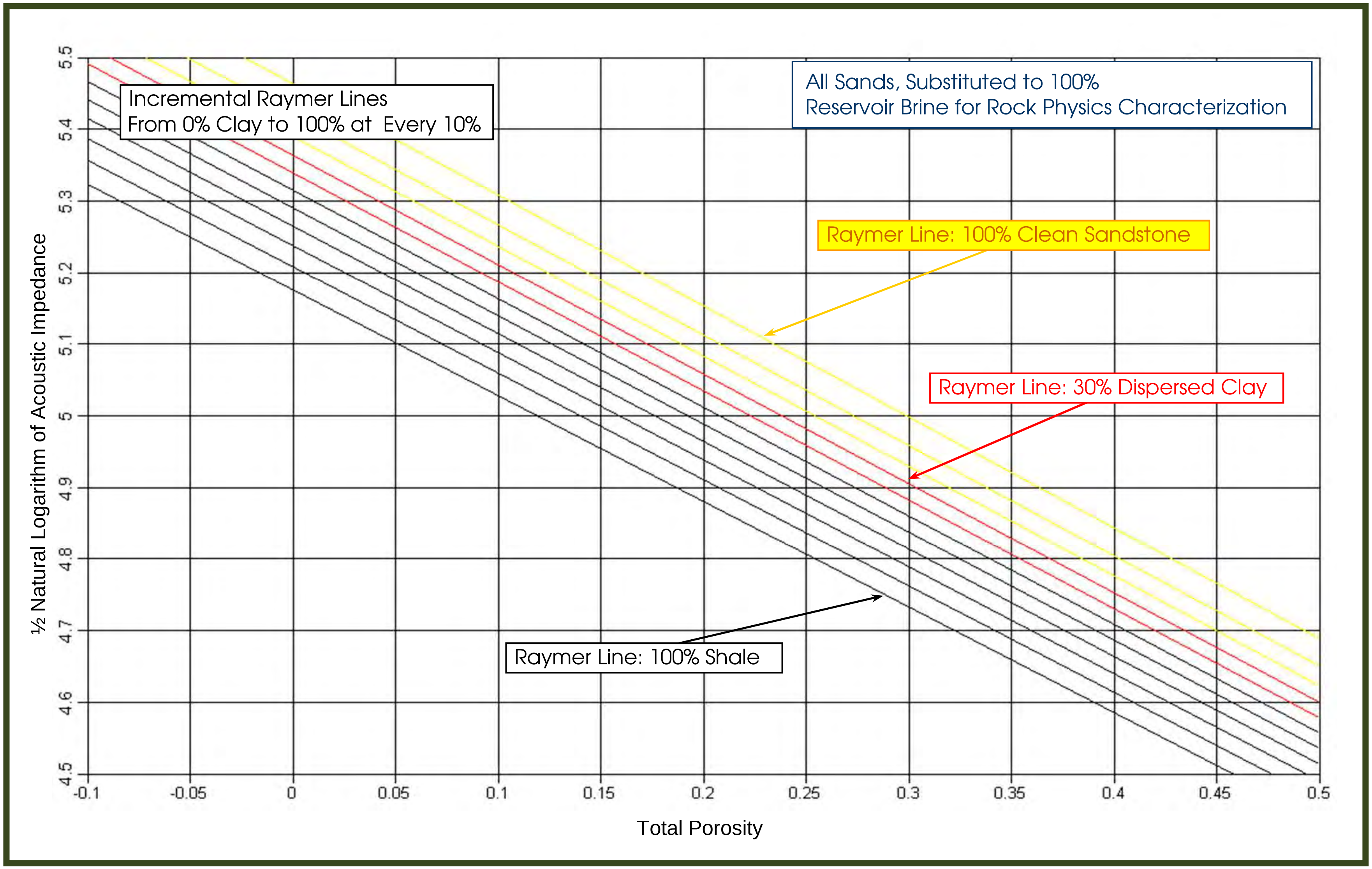
Total Porosity versus ½ ln Acoustic Impedance: “Raymer Plot”



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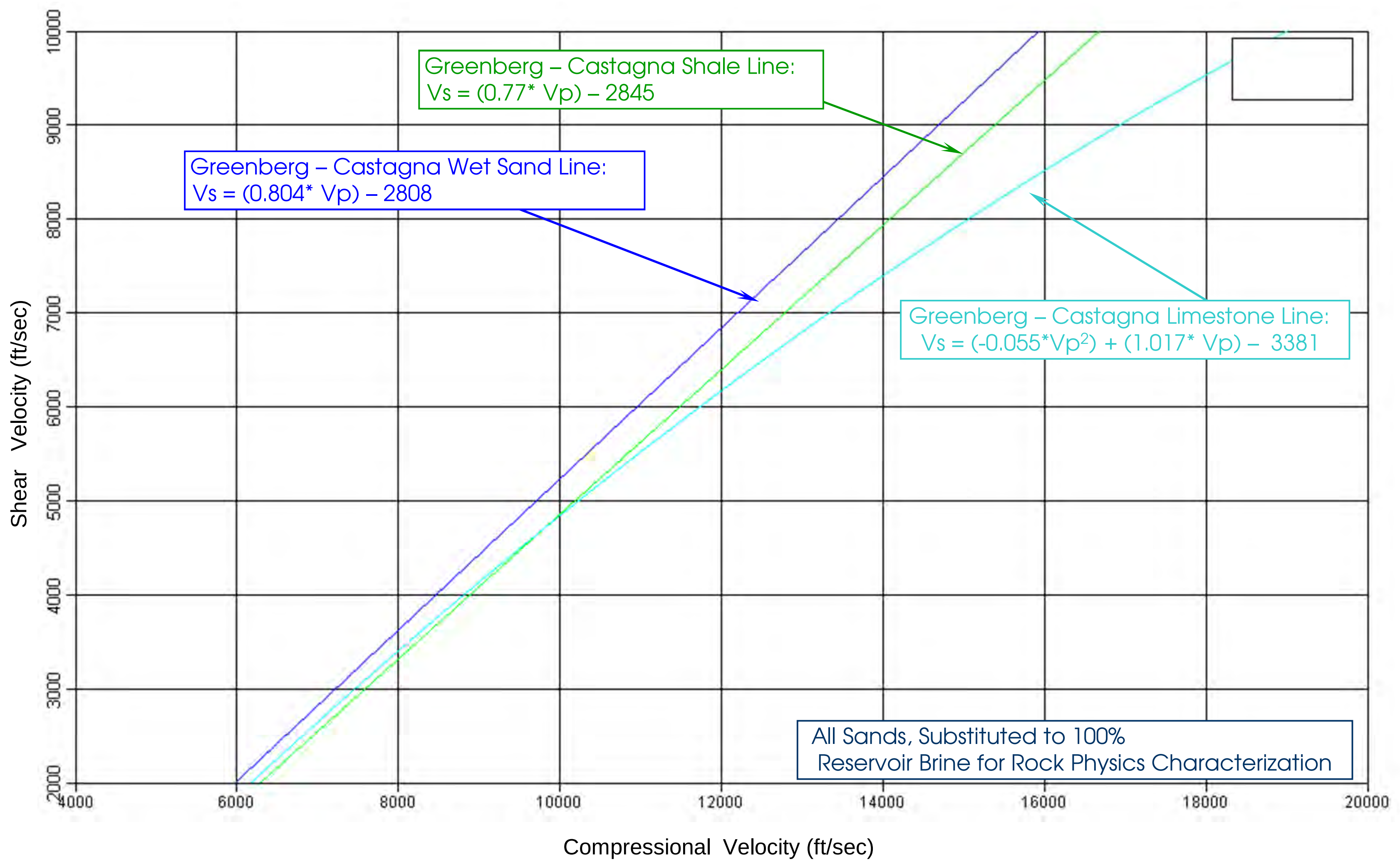
Compressional Velocity versus Shear Velocity



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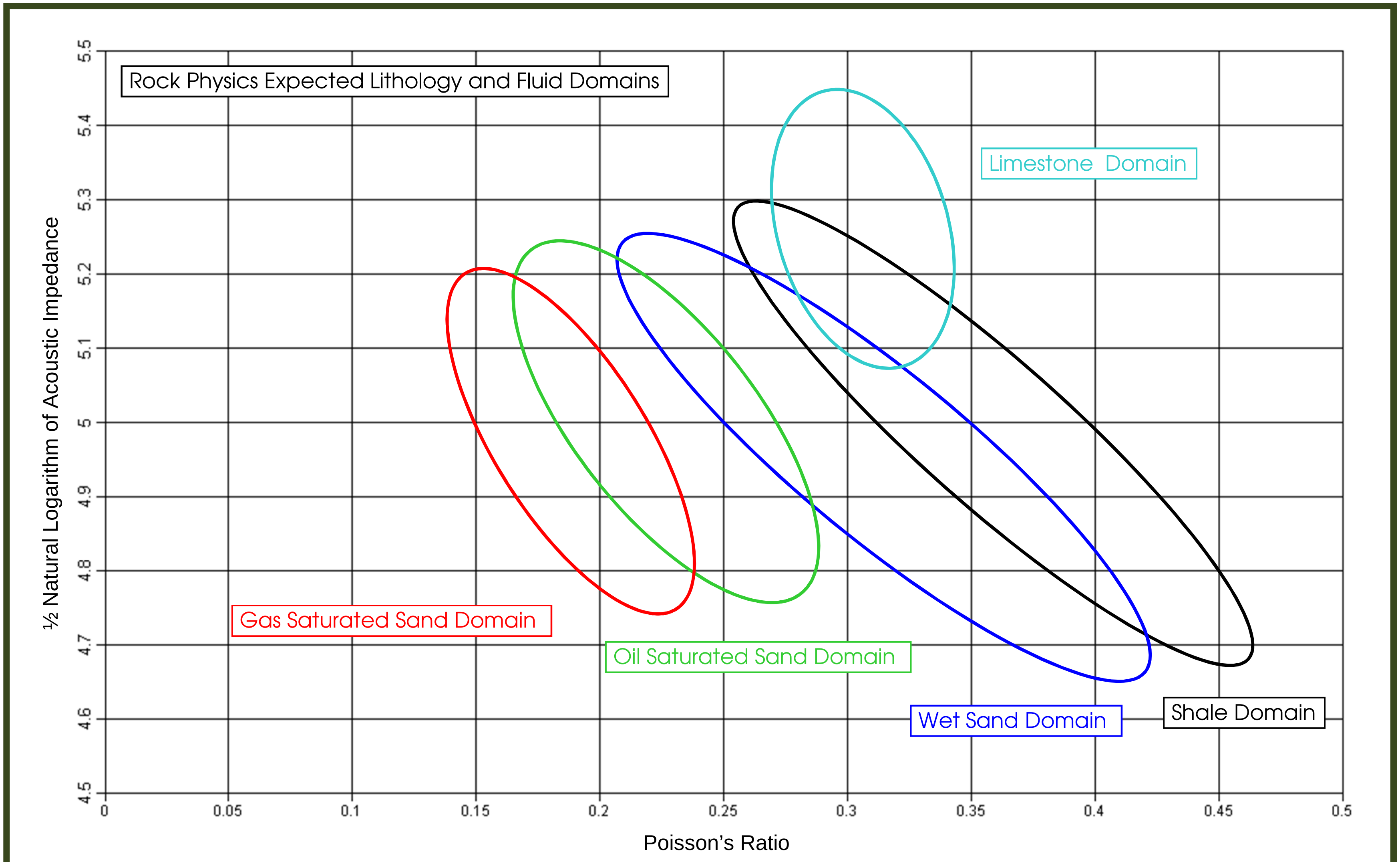
Poisson's Ratio versus ½ ln Acoustic Impedance



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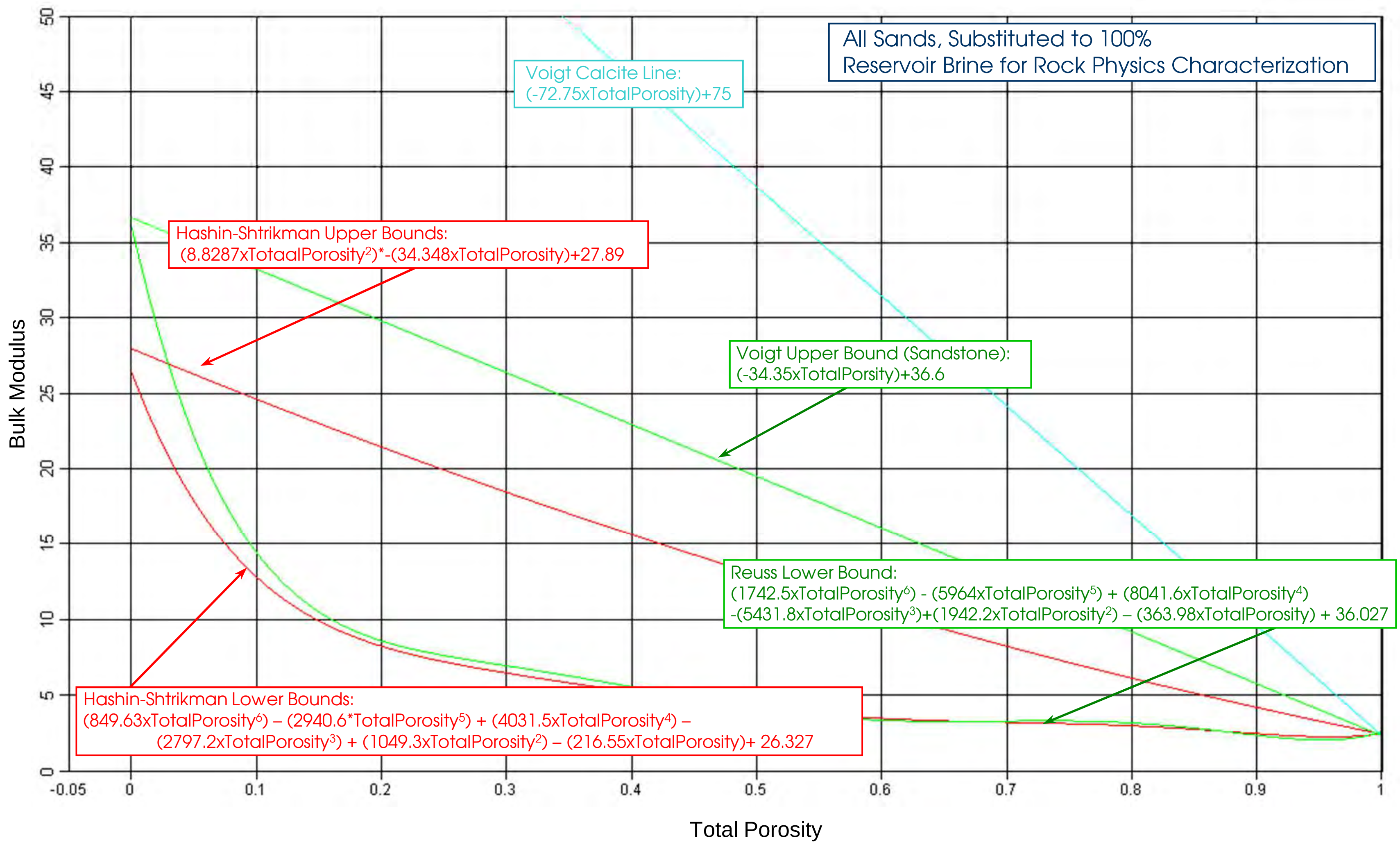
Total Porosity vs Bulk Modulus: Hashin-Shtrikman Cross-Plot



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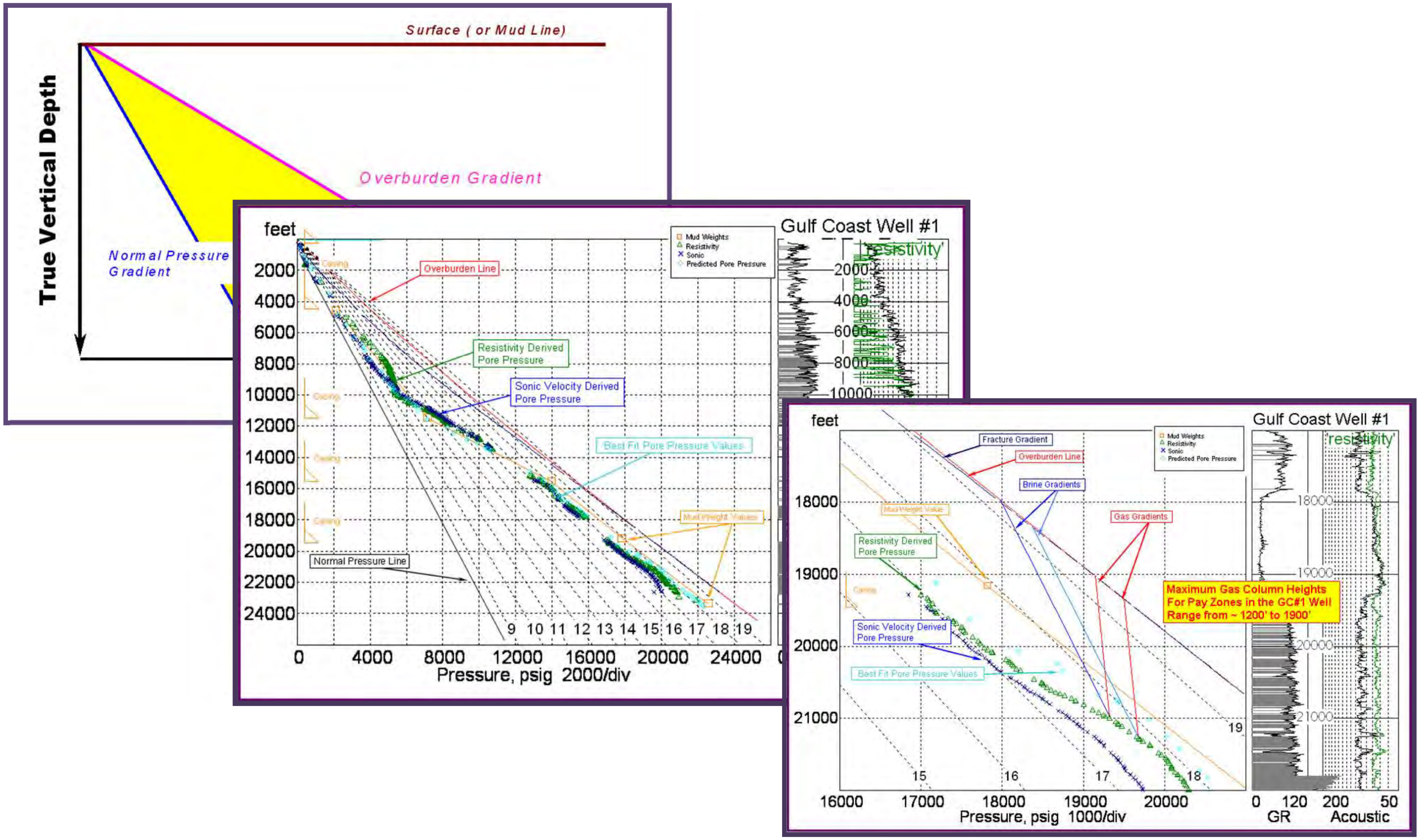
Abnormal Pore Pressure Evaluation



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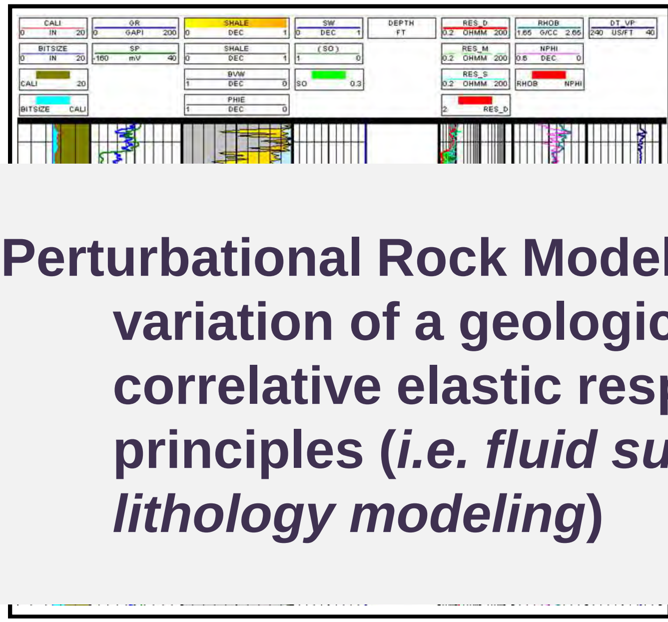
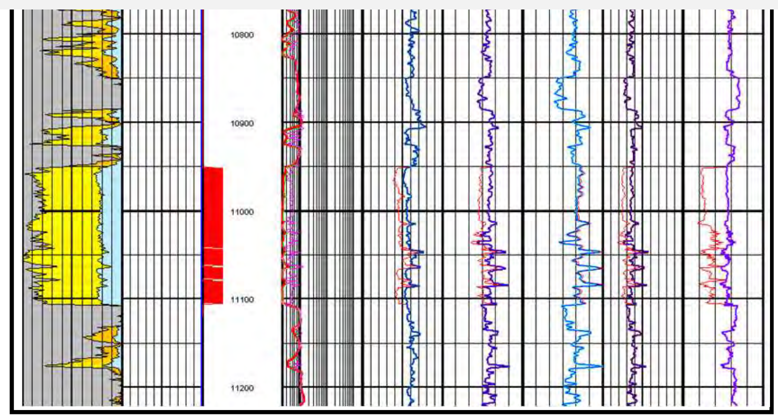
Perturbational Rock Modeling

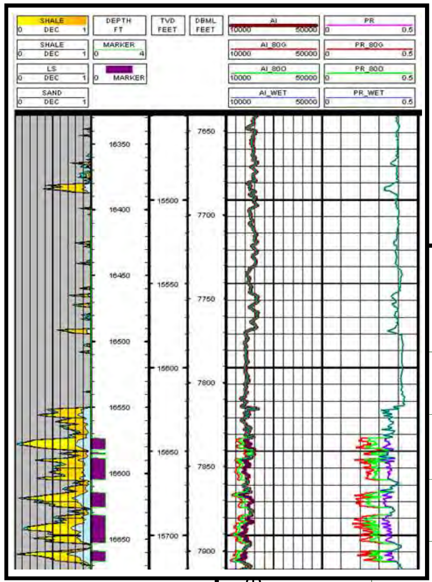


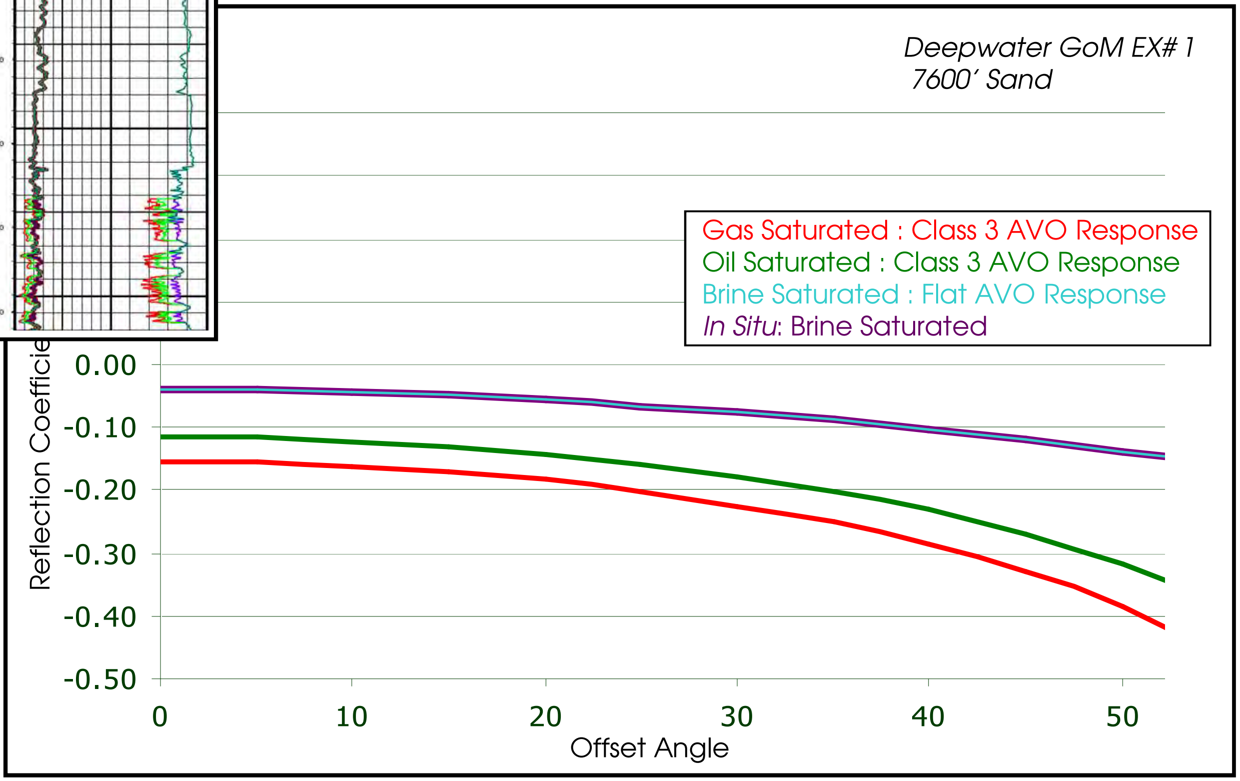
Perturbational Rock Modeling allows for the examination and variation of a geologically relevant property and the correlative elastic response based on rock physics principles (*i.e. fluid substitution, porosity modeling, or lithology modeling*)

Fluid Substitution



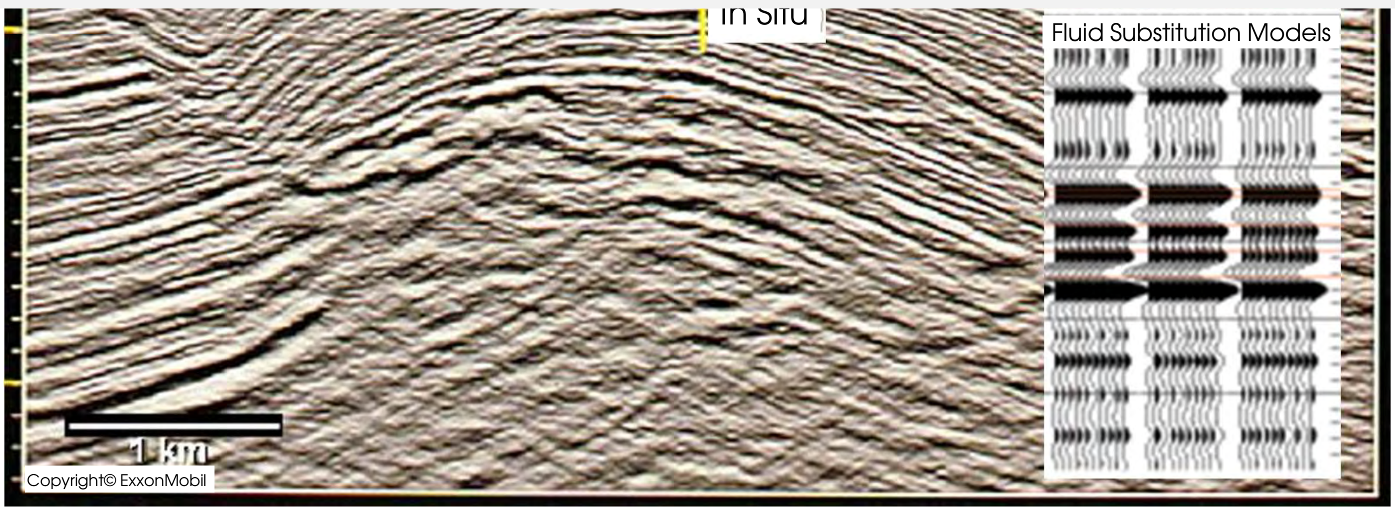
AVO Modeling and Analysis





Synthetic Seismic Forward Modeling

A main goal of Seismic Petrophysics is to produce a synthetic seismogram that will produce a robust representation of the subsurface in the acoustic and elastic domain. The unique *Seismic Petrophysics* workflows developed by QI, allow for consistent, robust well log data set that can be confidently applied for seismic reservoir characterization.



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Case Study South Louisiana

QI Petrophysics

Seismic Petrophysical Analysis, Rock Physics Modeling, and AVO Analysis

Onshore South Louisiana

Middle Miocene Sandstones

Study Scope

2 Wells Located Onshore South Louisiana *(SLA Wells 10-3 and 12-3)*

1.) Formation Evaluation and Seismic Petrophysical Analysis to Derive a Robust *In Situ* Density, Compressional Velocity, and Shear Velocity, Using the Modern Well #1 ST1 to Constrain the Modeling

2.) Rock Physics Models for Fluid Substitution in Middle Miocene Sandstones

3.) Rock Properties and AVO Analysis of Middle Miocene Sandstones

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Evaluation of Previous Work

Onshore Southern Louisiana

Middle Miocene Sandstones

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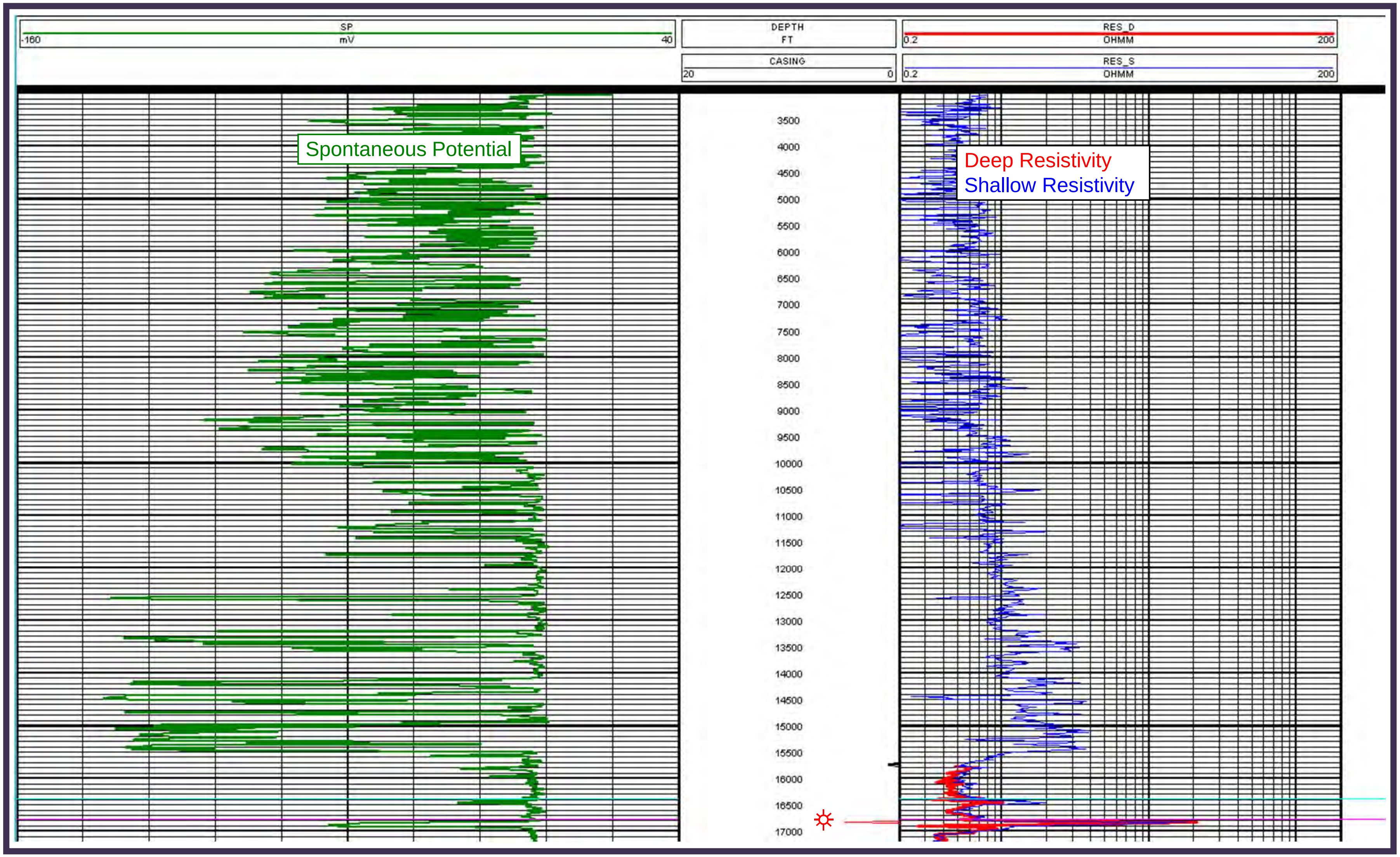
Data Inventory

Common Well Name	Year Drilled-Logged	Depth Range - MD (ft)	Original Well Log Curves
SLA 10-3 ☼	1964	3006 – 17,210	Spontaneous Potential, Shallow Resistivity: **3006 ft – 17,210 ft** Deep Resistivity: **15,765 ft – 17,210 ft**
SLA 12-3 ⌖	1963	3000 – 18,140	Spontaneous Potential, Deep and Shallow Resistivity: **3000 ft – 18,140 ft**
Modern Well #1 ST1 ⌖	2007	3900 – 16,750	*LWD ONLY: Gamma Ray, Multiple Resistivity Curves*: **3900 ft – 13,300 ft** Gamma Ray, Caliper, Multiple Resistivity Curves, Neutron Porosity, Density, Compressional and Shear Velocities: **13,300 ft – 16,750 ft**

Original Curves: SLA 10-3



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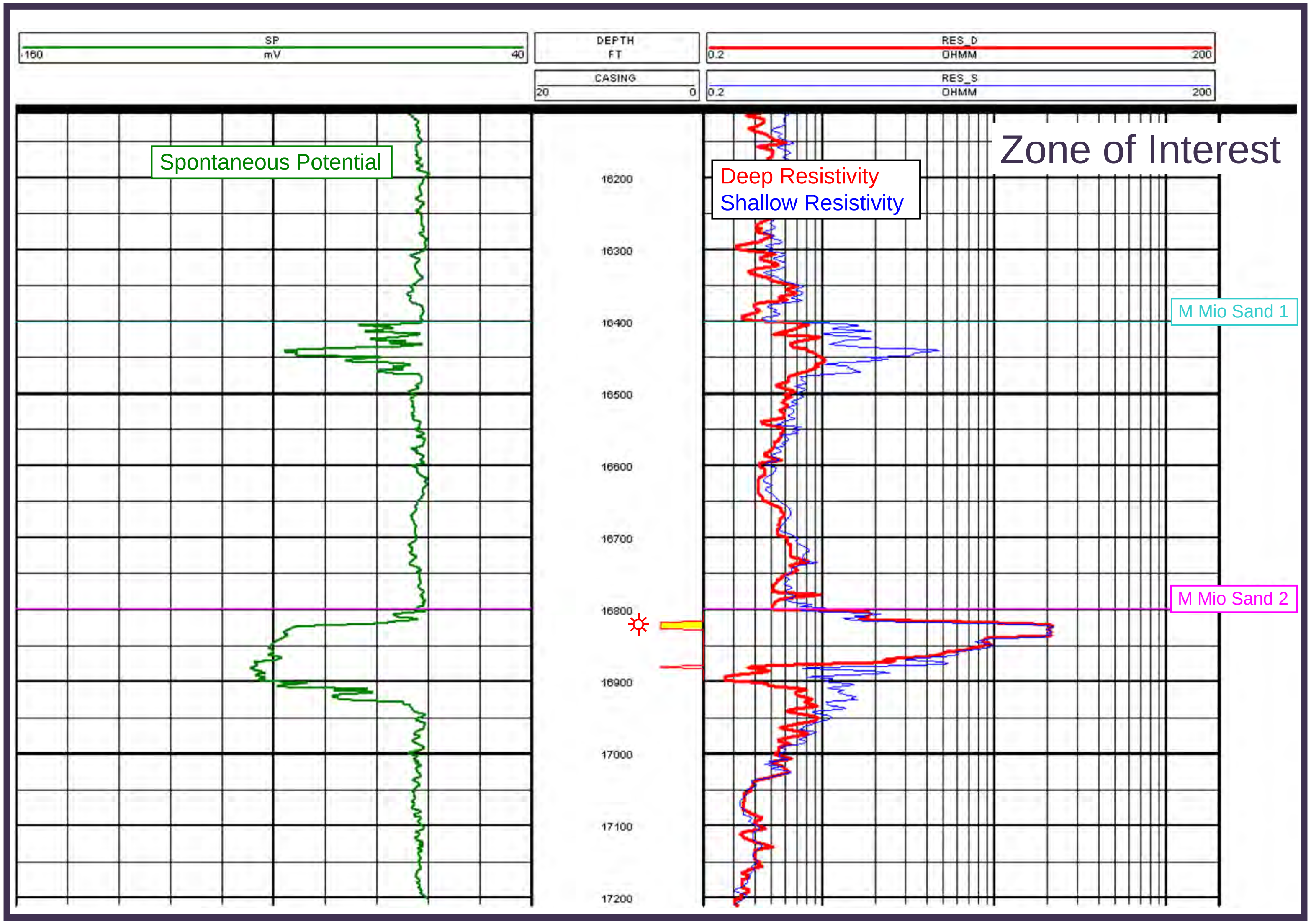
Original Curves: SLA 10-3



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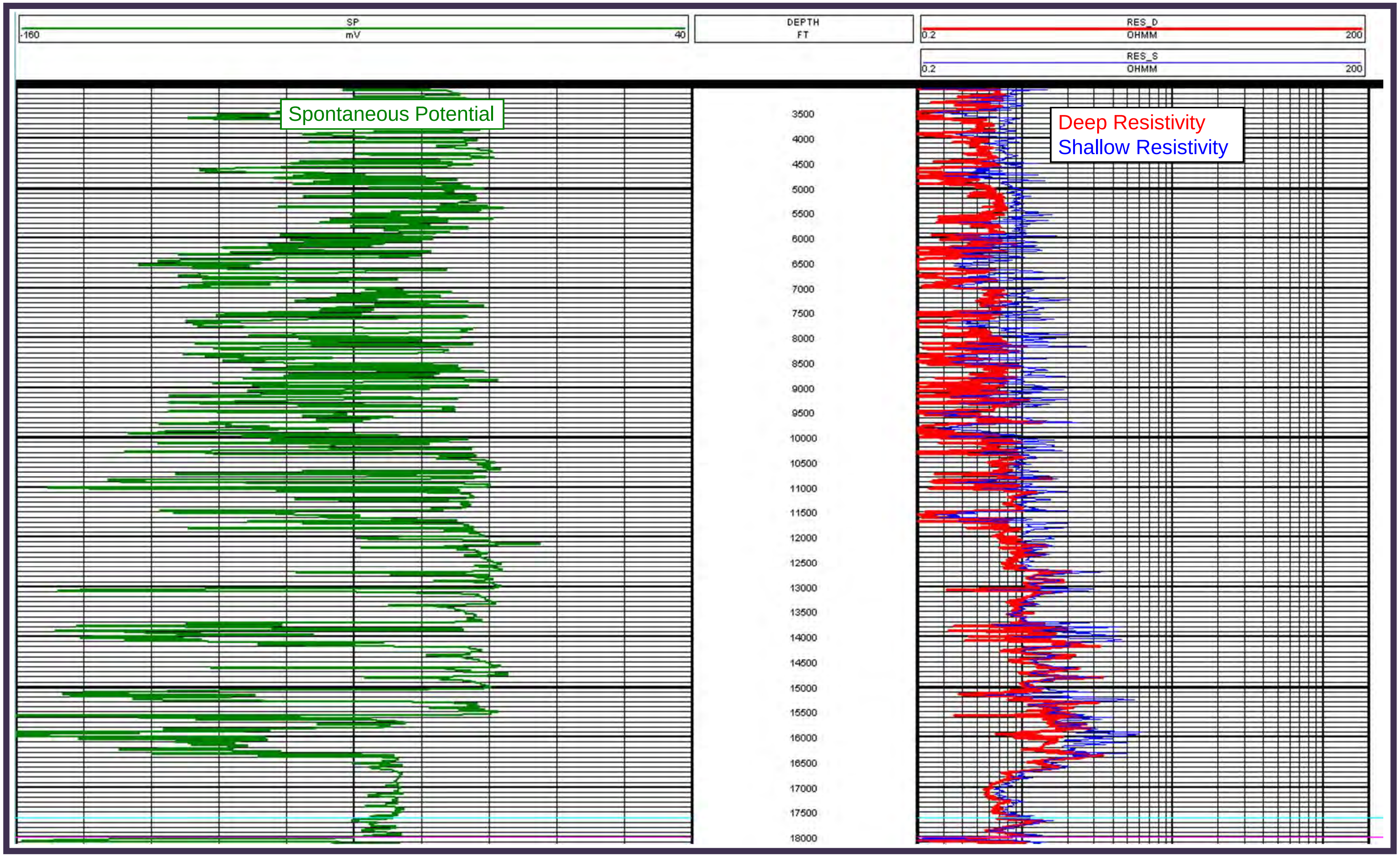
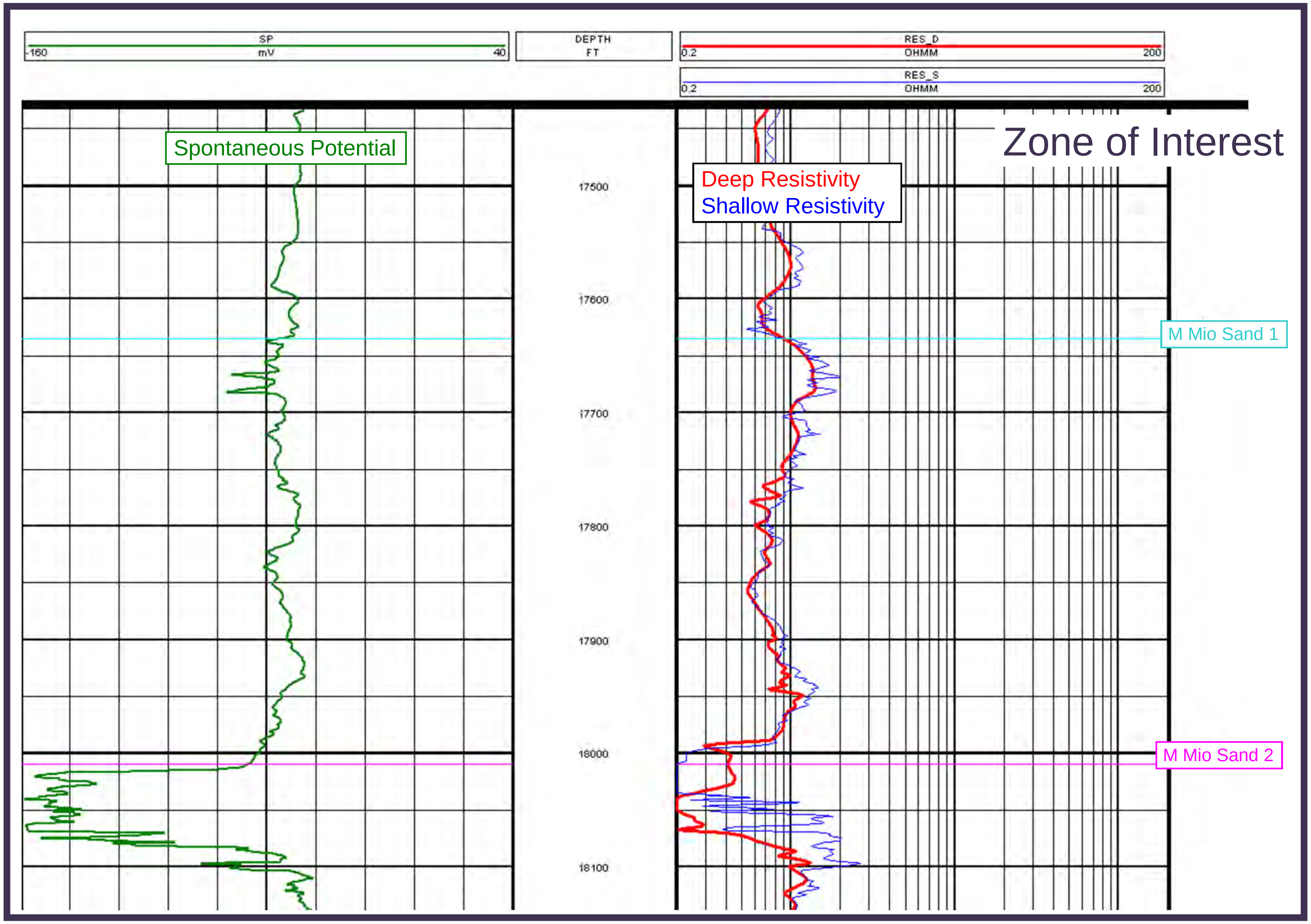
Original Curves: SLA 12-3



Original Curves: SLA 12-3



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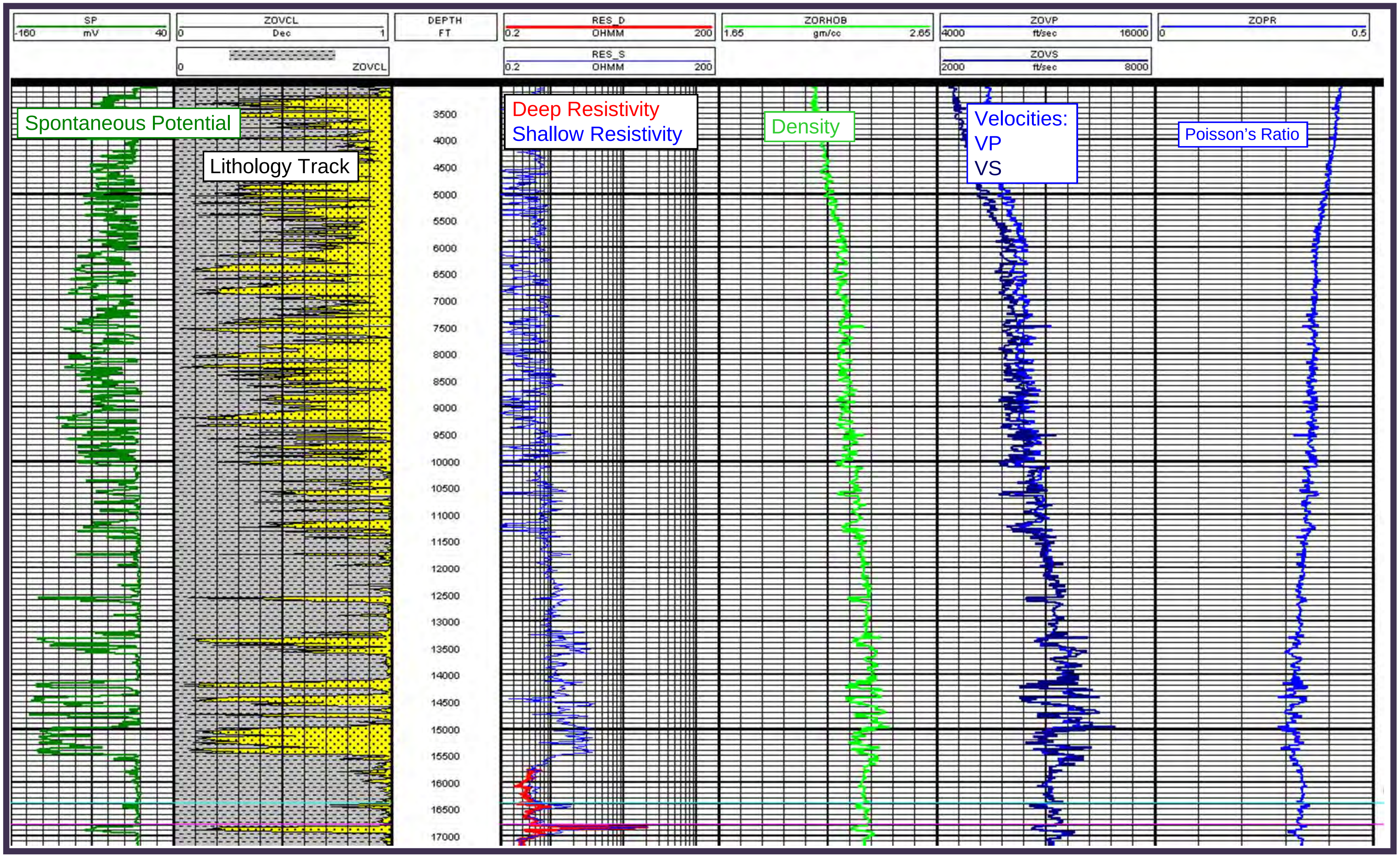
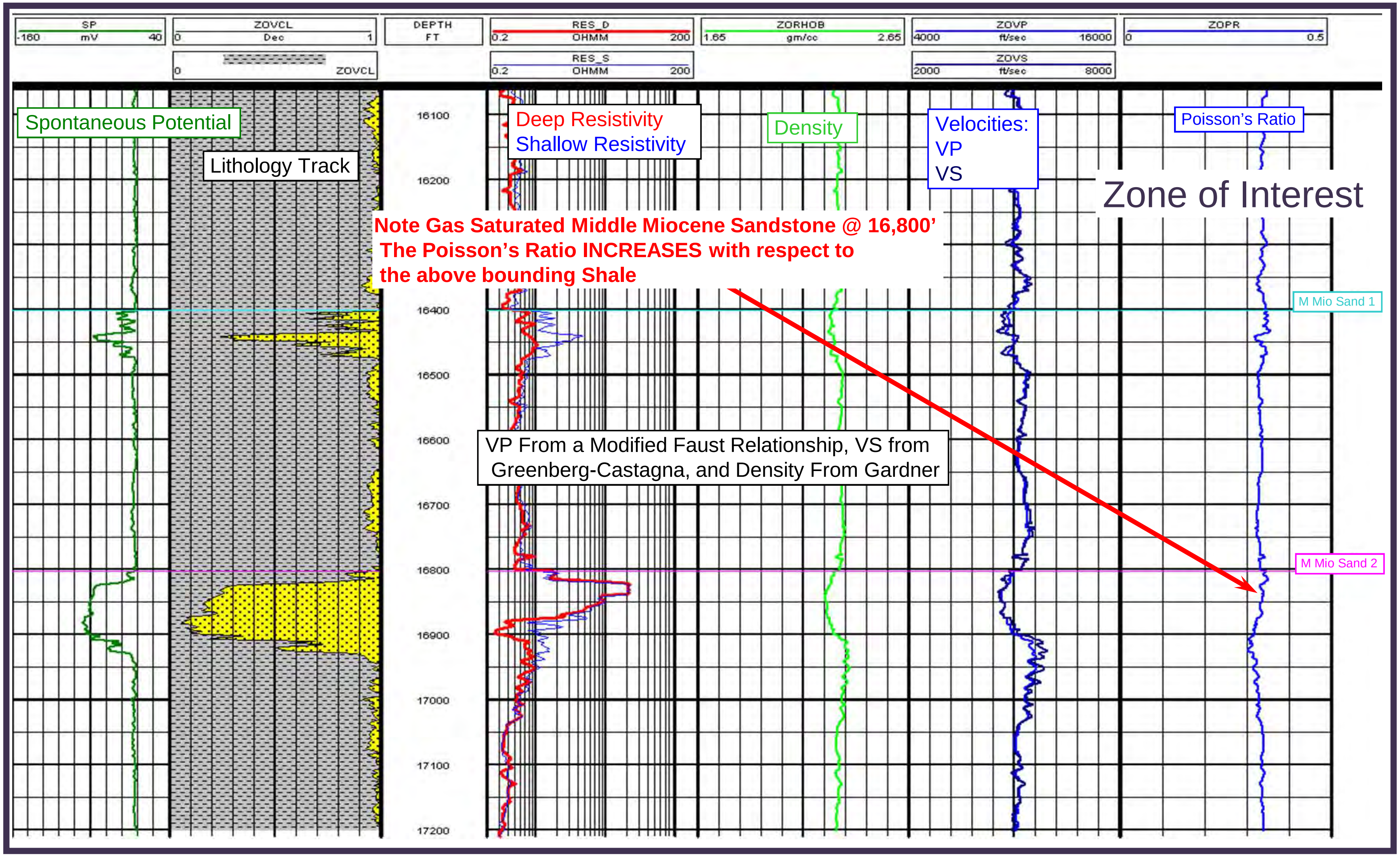
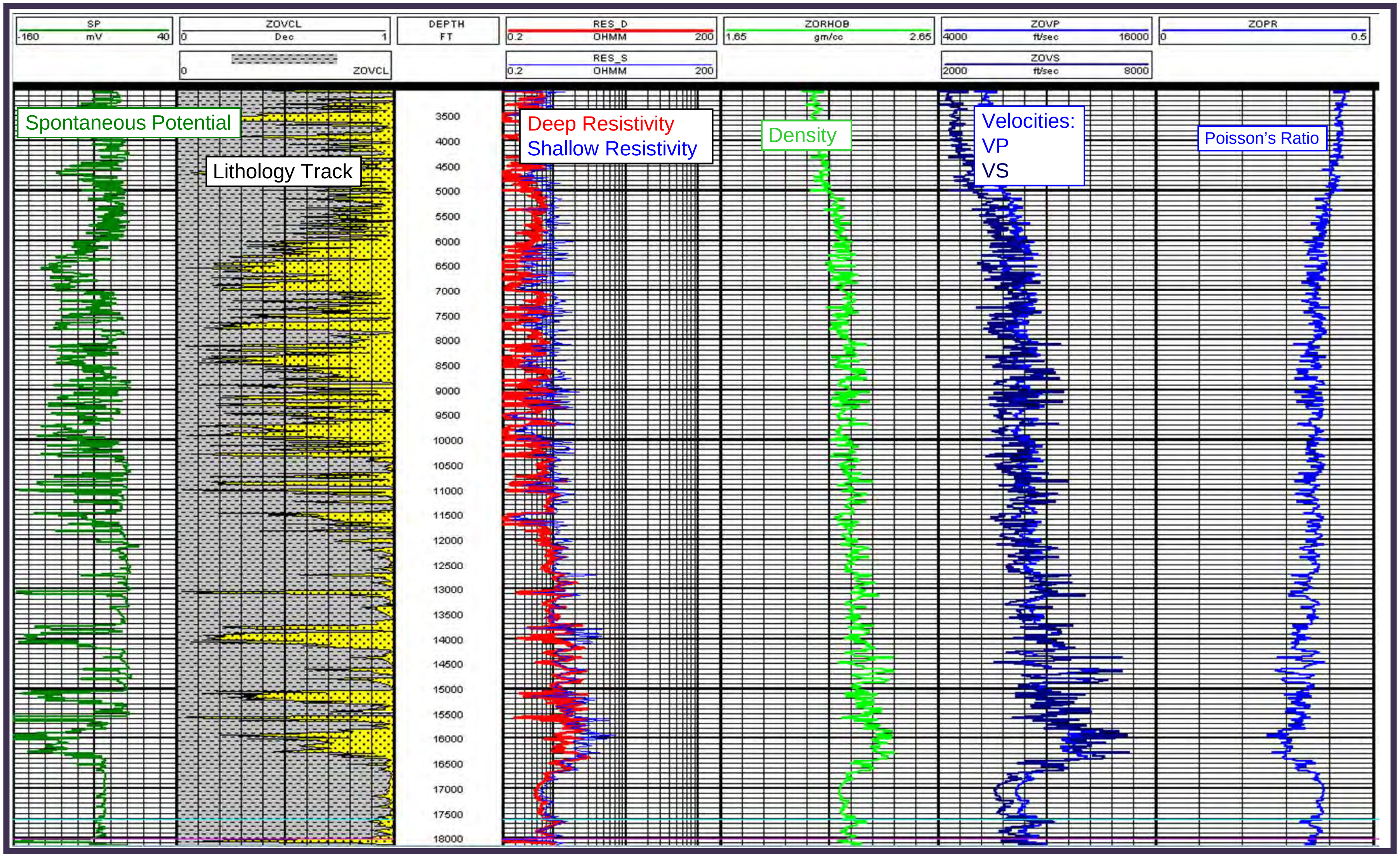
Petrophysical Analysis Provided By *Typical Inversion Company*: SLA 10-3



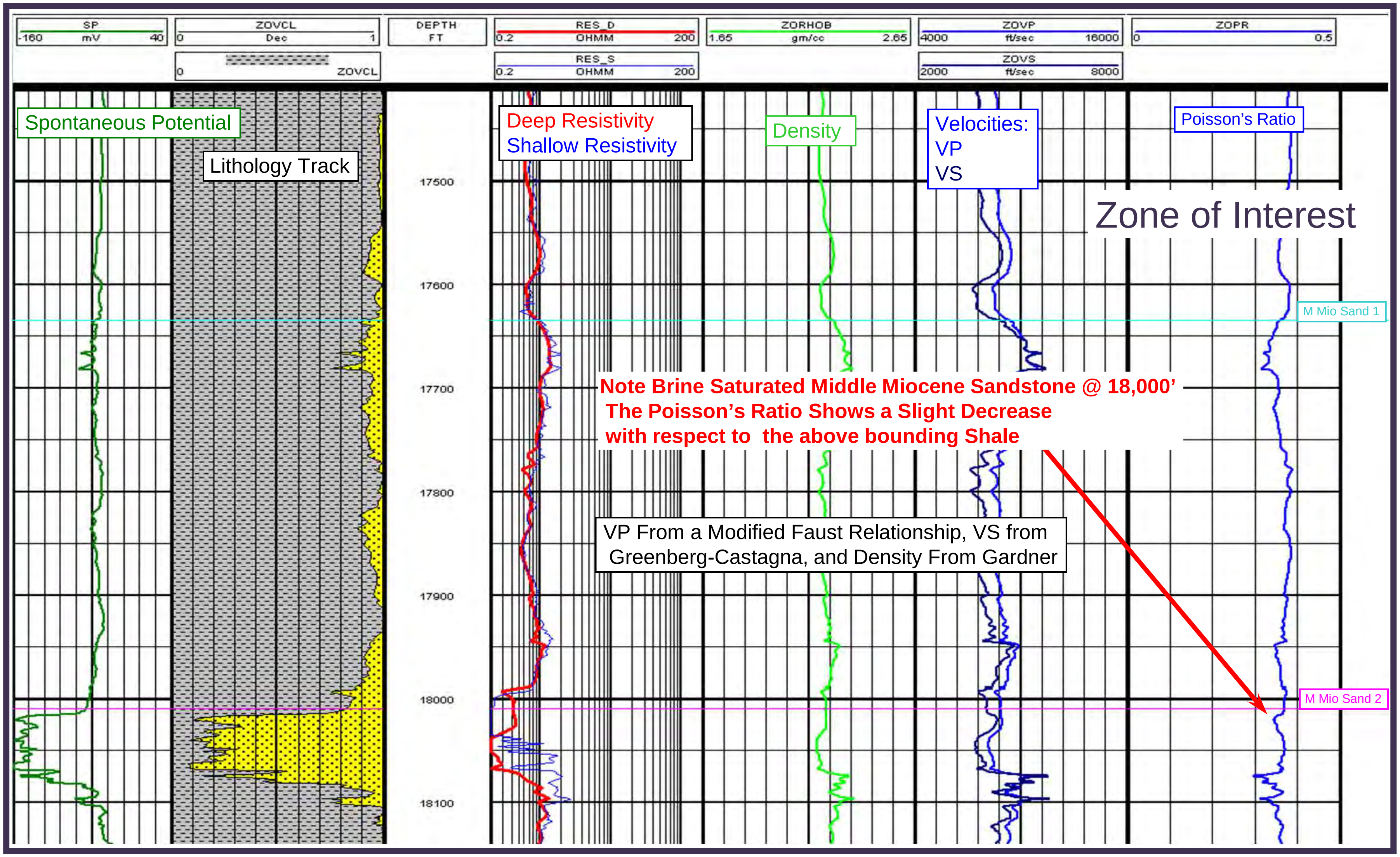
Petrophysical Analysis Provided By *Typical Inversion Company*: SLA 10-3



Petrophysical Analysis Provided By *Typical Inversion Company*: SLA 12-3



Petrophysical Analysis Provided By
Typical Inversion Company: SLA 12-3



Petrophysics

Petrophysical Analysis Provided By
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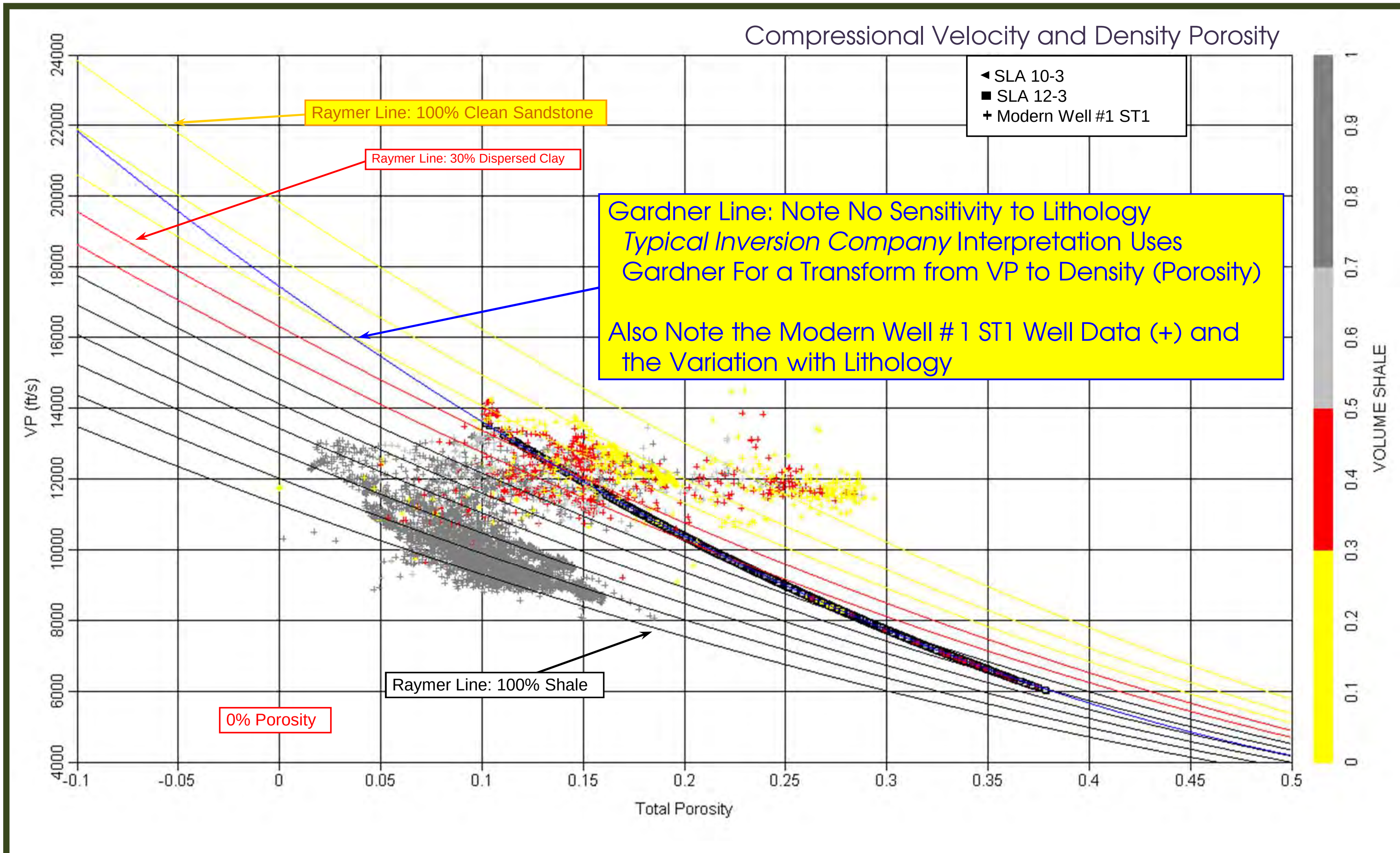

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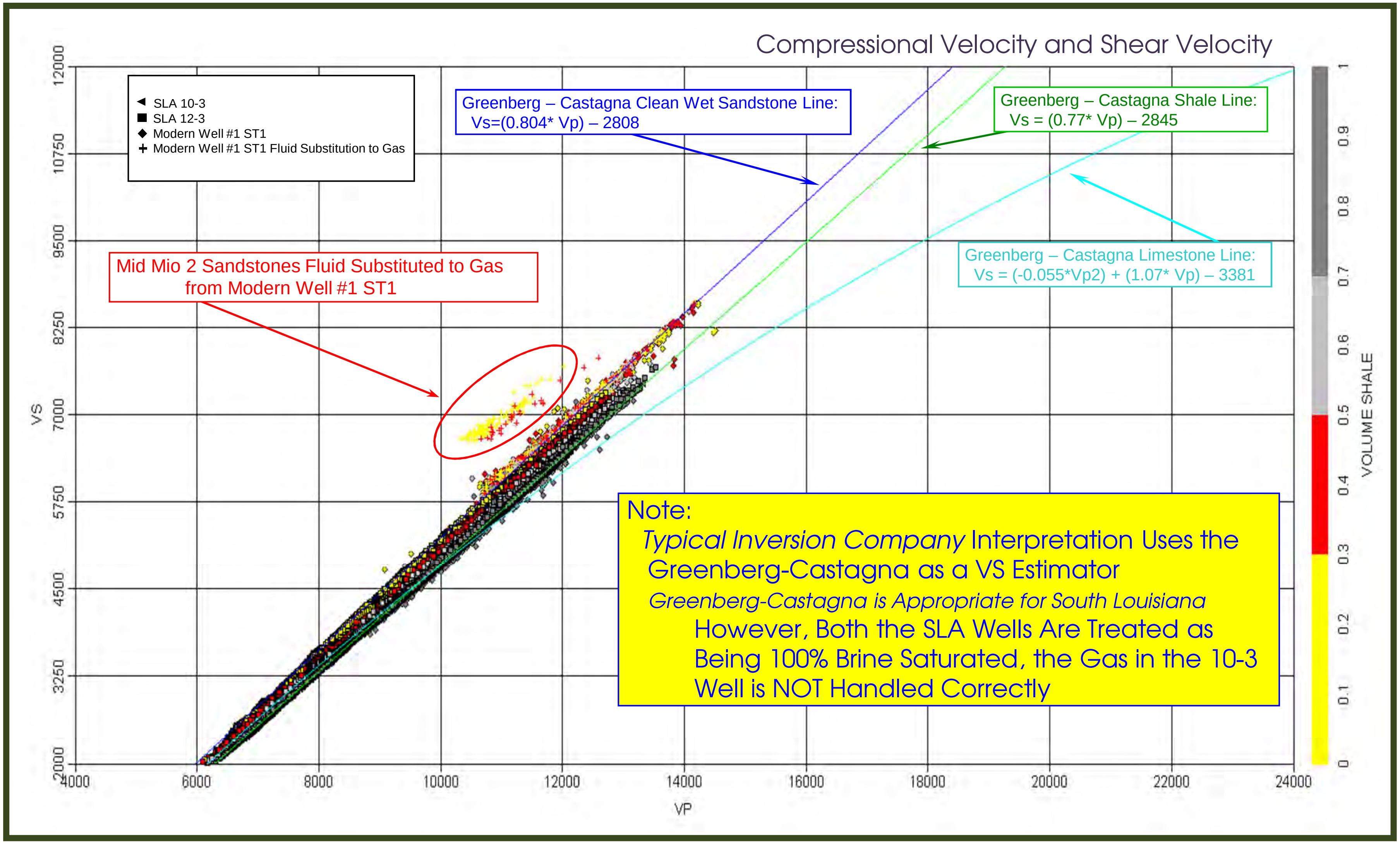
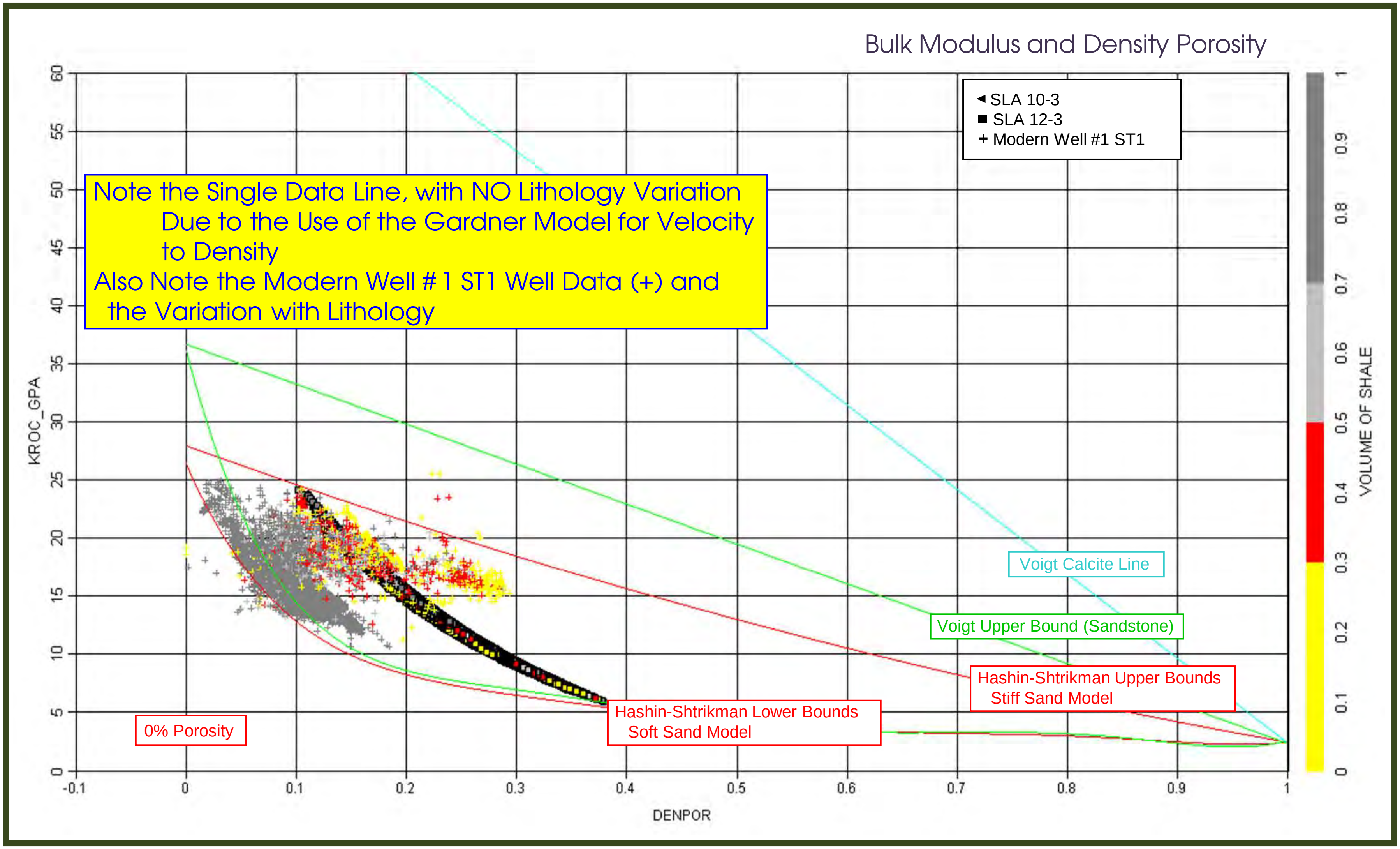


Petrophysical Analysis Provided By
Typical Inversion Company



QI Petrophysics

Summary of Previous Analysis

- **Examined Wireline Logs from the SLA Unit, and Integrated SLA Modern Well #1 ST1 to Analyze Petrophysical and Elastic Response**
- **Wireline Logs from 3 Wells Examined Middle Miocene Sand Zone of Interest**
  1. **Modern #1 ST1** (*2007, Brine Saturated Middle Miocene Sands*)
  2. **SLA Unit 10-3** (*1964, Gas Saturated Middle Miocene Sands*)
  3. **SLA Unit 12-3** (*1963, Brine Saturated Middle Miocene Sands*)
- **Typical Inversion Company Analysis:**

  Lithology Interpretation Consistent with South Louisiana Geology
  VP Estimated with a Modified Faust Relationship
  RHOB Estimated from Gardner (Single Relationship Regardless of Lithology or Fluid)
  VS Estimated from VP Using Greenberg-Castagna (Hydrocarbons Mishandled)

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Rock Properties Characterization:

Examine Petrophysical Variation and Elastic Response, Replace Poor or Missing Values with the Values from the Most Appropriate Effective Medium Model

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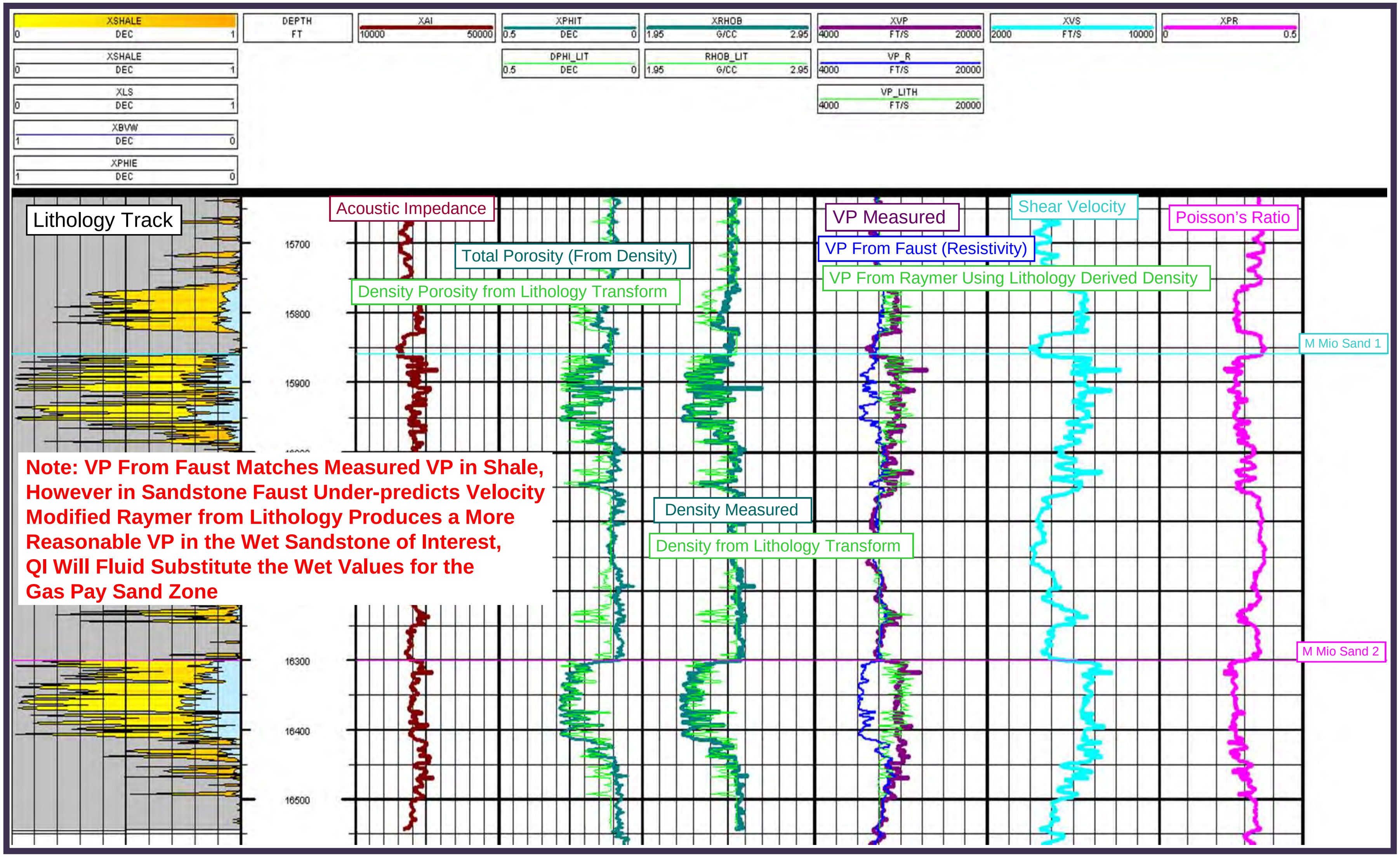
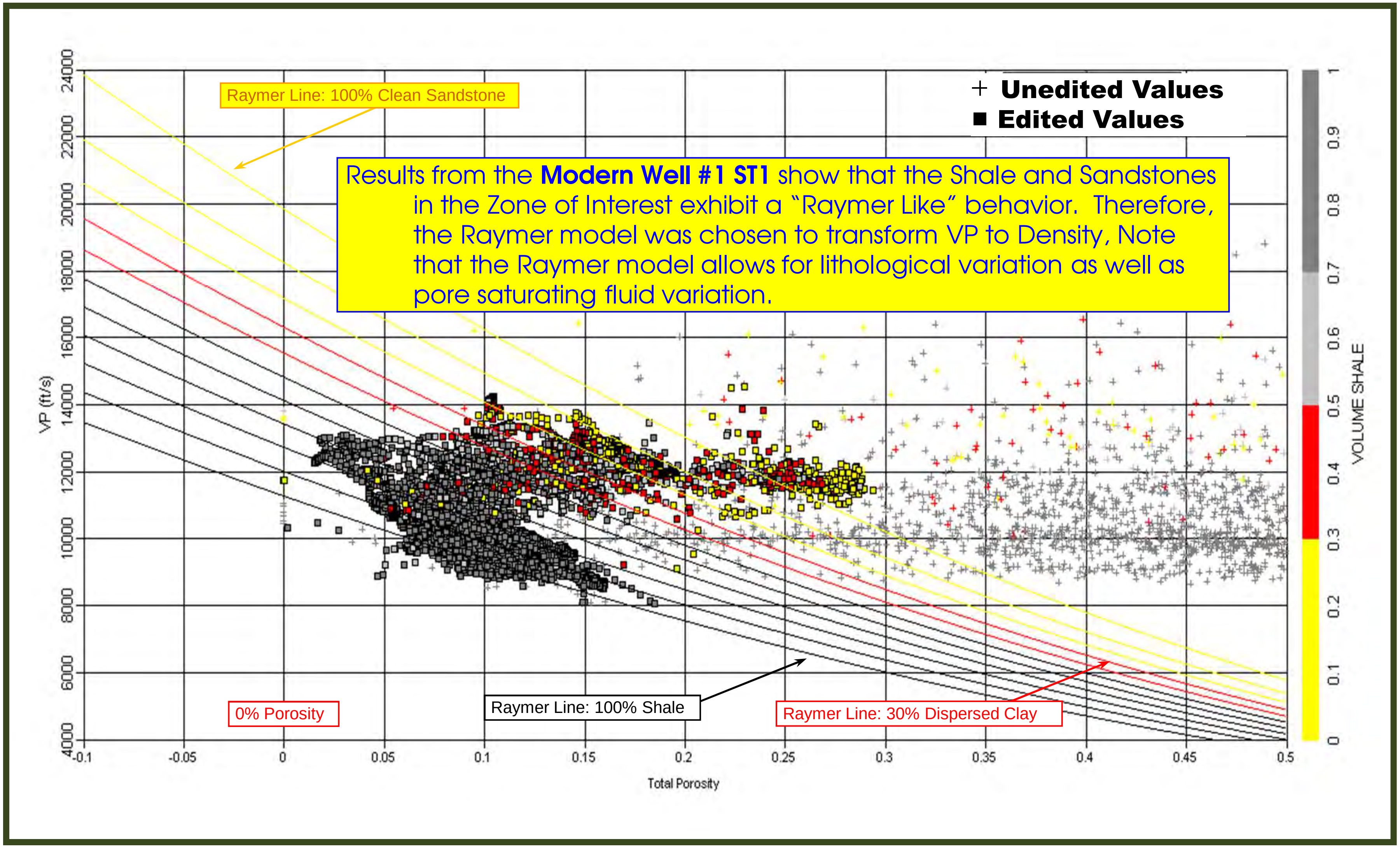
Velocity and Resistivity: Modern Well #1 ST1

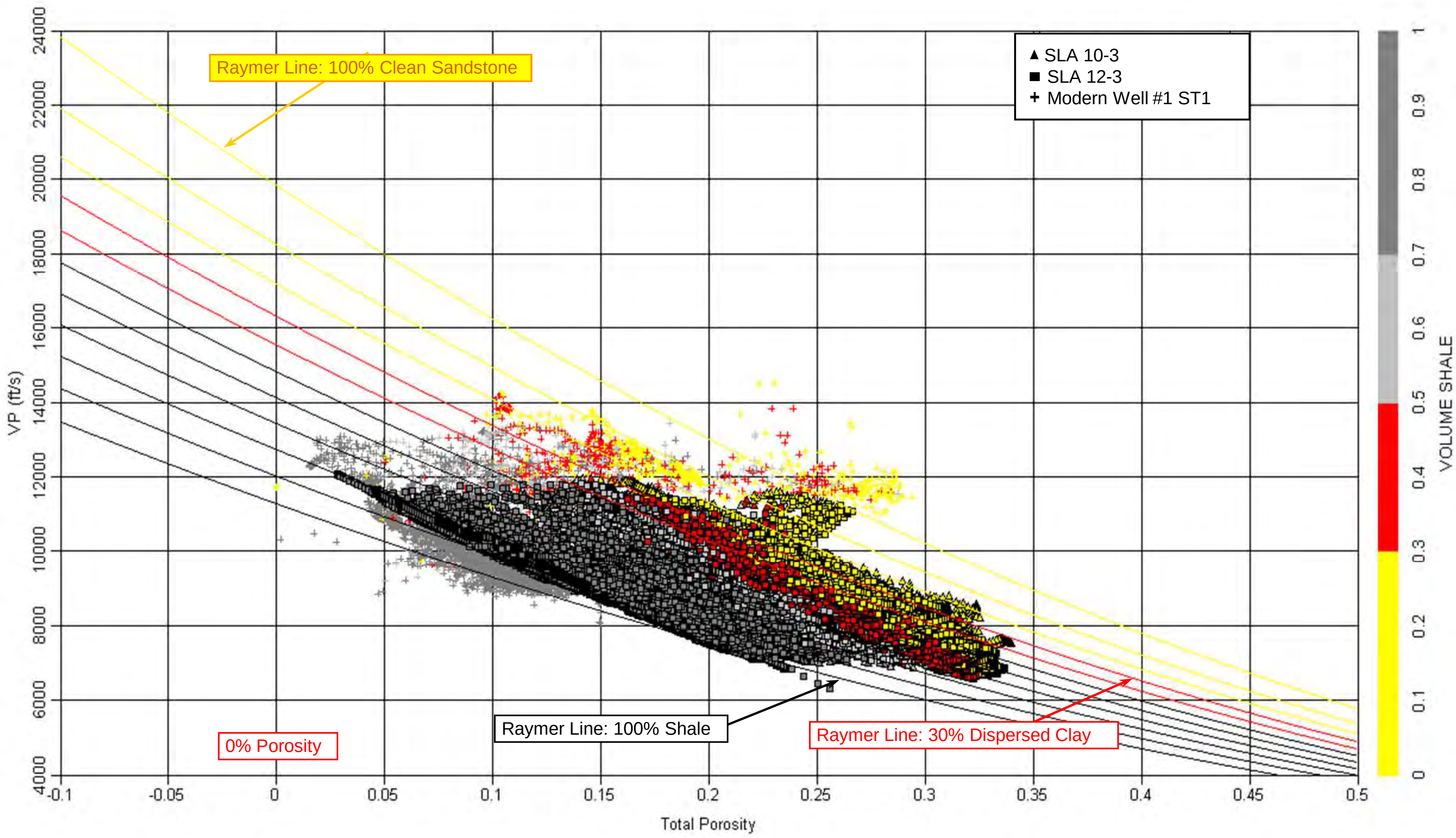


Velocity and Porosity: Modern Well #1 ST1

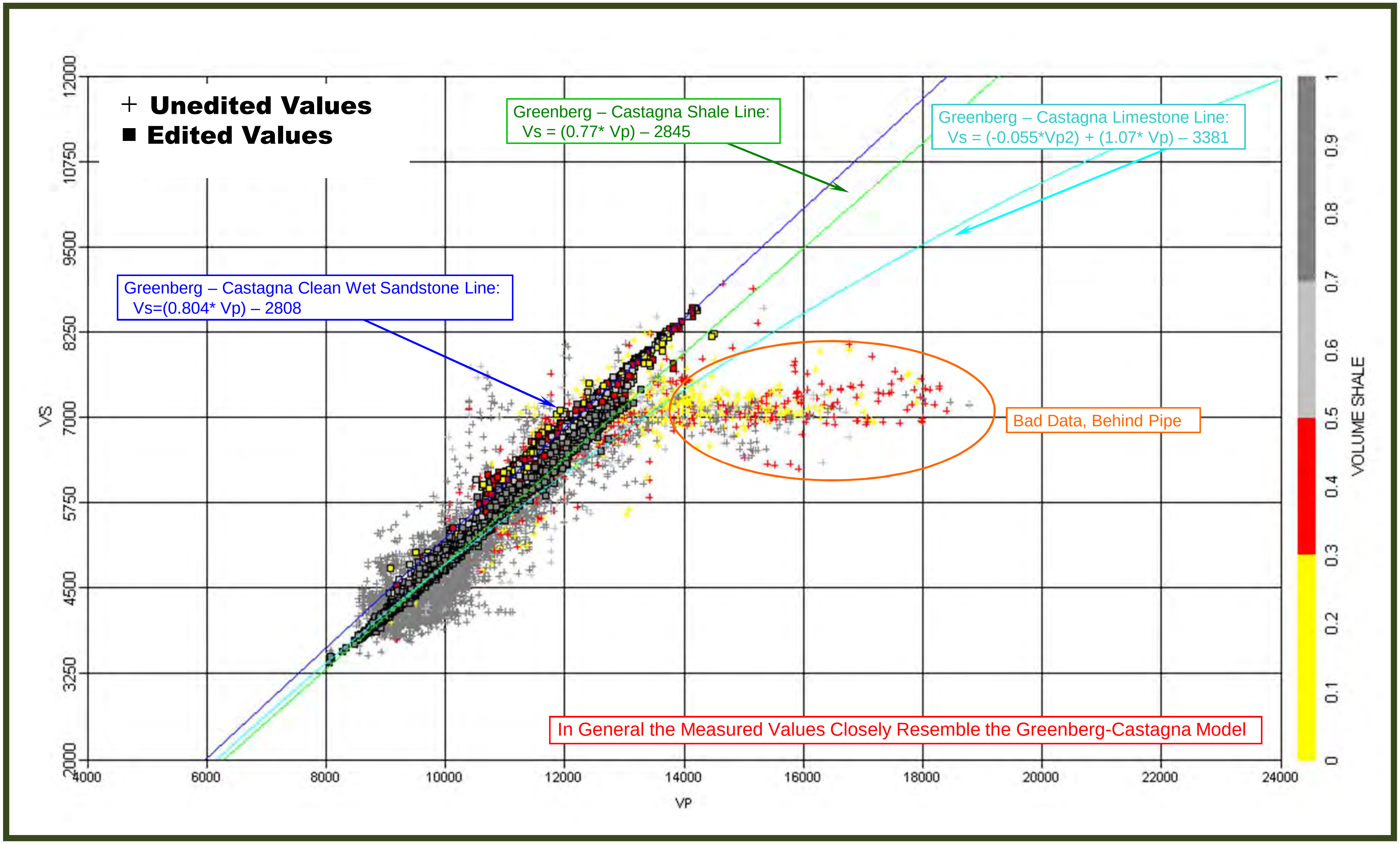


QI Petrophysics

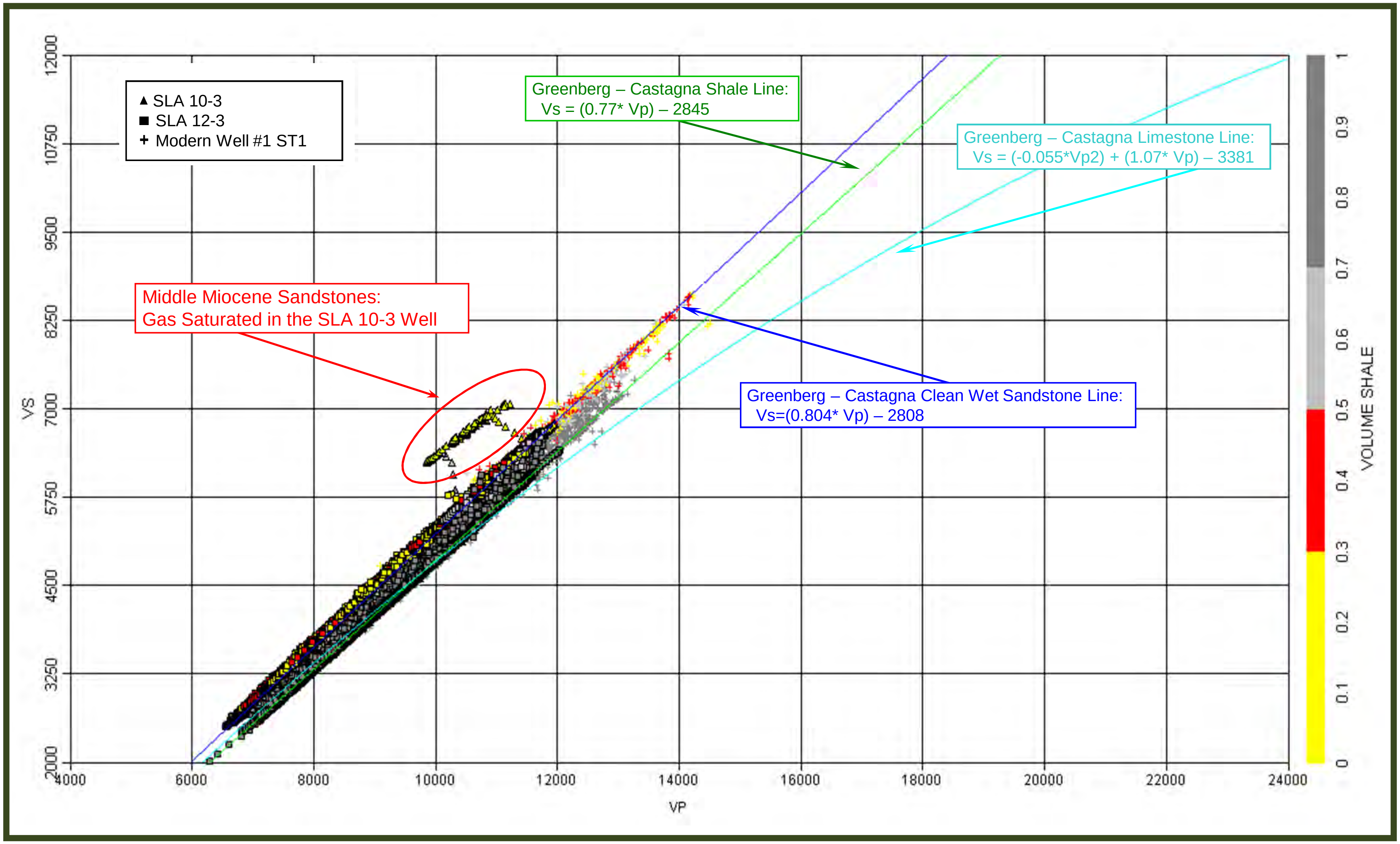
Edited Velocity and Porosity



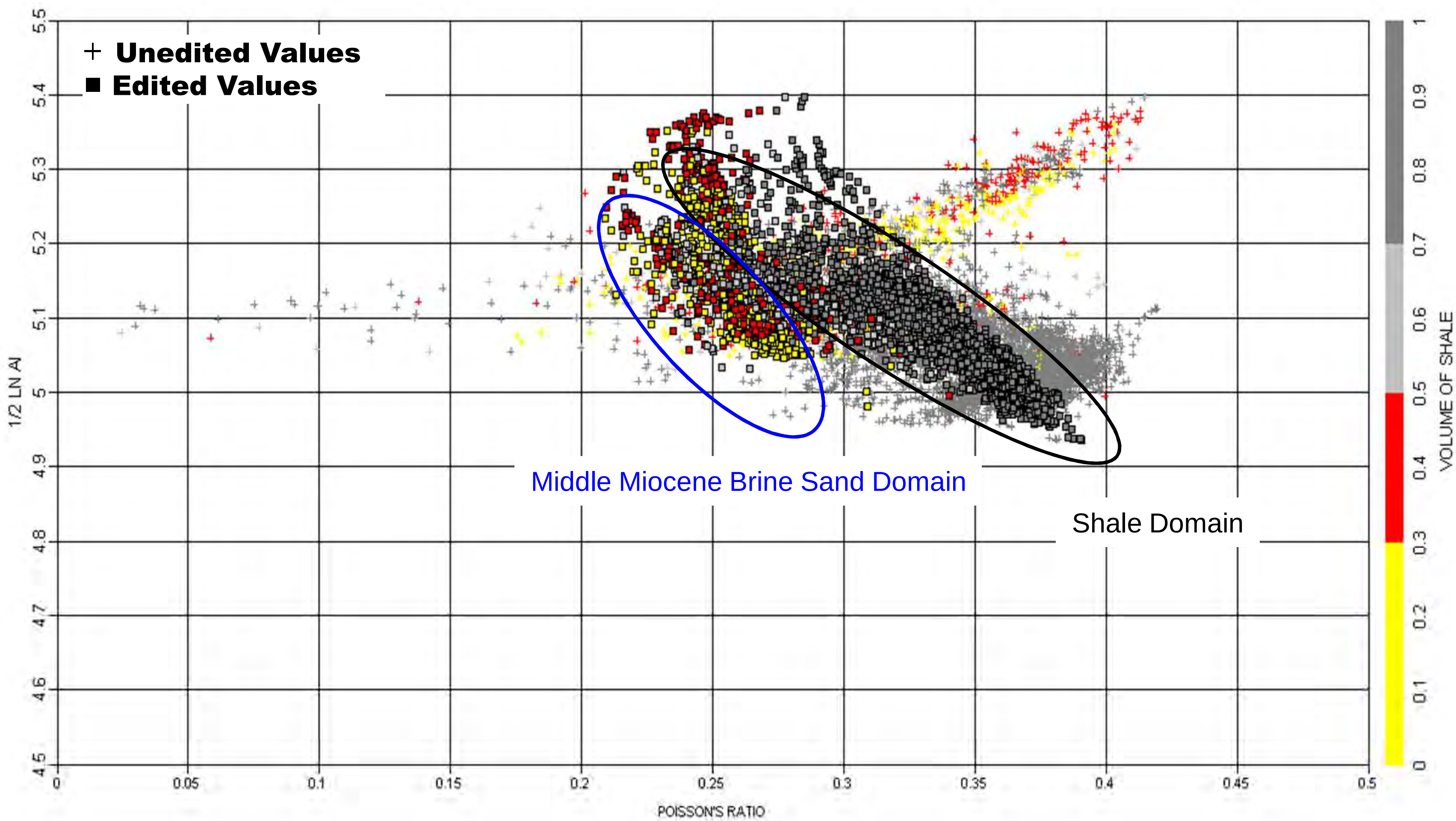
Compressional and Shear Velocities Modern Well #1 ST1



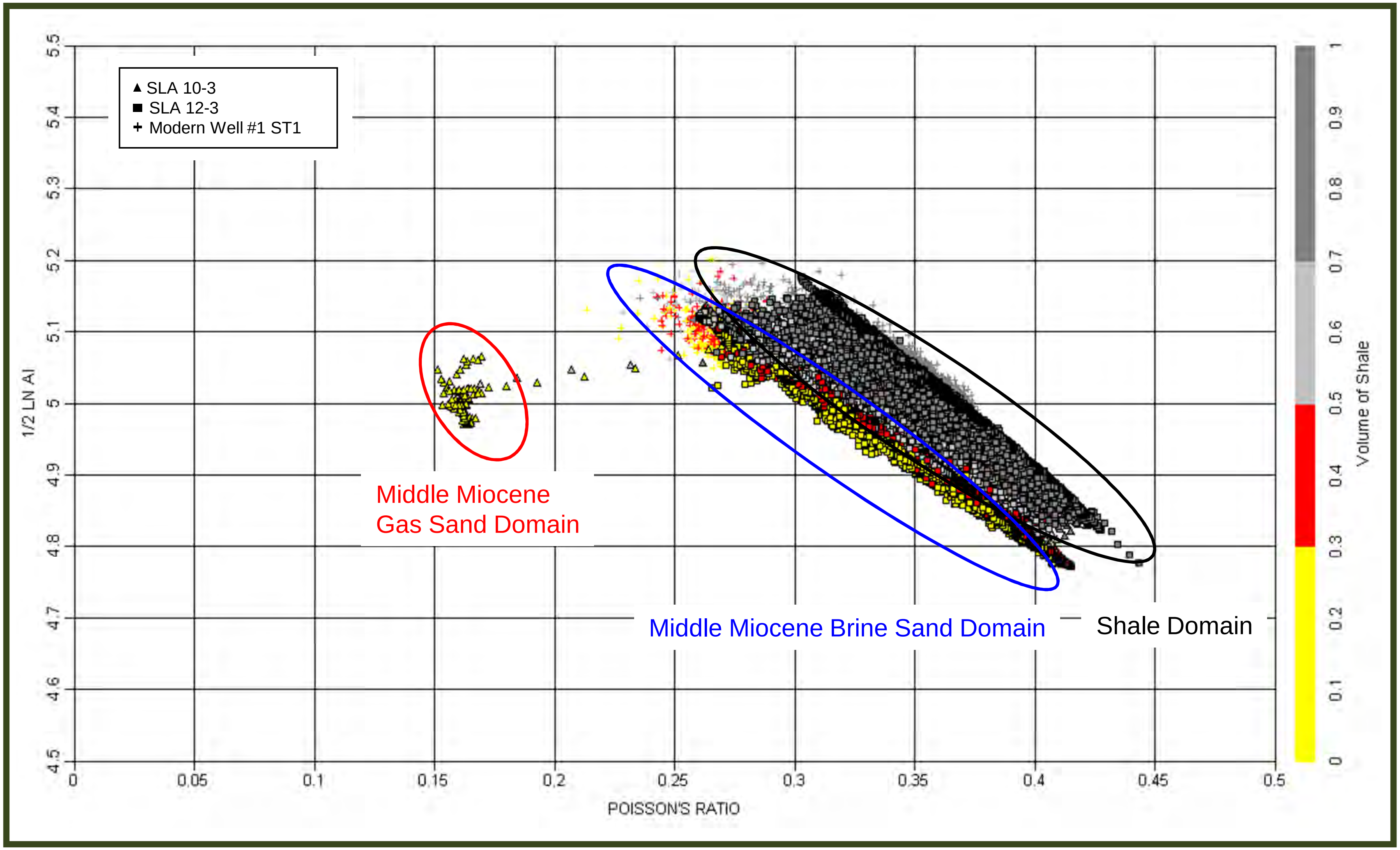
Compressional and Shear Velocities



Poisson's Ratio and Acoustic Impedance: Modern Well #1 ST1



Poisson's Ratio and Acoustic Impedance



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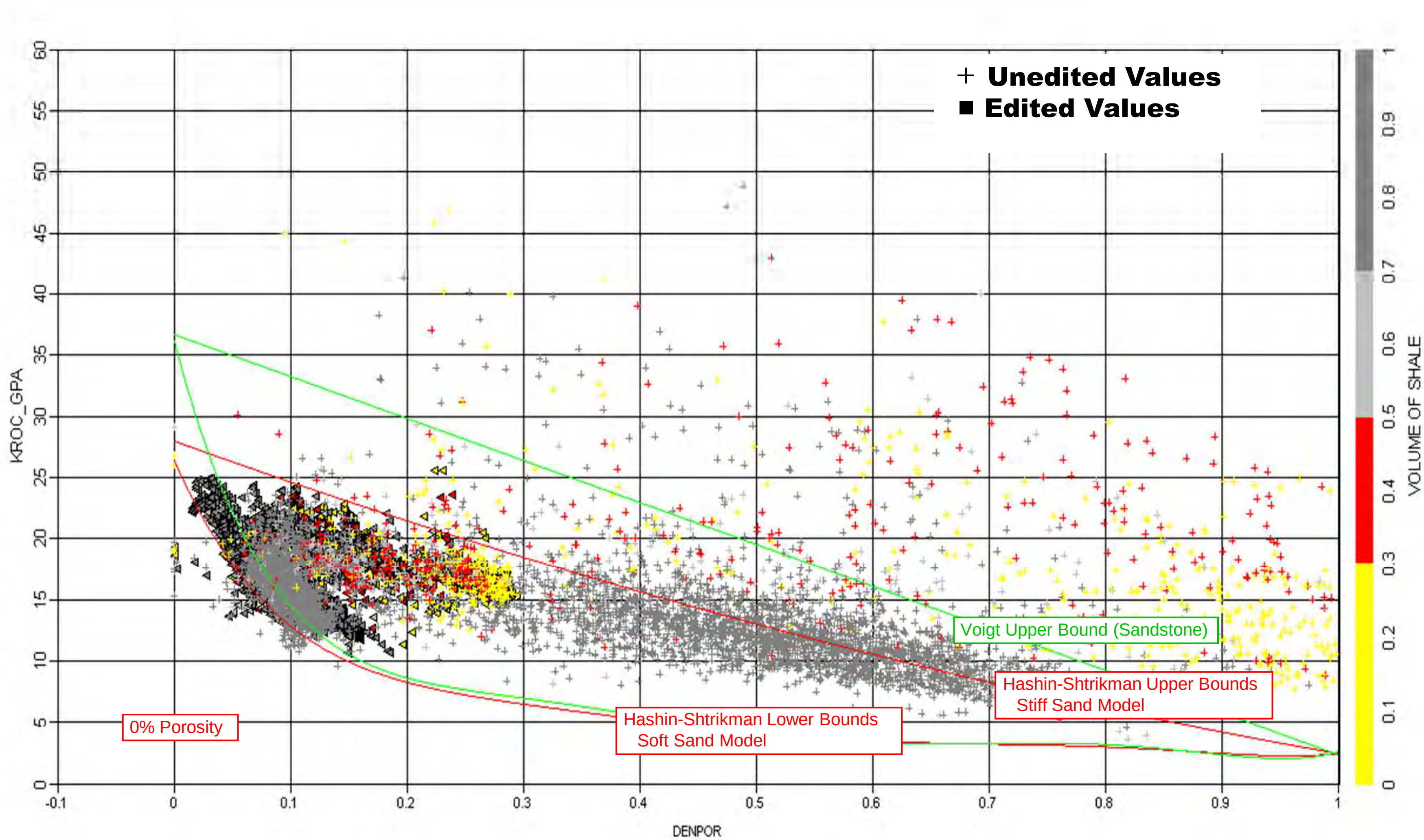
Porosity and Bulk Modulus: Modern Well #1 ST1



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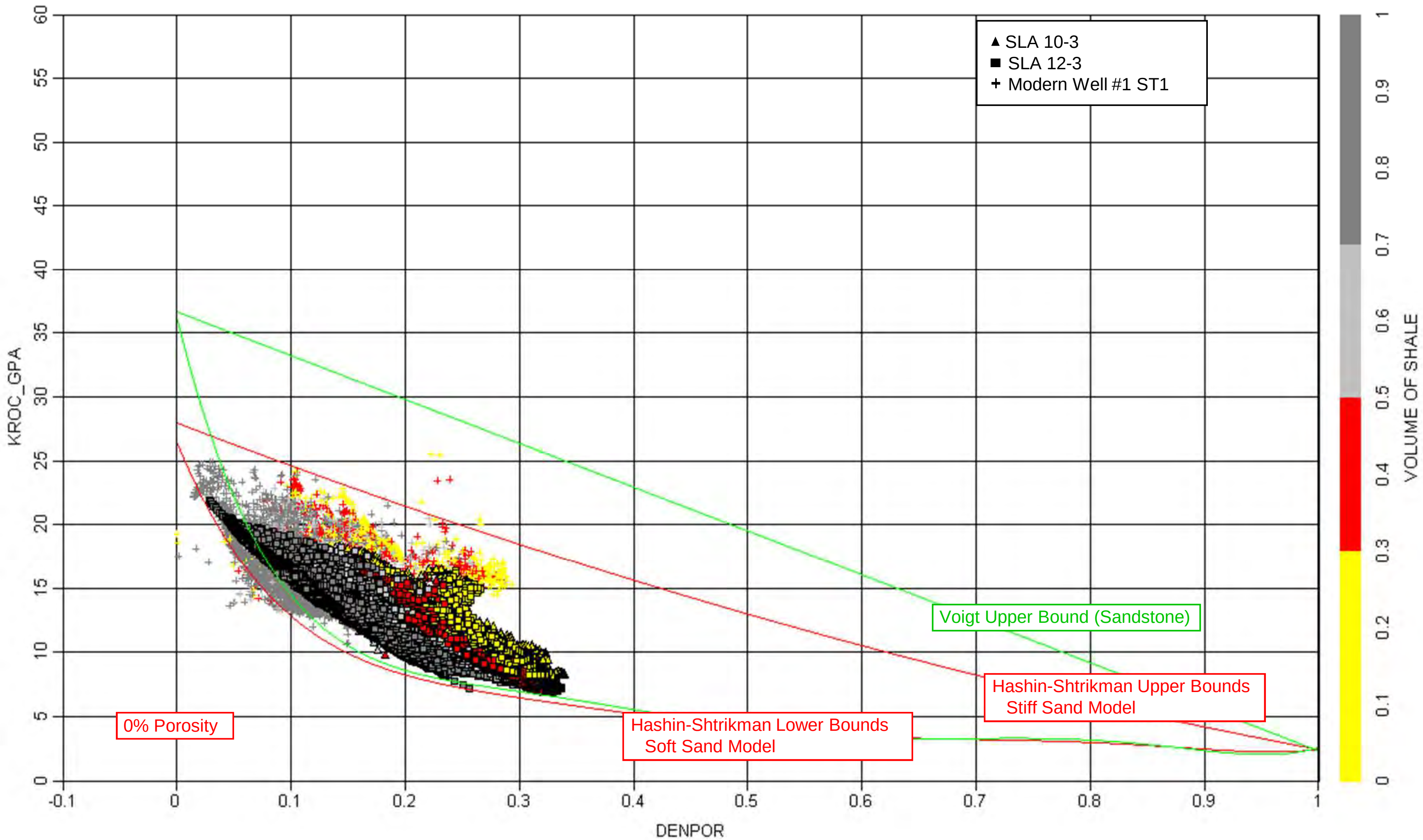
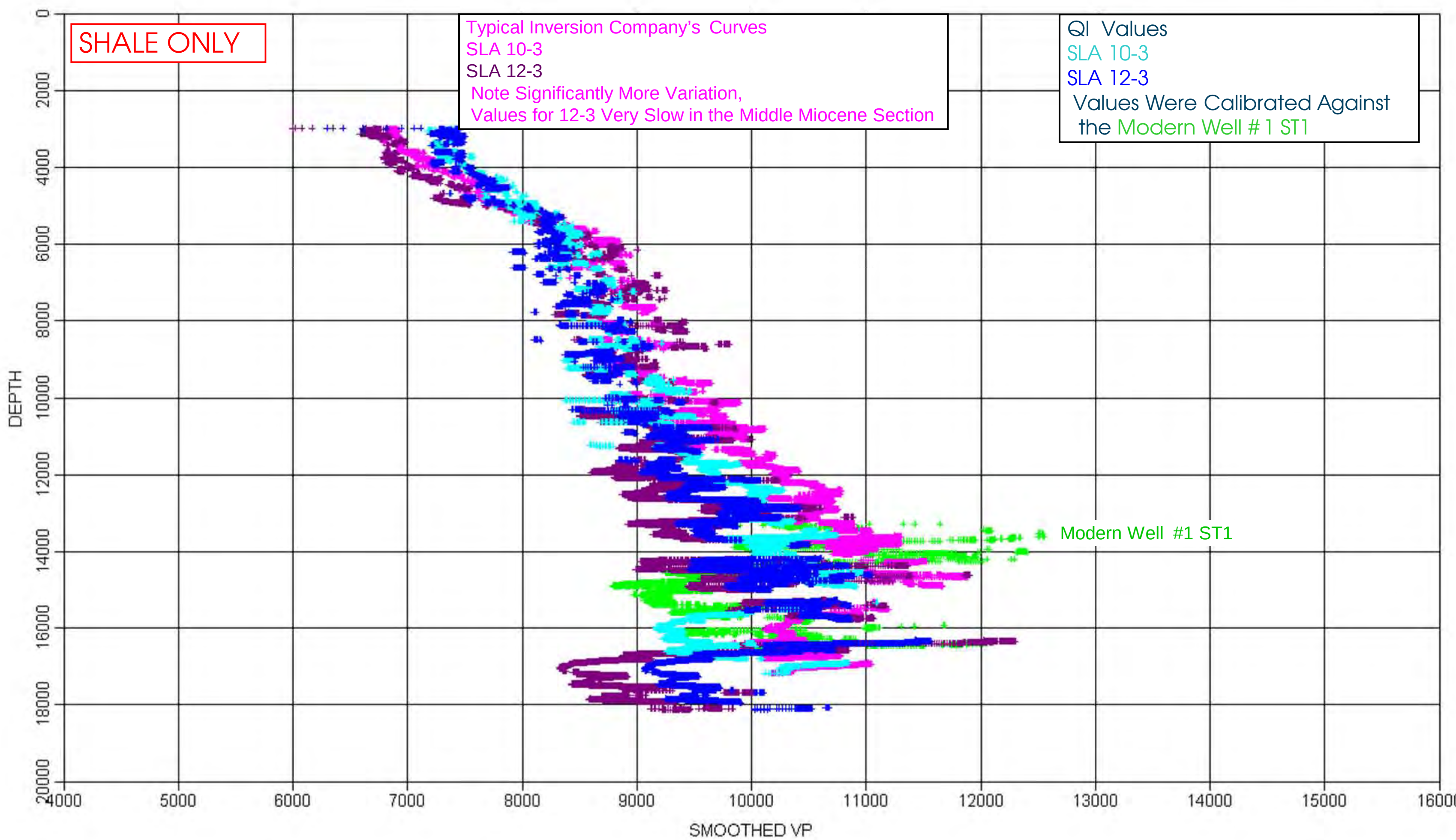
Porosity and Bulk Modulus

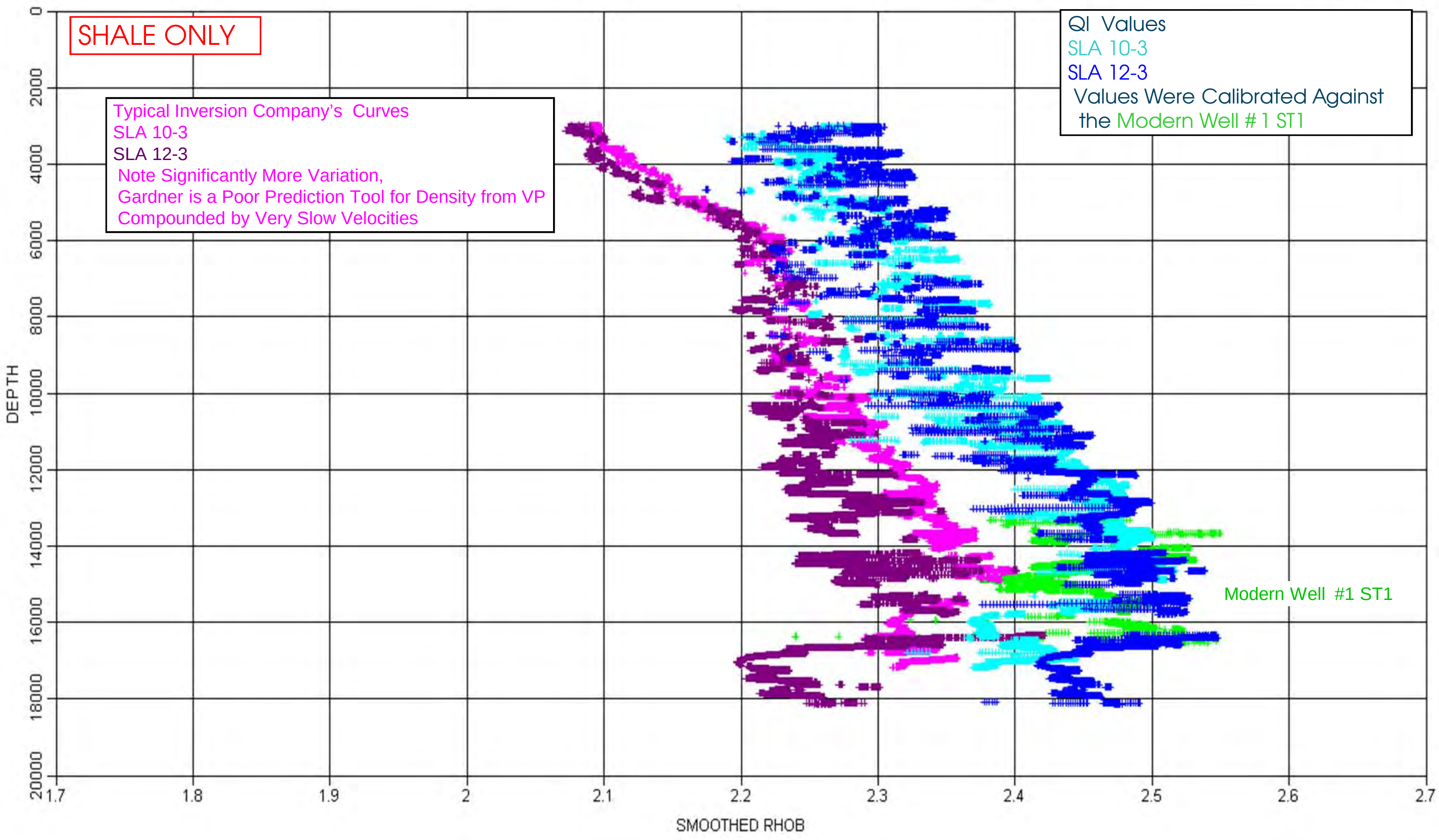


QI Petrophysics

Velocity and Depth



Density and Depth



QI Petrophysics

Summary of Rock Physics Characterization

- **Examined Wireline Logs from the SLA Unit, and Integrated SLA Modern Well #1 ST1 to Analyze Petrophysical and Elastic Response in the Middle Miocene Sandstones**

- **Wireline Logs from 3 Wells Examined Middle Miocene Sand Zone of Interest**
  - **1.) Modern #1 ST1** (*2007, Brine Saturated Middle Miocene Sands*)
  - **2.) SLA Unit 10-3** (*1964, Gas Saturated Middle Miocene Sands*)
  - **3.) SLA Unit 12-3** (*1963, Brine Saturated Middle Miocene Sands*)

- **Rock Physics Characterization:**
  - *Lithology Interpretation Consistent with South Louisiana Geology*
  - *Generated VP in Using Faust Resistivity to Compressional Velocity Relationship*
  - *Generated RHOB Using Modified Raymer Model*
  - *VS Estimated from VP Using Greenberg-Castagna*

- **QI Generated a More Robust Density, VP, and VS, Accounting for Lithologic and Fluid Variation**

- **All Values Were Calibrated Against New Modern Well #1 ST1 Well**

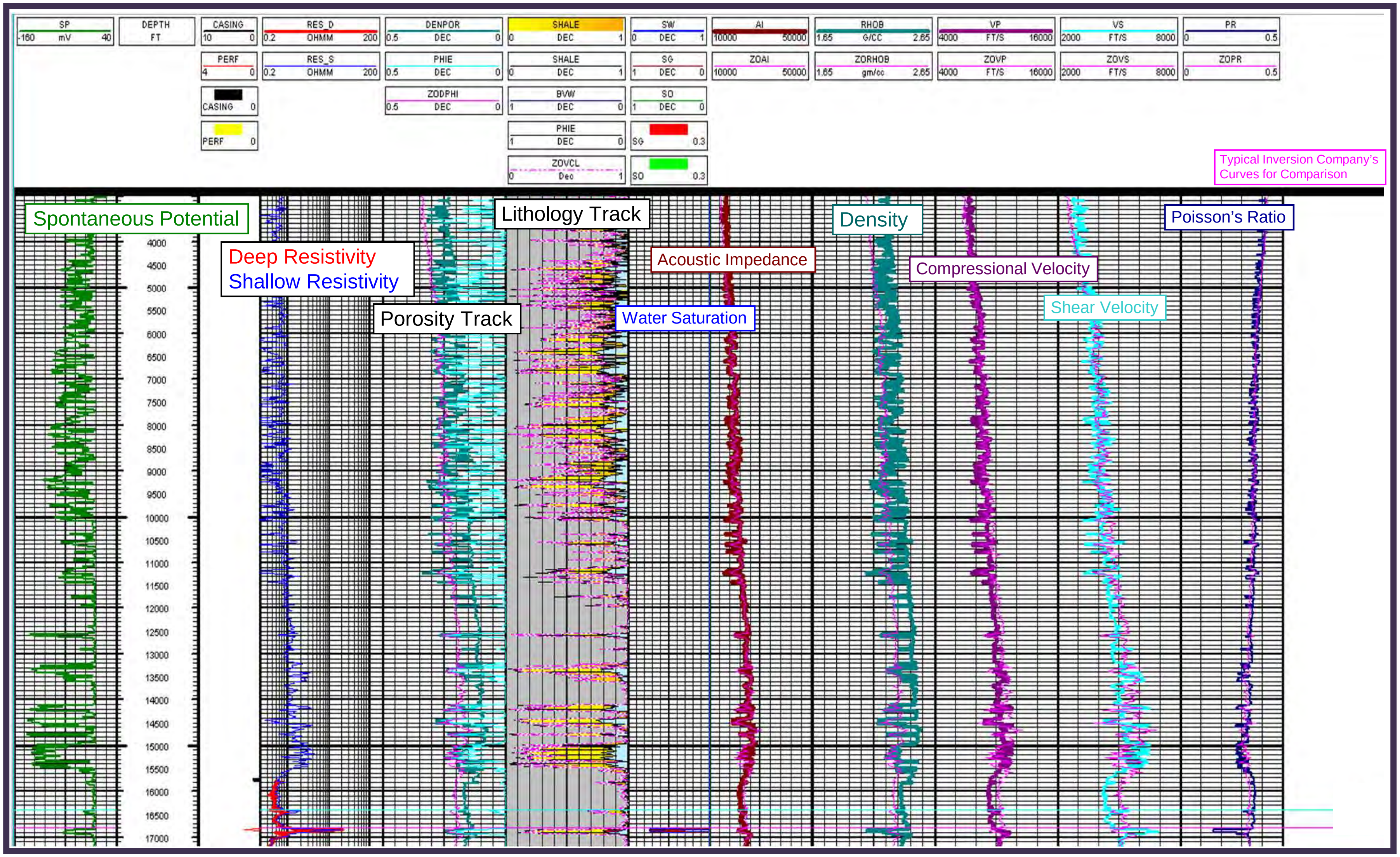
- **Results of the Seismic Petrophysics and Rock Physics Characterization were used for Fluid Substitution and AVO Analysis**

QI Petrophysics

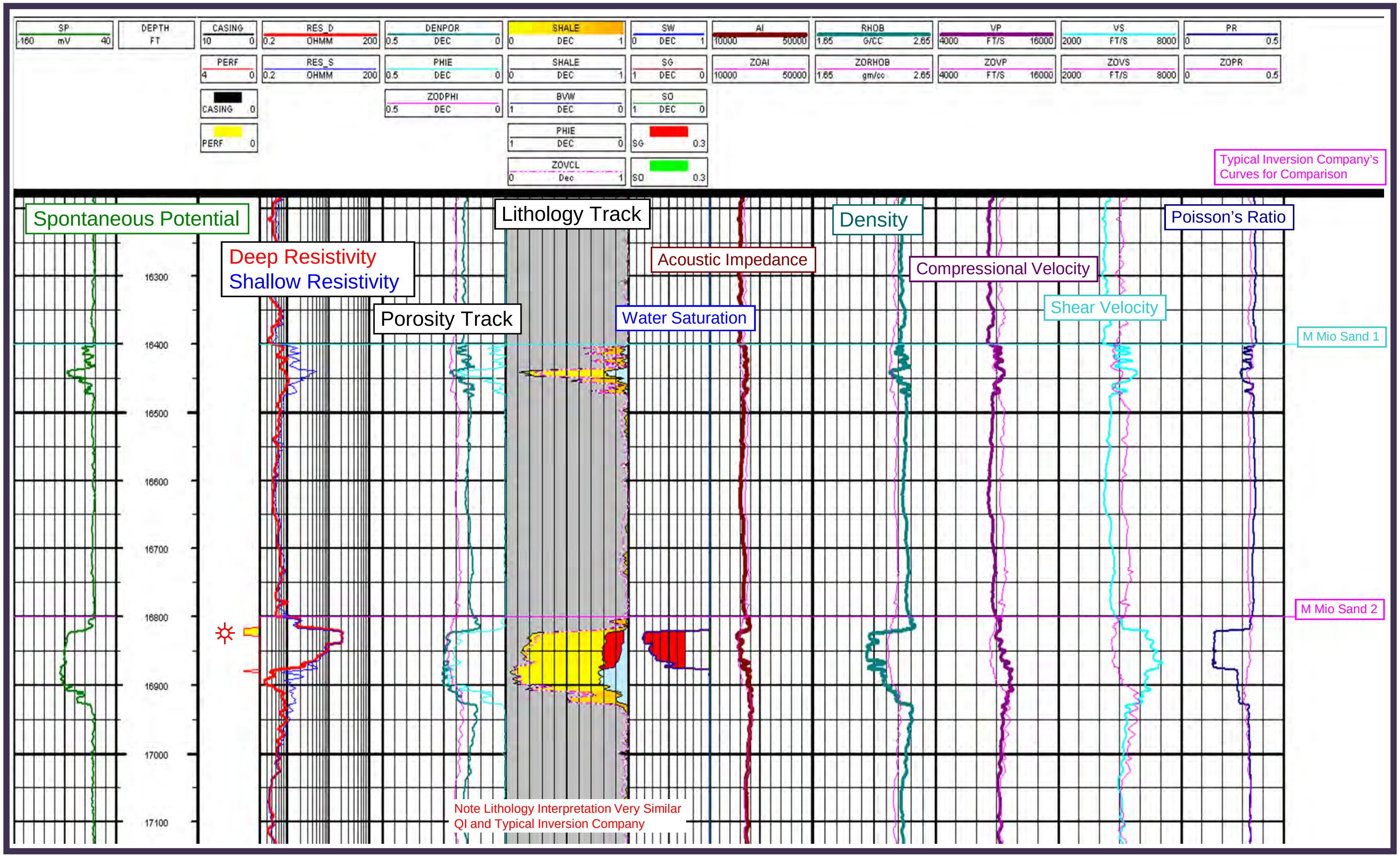
Final *In Situ* Well Log Curves

QI Petrophysics

Seismic Petrophysical Analysis: SLA 10-3



Seismic Petrophysical Analysis: SLA 10-3: Zone of Interest



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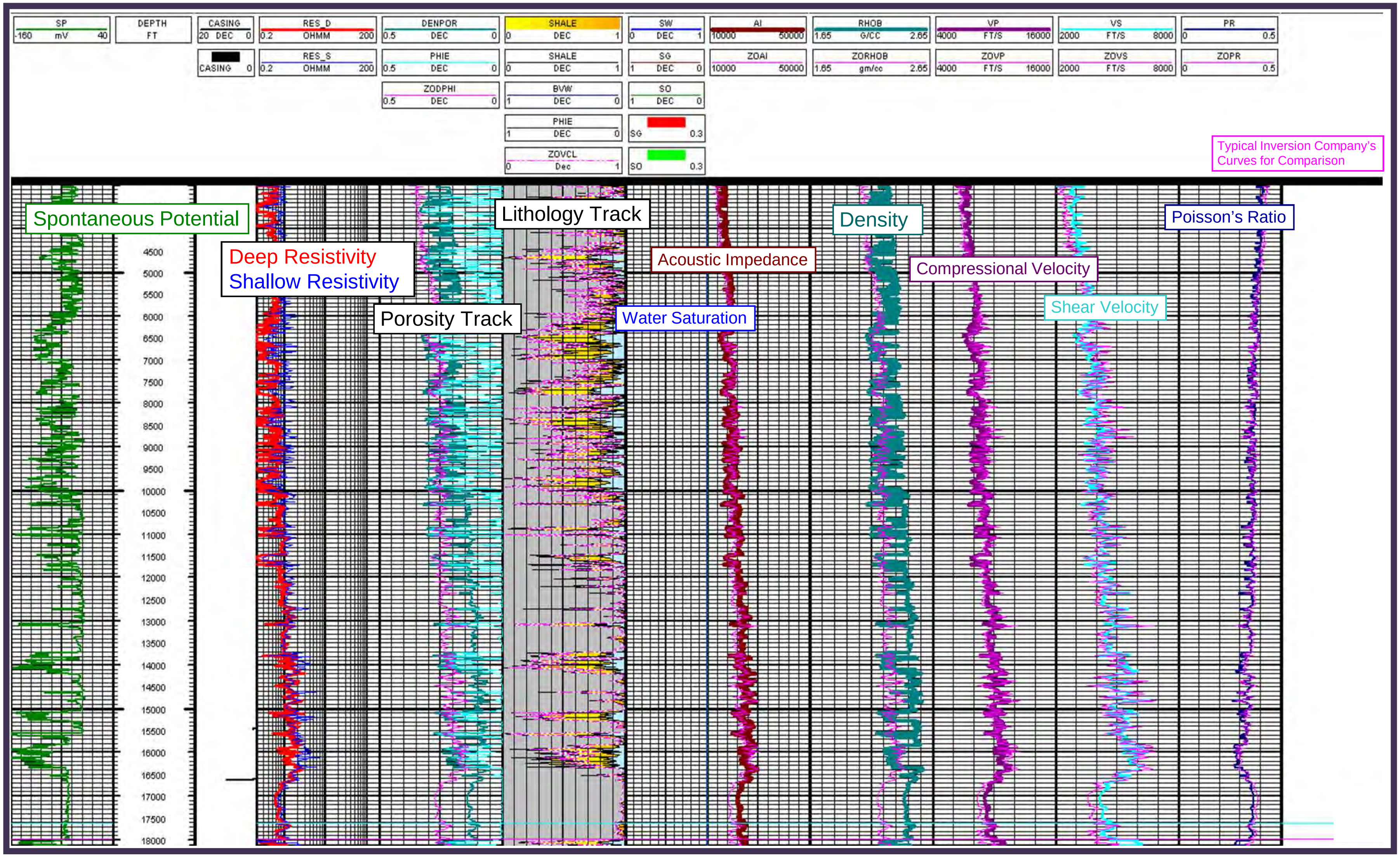
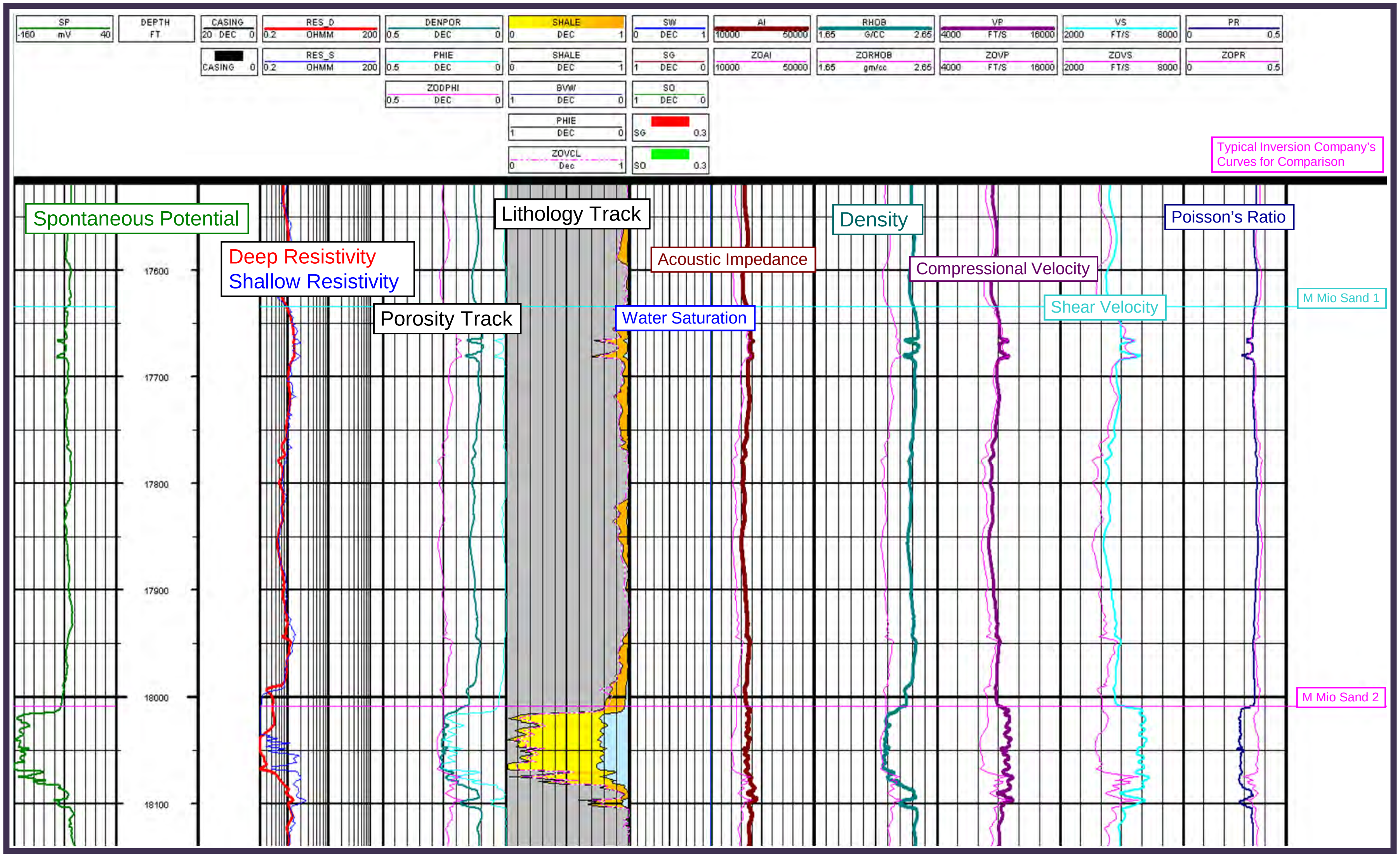
Seismic Petrophysical Analysis: SLA 12-3



Seismic Petrophysical Analysis: SLA 12-3: Zone of Interest



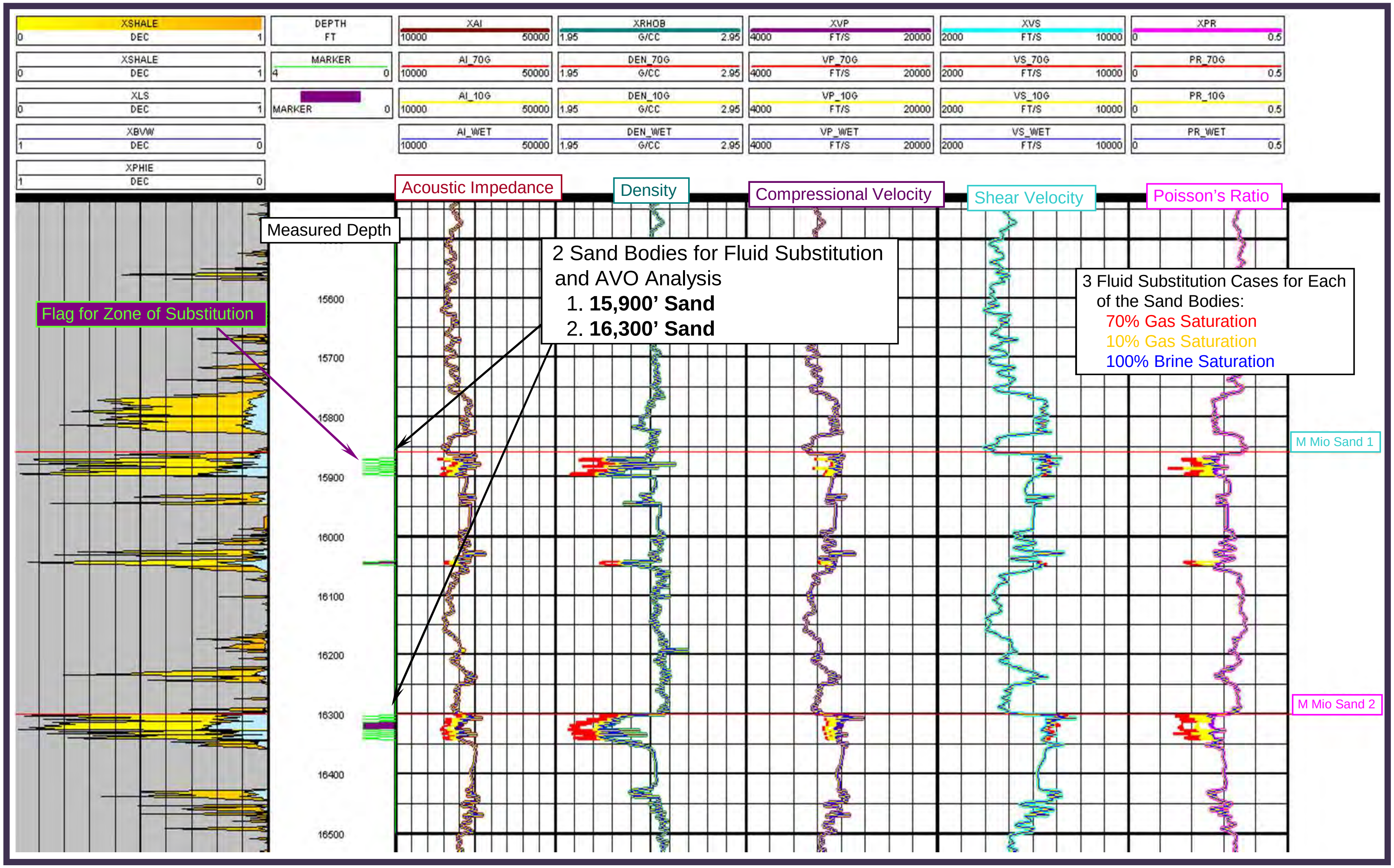
QI Petrophysics

Rock Physics Modeling and AVO Analysis

Southern Louisiana

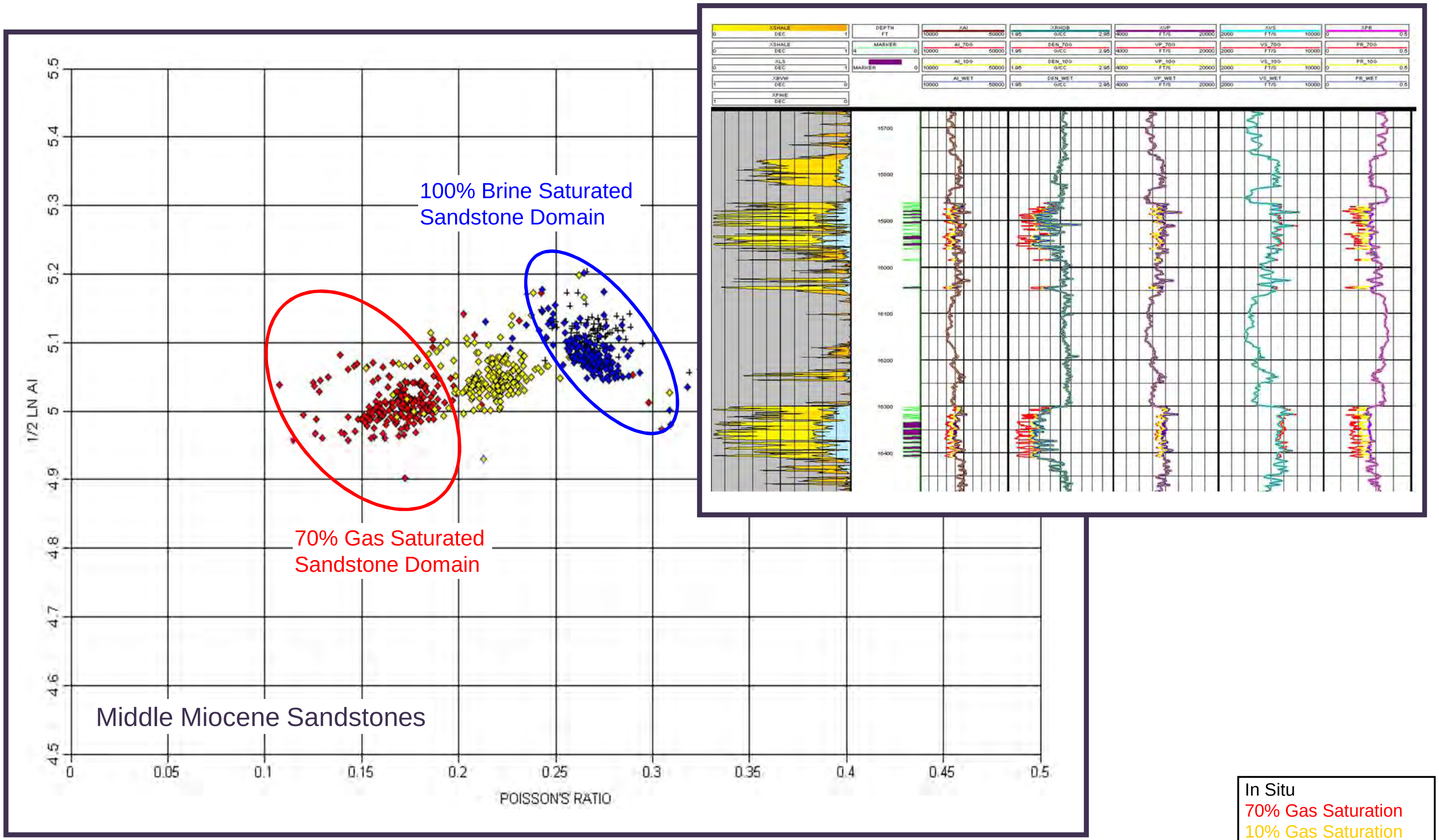
Modern Well #1 ST1

Fluid Substitution: Modern Well #1ST1



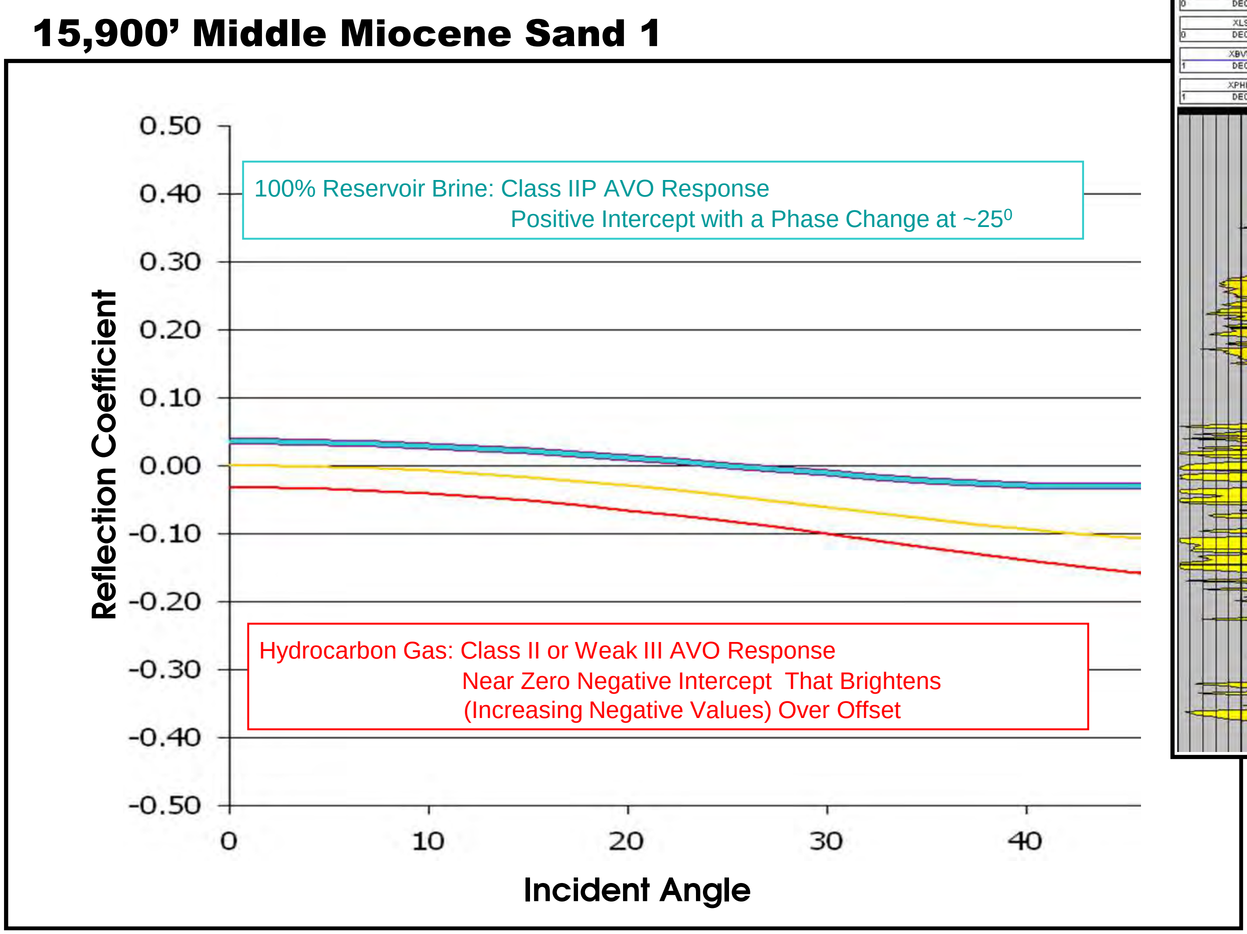
QI Petrophysics

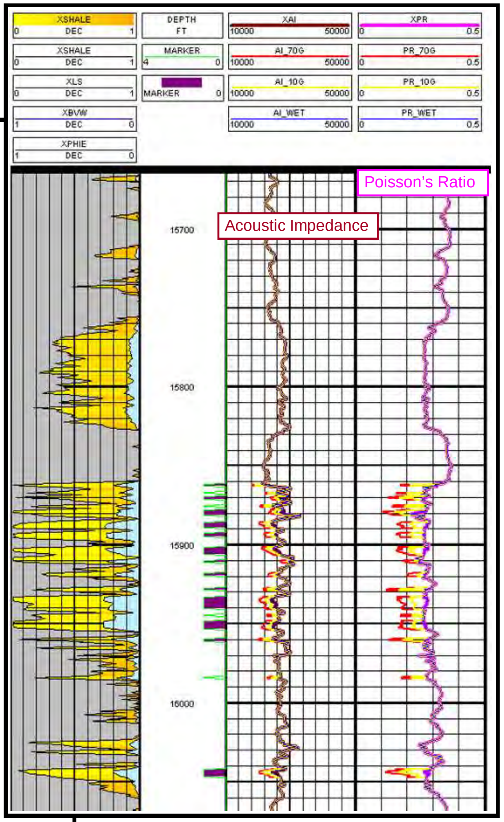
Poisson's Ratio and Acoustic Impedance Fluid Substitution Cases



In Situ
70% Gas Saturation
10% Gas Saturation
100% Brine Saturation

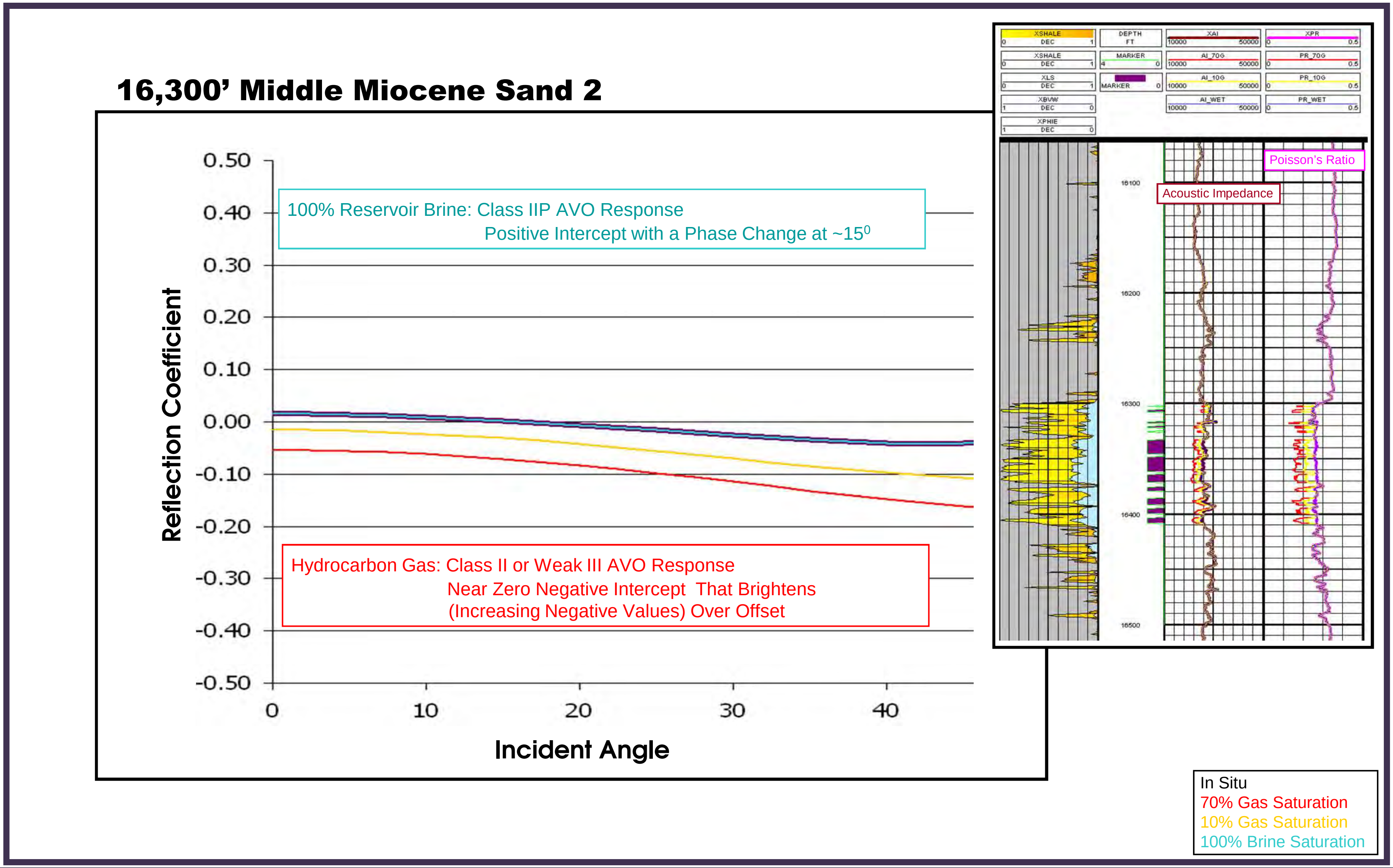
AVO Half Space Models: Modern Well #1ST1





In Situ
70% Gas Saturation
10% Gas Saturation
100% Brine Saturation

AVO Half Space Models: Modern Well #1ST1

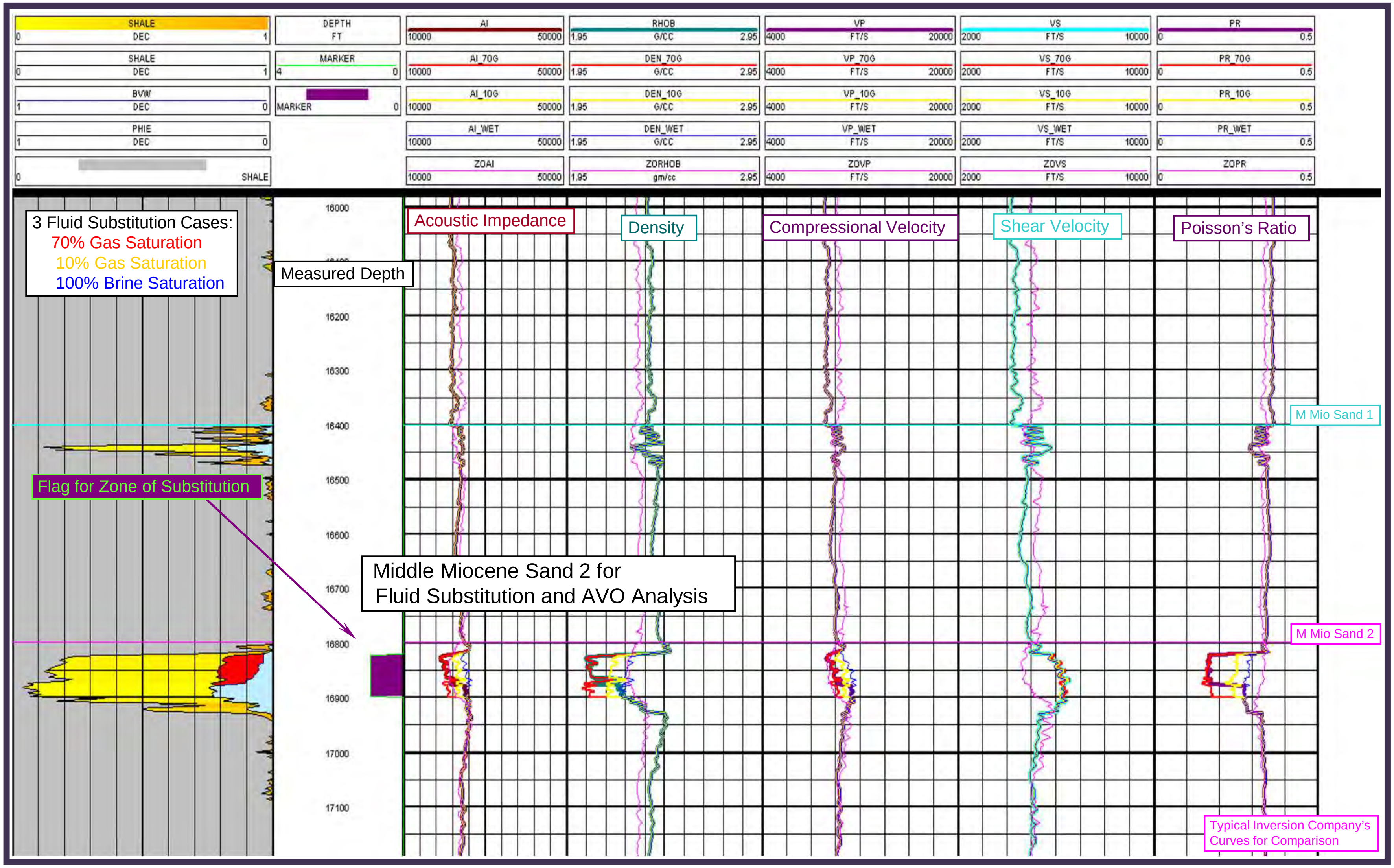


QI Petrophysics

Rock Physics Modeling and AVO Analysis

SLA Unit 10-3 & 12-3

Fluid Substitution: SLA 10-3



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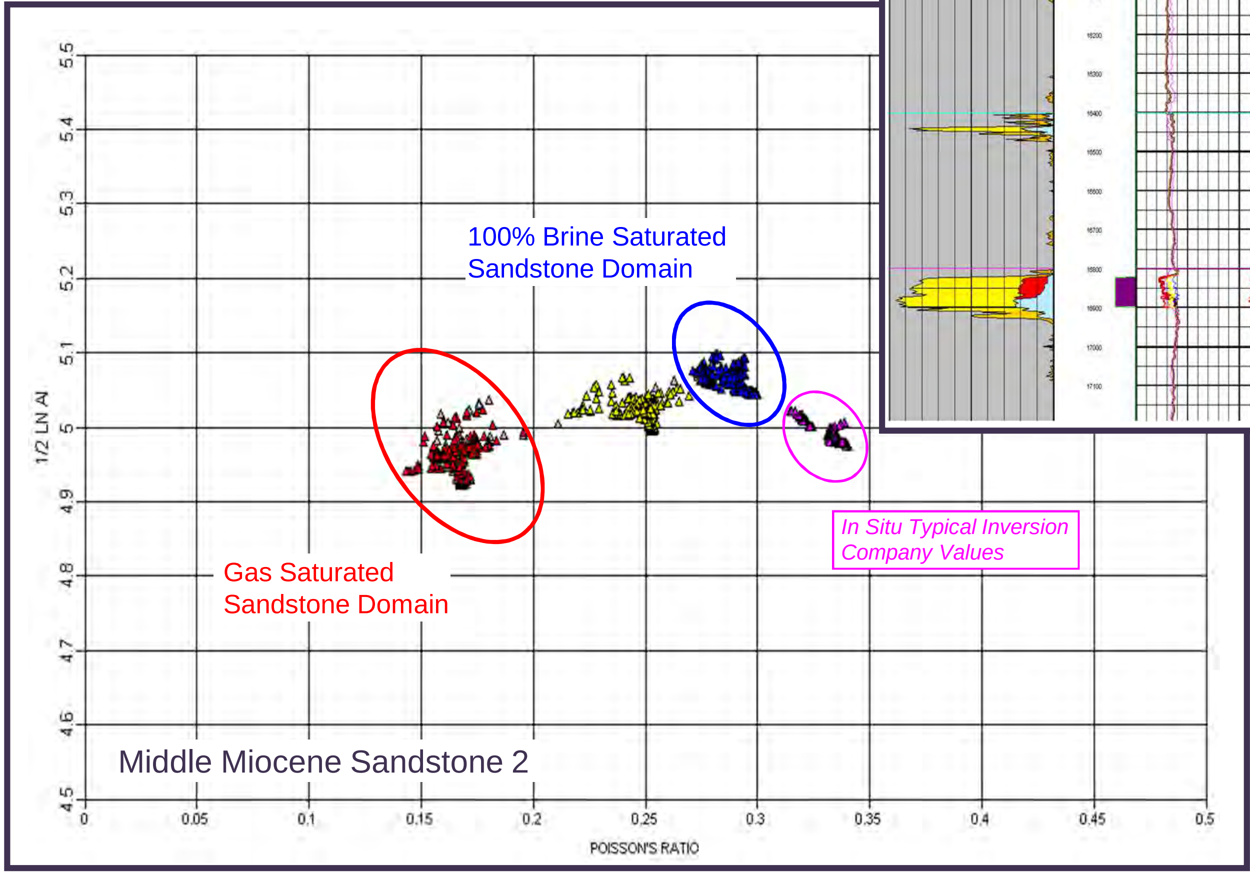
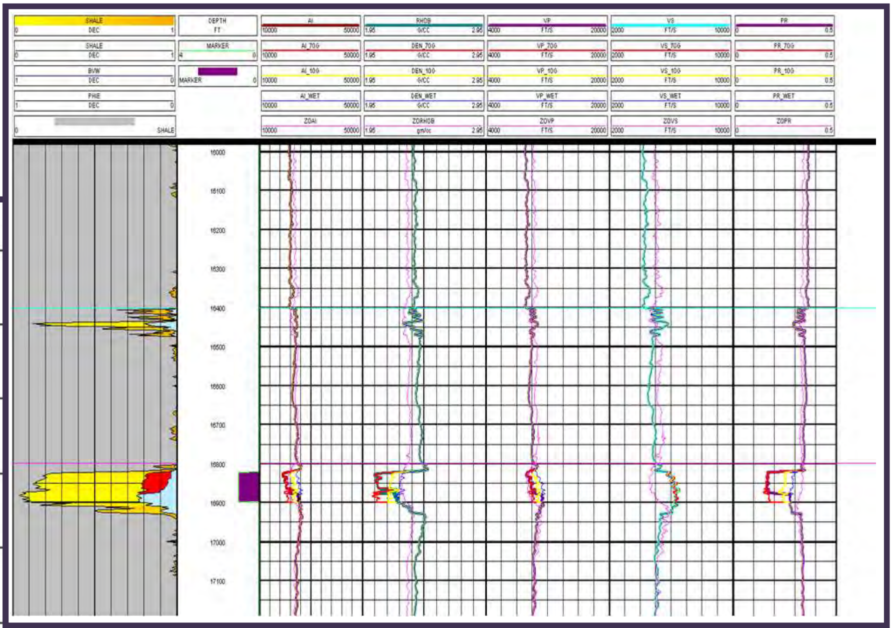
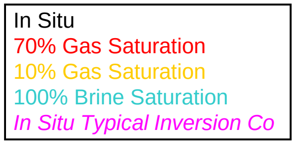
Poisson's Ratio and Acoustic Impedance Fluid Substitution Cases

SLA 10-3







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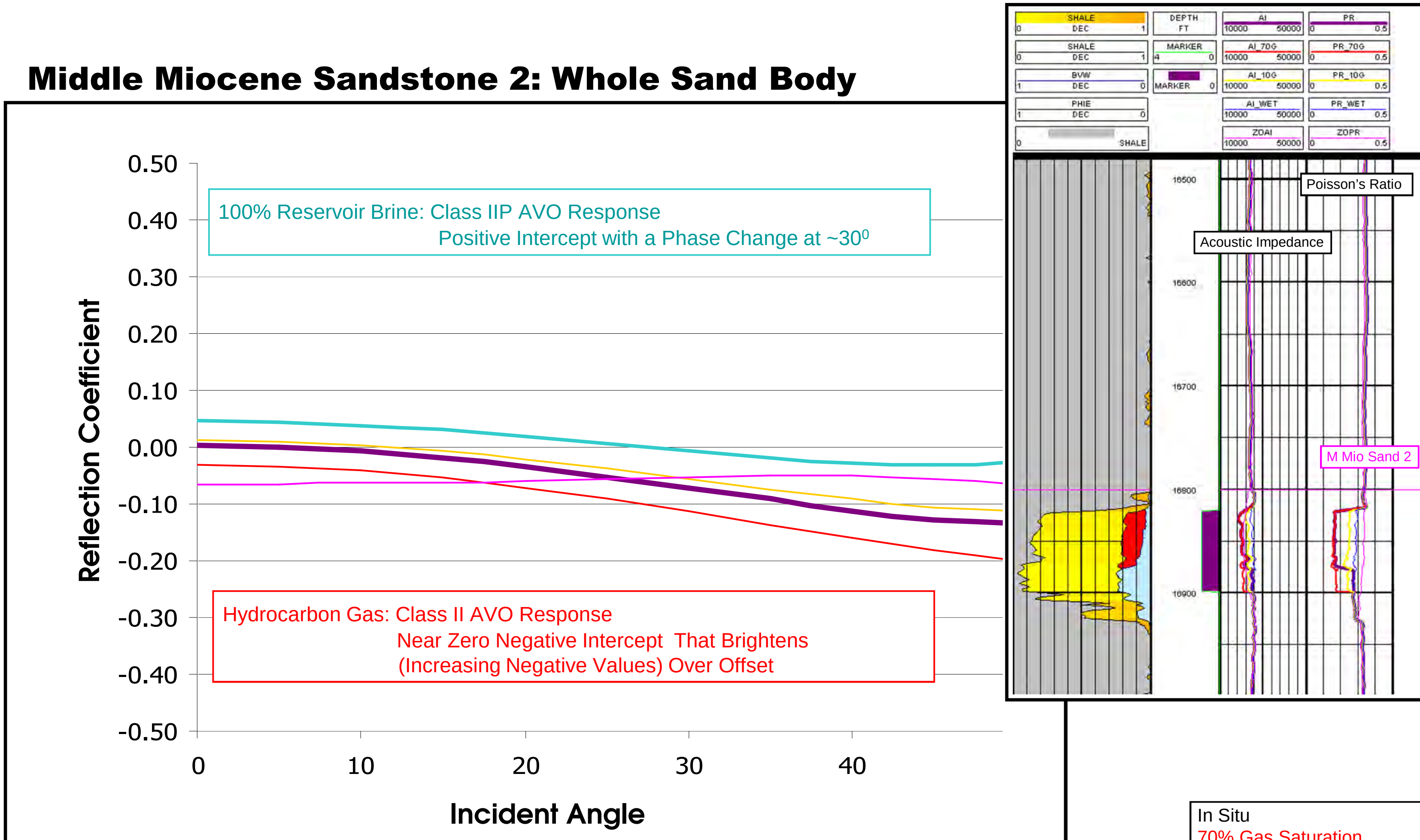
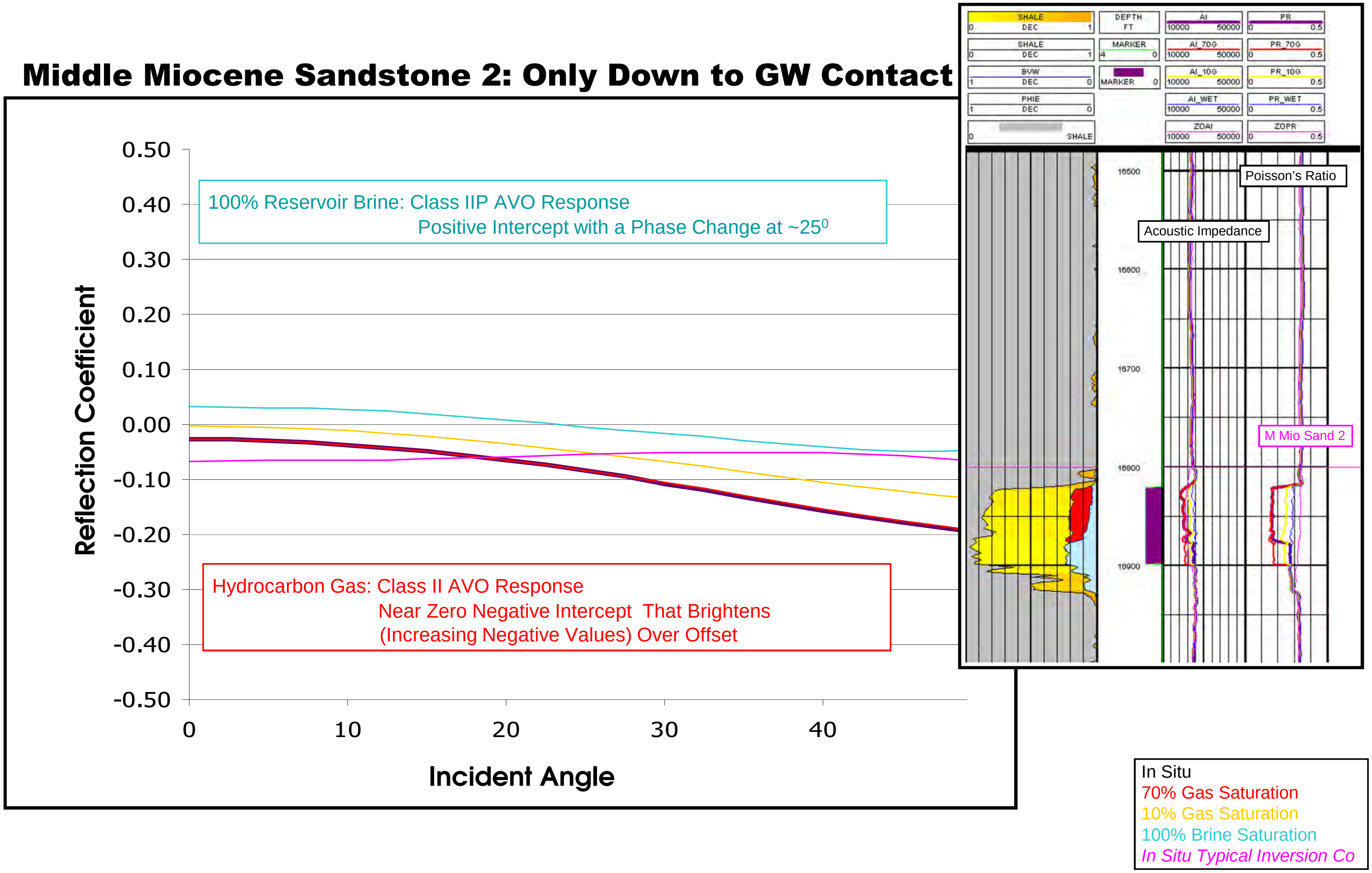
AVO Half Space Models: SLA 10-3



In Situ
70% Gas Saturation
10% Gas Saturation
100% Brine Saturation
In Situ Typical Inversion Co

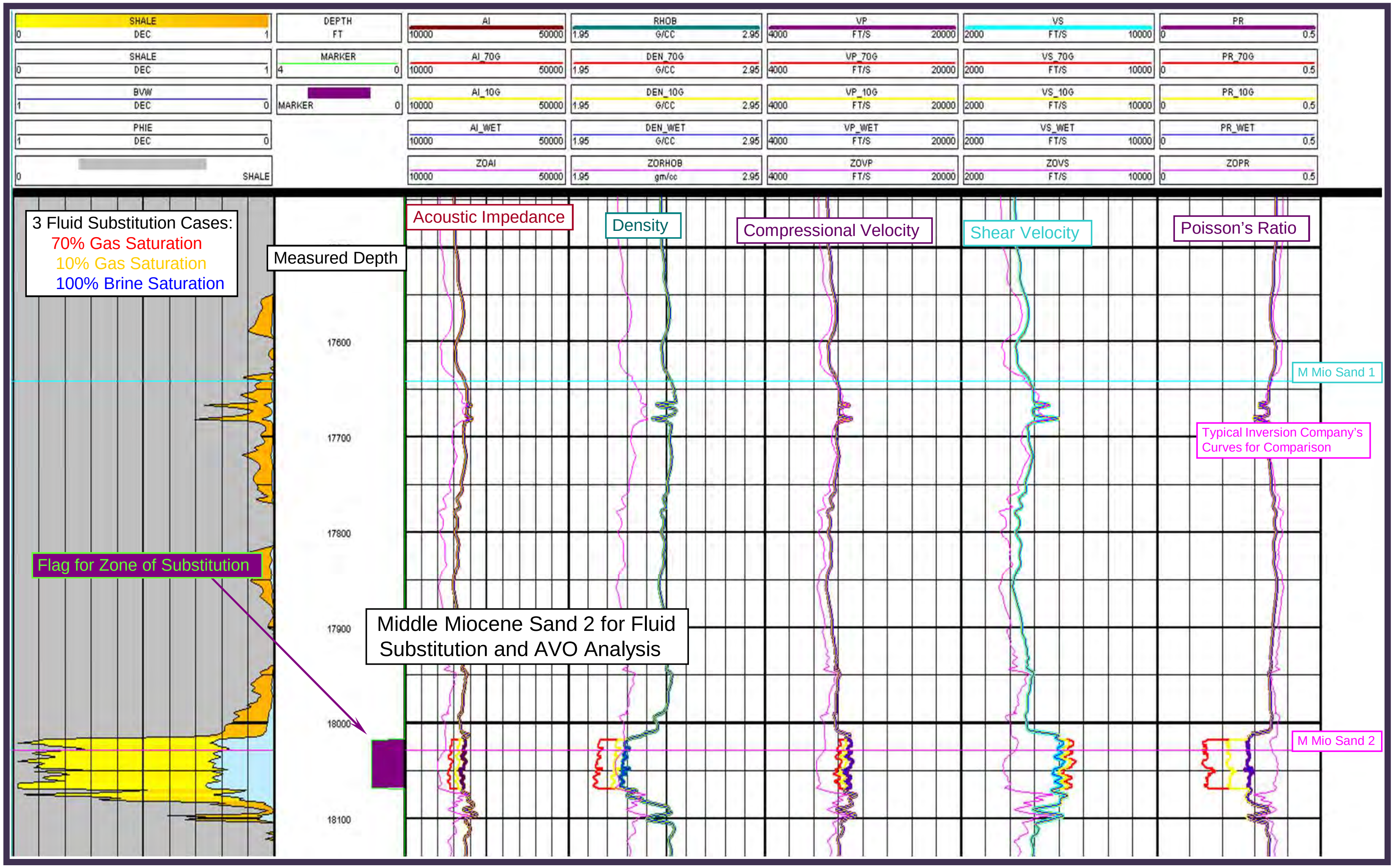
AVO Half Space Models: SLA 10-3

Middle Miocene Sandstone 2: Only Down to GW Contact



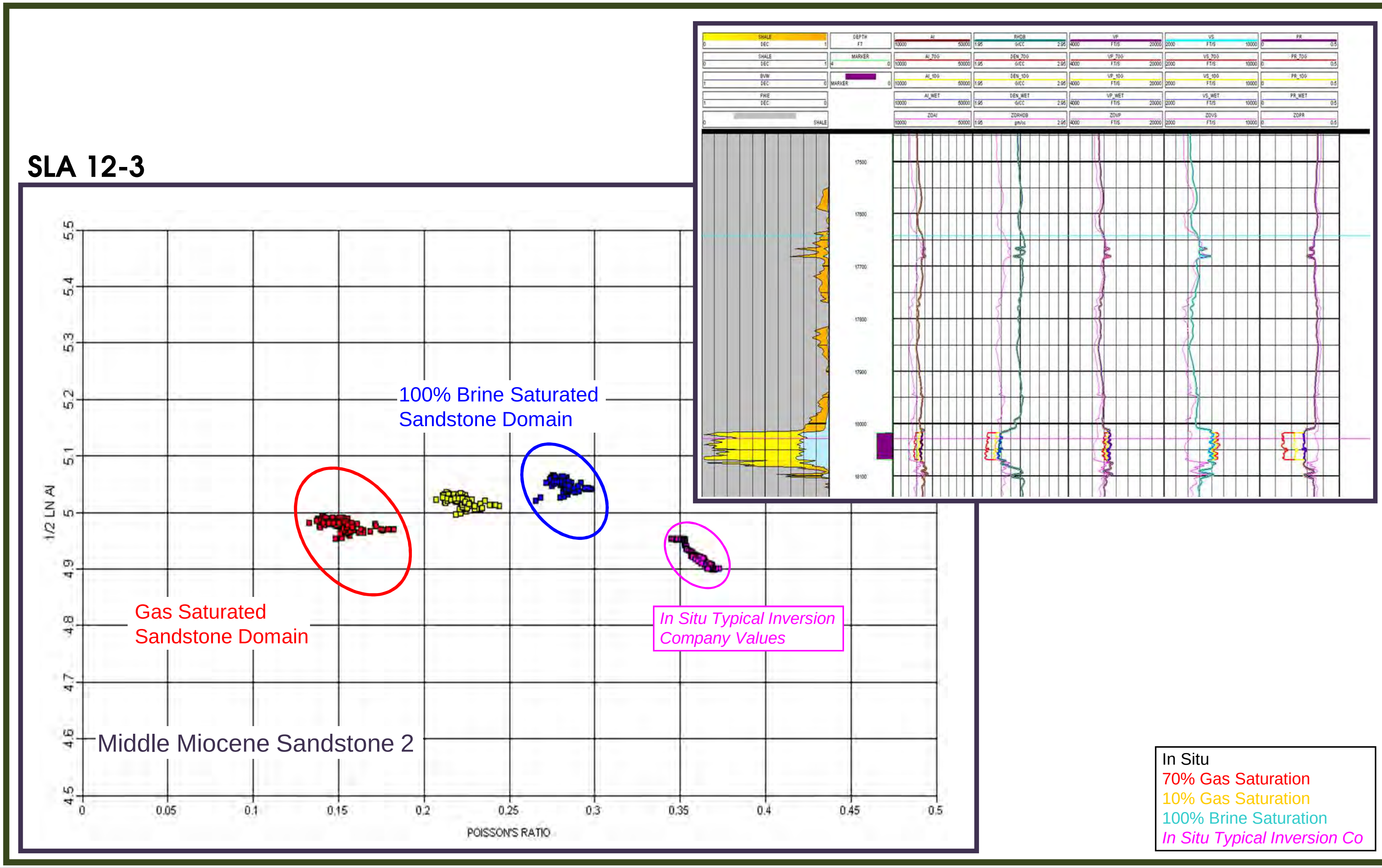
QI Petrophysics

Fluid Substitution: SLA 12-3



QI Petrophysics

Poisson's Ratio and Acoustic Impedance Fluid Substitution Cases



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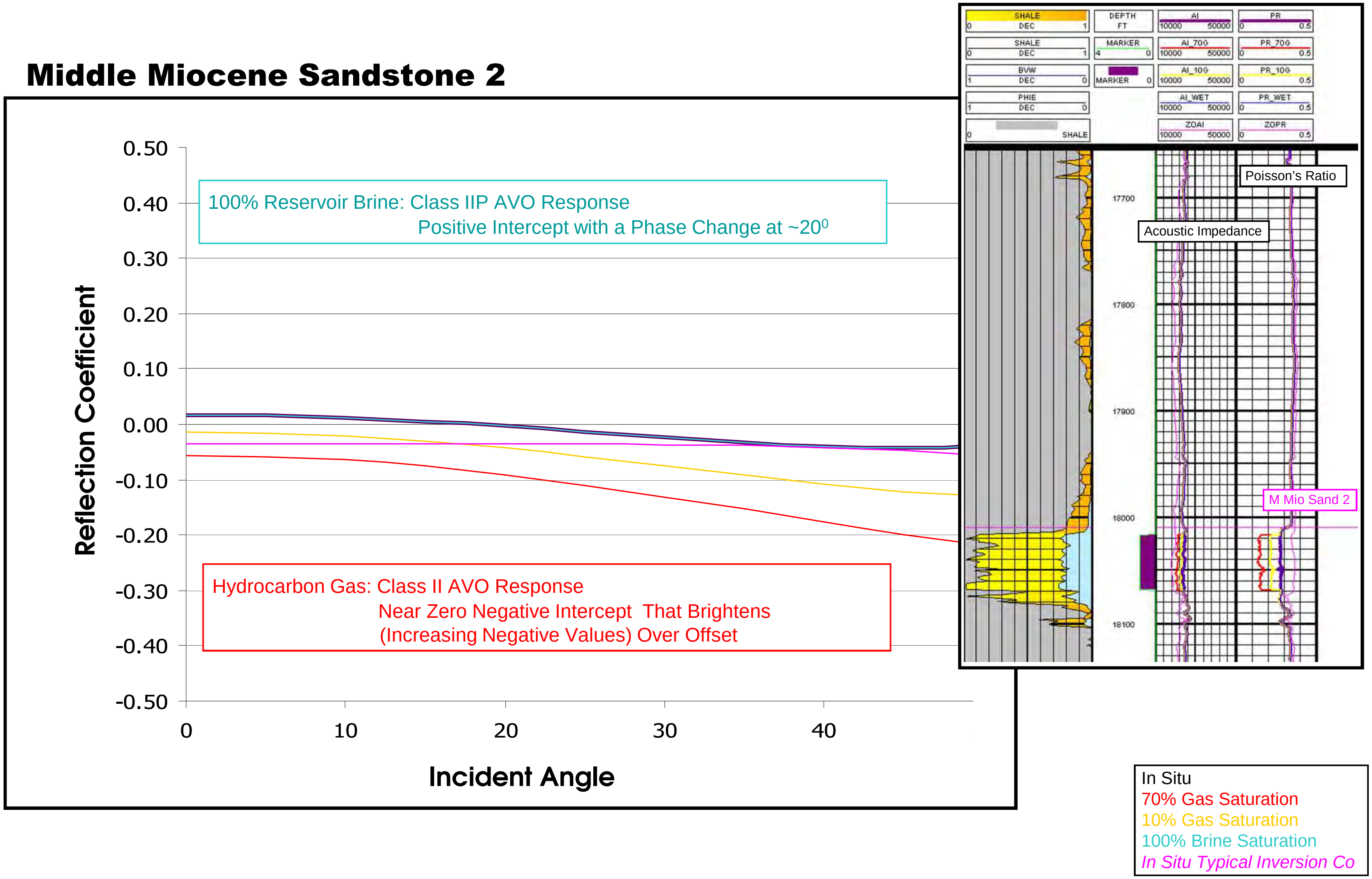
AVO Half Space Models: SLA 12-3



QI Petrophysics

Summary

- Examined Wireline Logs from the SLA Unit, and Integrated SLA Modern Well #1 ST1 to Analyze Petrophysical and Elastic Response in the Middle Miocene Sandstones of Interest
- Employed Rock Physics Characterization and Calibrated Values to SLA Modern Well #1 ST1 to Generate Lithology, and Robust Density, VP, and VS Consistent with South Louisiana Geology
- Results of the Seismic Petrophysics and Rock Physics Characterization was used for Fluid Substitution and AVO Analysis
- Fluid Substitution in Middle Miocene Sand Zones for Both Wells Consisted of “Dry-Gas” at 70% and 10%, and Reservoir Brine at 100% Saturation
- Fluid Substitution and AVO Analysis Indicate Middle Miocene Sands Possess:
  - Class IIP AVO Response when Brine Saturated
  - Class II (*Slight Negative Intercept*) when Hydrocarbon Saturated
- Resulting Well Log Curves Can be Used to Tie Seismic Data as Well as Calibrate Acoustic and Elastic Response in the Middle Miocene Zone of Interest

QI Petrophysics

Bottom Line

Poor Handling of the Original Well Log Data, Resulted in an Inversion that Could Find Wet Sand

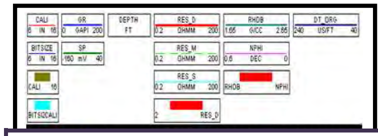
The Modern Well Was Drilled and Found to be Filled With WET SAND

Cost of the Inversion, Cost of the other G&G, Land and Dry Hole For Lack of Robust Seismic Petrophysics

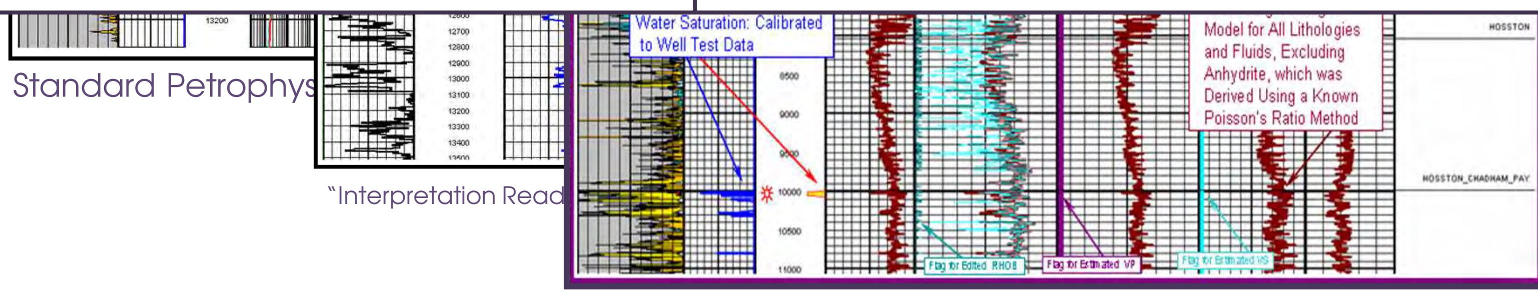
Before You Invert….Quantify, Quantify

QI Petrophysics

Petrophysical Interpretation Matrix



Level of Well Log Analysis	Fit for Purpose
Raw Logs/Quick Look Analysis	Tops and Quick Estimate of Reservoir Properties
“Interpretation Ready” ***NOTE THIS EQUALS A COMPOSITE RAW LOG*** ***NO INTERPRETATION***	Initial Attempt for Seismic Tie
Standard Petrophysics	Tops and Pay Counts
Seismic Petrophysical Analysis	**Quantitative Geophysical Integration Ready**



Standard Petrophys

“Interpretation Read

Seismic Petrophysical Analysis

Quantitative Interpretation offers a competitive advantage when driven by rigorous integrated analysis, grounded in rock physics, to provide the cost effective link between petrophysical properties and elastic response.

Perturbational Rock Modeling

QI Petrophysics