Optimized Well Placement from the Integration of Geoscientific Measurements*

Gorka Garcia Leiceaga[1]

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Abstract

A well placement strategy has been investigated by integrating various geoscientific measurements. Current drilling decisions are driven by Poisson's ratio. This study utilizes prestack seismic, vertical and horizontal well information, and production data to determine a spatial distribution of a reservoir's capacity to produce hydrocarbons and to help evaluate hydrocarbon production capacity in unconventional plays such as tight or shale formations. Microseismic data along with a volume of seismic discontinuities representing natural faults and fractures may be used to better quantify the rock, which contributed to production during a stimulation campaign.

Use of inversion methods allows for 1D-borehole measurements to be parameterized into 3D space by analyzing the relationship between well and seismic data. The main inputs include seismic partial stacks, wavelets and low frequency models. Results from prestack inversion matched well with log data, which gives confidence in the post-inversion work. An important factor for success includes determining which elastic properties correlate best with production classes. Differences between high and medium producing reservoir was difficult to determine in certain areas; this is where seismic discontinuities representing natural fractures and faults may prove useful. Microseismic data should be utilized in order to increase precision on determining the amount of rock volume, which was stimulated. Results may be used for avoiding low producing zones with a high degree of confidence. The total success rate for the reservoir quality prediction is approximately 70%. The workflow presented in this paper demonstrates how many pieces of the geoscience puzzle may fit together to potentially enhance recovery rates from optimized well placement.

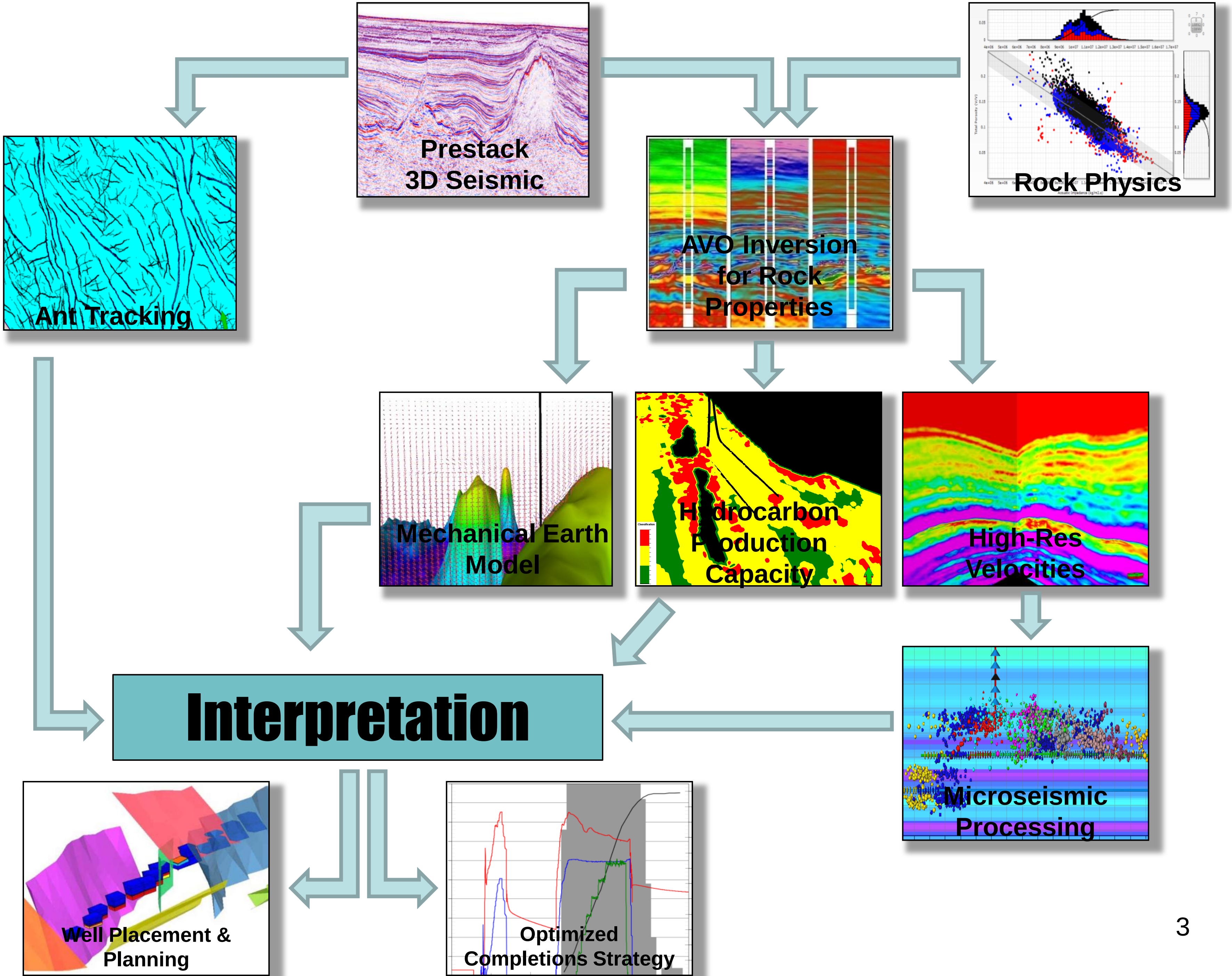
Optimized Well Placement From the Integration of Geoscientific Measurements

Gorka Garcia Leiceaga

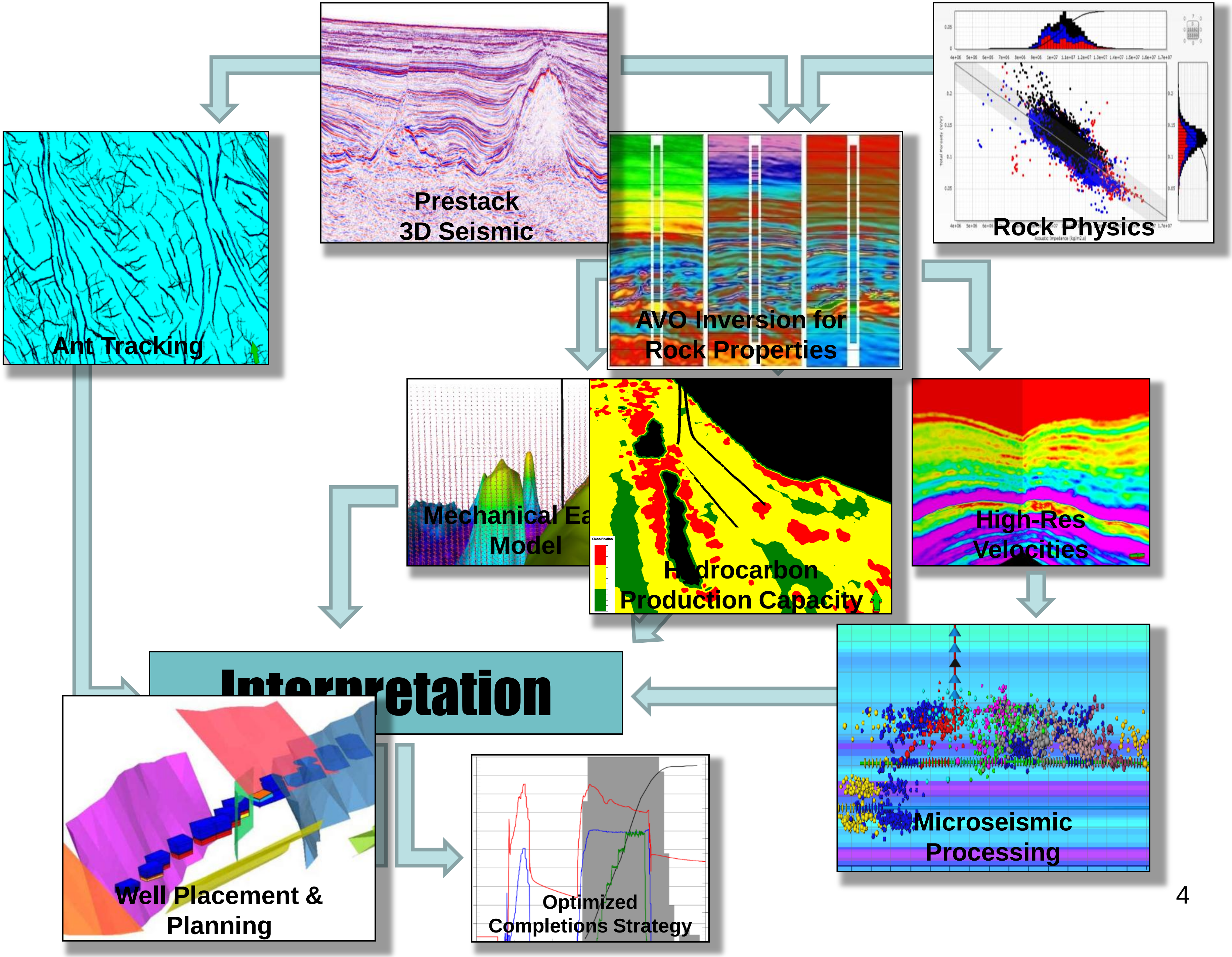
February 25, 2014

Introduction

- A well placement strategy has been investigated by integrating various geoscientific measurements
- Current drilling decisions are driven by Poisson's ratio
- Study utilizes prestack seismic, vertical and horizontal well information, and production data to determine a spatial distribution of a reservoir's capacity to produce HC
- Microseismic data along with a volume of seismic discontinuities representing natural faults and fractures may be used to better quantify the rock which contributed to production during a stimulation campaign



Prestack 3D Seismic
Rock Physics
Ant Tracking
AVO Inversion for Rock Properties
Mechanical Earth Model
Hydrocarbon Production Capacity
High-Res Velocities
Microseismic Processing
Interpretation
Well Placement & Planning
Optimized Completions Strategy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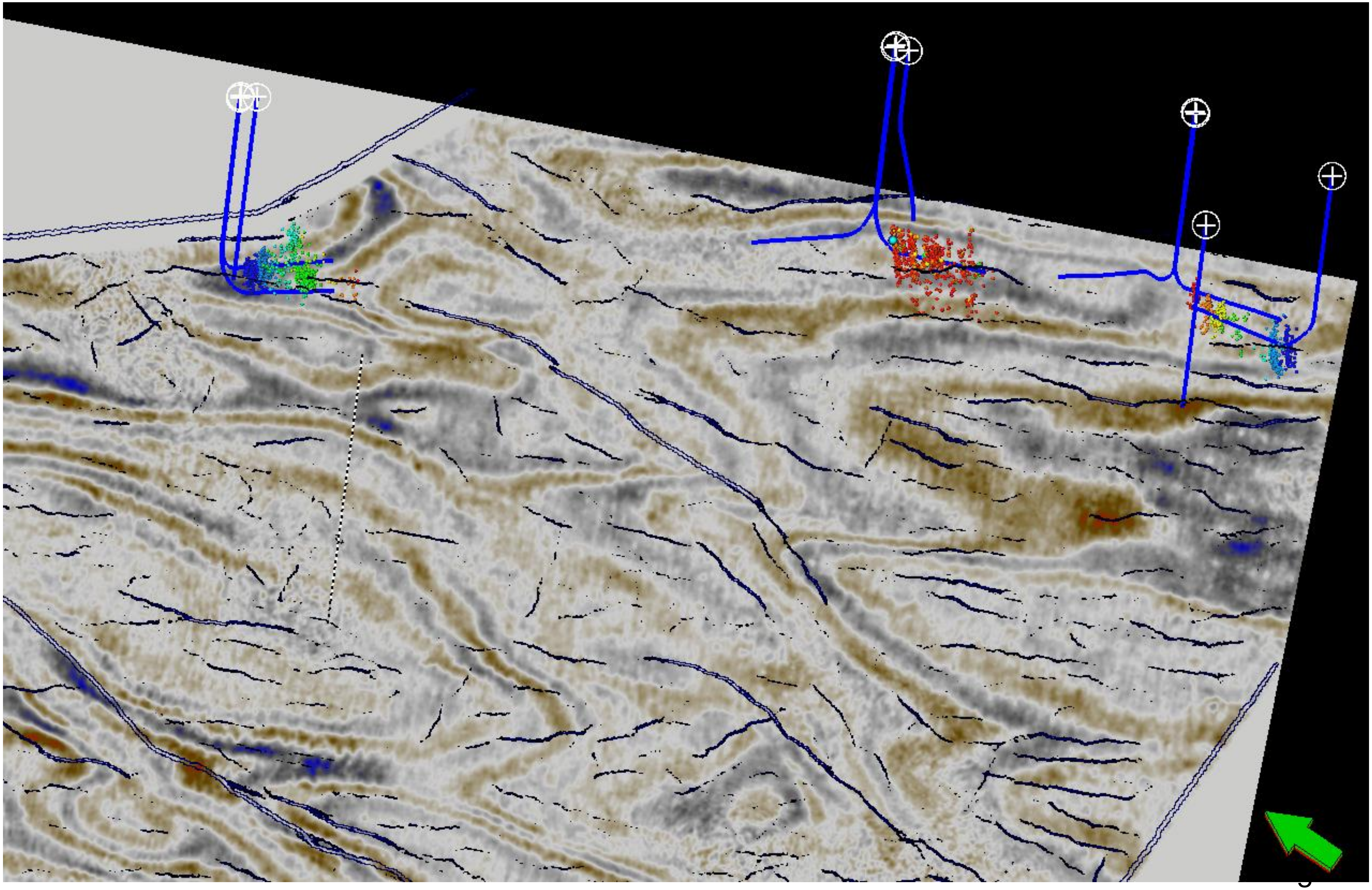
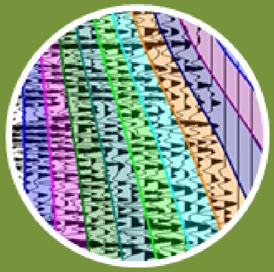
Completions Strategy

Wells Used in Analysis

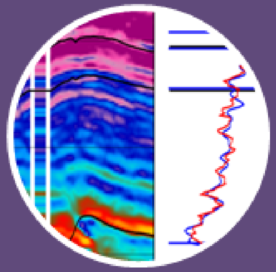


Workflow



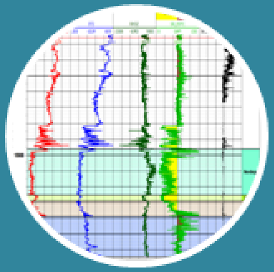
Seismic Preconditioning

- Noise attenuation
- Gather flattening



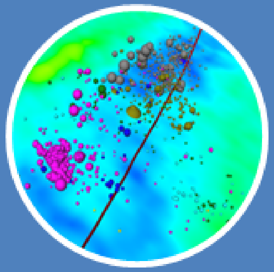
AVO Inversion

- Log calibration
- Wavelet extraction
- A priori model



Seismic Petrophysics

- Petrophysical evaluation
- Cluster analysis
- Bayesian theory



Interpretation

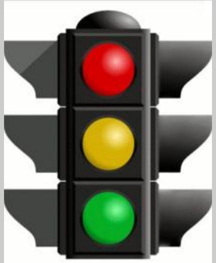
- Natural fractures and faults
- Microseismic data analysis

Capacity to Produce Hydrocarbons

Low

Medium

High



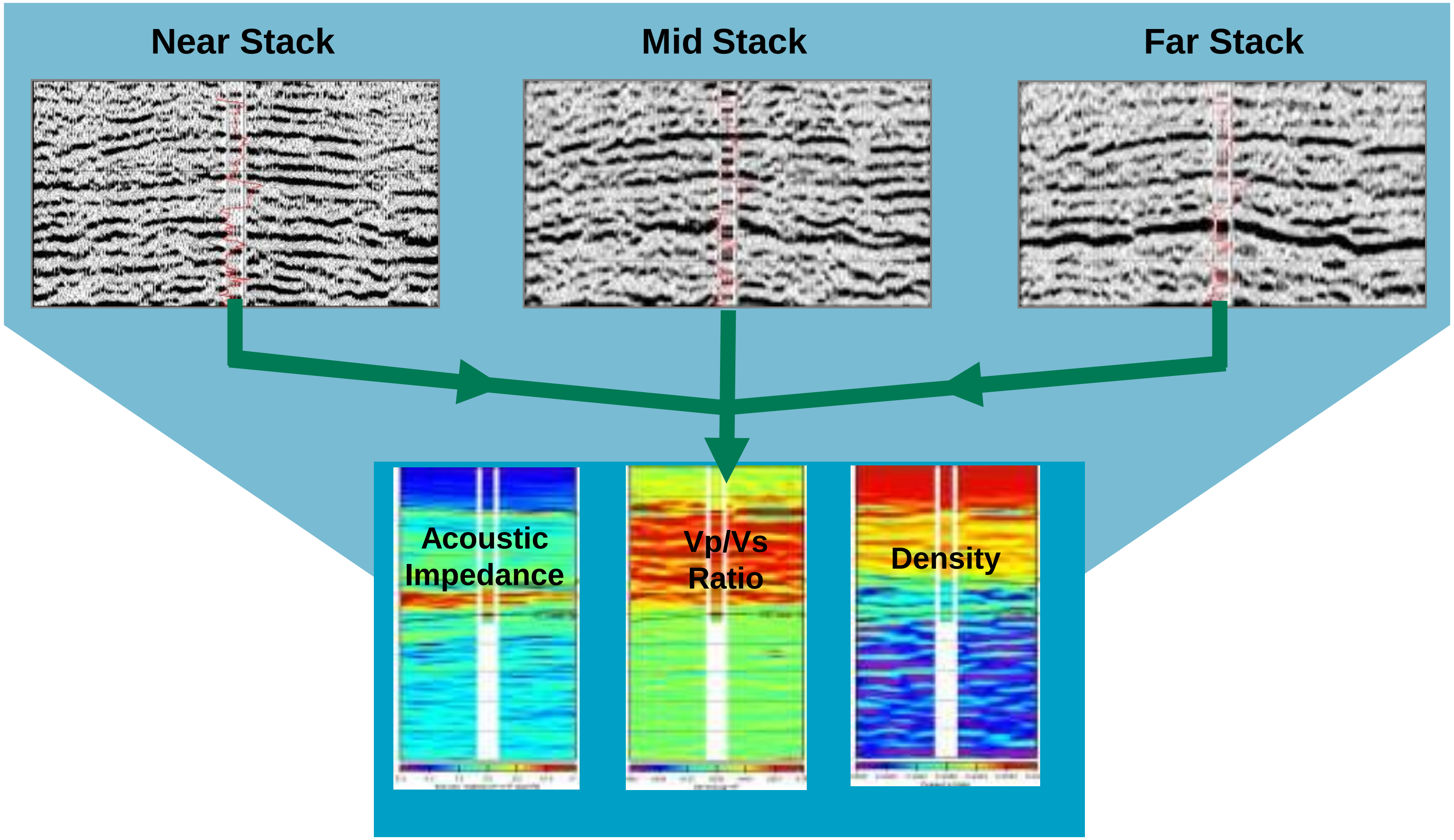
Seismic Inversion Processes and Applications

AI = Acoustic Impedance, SI = Shear Impedance, PR = Poisson's Ratio, LR = LambdaRho, MR = MuRho, LM = LambdaMu, FF = Fluid Factor, K = Bulk Modulus, E = Young's Modulus, M = P Wave Modulus, G = Shear Modulus, lambda = Lamé's 1st Parameter

Inversion Processes	Method	Required Seismic Data	Required Well Data	Output Volumes
Acoustic Inversion	Deterministic	Fullstack	Vp, RHOB	AI
AVO Inversion	Deterministic	Prestack	Vp, Vs, RHOB	AI, SI, Vp/Vs, PR, RHOB, LR, MR, LM, FF, K, E, M, G, lambda
Acoustic Inversion	Stochastic	Fullstack	Vp, RHOB	AI
AVO Inversion	Stochastic	Prestack	Vp, Vs, RHOB	AI, SI, Vp/Vs, PR, RHOB, LR, MR, LM, FF, K, E, M, G, lambda
Acoustic Inversion	Discrete Spike	Poststack	Vp, RHOB	AI
AVO Inversion	Discrete Spike	Prestack	Vp, Vs, RHOB	AI, SI, Vp/Vs, PR, RHOB, LR, MR, LM, FF, K, E, M, G, lambda
Poststack Multi-Component Inversion	Deterministic	PP Fullstack, PS Fullstack	Vp, RHOB	AI, SI
Multi-Component AVO Inversion	Deterministic	PP Prestack, PS Prestack	Vp, Vs, RHOB	AI, SI, Vp/Vs, PR, RHOB, FF, K, E, M, G, lambda
Poststack Time-Lapse Inversion	Deterministic	Baseline Fullstack, n-vintages Monitor Fullstack	Vp, RHOB	Baseline AI, n-vintages Ratio Change AI
Time-Lapse AVO Inversion	Deterministic	Baseline Prestack, n-vintages Monitor Prestack	Vp, Vs, RHOB	Baseline AI, n-vintages Ratio Change AI, SI, Vp/Vs, PR, RHOB, LR, MR, LM, FF, K, E, M, G, lambda
AVO Azimuthal Inversion	Deterministic	Prestack Azimuthal Stacks	Vp, Vs Isotropic, Vs Fast, Vs Slow, Vs Fast Azimuth, RHOB	AI, RHOB (Vertical Isotropic), SI Fast, SI Slow, SI Fast Azimuth, SI Slow/SI Fast Ratio
Crosswell Inversion	Deterministic	Fullstack	Vp, RHOB	AI, PHIT, Vp
AVO Crosswell Inversion	Deterministic	Prestack	Vp, Vs, RHOB	AI, SI, Vp/Vs, PR, RHOB, LR, MR, LM, FF, K, E, M, G, lambda
Inversion Applications	**Method**	**Seismic Data**	**Well Data**	**Output Volumes**
Lithology Prediction	Rock Physics	Prestack	Vp, Vs, RHOB, Vcl, Sw, PHIT	User Defined Lithology and Associated Probabilities
Porosity	Crossplot Analysis	Poststack, Prestack	Vp, RHOB, PHIT, (Vs for Prestack)	Total Porosity
Joint Porosity and Saturation	Rock Physics	Prestack	Vp, Vs, RHOB, PHIT, Sw	Total Porosity, Water Saturation and Associated Probabilities
Water Saturation, Resistivity	Neural Networks	Prestack	Vp, Vs, RHOB, Sw	Water Saturation, Resistivity
Volume of Shale, Volume of Clay	Rock Physics, Neural Networks	Prestack	Vp, Vs, RHOB, Vsh, Vcl	Volume of Shale, Volume of Clay
Pore Pressure (High Resolution Vels)	Geomechanics	Prestack	Vp, Vs, RHOB, Vsh, Vcl	Pore Pressure
Mechanical Earth Modeling	Geomechanics	Prestack	Vp, Vs, RHOB, PHIT, PHIE, GR, Vcl	Stress
Wellbore Stability	Geomechanics	Prestack	Vp, Vs, RHOB, PHIT, PHIE, GR, Vsh, Vcl	Shear Failure Gradient, Fracture Gradient, Breakout and Breakdown Failures

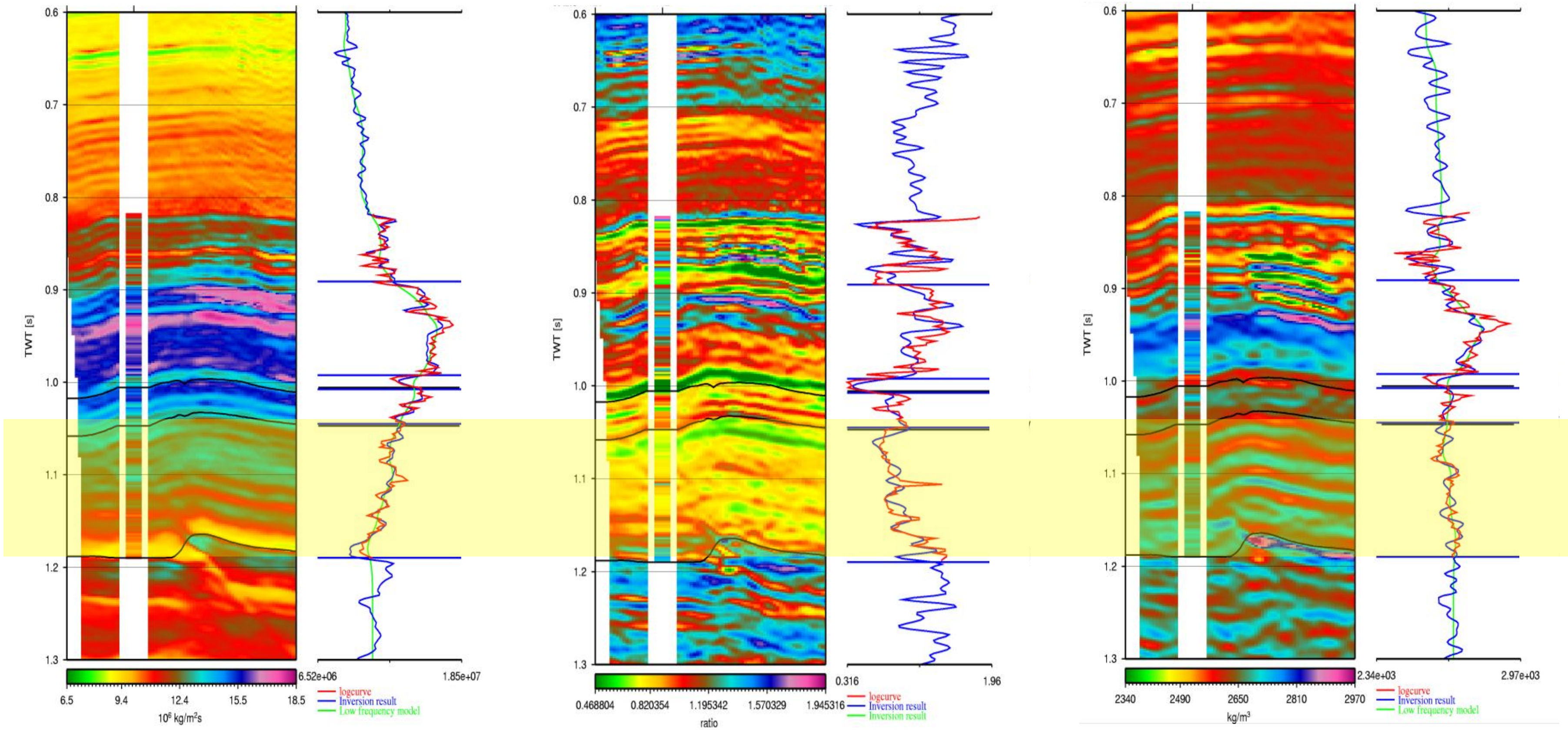
Prestack Seismic Inversion

- Use of inversion methods allows for 1D borehole measurements to be parameterized into 3D space by analyzing the relationship between well and seismic data
- Main inputs include: seismic partial stacks, wavelets and low frequency models



Prestack Simultaneous Inversion Results

Acoustic Impedance (kg/m²s) | Lambda/Mu (ratio) | Density (kg/m³)

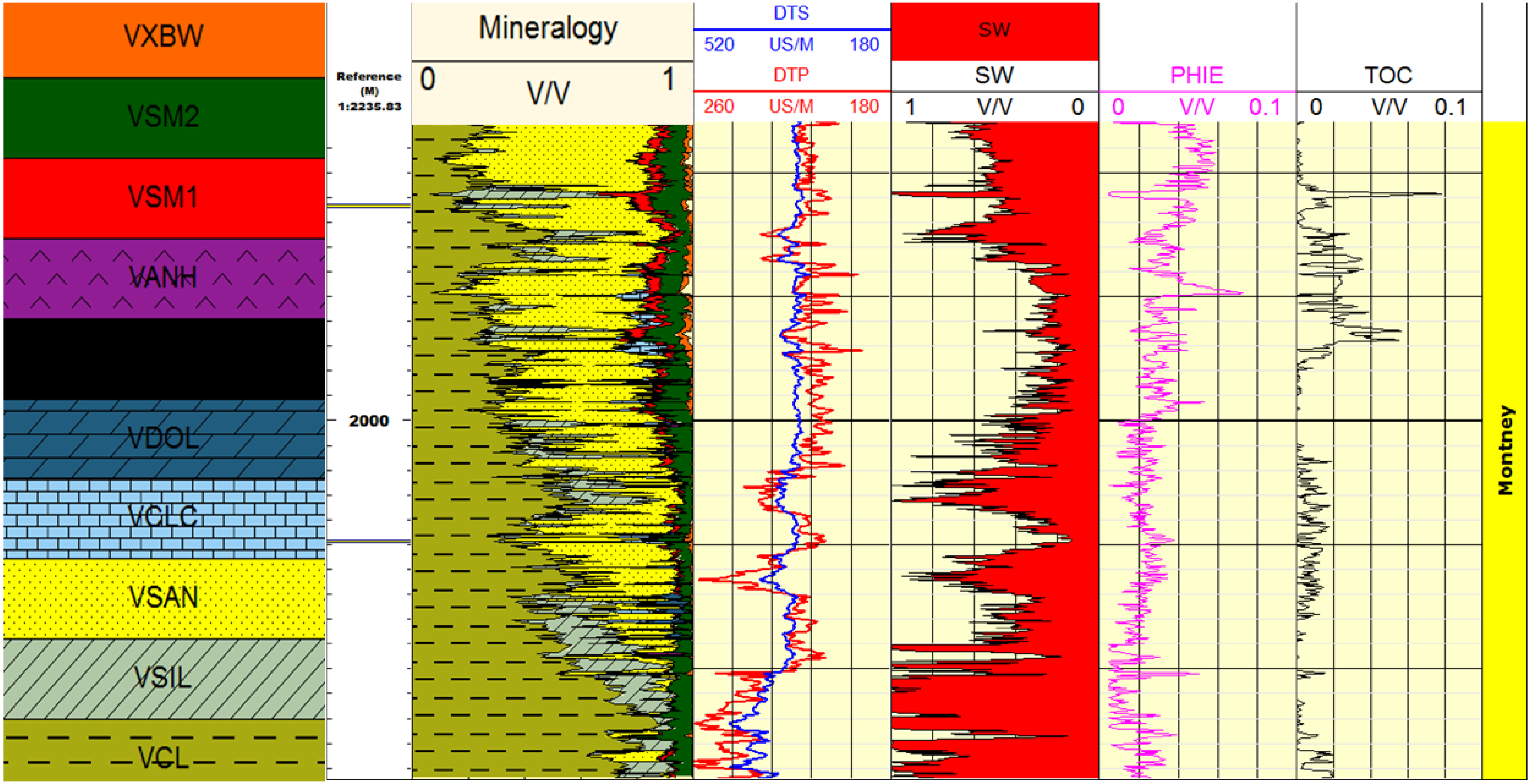


- Formation of interest is indicated in yellow
- Good match between inversions result and measured logs

Seismic Petrophysics

- All horizontal and vertical wells were broken down into three categories based on gas production data (high, medium and low)
  - Medium producer falls within 3-5 MMCF/day
  - 30 day average of IP rate
  - Production rates normalized to lateral length of horizontal wells
- Following the inversion, a spatial distribution of HC Production Capacity based on seismic inversion outputs was carried out
- Steps include:
  - Class definition based on petrophysical properties and/or elastic properties
  - Elastic property cluster analysis
  - Generate and optimize probability density function
  - Apply PDF to inversion results
- Outputs include HC Production Capacity indicator cube and associated probabilities

Well Log Data

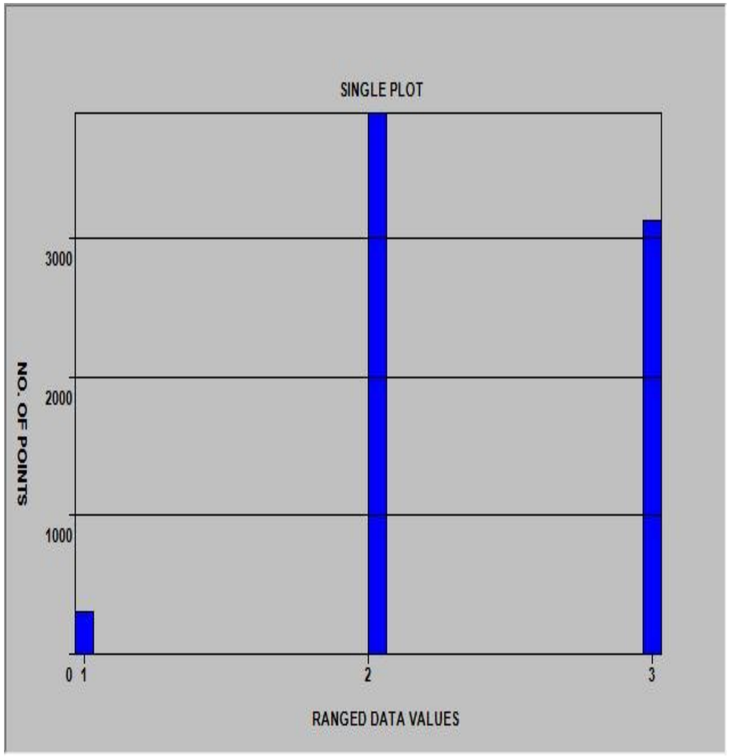


- Perforated locations are indicated by horizontal lines in depth track
- VSM1 = Kerogen
- VSM2 = Heavy minerals

Class Log Definition

- Reservoir quality split into three classifications
- Cut-offs:
  - 1) High Quality Reservoir: Vcl <= 15%, PHIE >= 5%, Sw < 40%
  - 2) Medium Quality Reservoir: 15% < Vcl < 40%, 2% < PHIE < 5%, 40% < Sw < 65%
  - 3) Low Quality Reservoir: Vcl >= 40%, PHIE <= 2%, Sw >= 65

Class Log Histogram - Vertical Wells



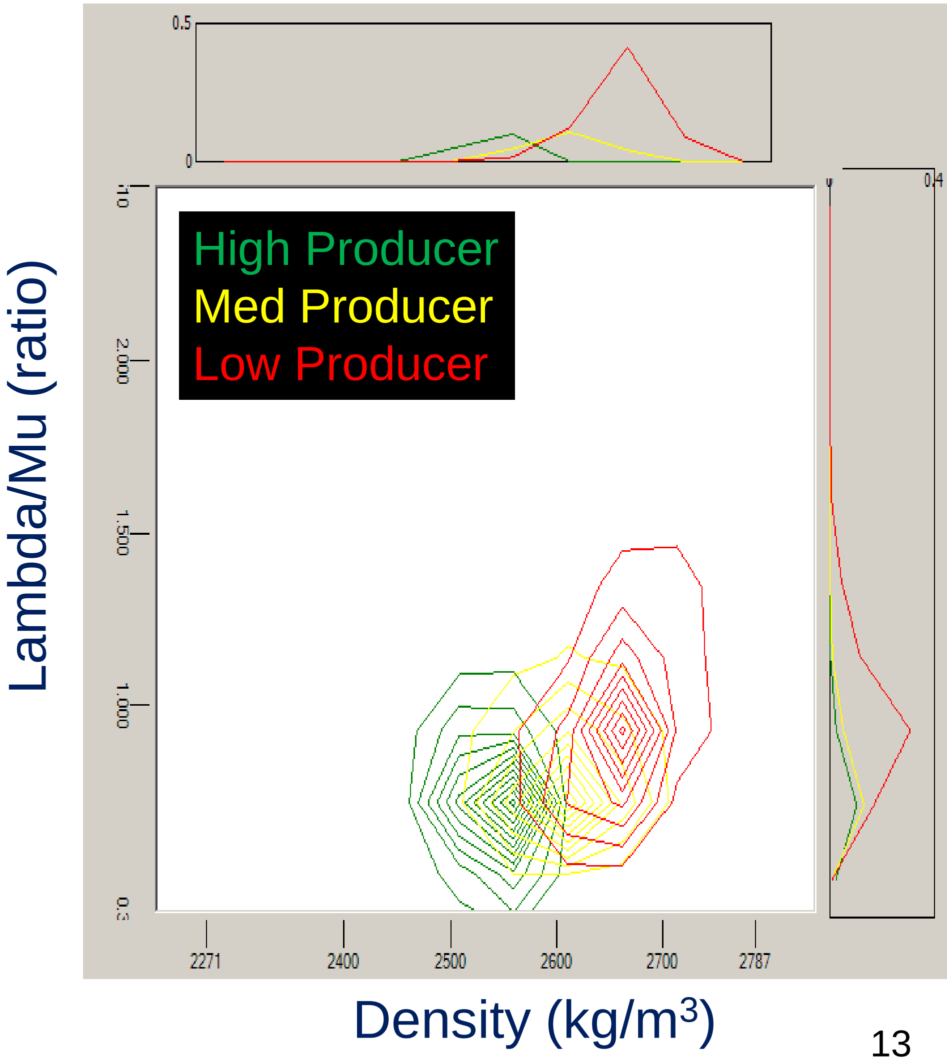
Probability Density Function (PDF)

- Suite of seismic-derived elastic properties tested:

Elastic Property	Symbol
Poisson's Ratio	σ
Static Young's Modulus	E
Bulk Modulus	K
Shear Modulus	G
P-wave Modulus	M
LambdaRho	$\lambda\rho$
MuRho	$\mu\rho$
Lambda/Mu	λ/μ
Lame's First Parameter	λ

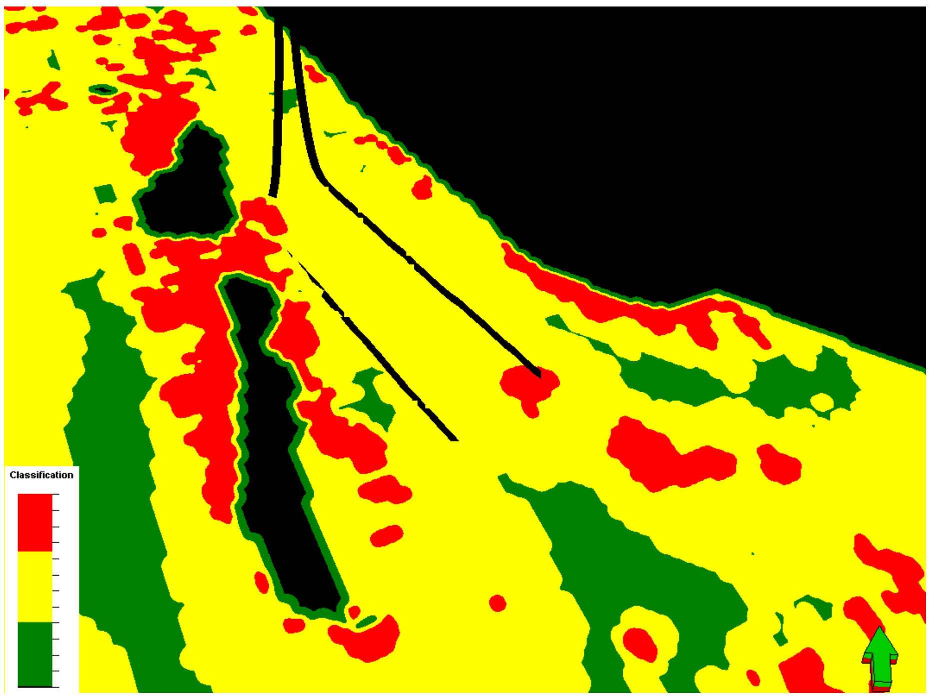
- Lambda/Mu and Density best correlate with production, and therefore used in generating the PDF

2D Probability Density Function

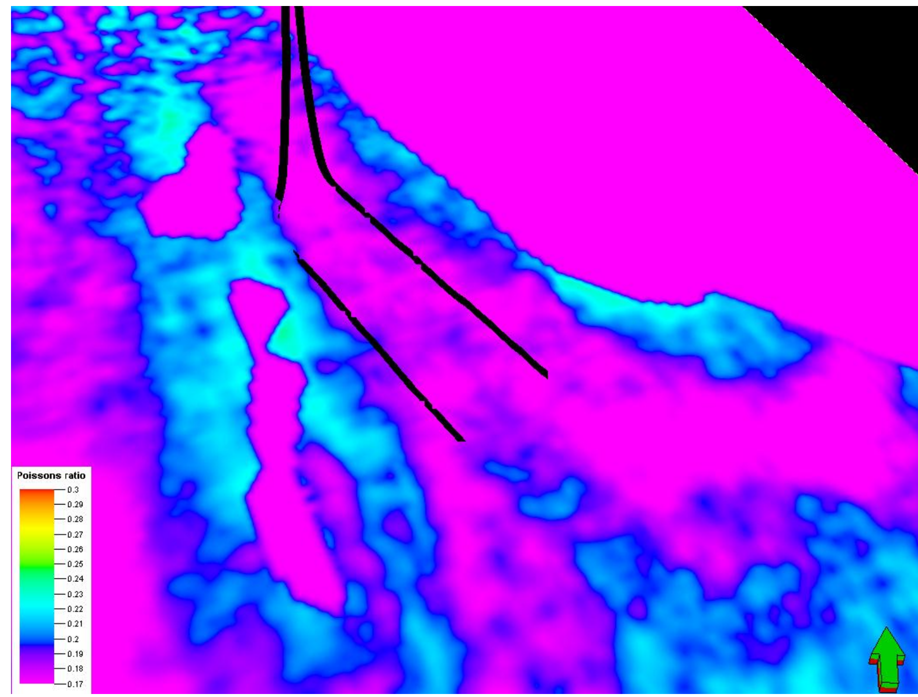


HC Production Capacity vs Poisson’s Ratio – Depth Slice: 924 m TVD

HC Production Capacity Cube



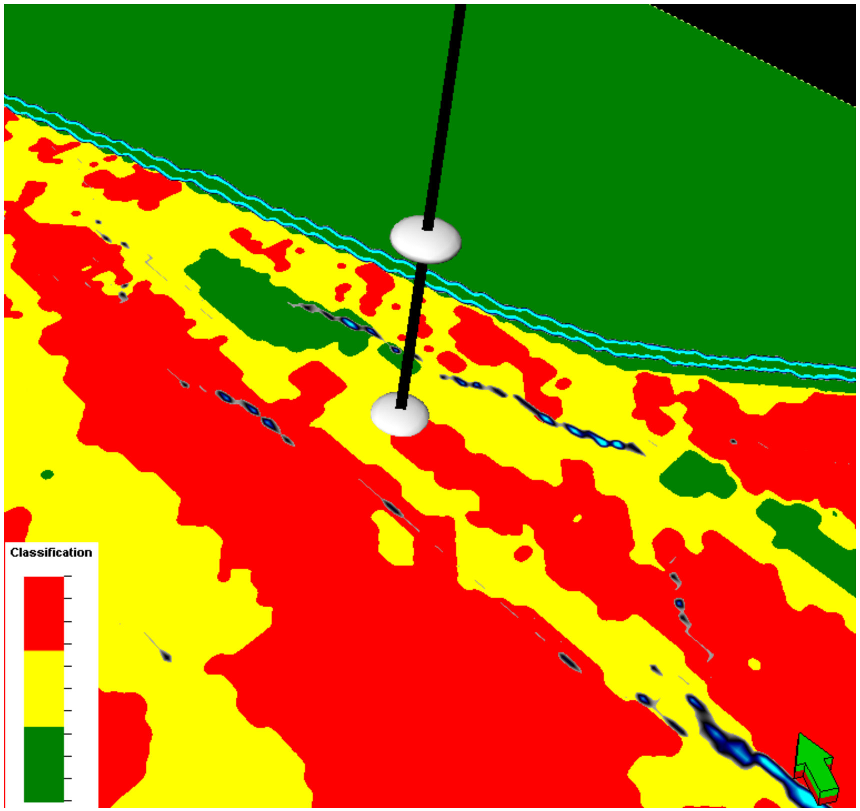
Poisson’s Ratio



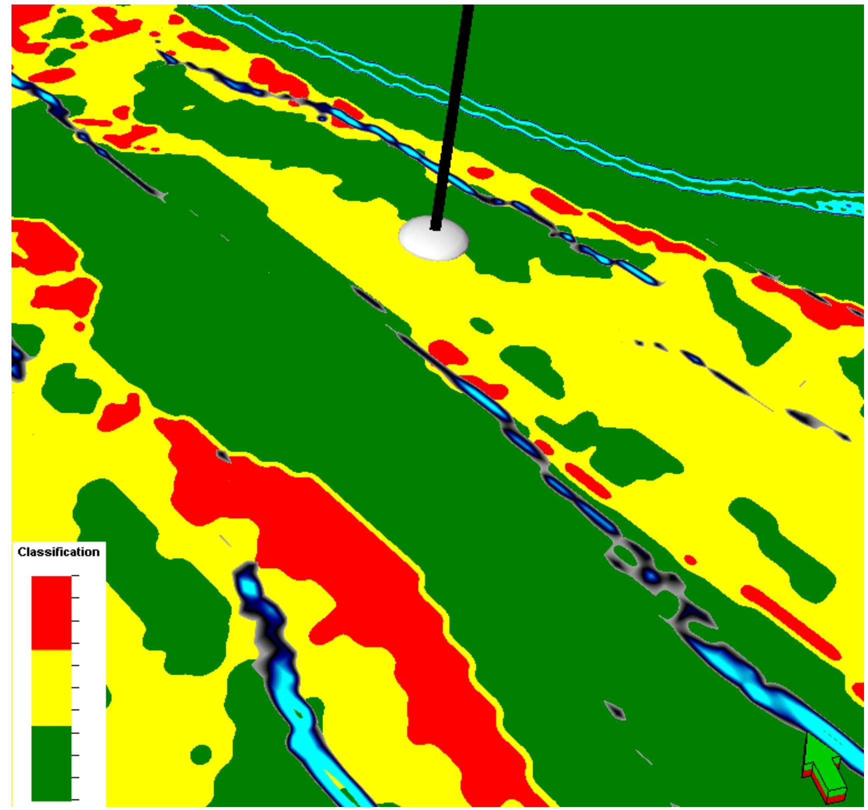
- Wells drilled based on Poisson’s ratio
- Medium production from both wells
- HC Production Capacity cube accurately predicts observed production

HC Production Capacity Result – Vertical Well with 2 Perfs

Lower: 1049 m TVD – Med Production

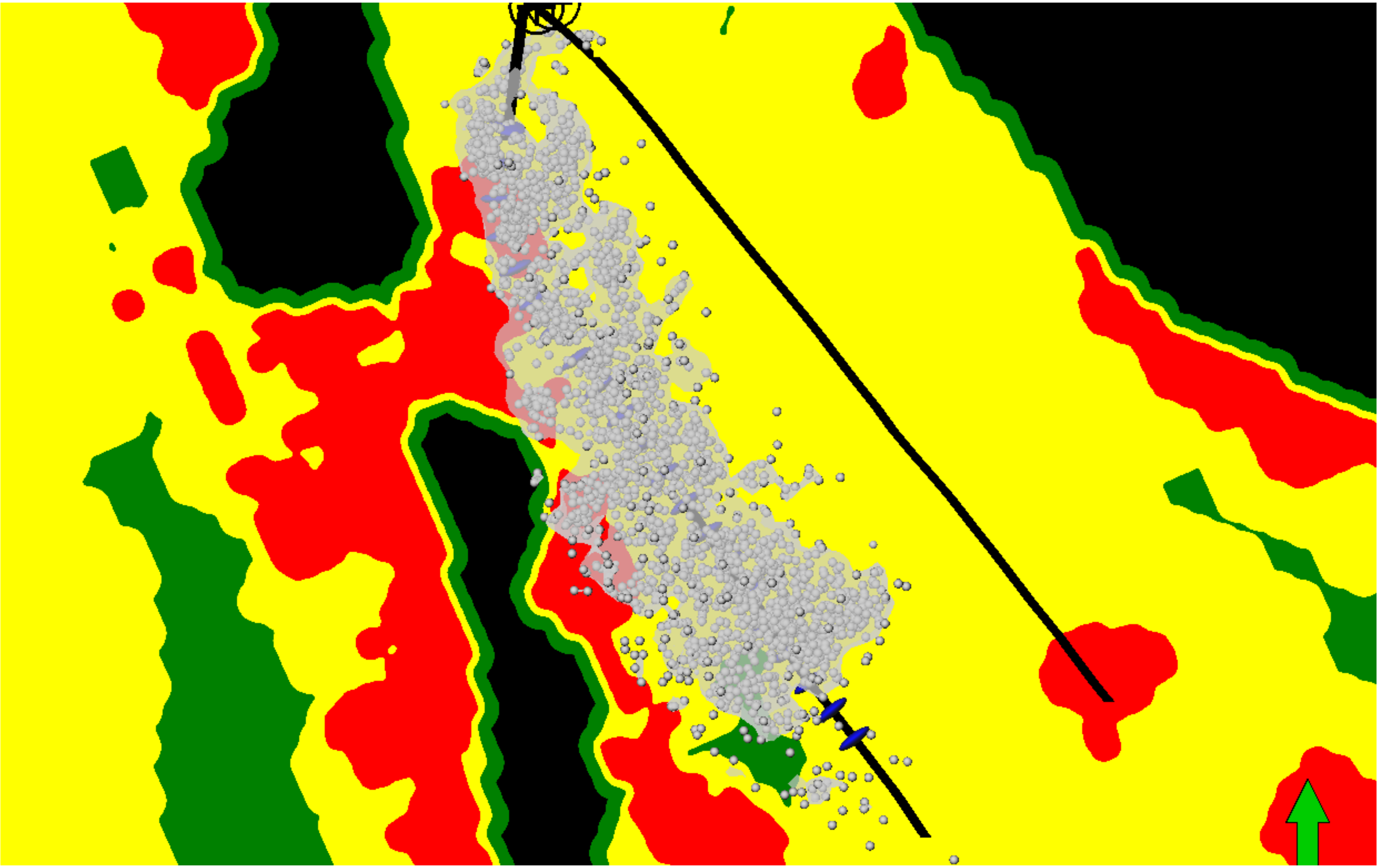


Upper: 914 m TVD – High Production



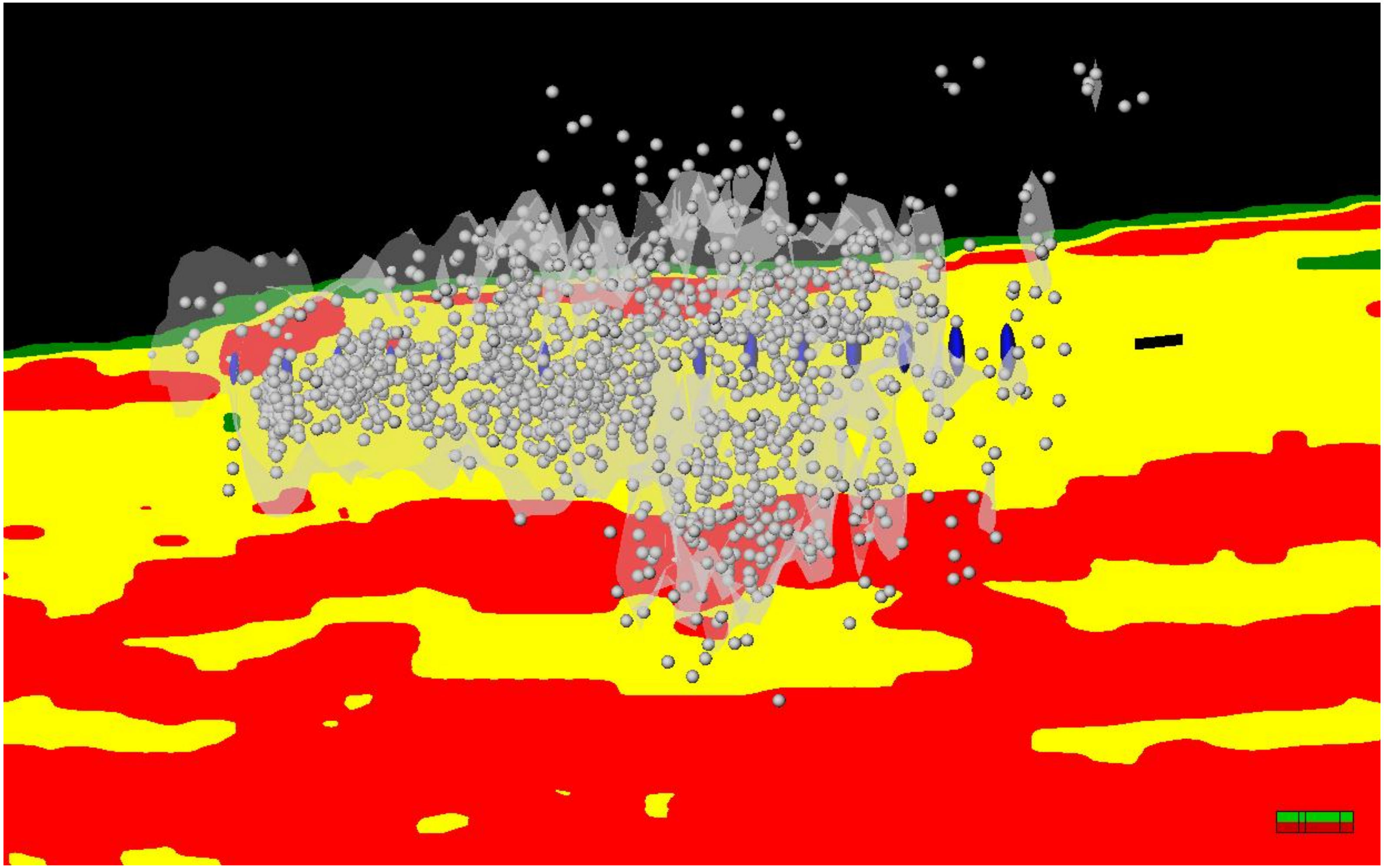
- Upper and lower perforations for Well B displayed
- Ant Tracking cube also displayed

Microseismic Data Evaluation – Depth Slice: 924 m TVD



- Estimated stimulated volume (ESV) displayed along medium producer
- Indicator of reservoir contact
- Bulk of ESV is within medium production estimation zone

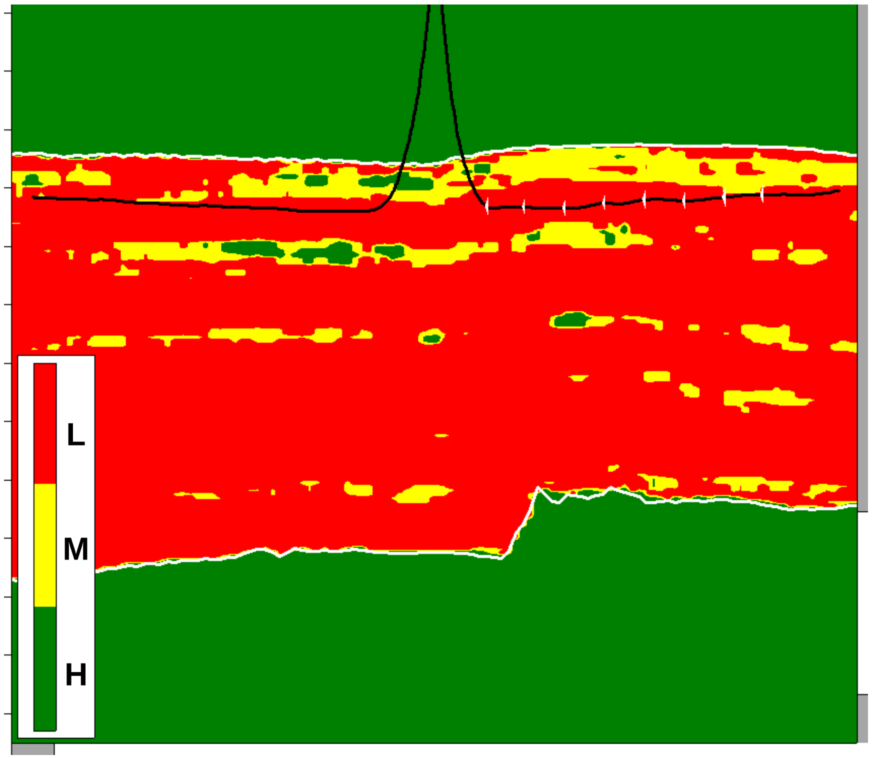
Microseismic Data Evaluation – Arbitrary Line



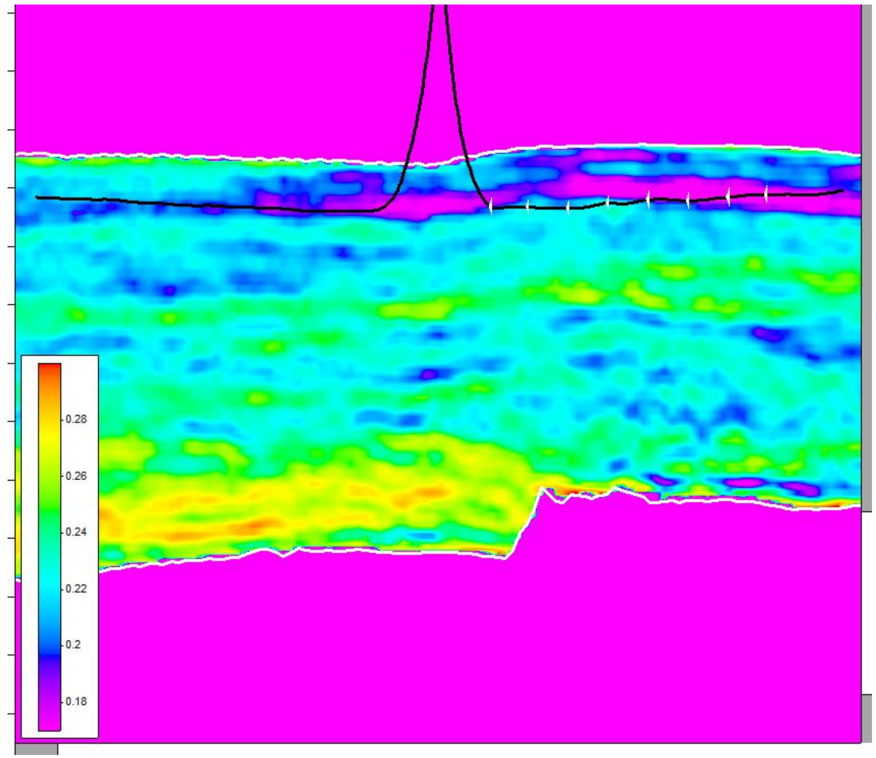
- Estimated stimulated volume (ESV) displayed along medium producer
- Indicator of reservoir contact
- Bulk of ESV is within medium production estimation zone

HC Production Capacity vs Poisson's Ratio – Arbitrary Line

HC Production Capacity Cube

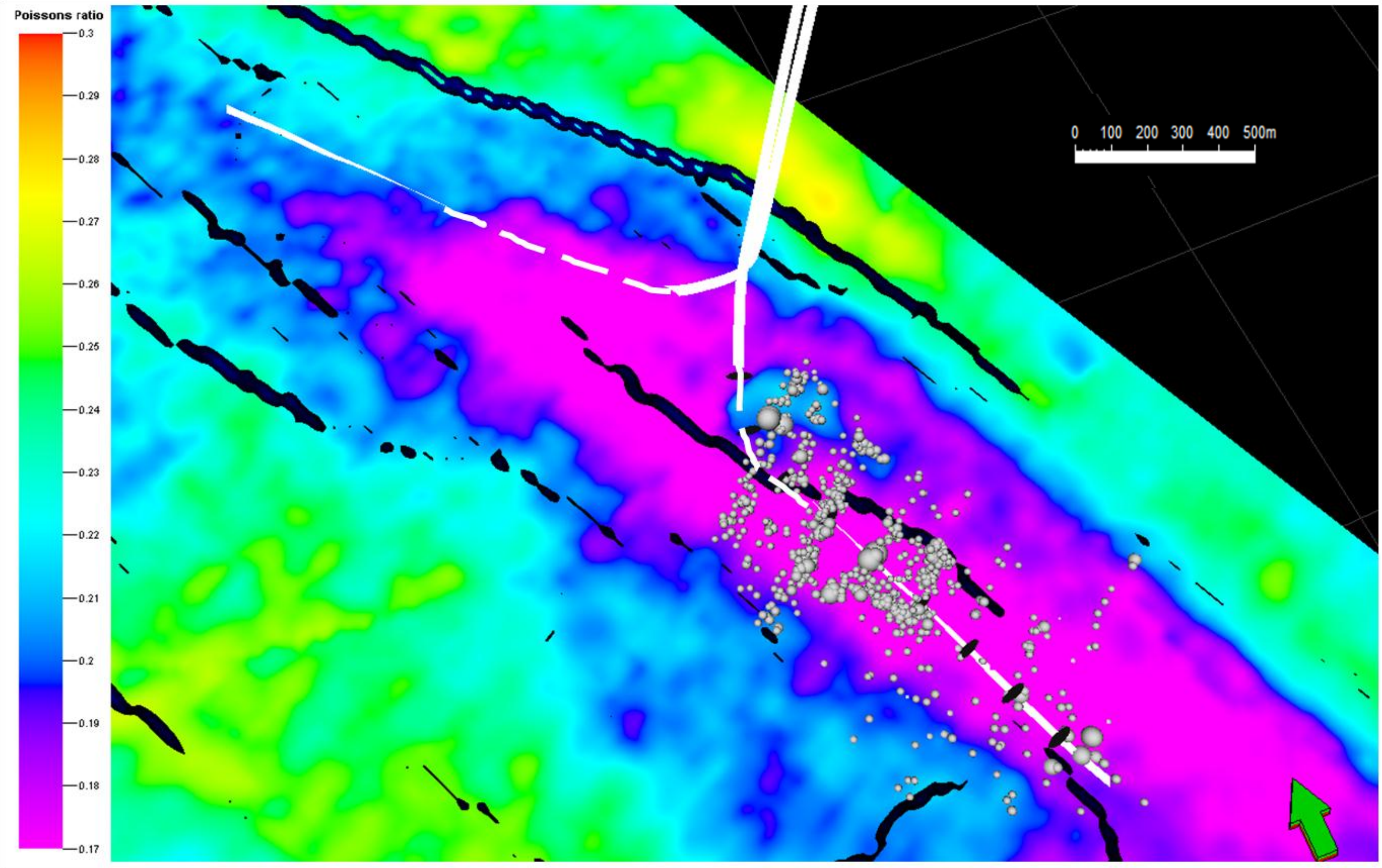


Poisson's Ratio

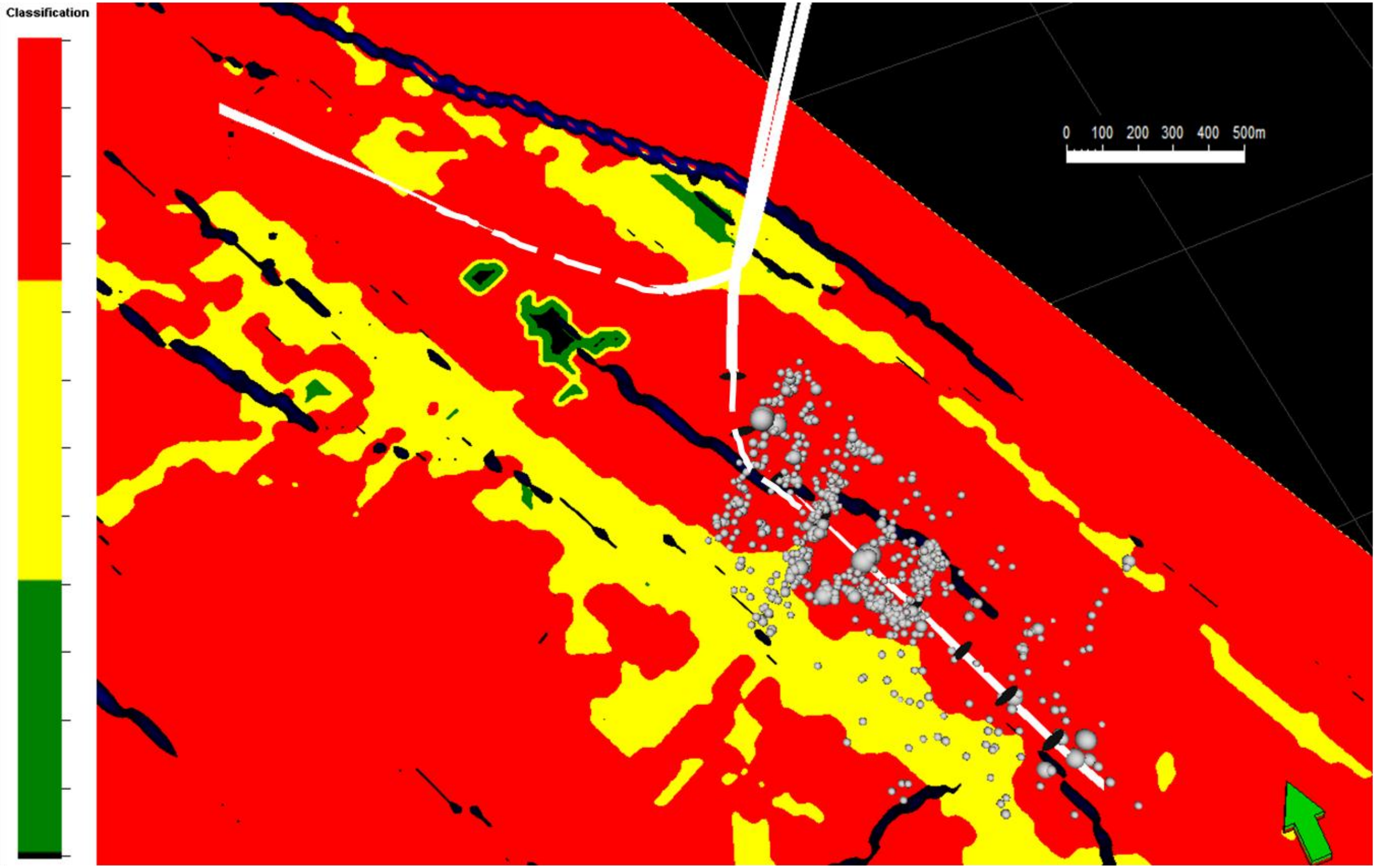


- Wells drilled based on Poisson's ratio
- Low production from both wells
- HC Production Capacity cube accurately predicts observed production
- Perforation indicated where available

Poisson's Ratio Depth Slice

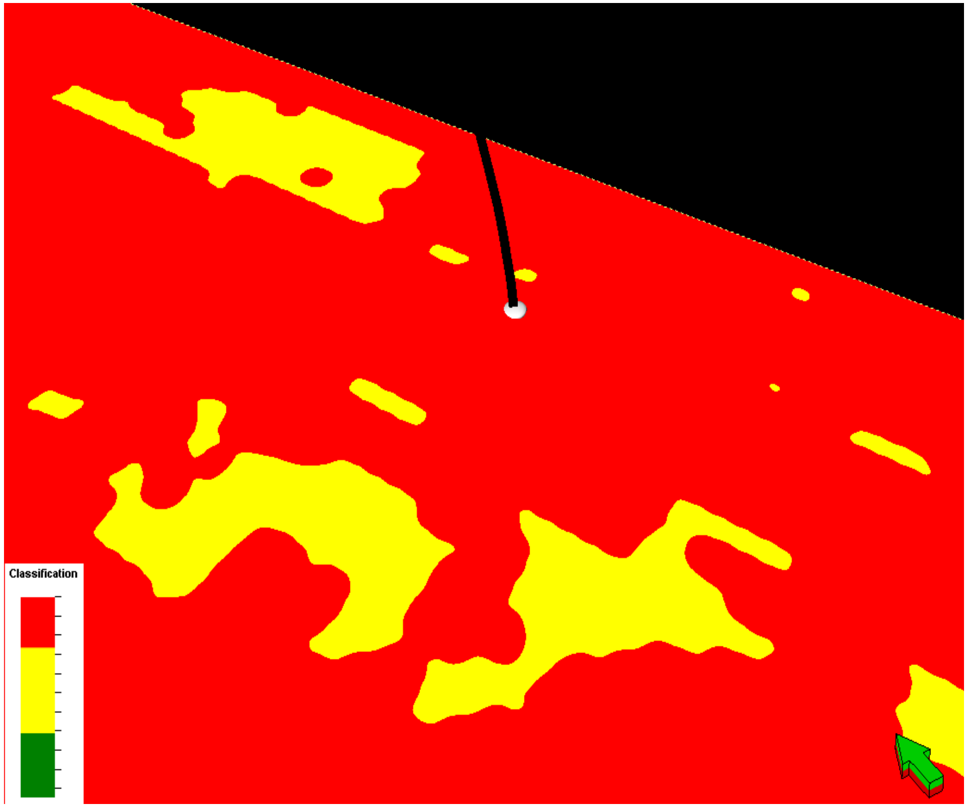


Hydrocarbon Production Capacity Depth Slice

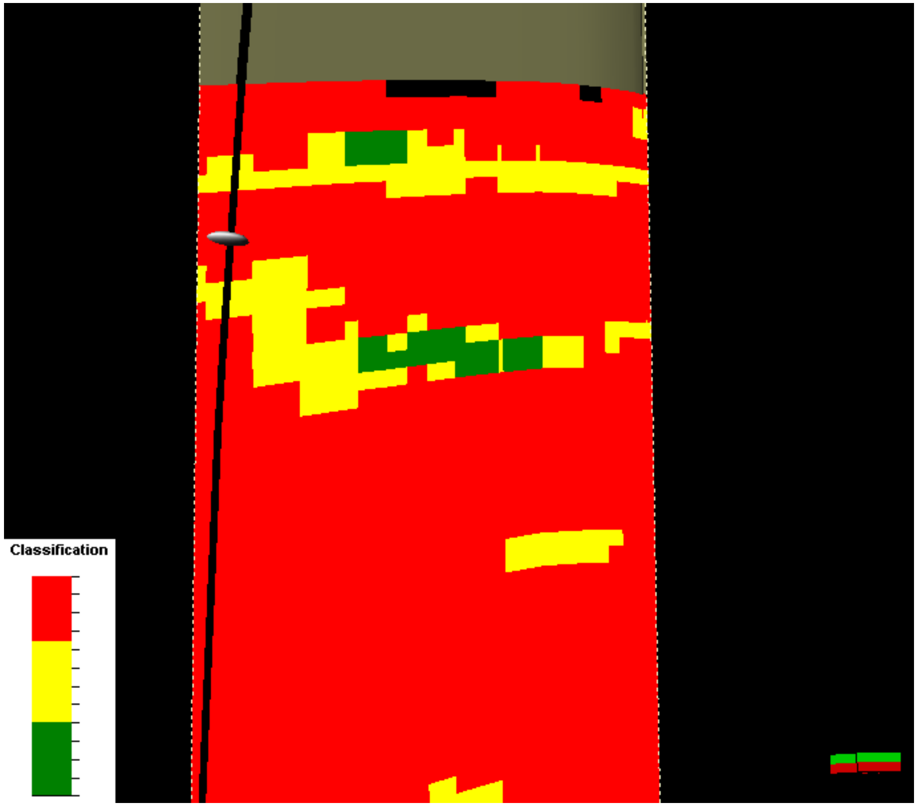


HC Production Capacity Result – Low Producing Vertical Well

Depth Slice: 934 m TVD



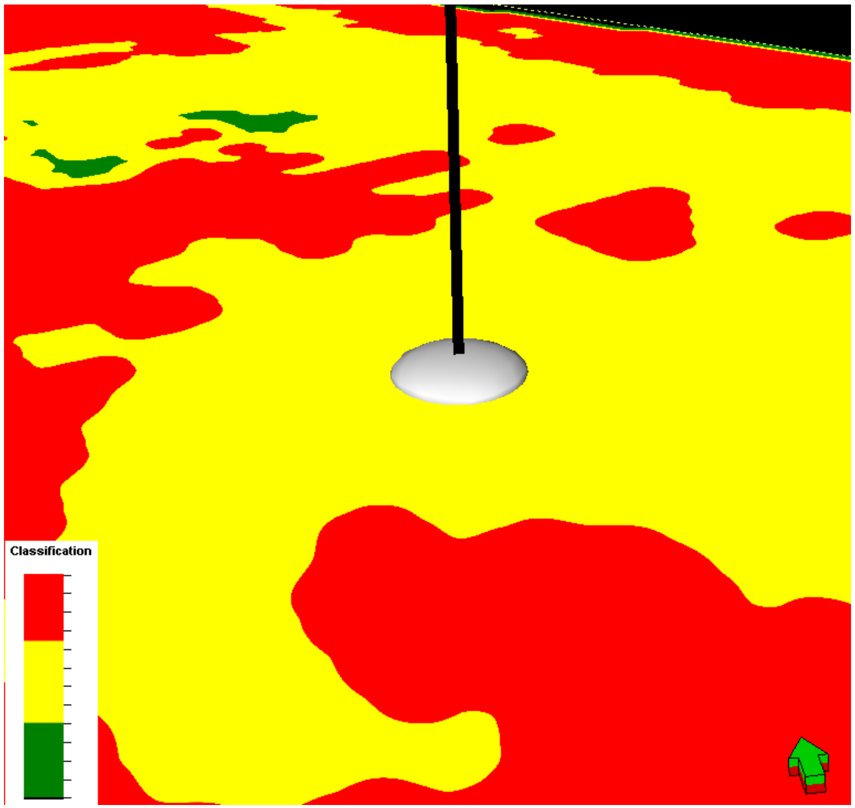
Vertical Intersection



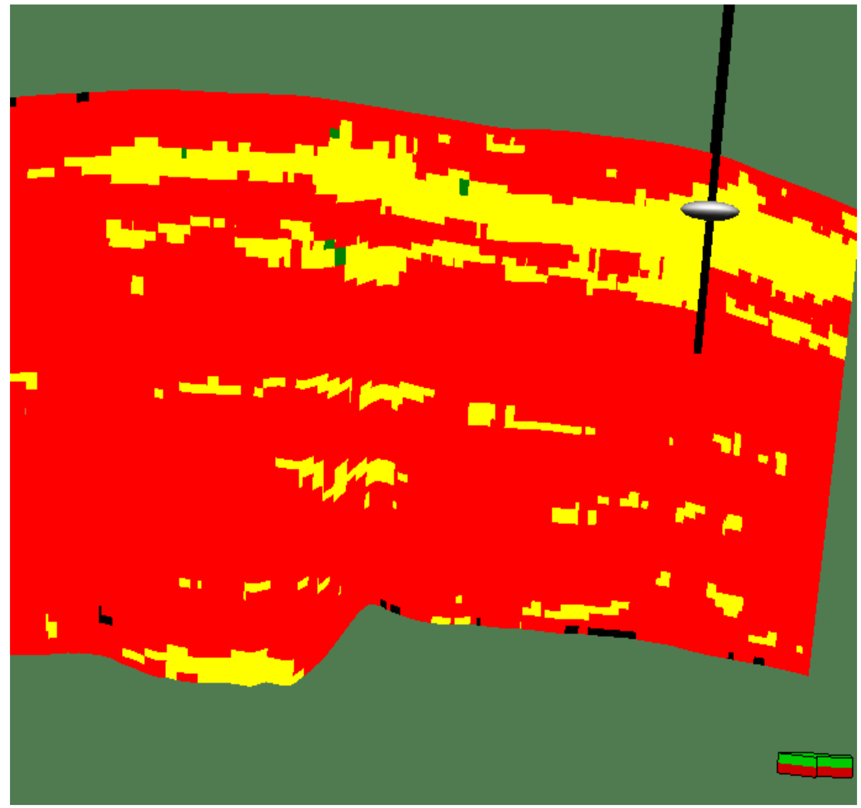
- Low producing well displayed
- HC Production Capacity result is in agreement with well production

HC Production Capacity Result – High Producing Vertical Well

Depth Slice: 934 m TVD

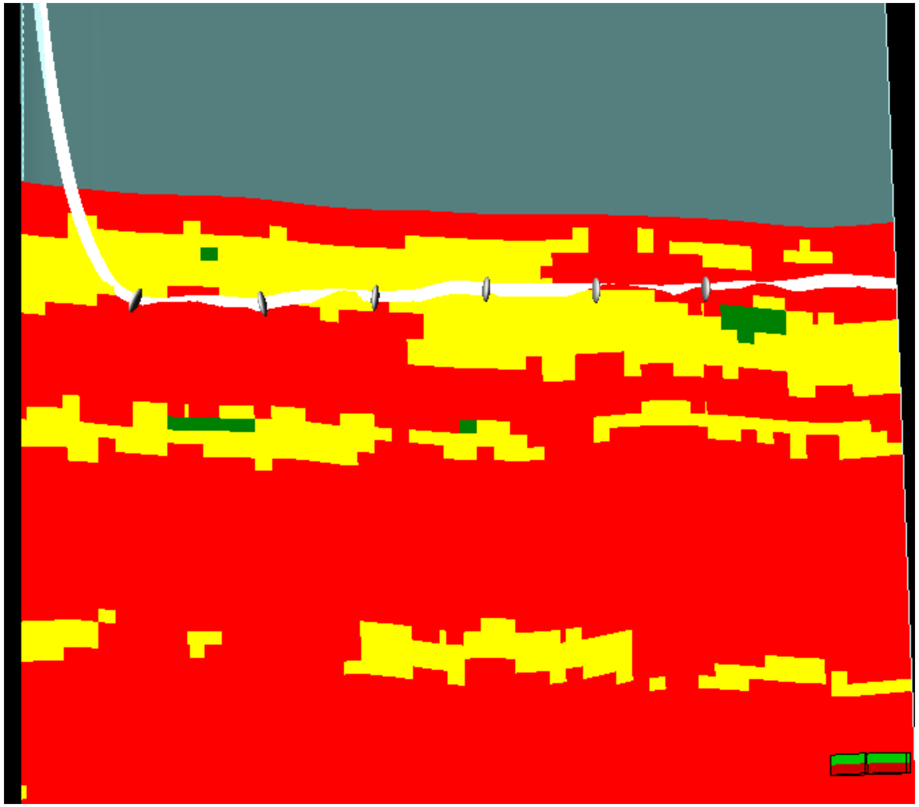


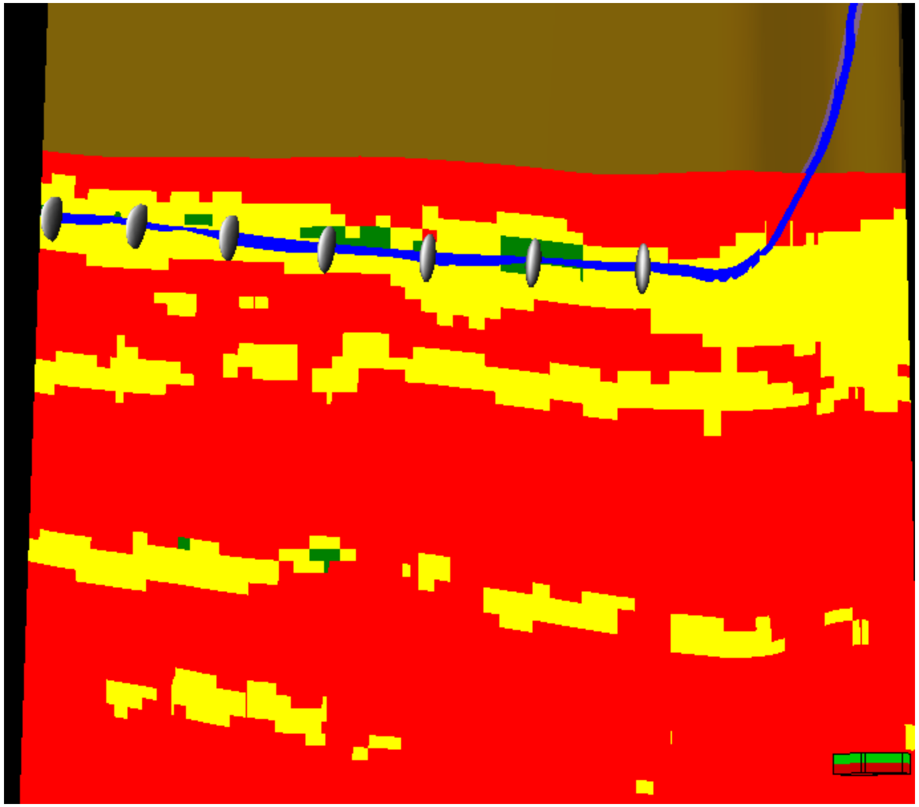
Vertical Intersection



- Well displayed is a high producer
- HC Production Capacity result is dominated by a medium producing zone

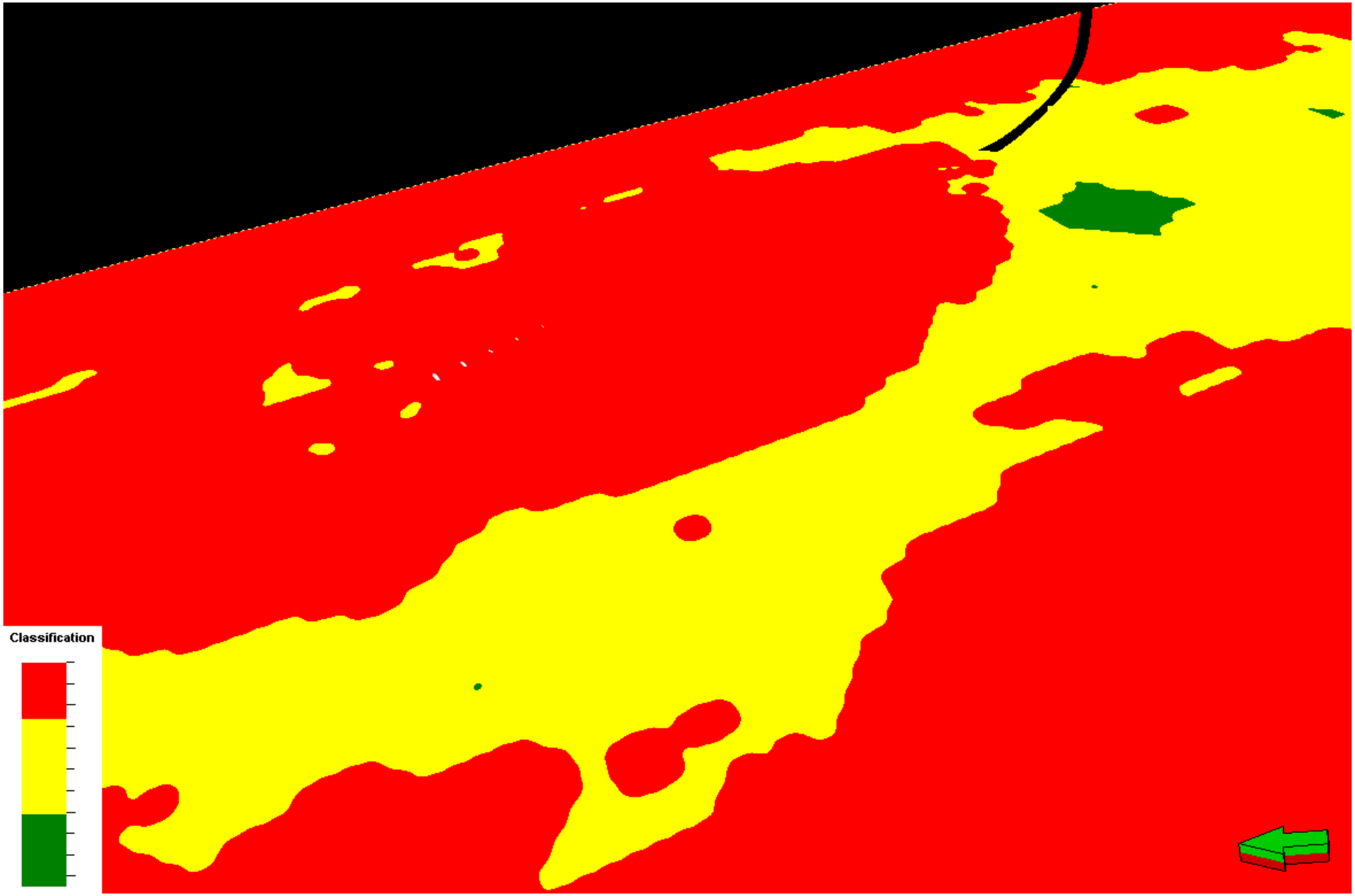
HC Production Capacity Vertical Intersections


Medium Producer


High Producer

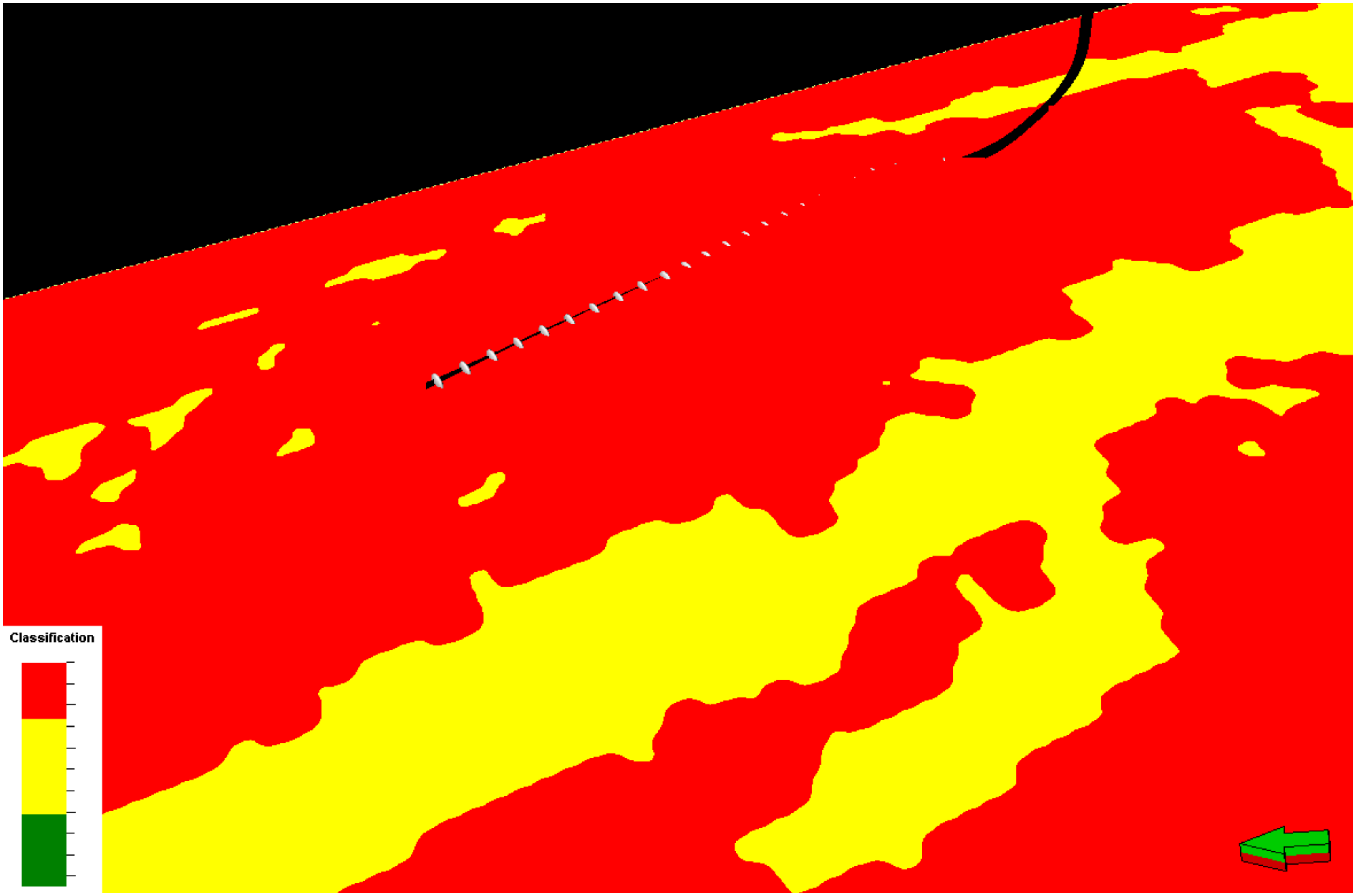
- Acceptable match at medium producing well
- High producing well is dominated by medium reservoir quality
- Three perfs are adjacent to zones of high reservoir quality

HC Production Capacity Depth Slice: 920 m TVD



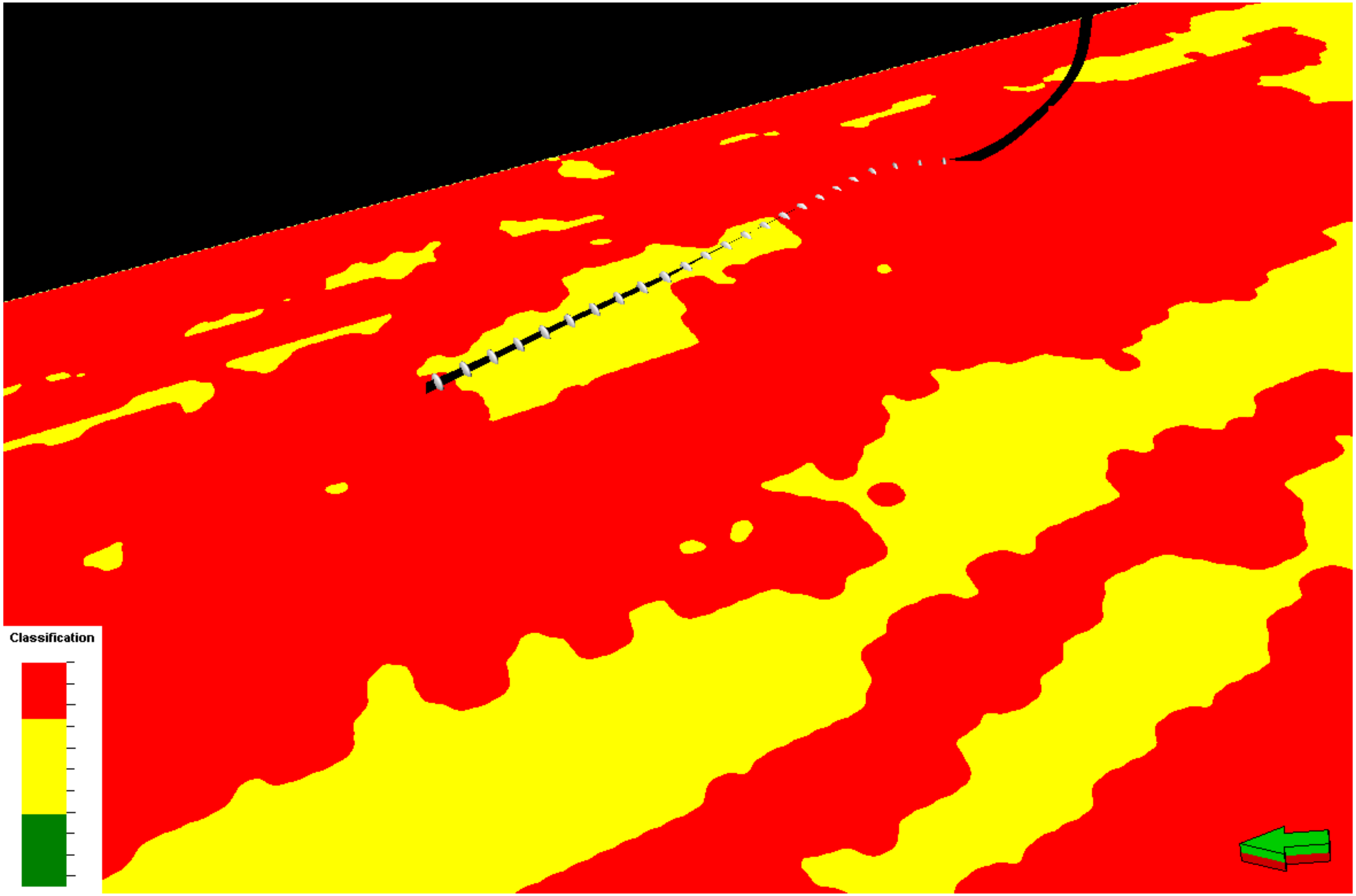
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity Depth Slice: 934 m TVD



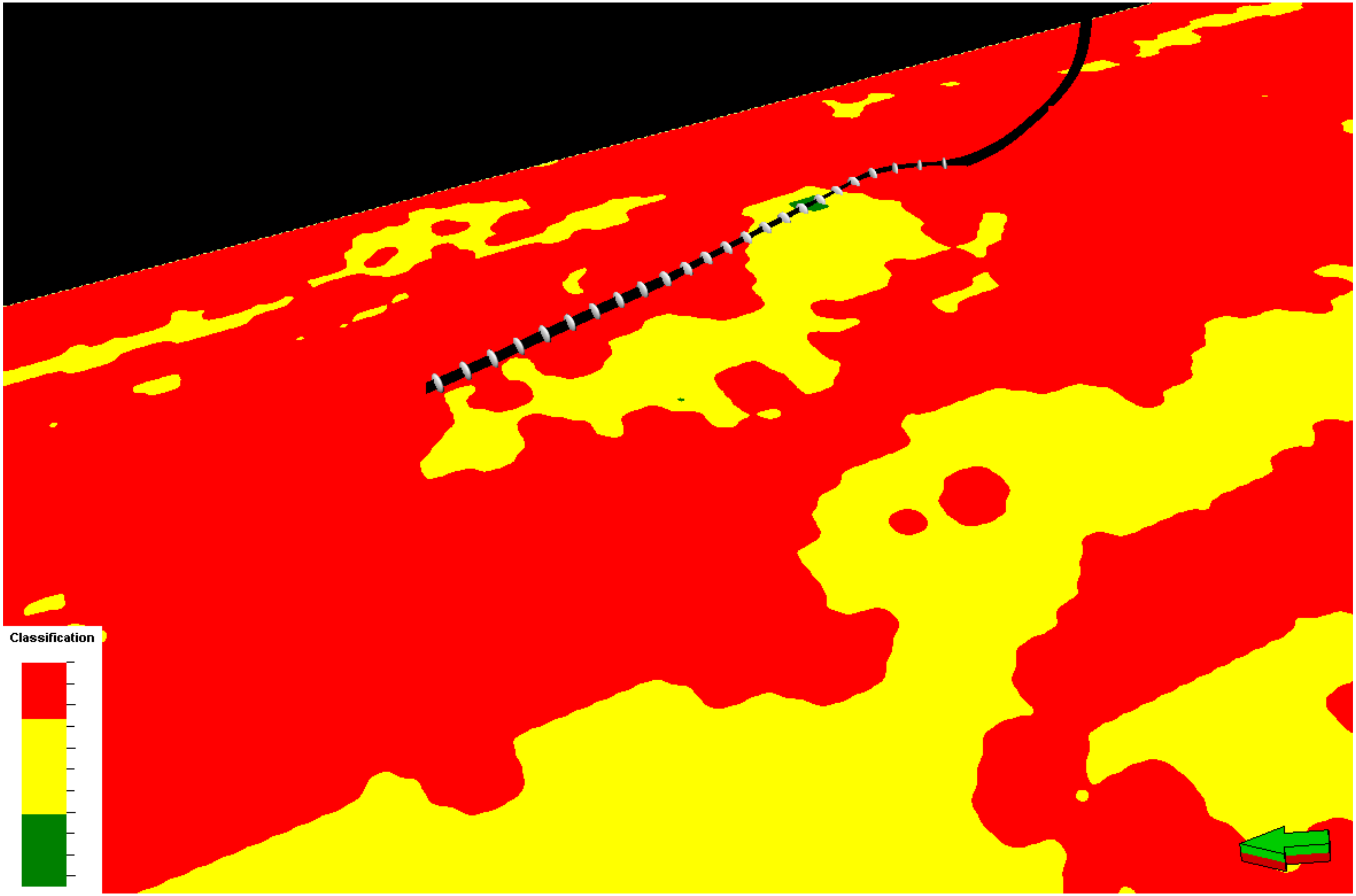
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity Depth Slice: 941 m TVD



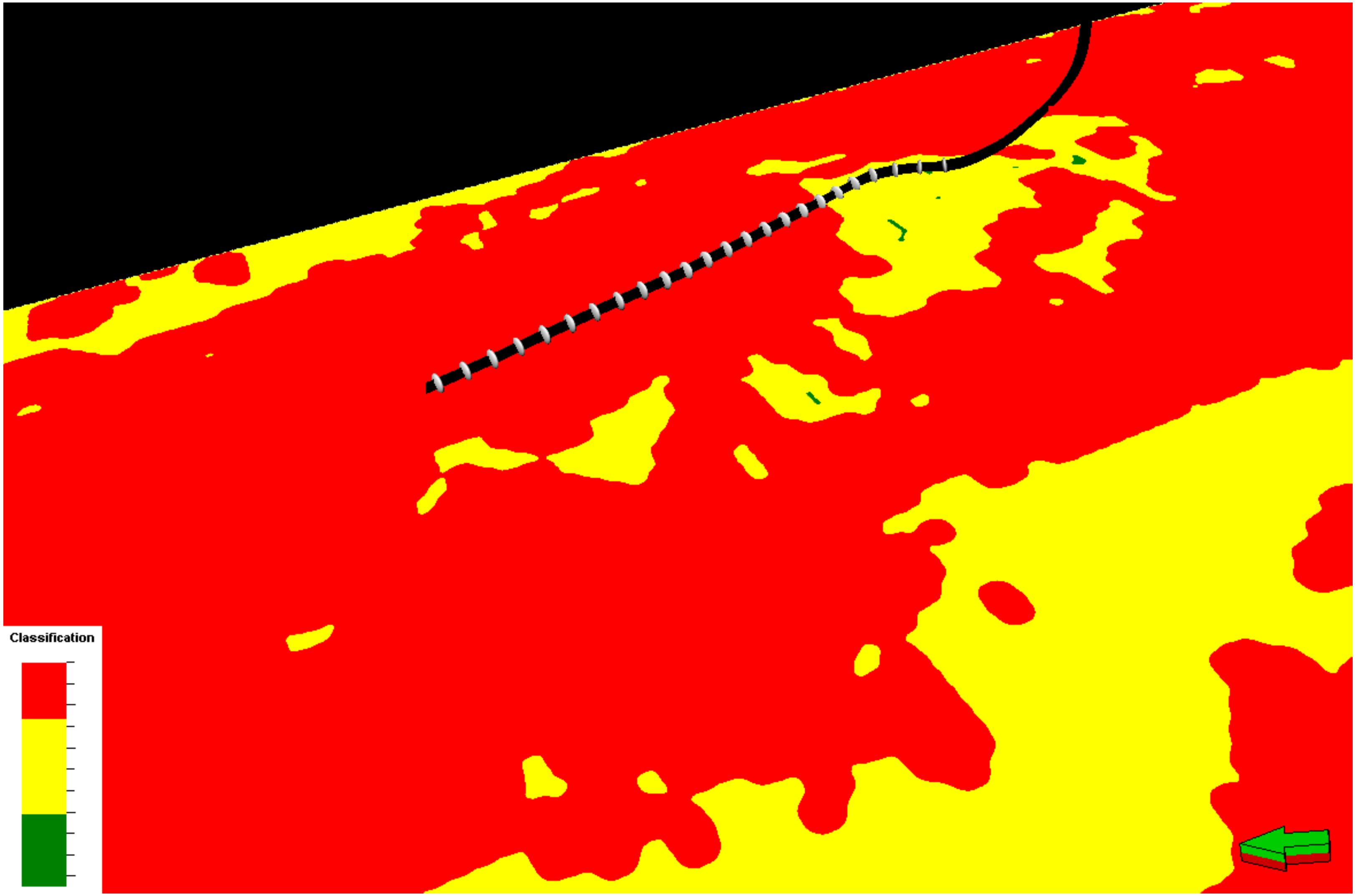
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity Depth Slice: 951 m TVD



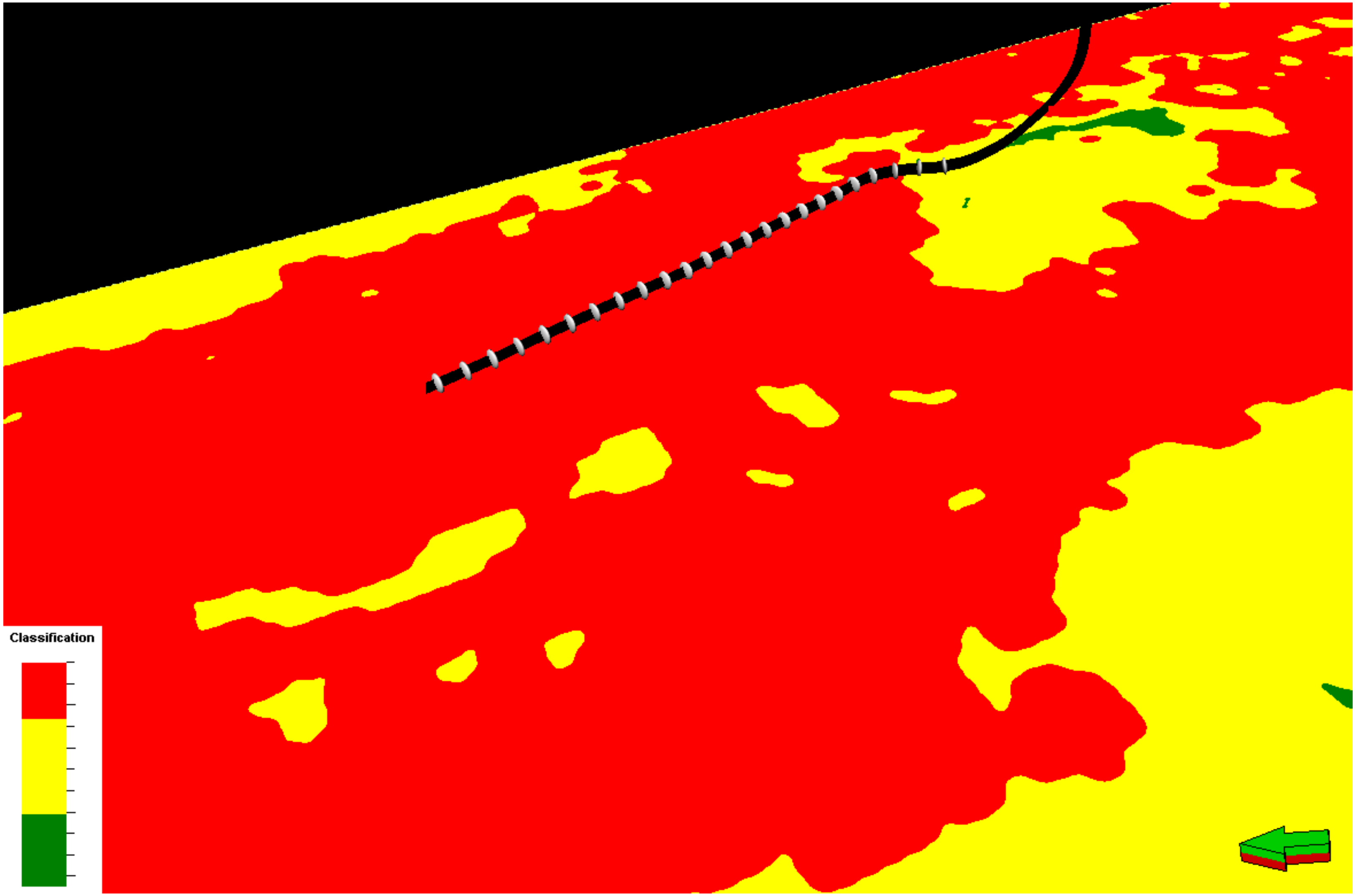
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity Depth Slice: 961 m TVD



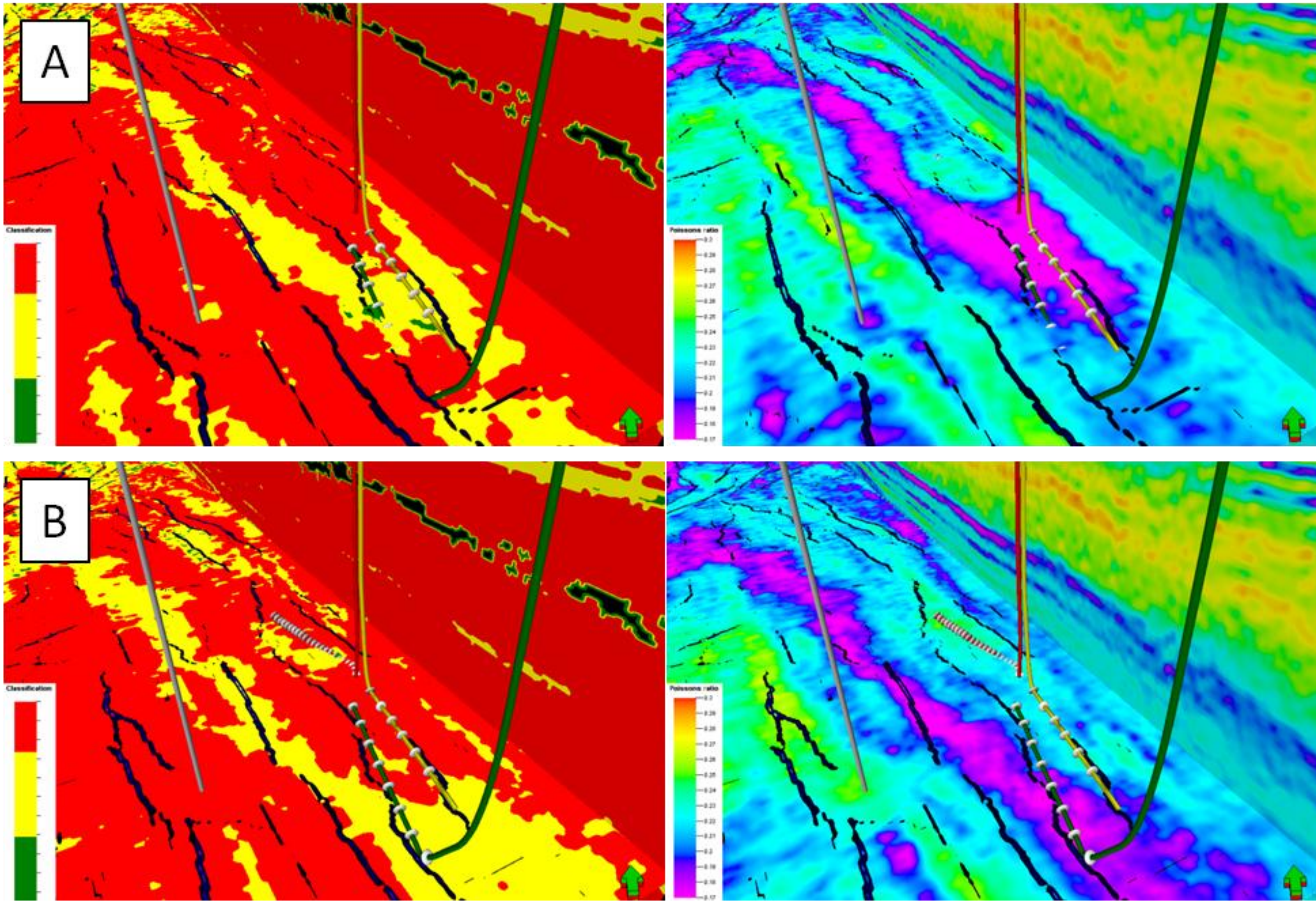
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity Depth Slice: 968 m TVD



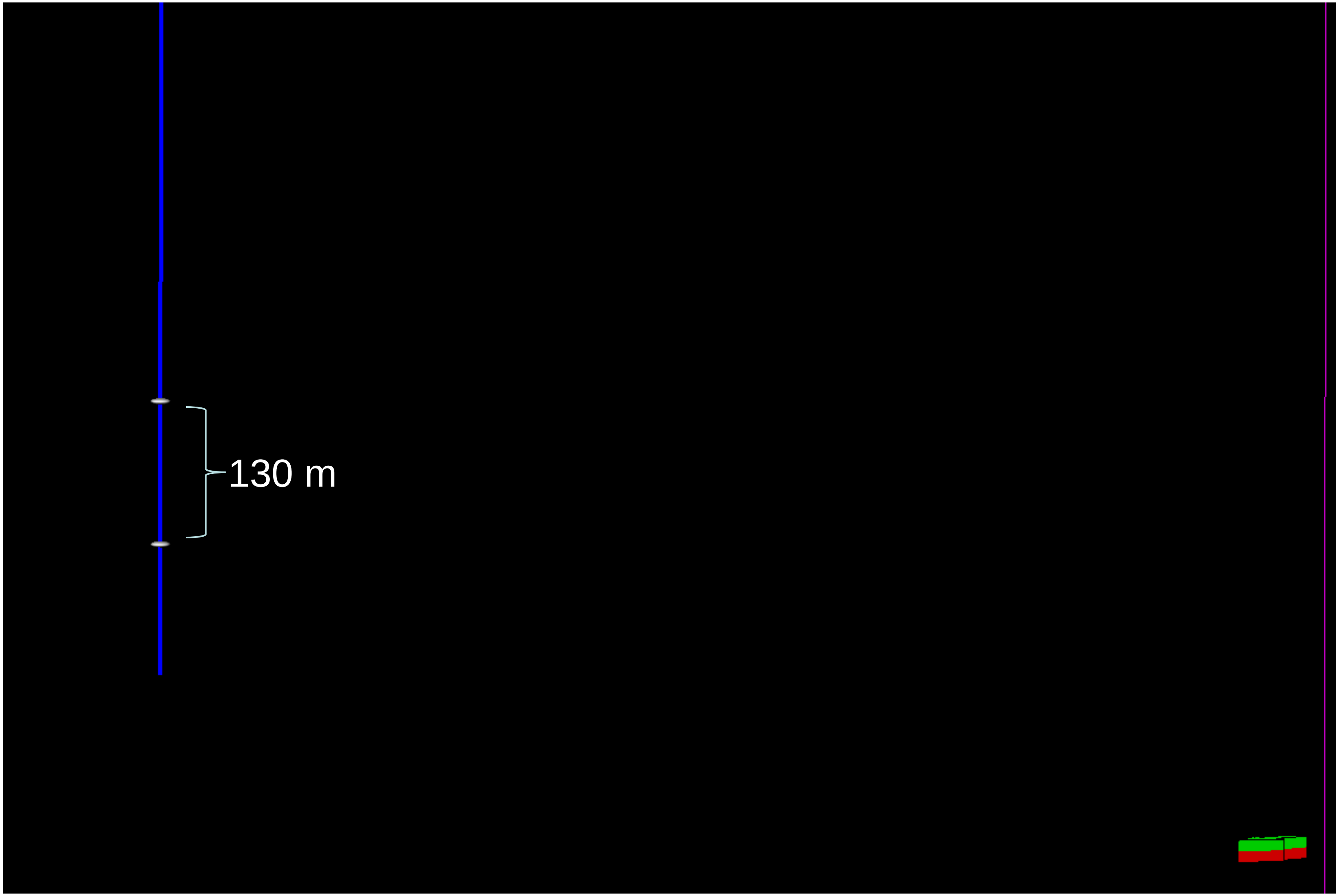
- Displayed well is a low producer
- Reservoir quality result agrees with well production

HC Production Capacity and Poisson's Ratio



- Hydrocarbon production capacity (left) and PR (right); Ant-Tracking shown in both
- Depth: A) 931 and B) 951 m TVD

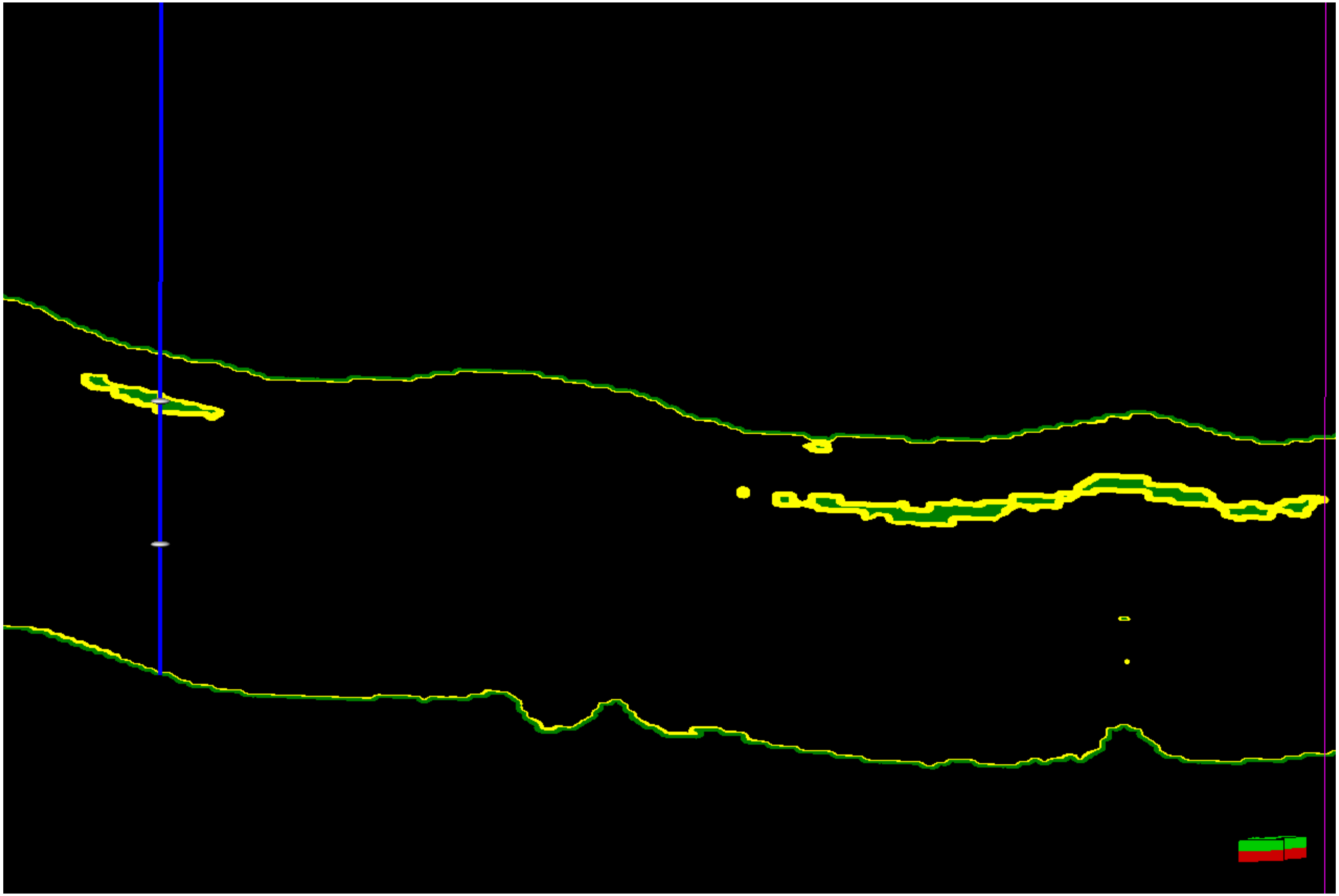
Vertical Blind Well Section Plot



□High production from upper perforation

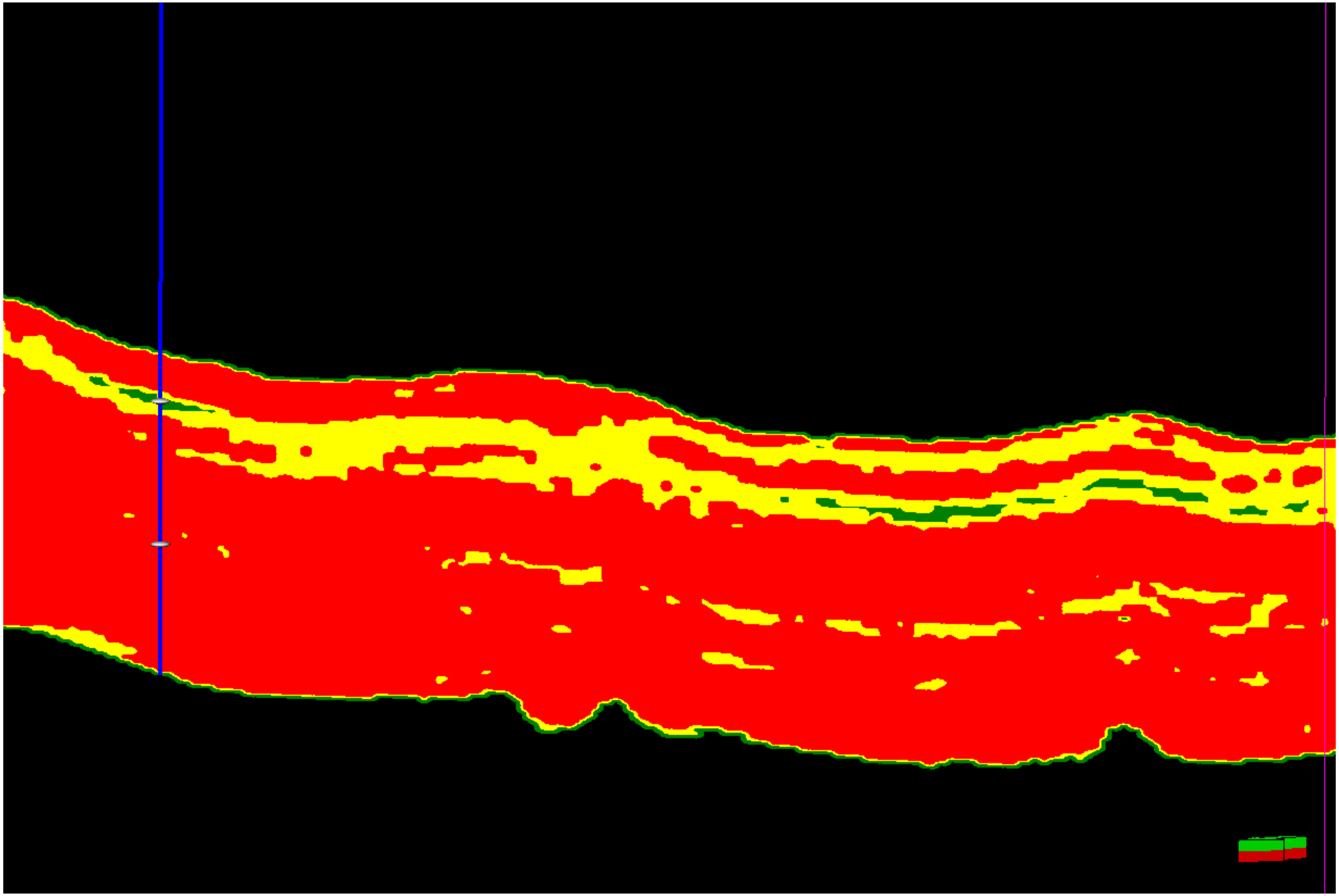
□Low production from lower perforation

Vertical Blind Well Section Plot



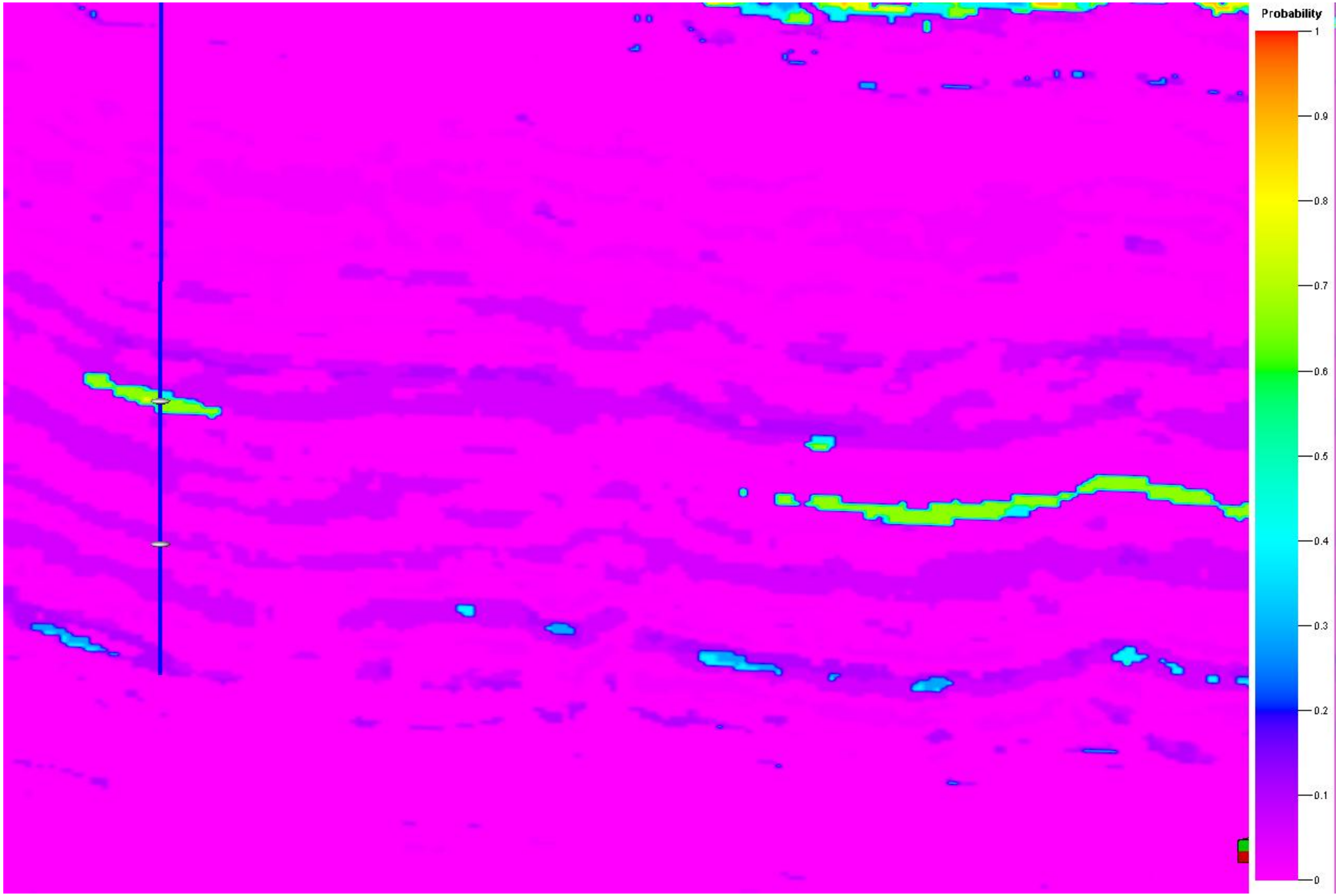
□High production from upper perforation
□Low production from lower perforation

Vertical Blind Well Section Plot



- High production from upper perforation
- Low production from lower perforation

Vertical Blind Well Section Plot (Probability Cube)



- High production from upper perforation; Probability = ~66%
- Low production from lower perforation

Vertical Blind Well Section Plot (Probability Cube)

- Potential future well (~ 2,900 m away) has a probability of ~67% that it will produce > 5 MMCF/day

Conclusions I

– Results from prestack inversion matched well with log data, which gives confidence in the post-inversion work

– Important factor for success includes determining which elastic properties correlate best with production classes

– Difference between high and medium producing reservoir was difficult to determine in certain areas; this is where seismic discontinuities representing natural fractures and faults may prove useful

– Microseismic data should be utilized in order to increase precision on determining the amount of rock volume which was stimulated

Conclusions II

– Results may be used for avoiding low producing zones with a high degree of confidence

– Total success rate for the reservoir quality prediction is ~ 70%

Acknowledgements

- Progress Energy
  - Mark Norton
  - Joe Leonard
  - Wayne Hovdebo
- Schlumberger
  - James Johnson
  - Innocent Kalu

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Questions and Discussion