Integrating Seismic Elastic Properties and Discontinuity Analysis into Reservoir Modeling and Simulation – A Case History from the Gulf of Mexico Shelf*

Randal Utech[1], Dan Shan[1], Ellya Saudale[1], Dianna Shelander[1], Kirk Rodgers[1], Ahmed Ammar[2], Tim Wilkinson[2], and Rick Clark[2]

Search and Discovery Article #41820 (2016)**
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[1]Schlumberger, Houston, Texas (rutech@slb.com)
[2]Energy XXI, The Woodlands, Texas

Abstract

Effective integration of seismic information into reservoir modeling and simulation may significantly improve the understanding of the reservoir, leading to enhanced field recovery, better field management decisions and improved identification of un-swept potential for new drilling opportunities.

Conventional reservoir modeling and simulation studies frequently underutilize seismic information. Wells sample the earth with high vertical resolution at a single location, but seismic provides highly sampled information in the intra-well space. The utilization of depth calibrated, properly conditioned intra-well seismic information can lead to better definition of the reservoir and simulation results.

The classification of elastic properties obtained from pre-stack seismic inversion can be used to populate lithology distributions in the reservoir model and to improve delineation of the reservoir. Seismic discontinuity analyses provide a framework for candidate reservoir compartment baffles and barriers. Together, these seismic properties serve to enhance the accuracy of the geologic model and lead to a better understanding of reservoir drainage dynamics.

A seismic to simulation study of the J6 'Pod B' reservoir in Main Pass 61 demonstrates the value of integrating seismically derived litho-fluid properties to define reservoir boundaries and facies distributions. Effective porosity is modeled using well petrophysics and seismic trends obtained from a multivariate analysis of elastic properties, including litho-fluid probability volumes derived from Bayesian rock physics classification. Further, seismic discontinuity analyses provided a means to identify compartment boundaries, baffles and lithologic barriers to fluid flow. The modeling and simulation results highlighted the complexities of reservoir and provided a key basis for new drilling designed to drain unswept oil. The drilling results from four successful post-study wells served to substantiate the simulation model which identified 4 MMBO of additional recoverable reserves.

Selected Reference

Utech, R., D. Shan, D. Shelander, E. Saudale, K. Rodgers, A. Ammar, T.Wilkinson, and R. Clark, 2014, Enhancing reservoir definition for field modeling and simulation with seismic elastic properties and discontinuity analysis—A case history for Main Pass 61, Gulf of Mexico (abstract): GCAGS Transactions, v. 64, p. 739.

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Schlumberger

Objective

- To increase the understanding of the J6 reservoir and its drainage dynamics in order to optimize production and recovery
- Our focus was to develop a more accurate dynamic simulation model in order to:
  - Refine estimates of recoverable oil
  - Optimize water injection, workovers and completions
  - Identify unswept oil for new drilling opportunities
  - Support reservoir management and development decisions

Main Pass 61 Pod B

Field discovered in 2001,

- Produces from several stacked reservoirs
- Main formation is Upper Miocene ‘J6’ sand
- Depth range: ~7400-8200 ft. TVDSS

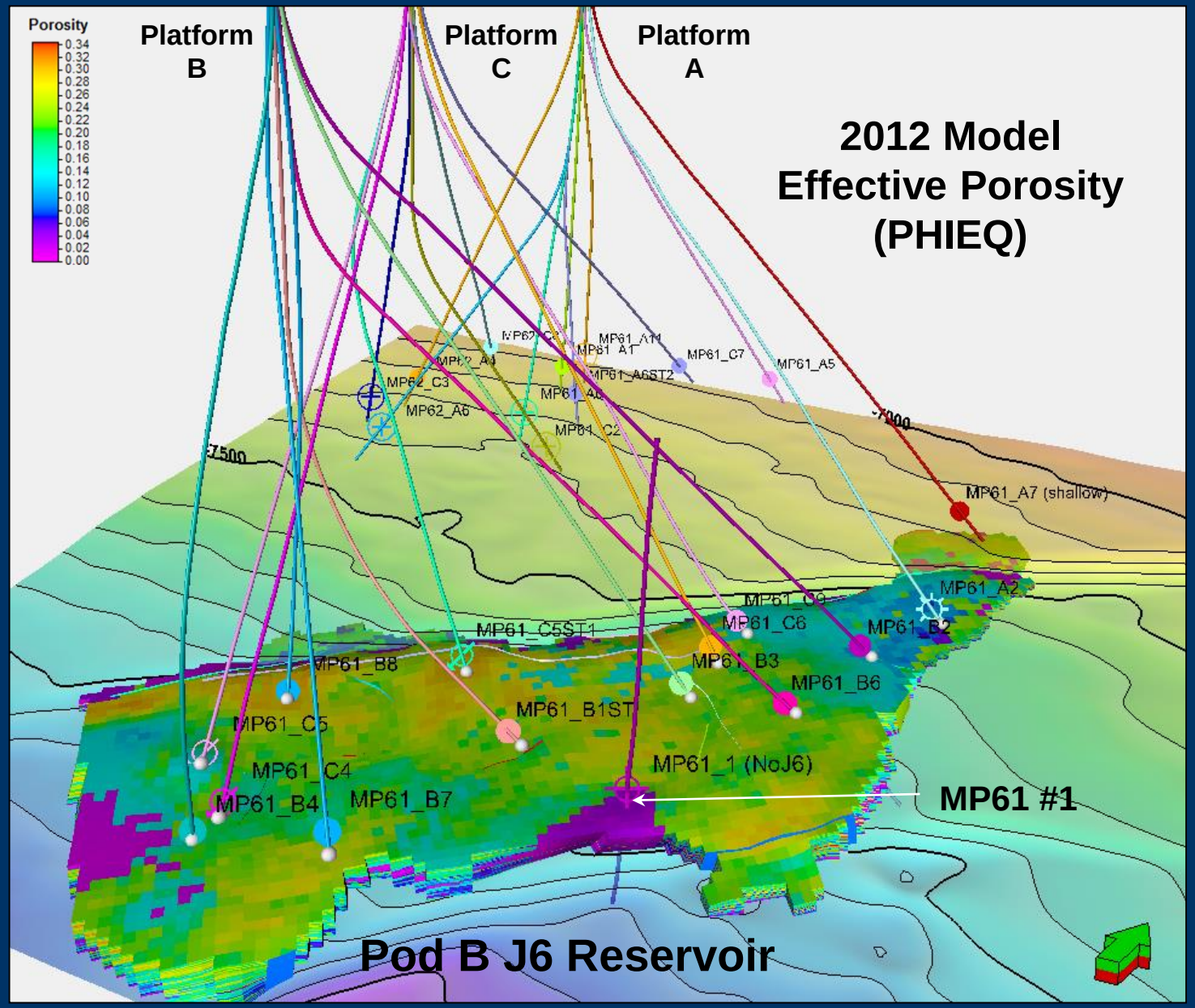
Cumulative Production (2002–2012):

- 17 million bbl of oil
- 12 billion ft^3 of gas
- 9 million bbl of water
- 22 million bbl of injected water (starting 2003)

As of July 2012, the field had:

- Six active wells (5 producers and 1 injector)
- 14 penetrations since discovery

Prior to this 2012 study, the legacy simulations and drilling results suggested that a better reservoir model was needed.

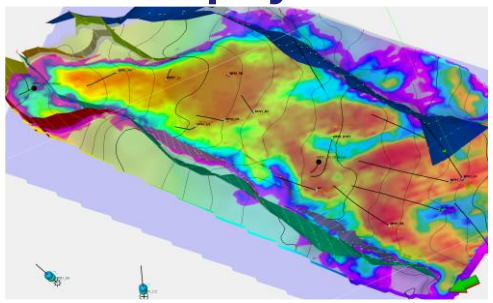


Improving the reservoir model

Conventional studies often underutilize seismic - An improved approach would:

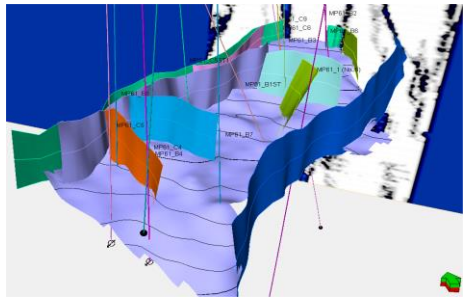
1. Use seismic inversion to improve reservoir delineation
2. Populate the reservoir model with estimates of seismic lithology
3. Use seismic discontinuity analysis to evaluate baffles and barriers to fluid flow

Geophysics



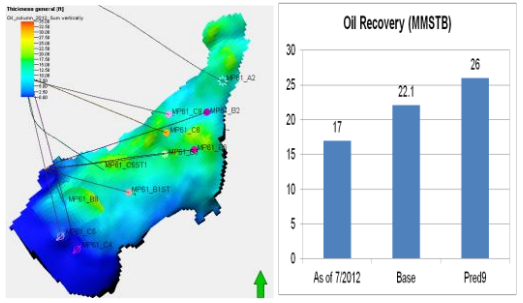
- Prestack seismic inversion
- Lithofluid prediction
- Seismic discontinuity analysis

Geological model



- Use elastic properties to populate the model and extrapolate lithofacies
- Incorporate baffles/barriers from seismic into the model

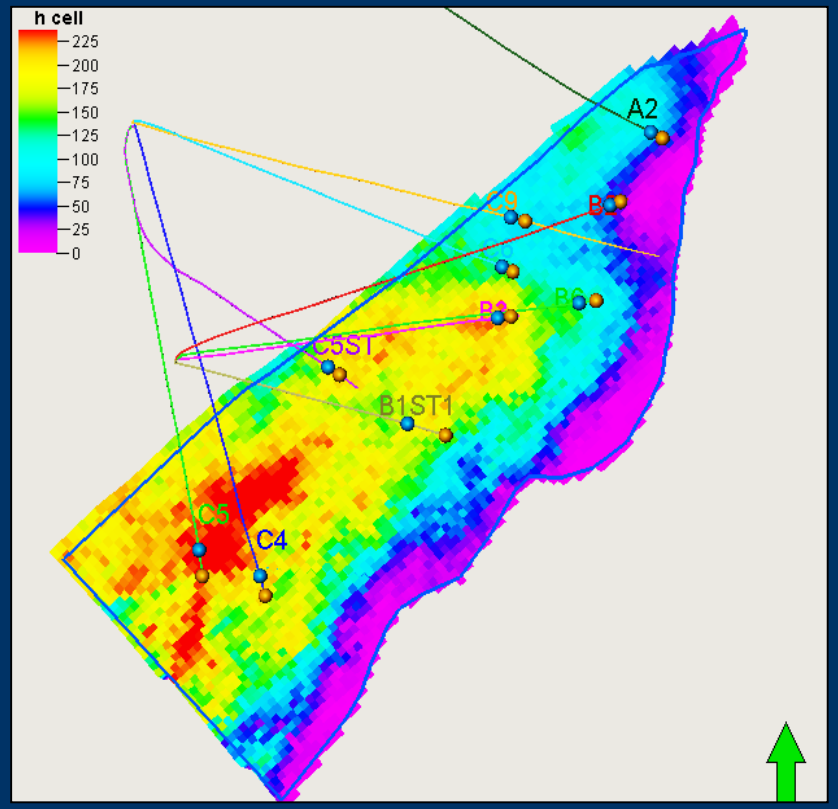
Simulation



- Identify fluid flow pathways using co-populated model
- Identify the transmissivity of barriers with history matching
- Develop a better dynamic model for field development

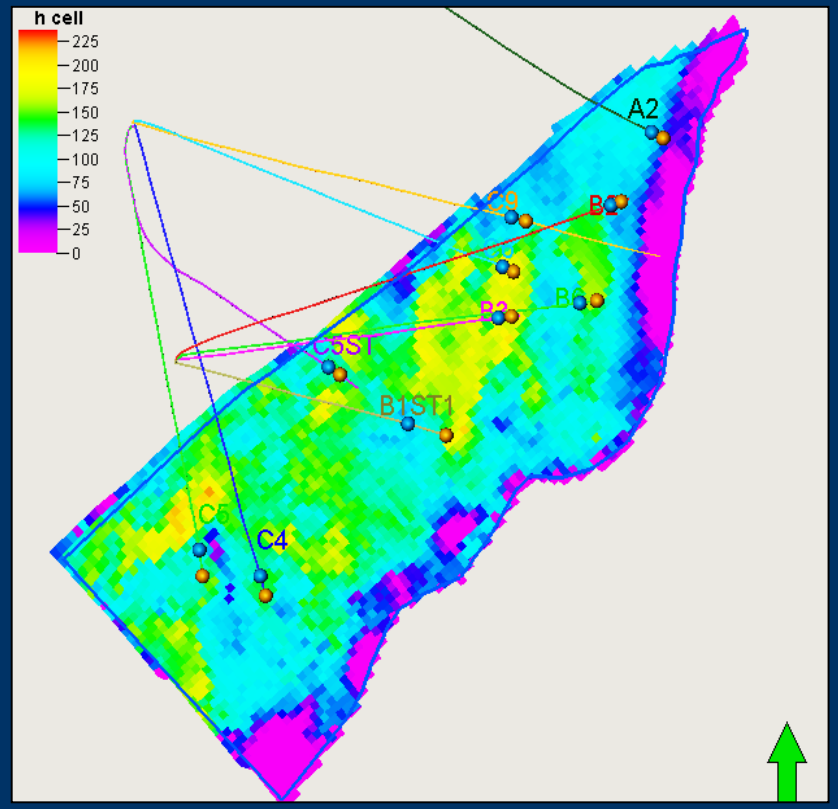
Net Sand Thickness Models

2010 Hand-Contoured



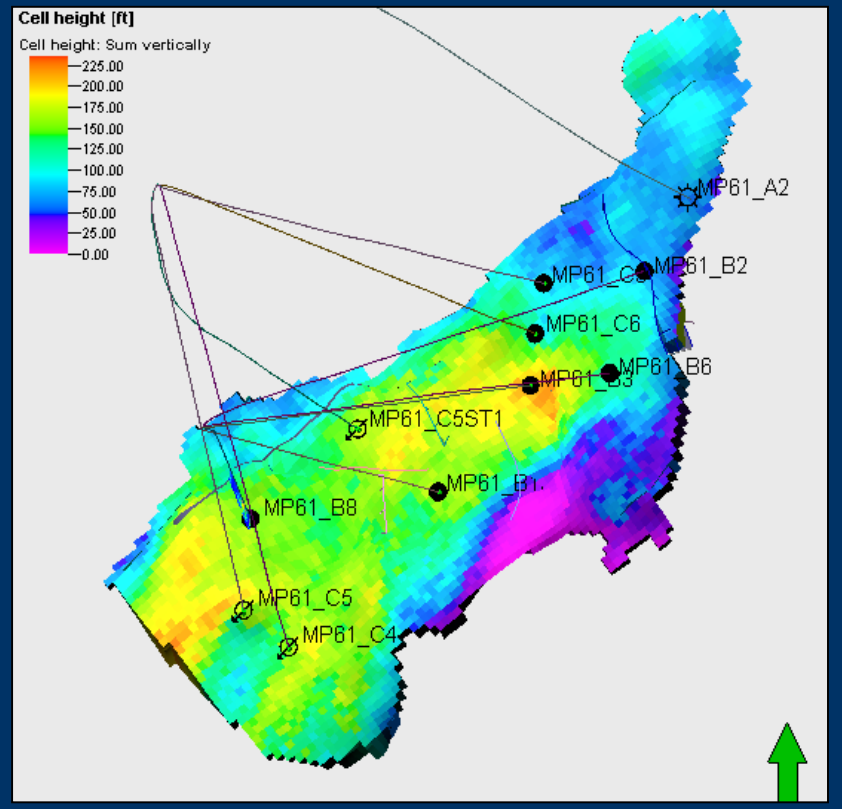
Well-based modeling without seismic enhancements.

2011 Amplitude RAI



Revised using relative acoustic impedance (RAI) geobodies.

2012 Inversion and LFP

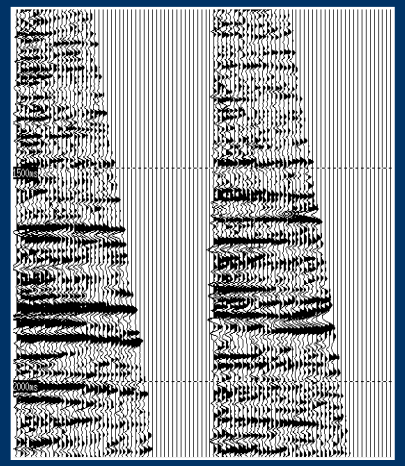


Enhanced by integrating prestack inversion and lithofluid prediction.

Workflow: Integrating Seismic Information

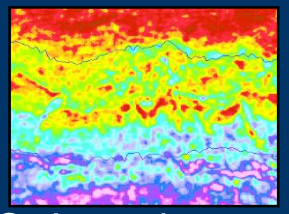
Prestack AVO Inversion

Prestack Seismic

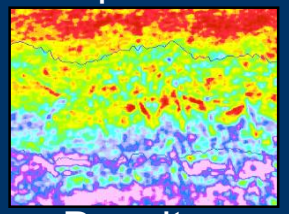


Conditioned Angle Gathers

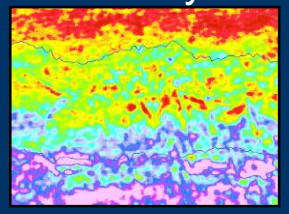
P- Impedance



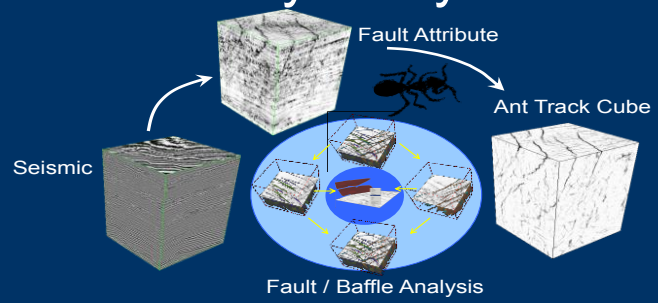
S- Impedance



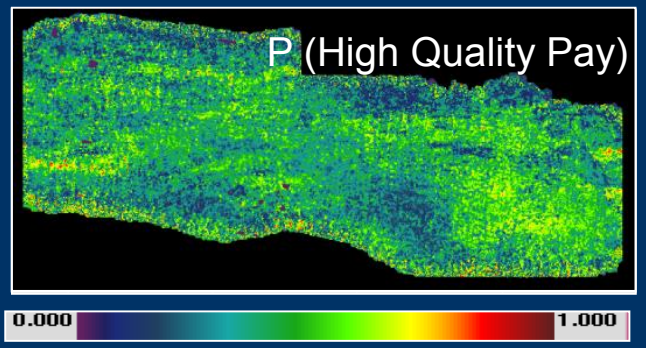
Density



Discontinuity Analysis

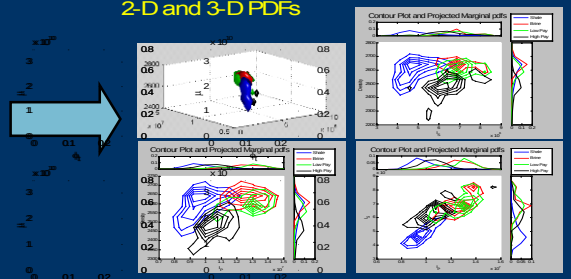


Seismic LithoClass Probability

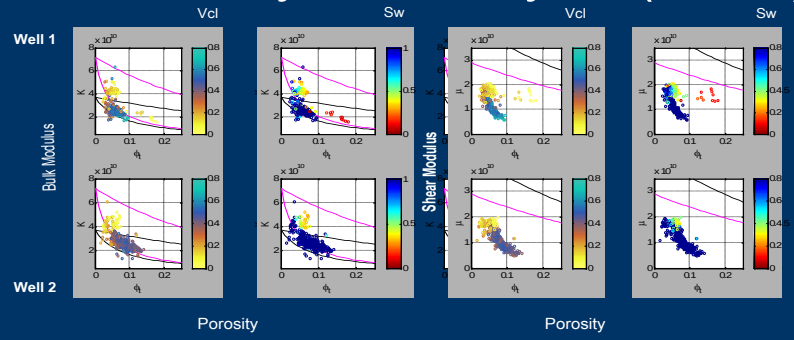


Bayesian Lithology Classification

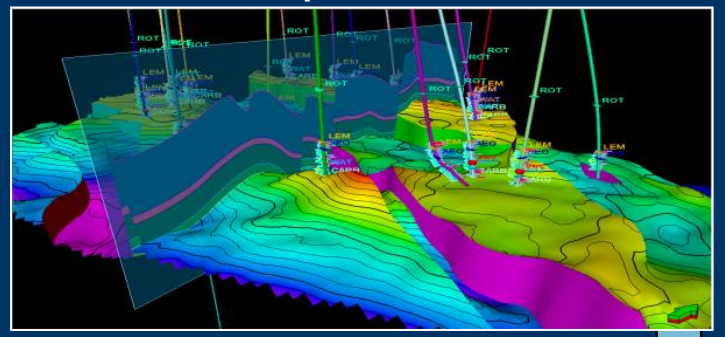
2-D and 3-D PDFs



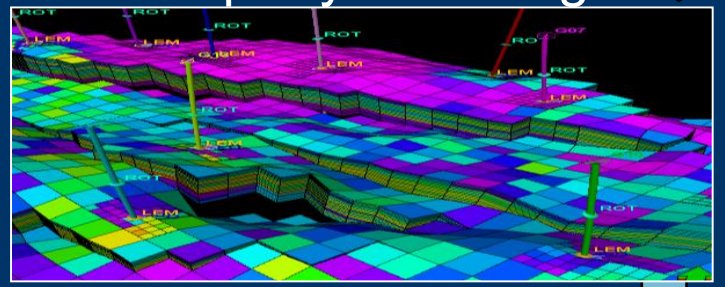
Rock Physics Analysis (Wells)



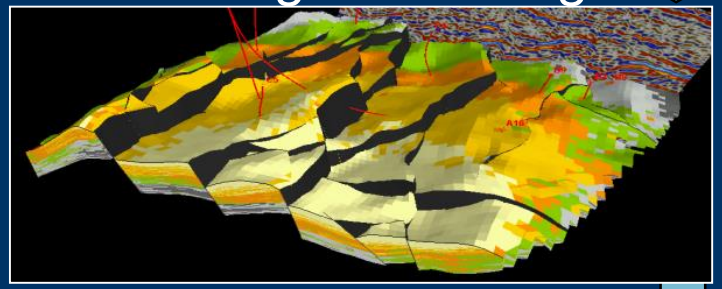
Interpretation



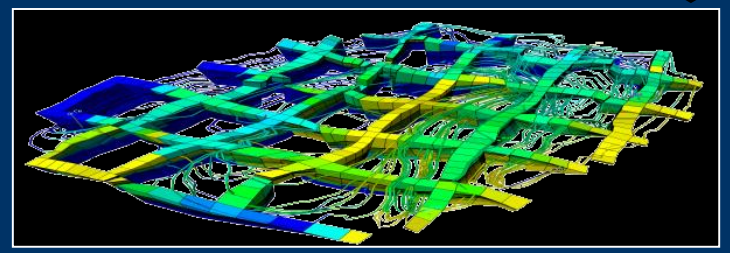
Property Modeling



Geologic Modeling



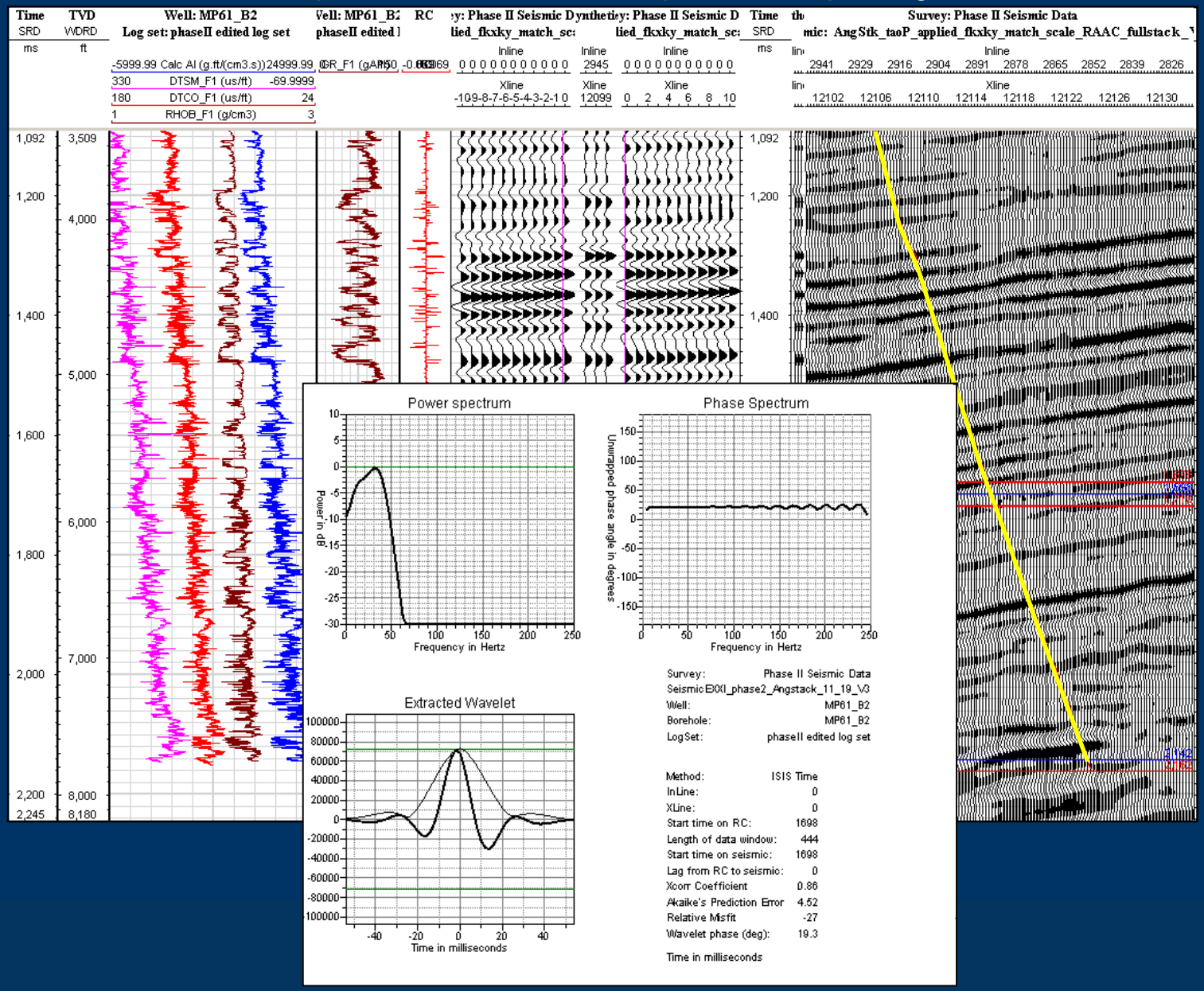
Reservoir Simulation



Seismic Conditioning and Well Ties

- Spatially consistent velocity analysis
- Parabolic radon transform for multiple removal
- F-Kx-Ky filtering for footprint removal
- TauP processing for signal enhancement
- Non-Rigid Matching for gather flattening
- RAAC and Angle stack creation (7 angle bands)
- Phase correction

The input seismic consisted of prestack depth migrated data



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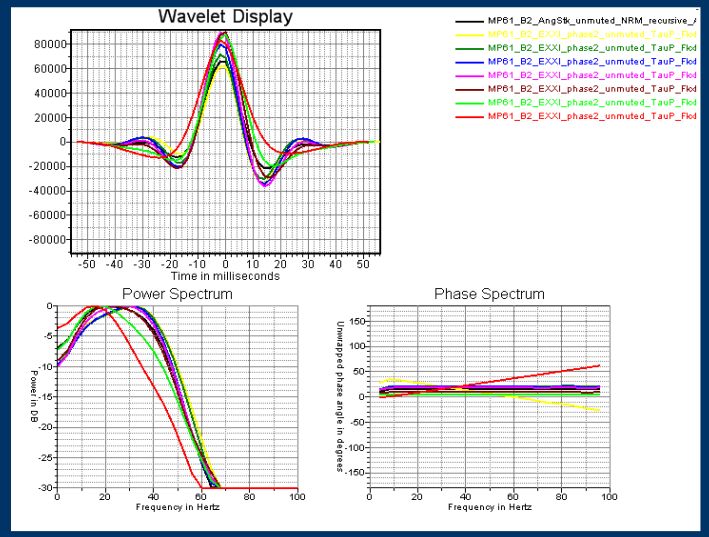
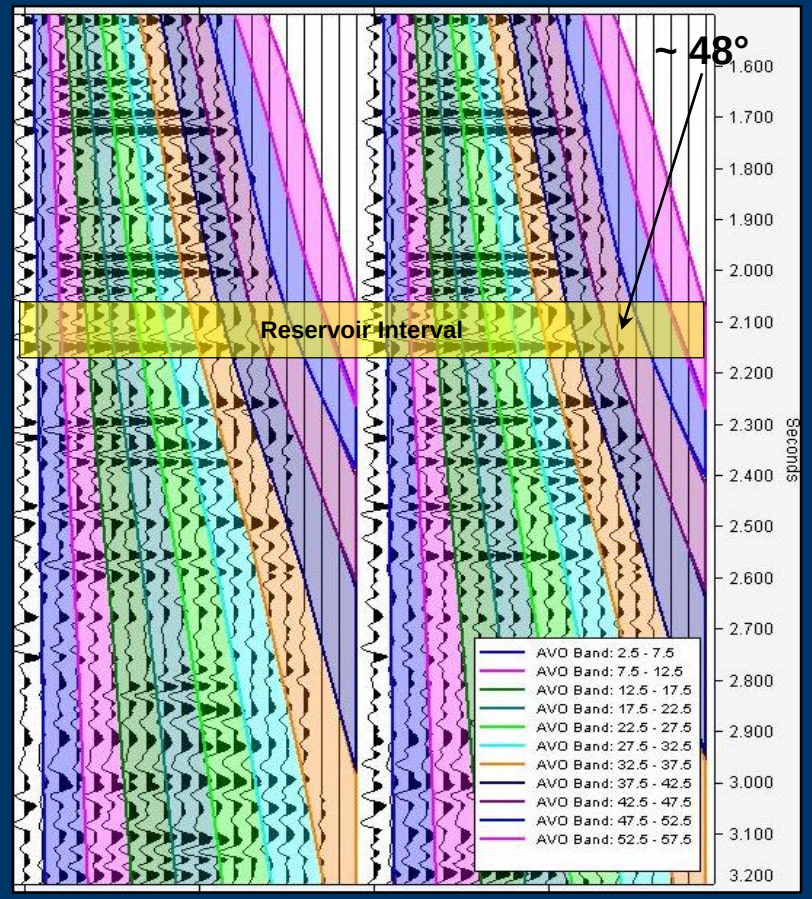
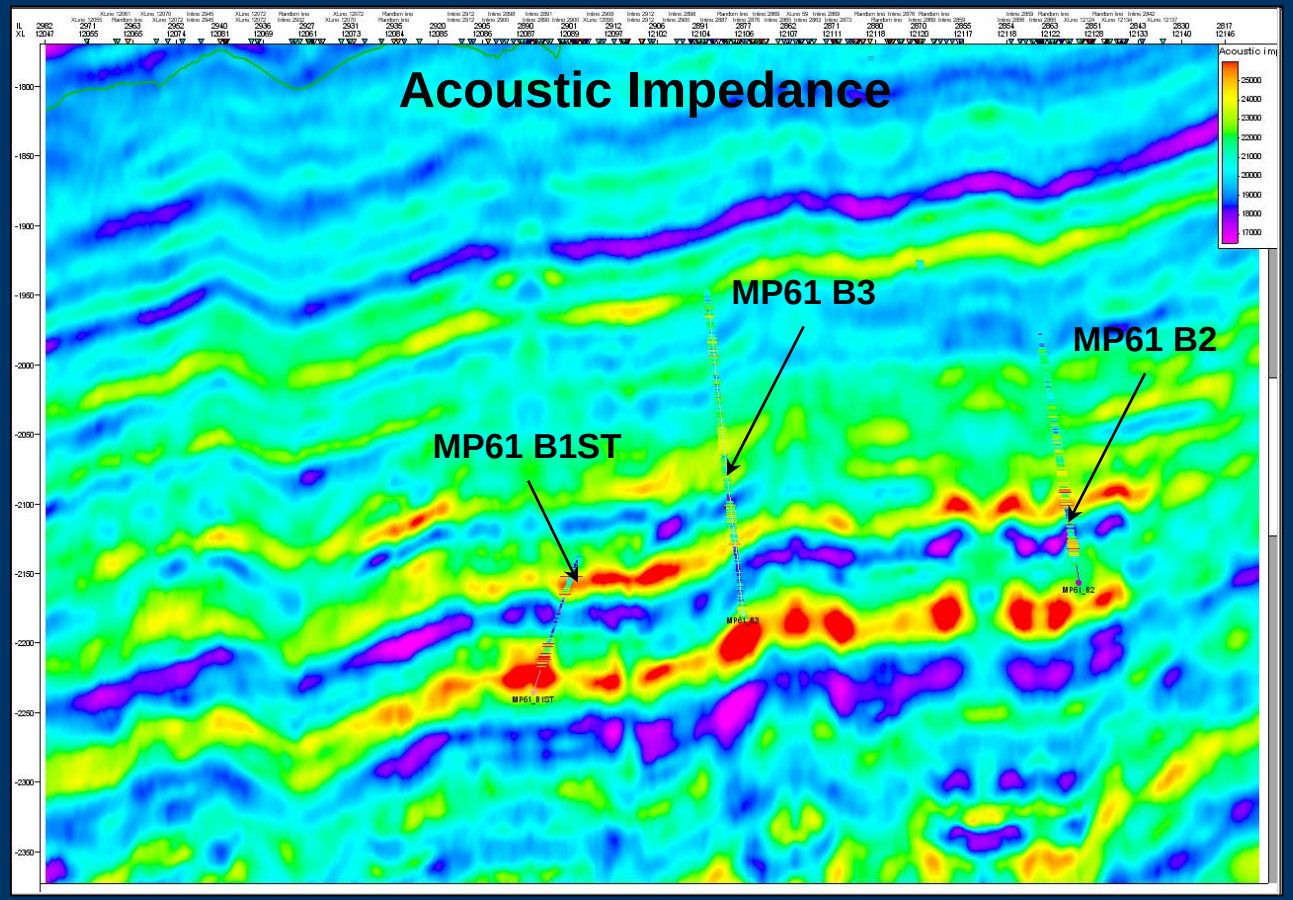


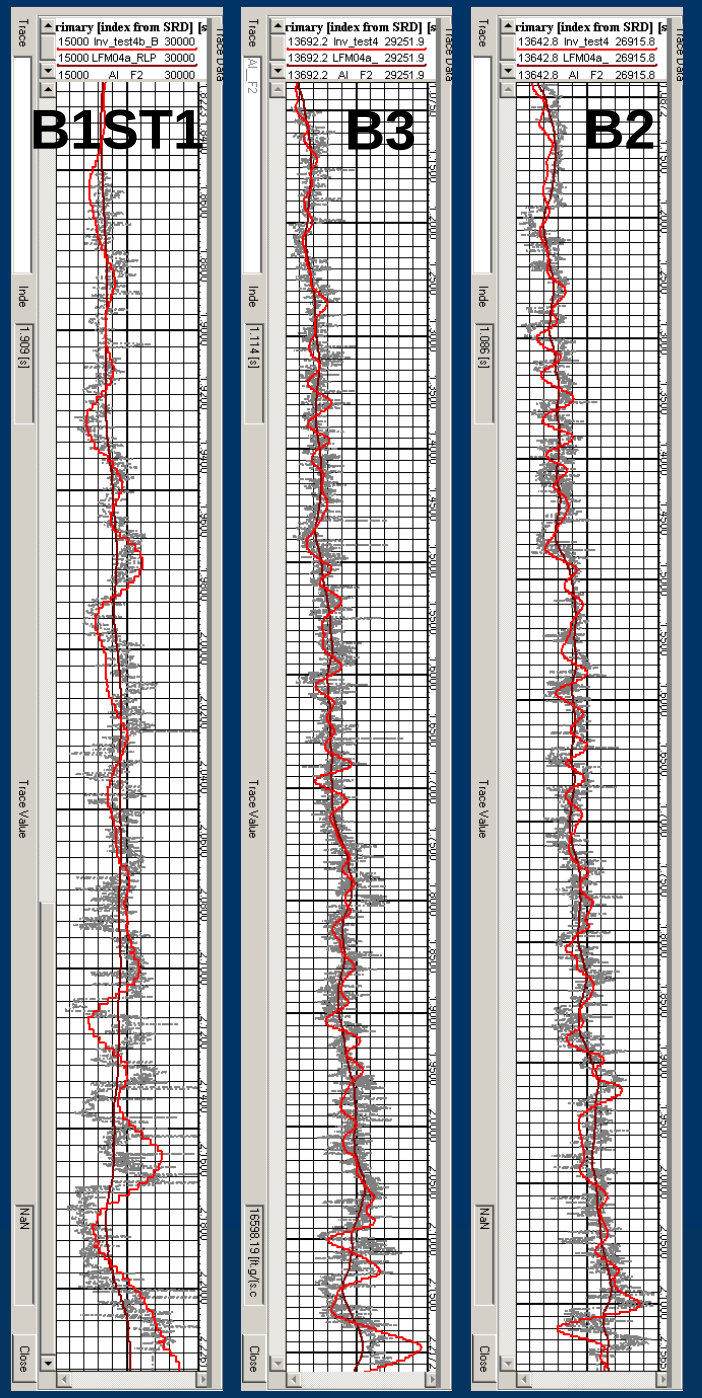
Synthetic tie and wavelet analysis completed for each angle set

Prestack gather trace offset-angle bands



Simultaneous Prestack Inversion and Quality Control



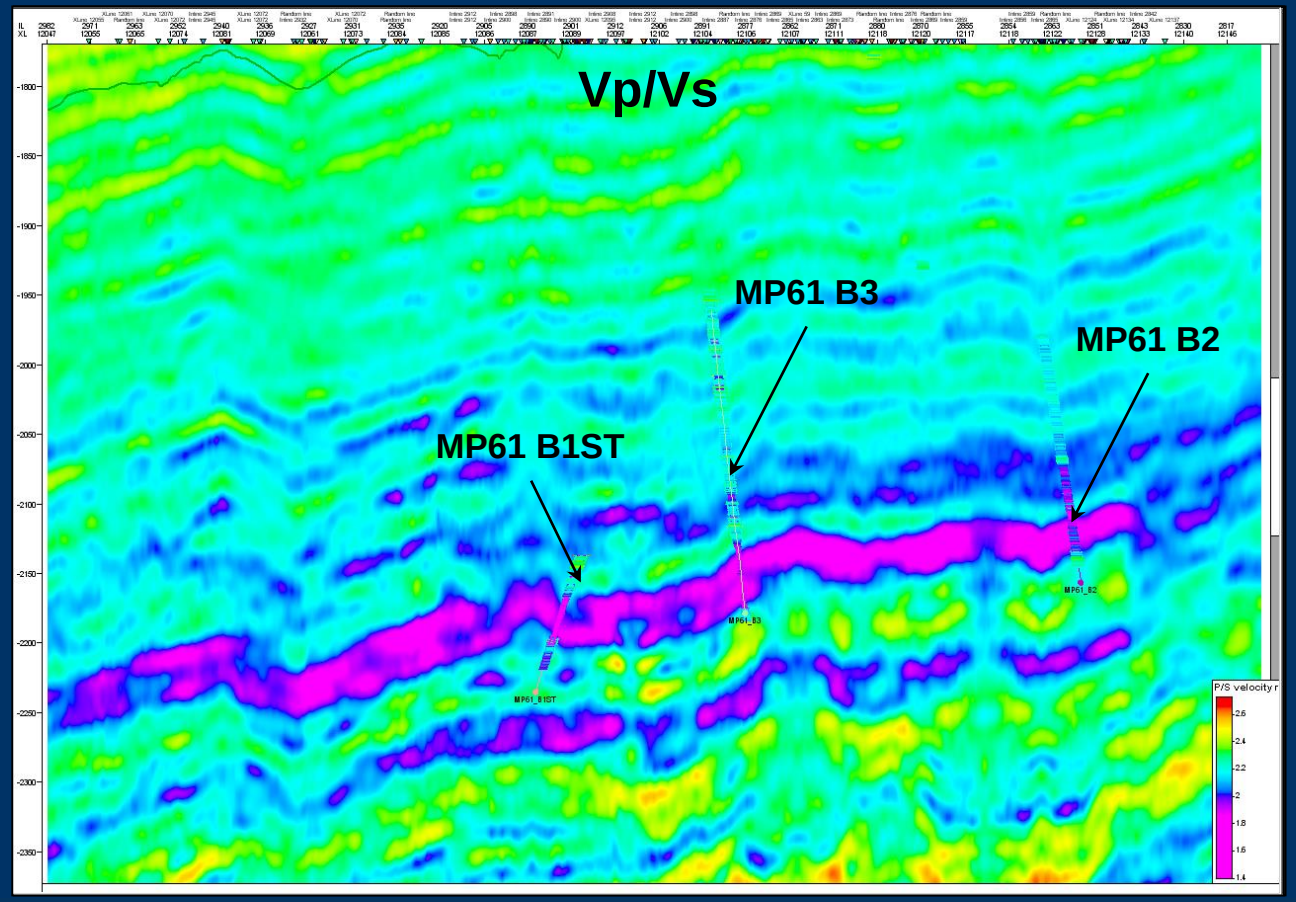


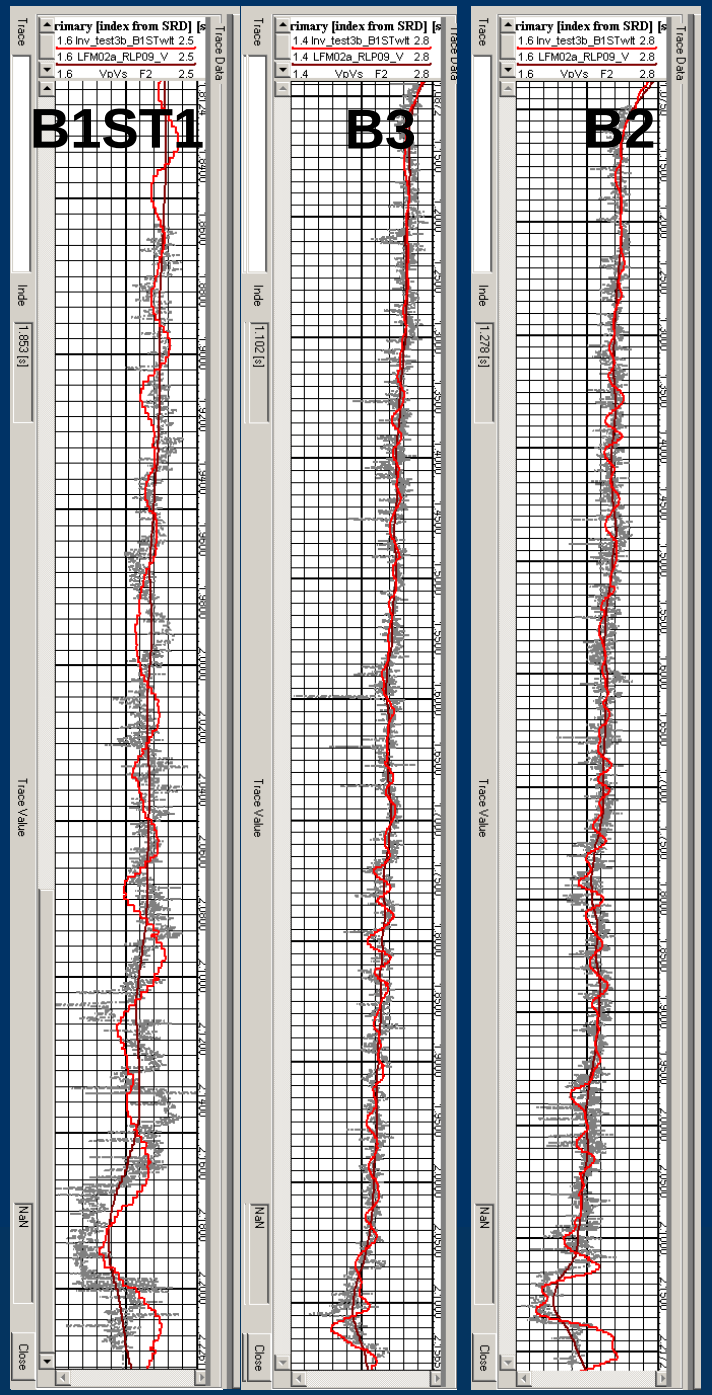
Well log (grey curve)

Inversion result (red curve)

Time, s

Simultaneous Prestack Inversion and Quality Control



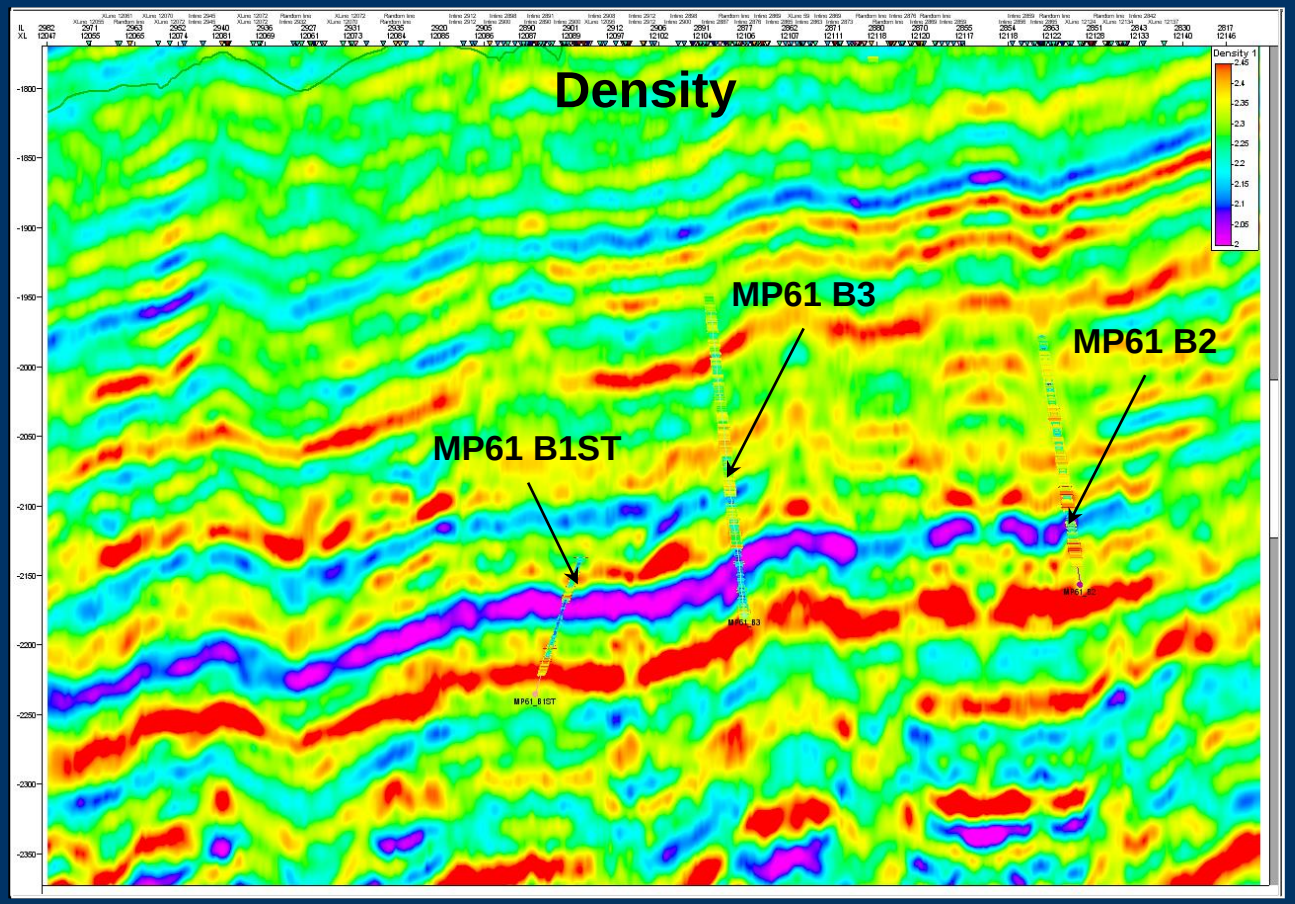


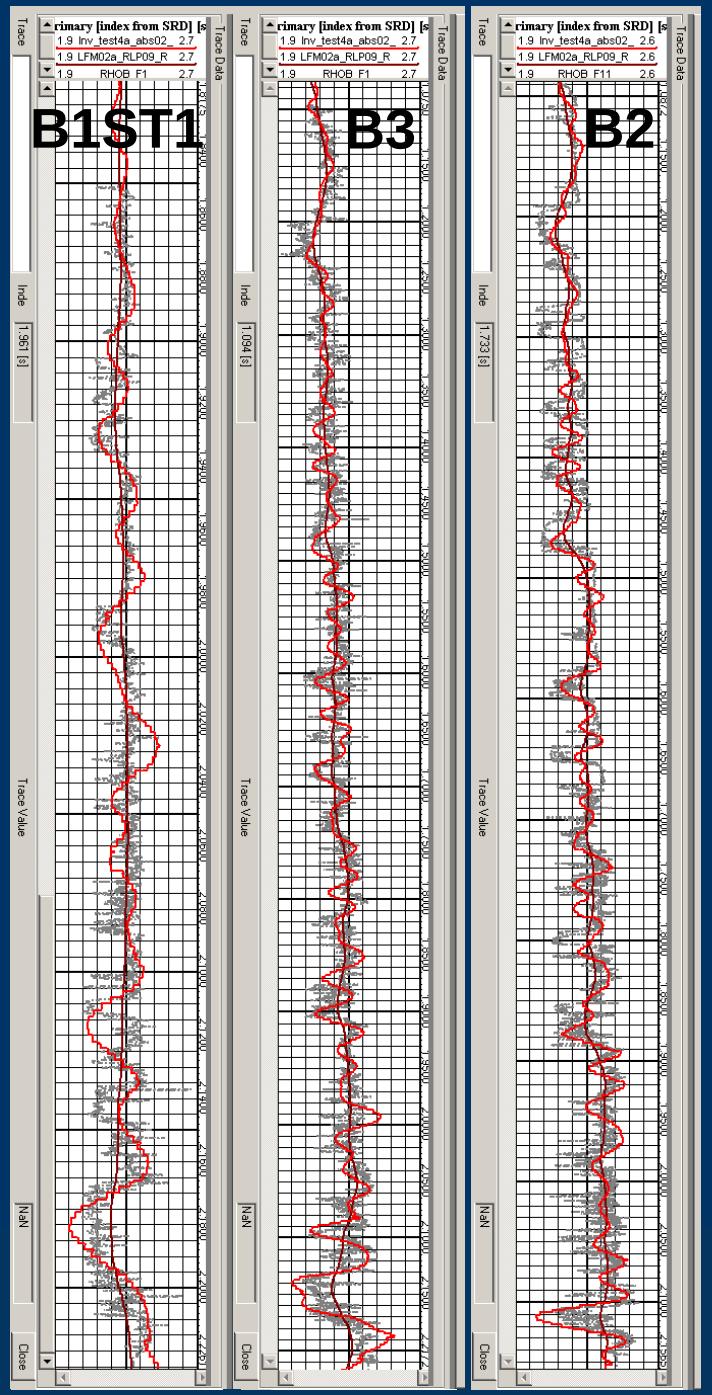
Well log (grey curve)

Inversion result (red curve)

Time, s

Simultaneous Prestack Inversion and Quality Control





Well log (grey curve)

Inversion result (red curve)

Time, s

Rock Physics Analysis

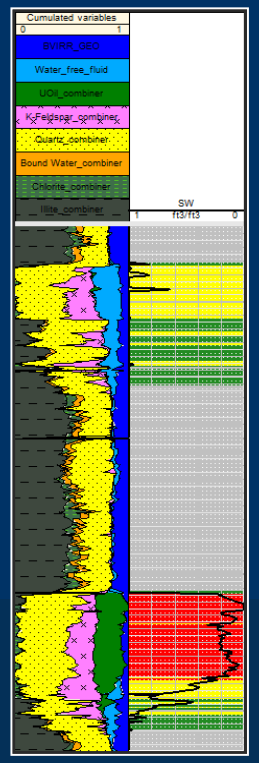
Rock Class Petrophysical Definition

Wet sand: V_{sh}<15%, S_w>60%

Shaley sand: 15%<V_{sh}<38%

Shale: V_{sh}>38%

HC sand: V_{sh}<15%, S_w<60%



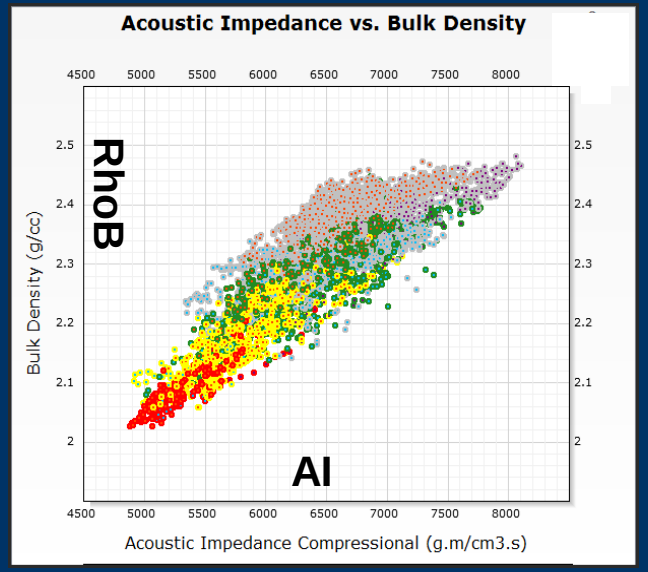
Wet sand

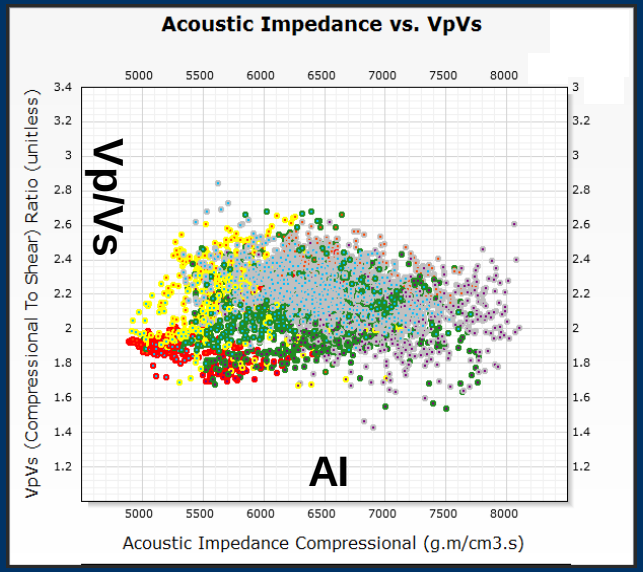
Shaley sand

Shale

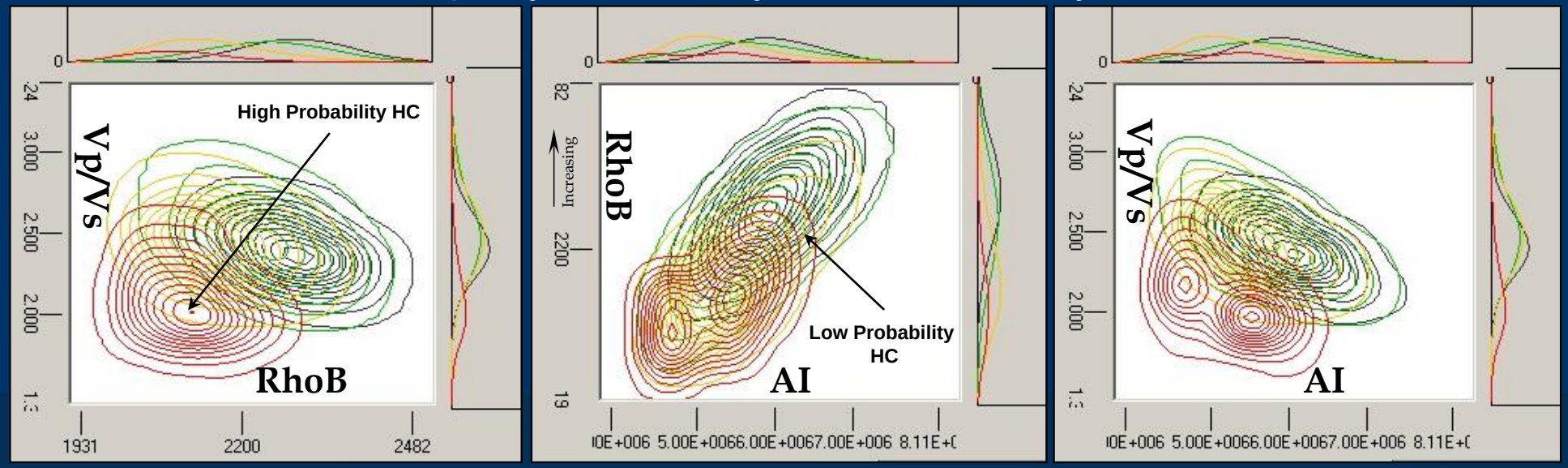
HC sand

Log Elastic Properties / Petrophysics



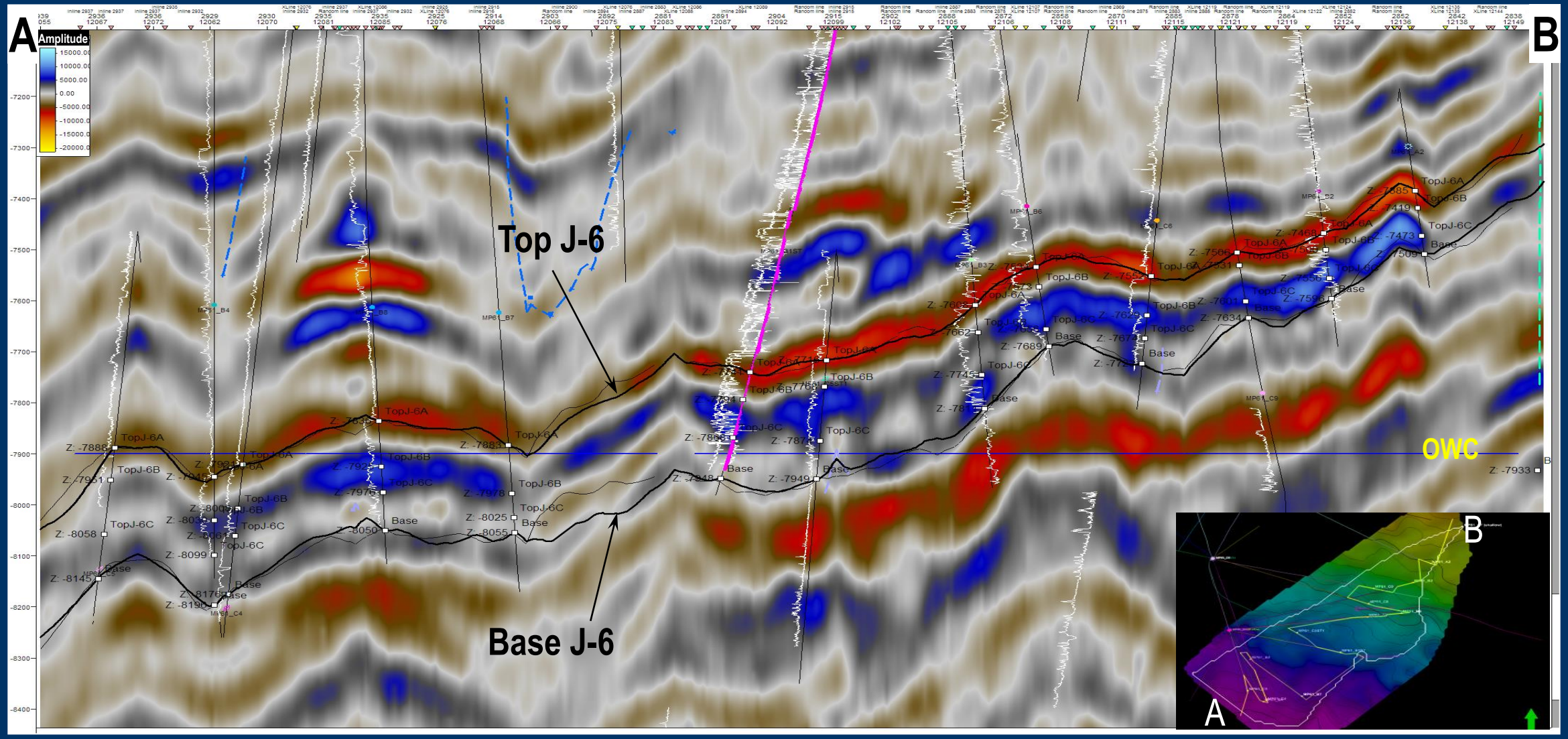


Elastic Property Probability Distributions by Rock Class

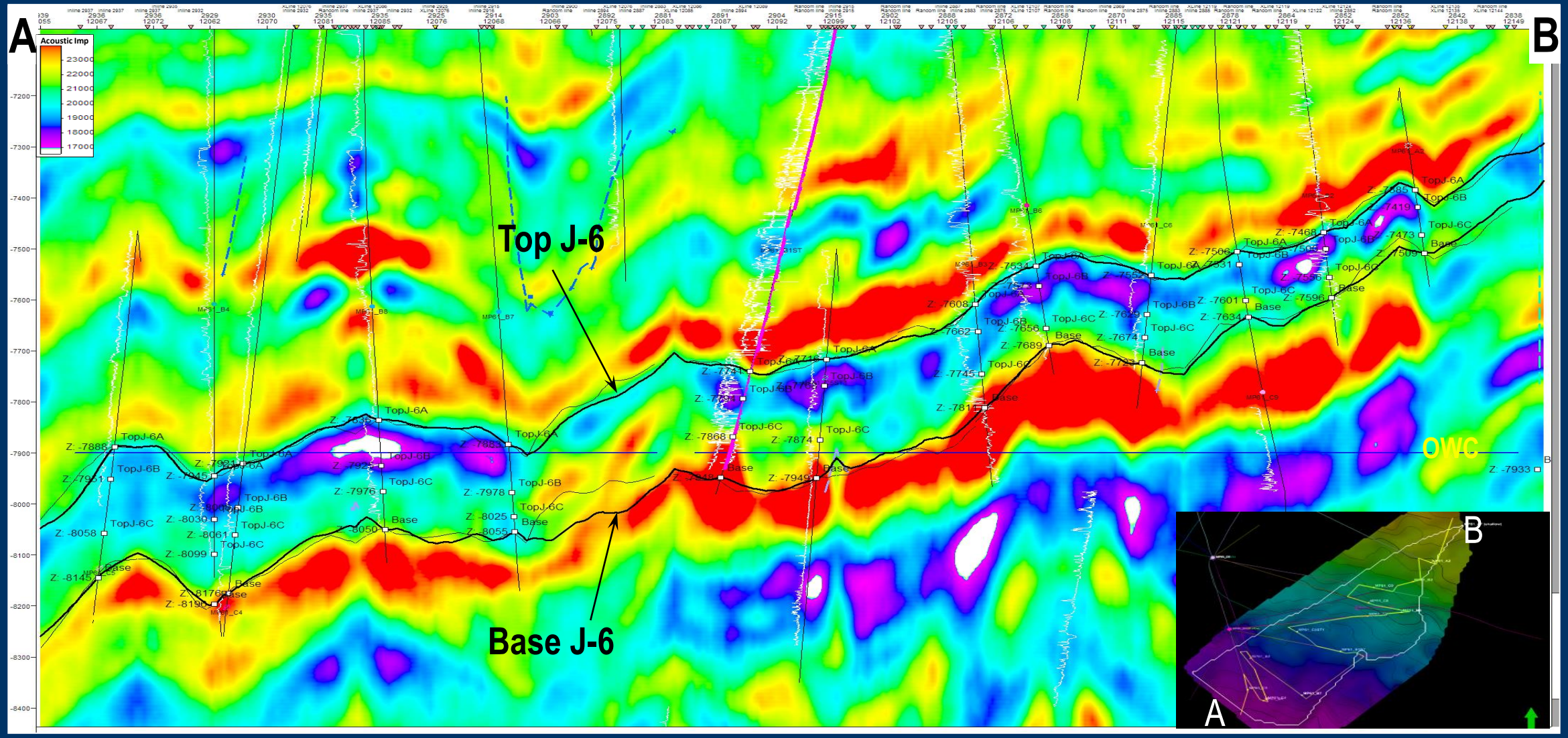


HC sand Wet sand Shaley sand Shale

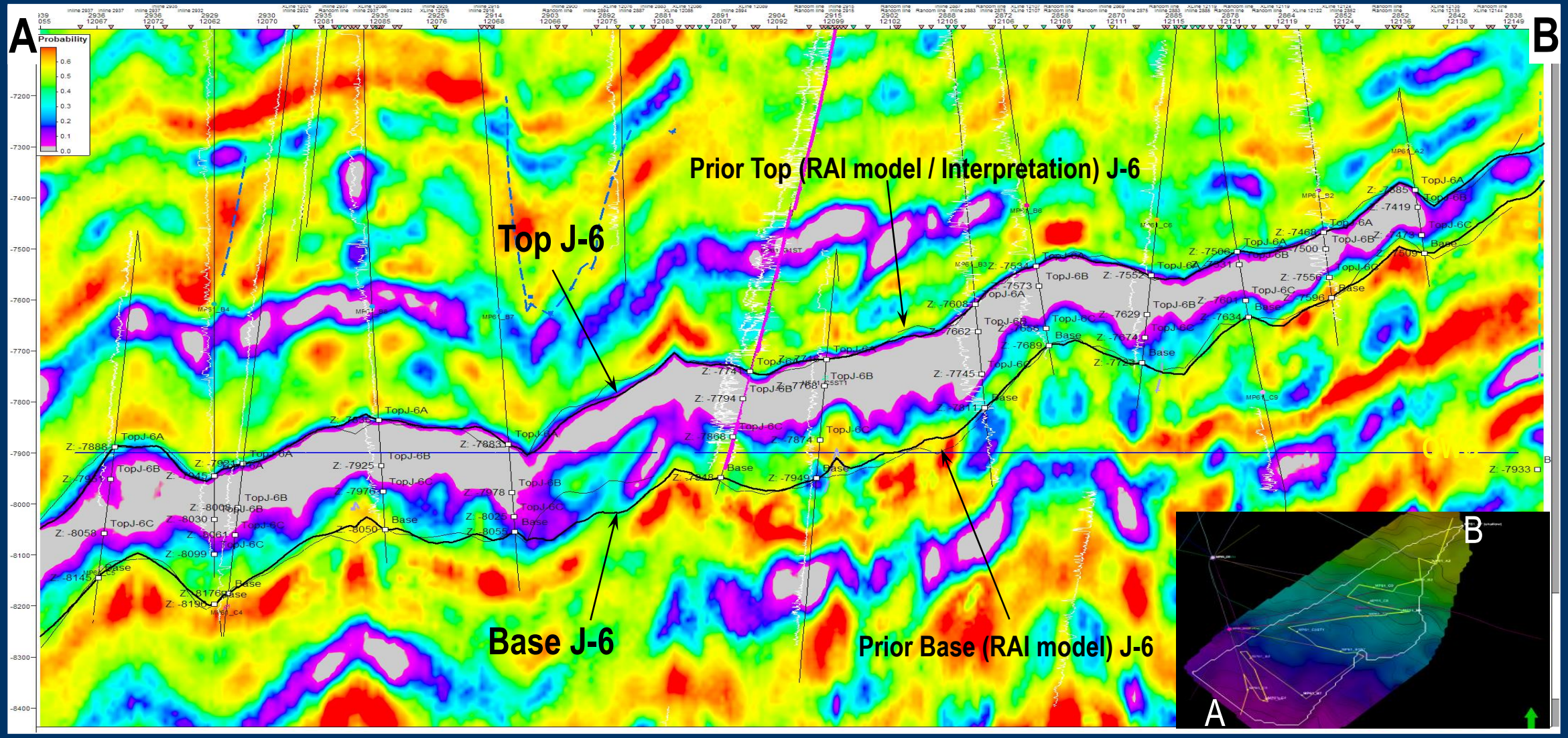
Stack Seismic—Well Tie Line



Acoustic Impedance—Well Tie Line

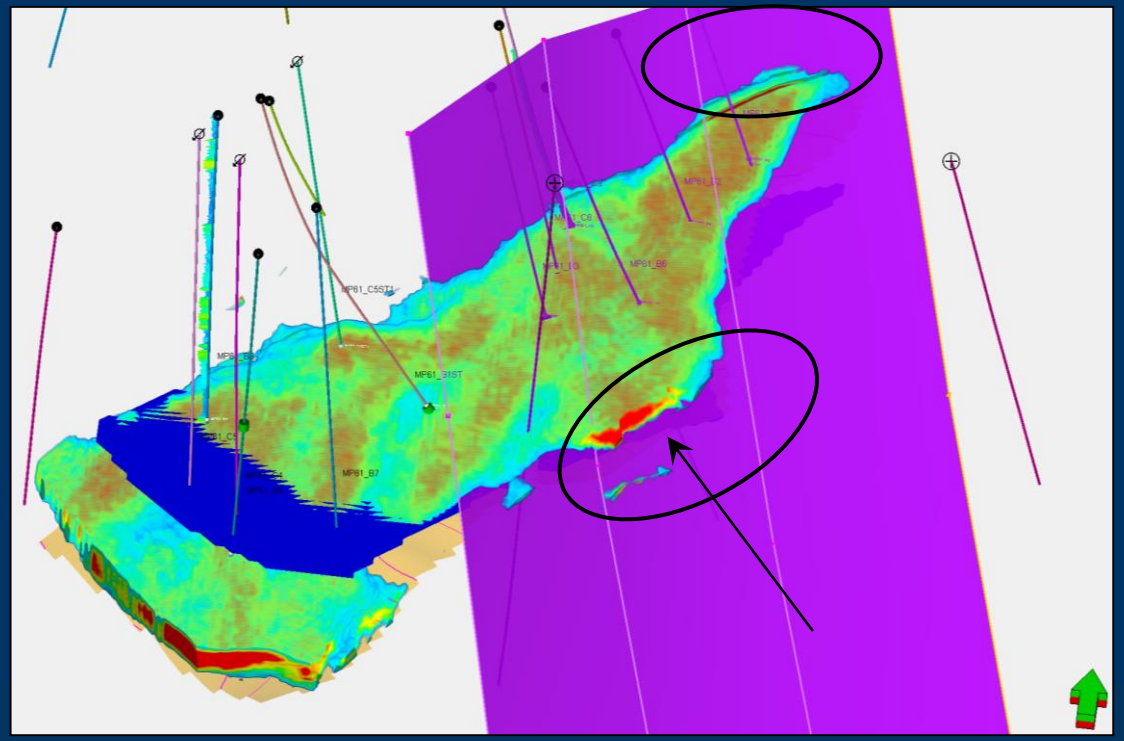


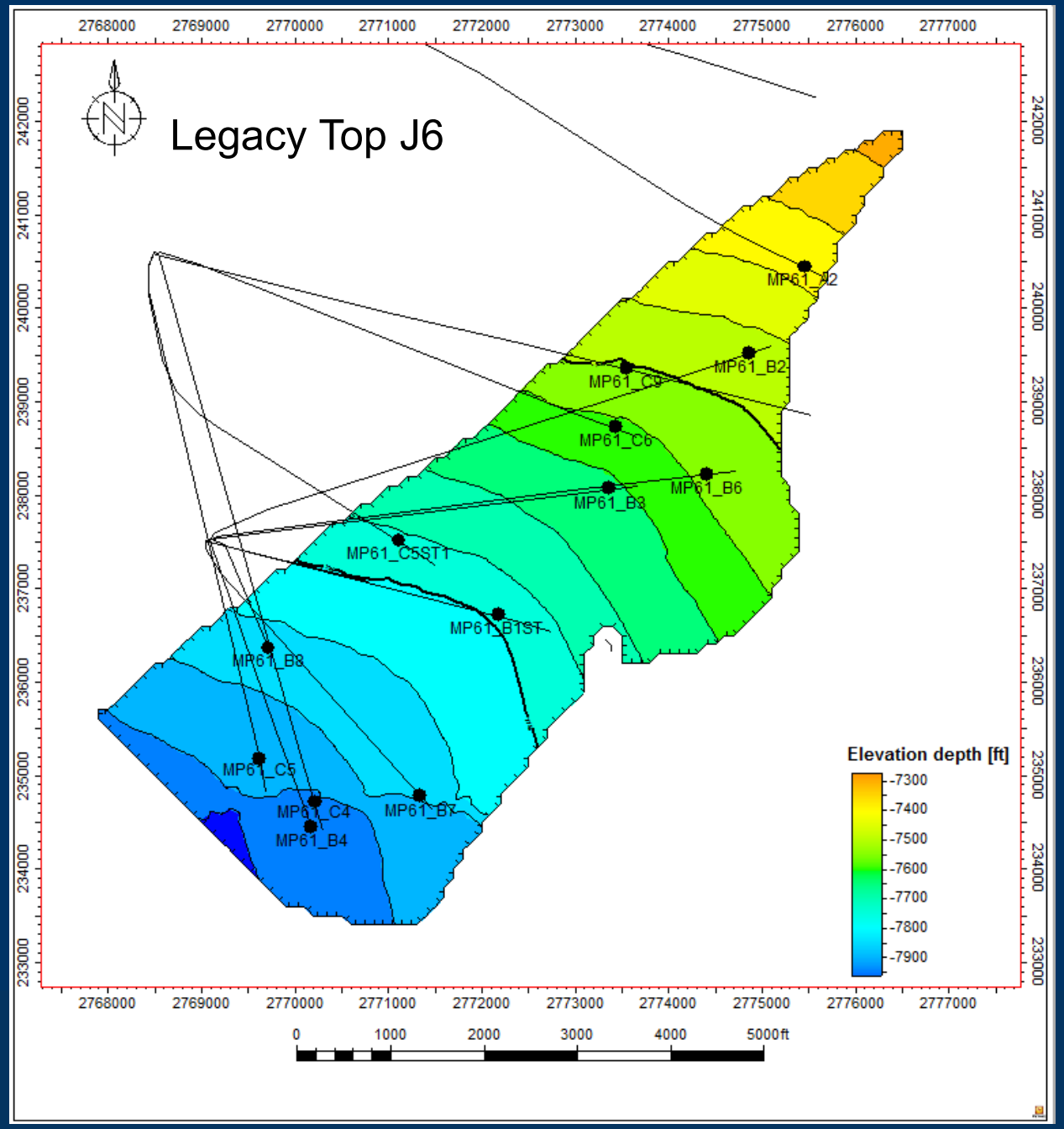
Shale Probability—Well Tie Line



Improving delineation of the reservoir

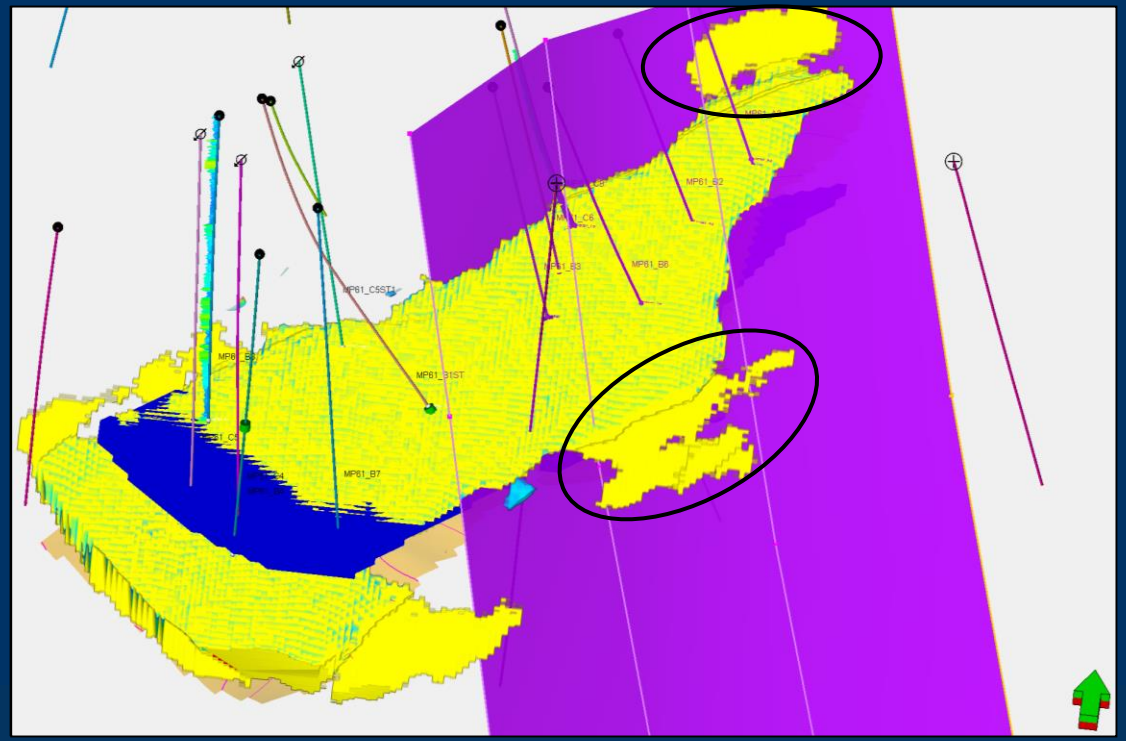
The inversion geobodies were truncated by the legacy boundaries of the model

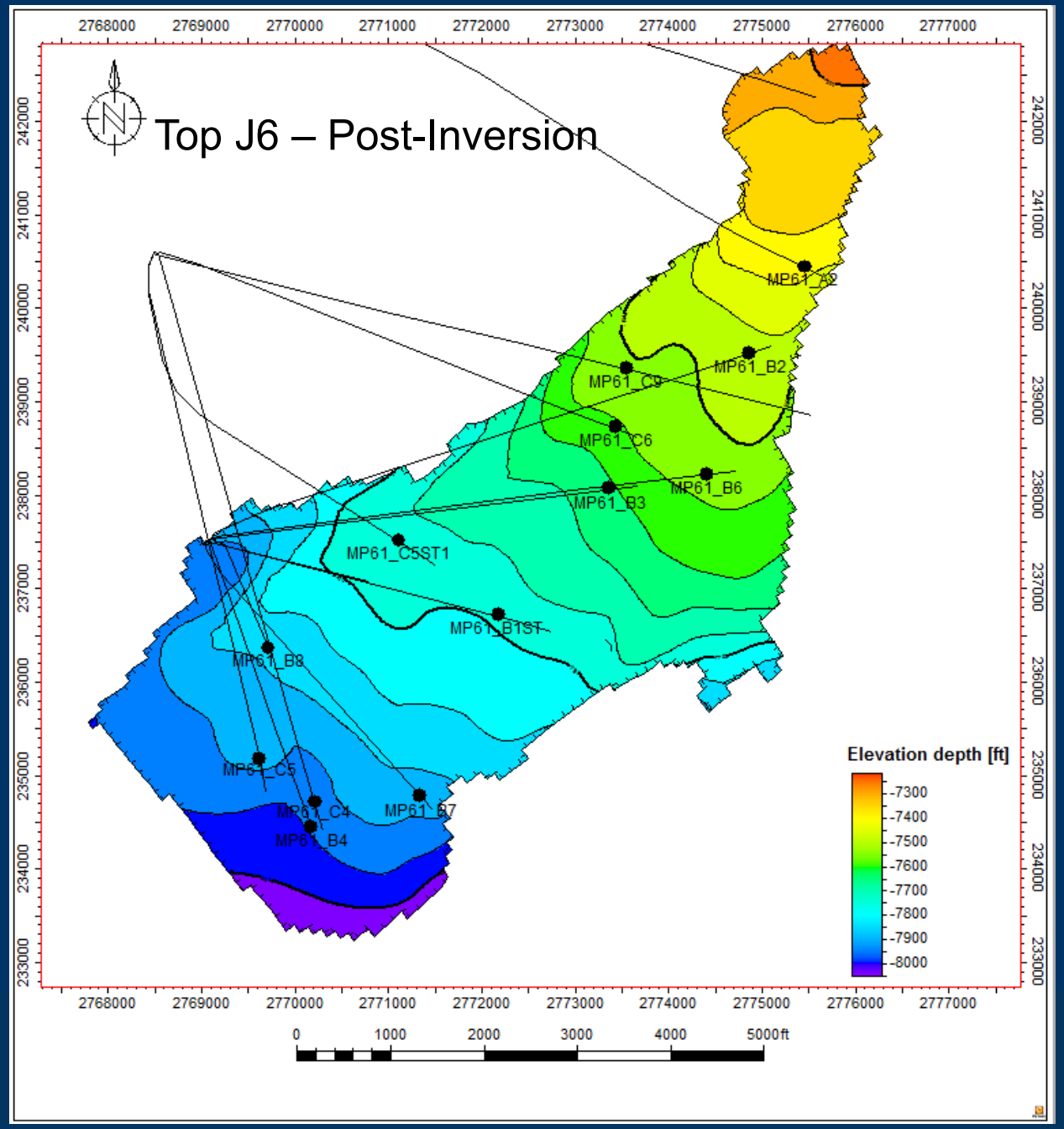




Improving delineation of the reservoir

Modification of J6 reservoir boundaries based on AI and hydrocarbon probability





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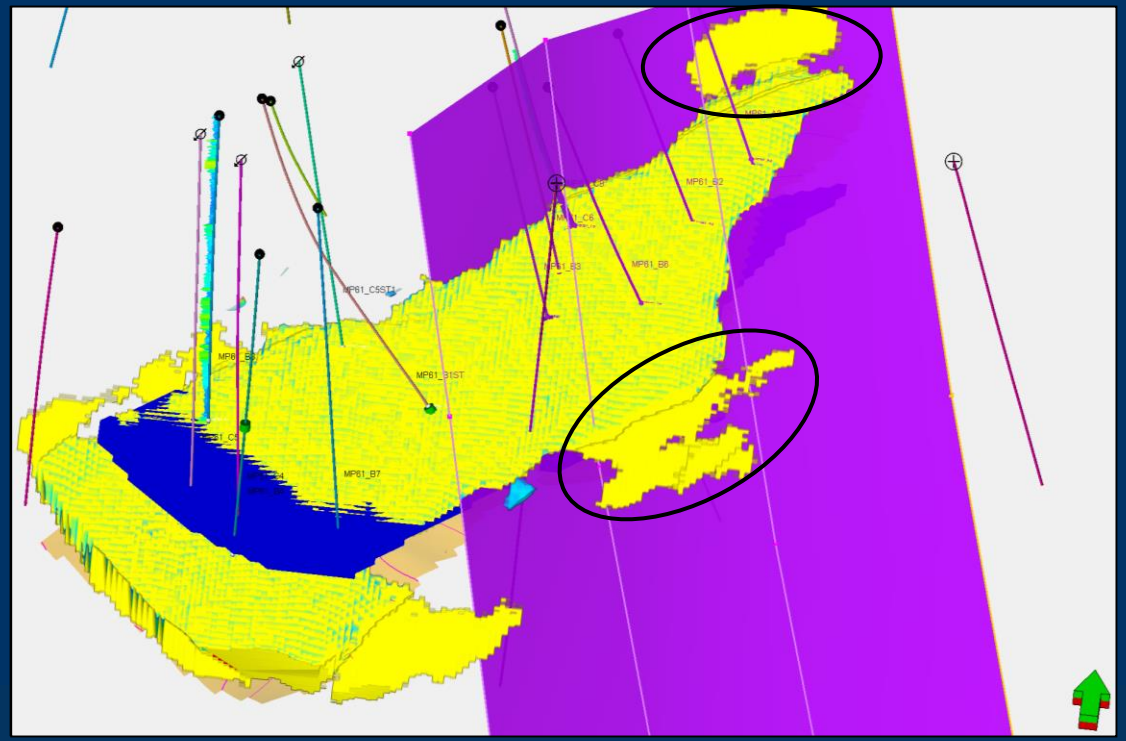
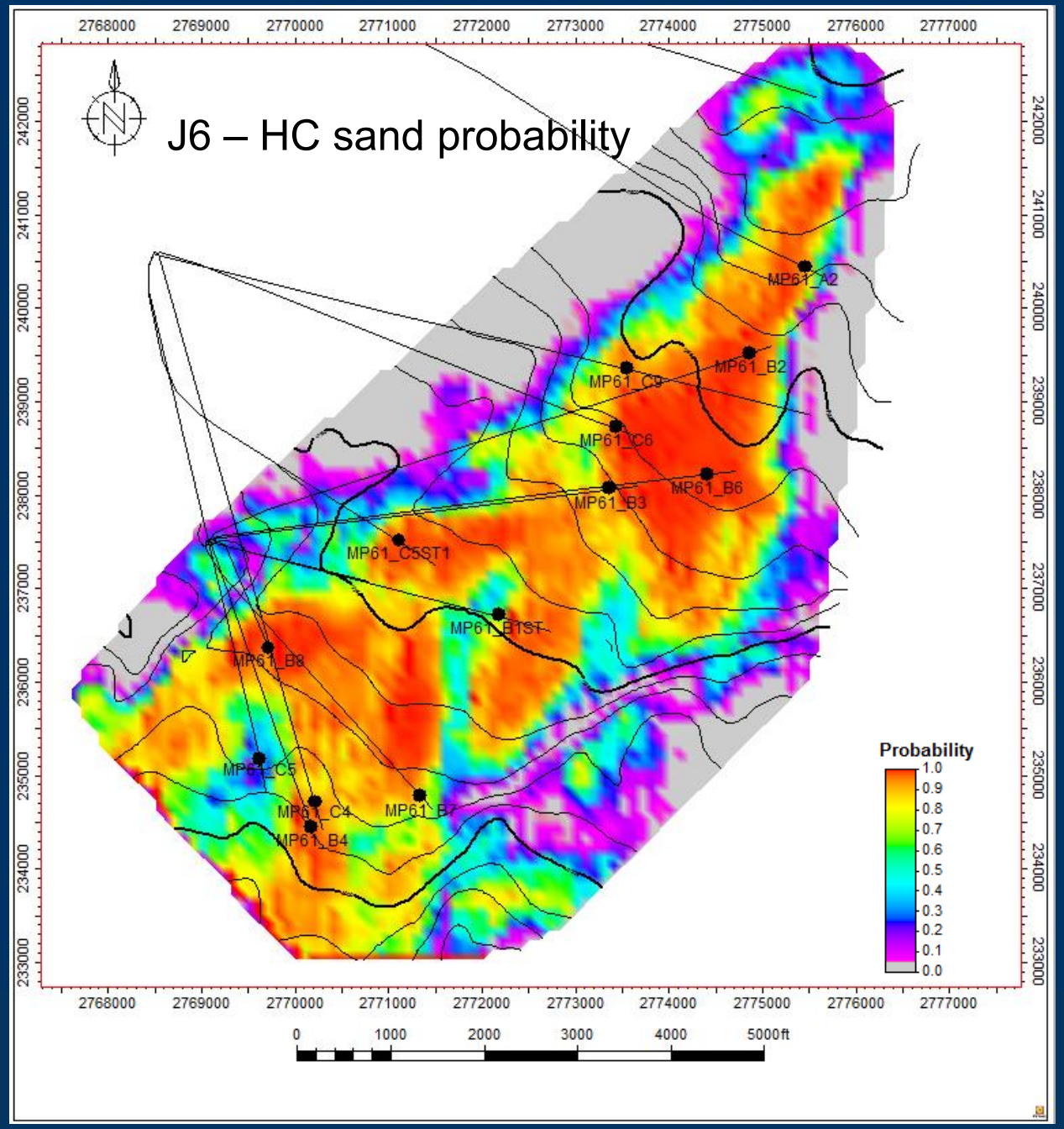
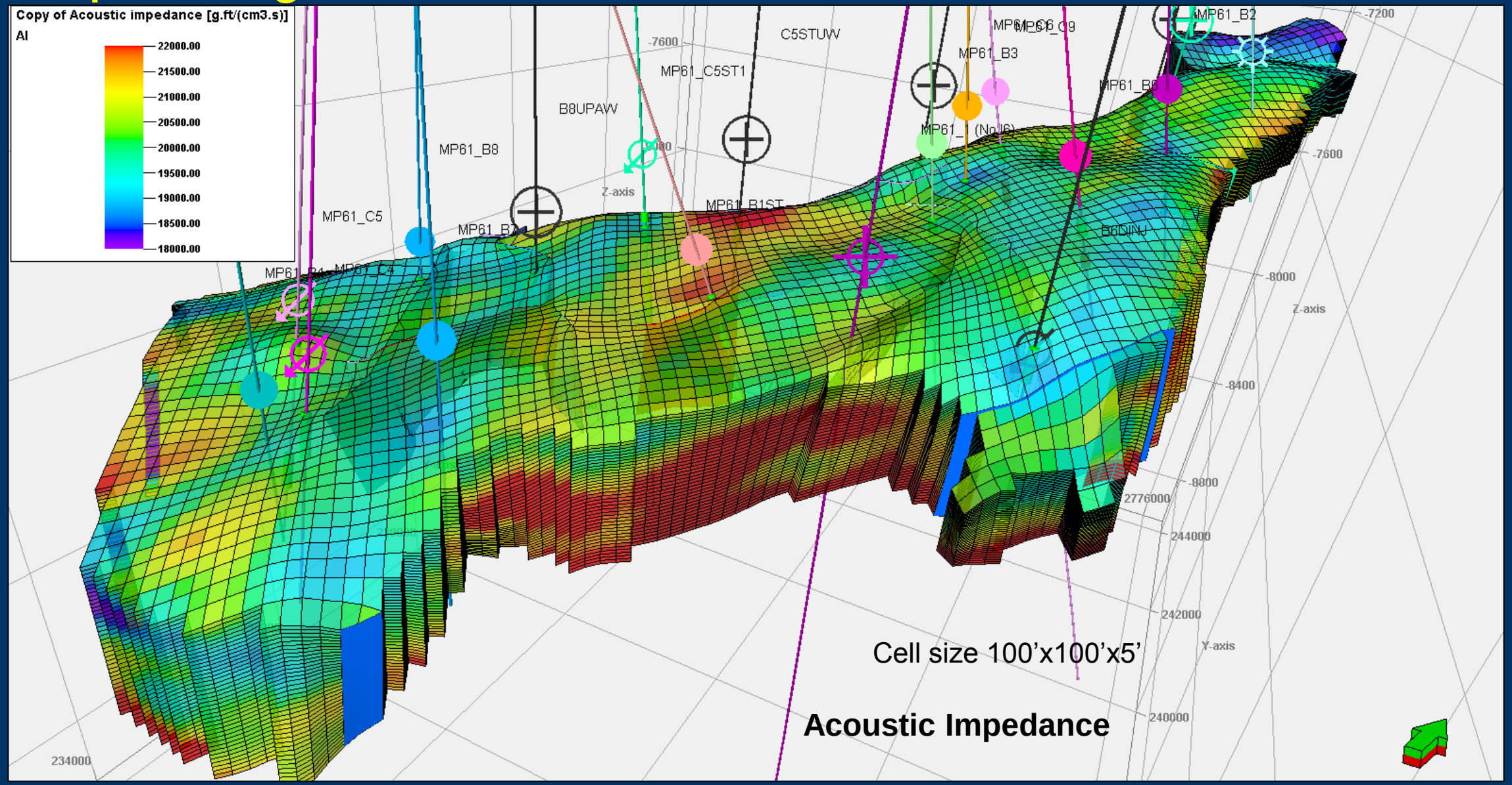
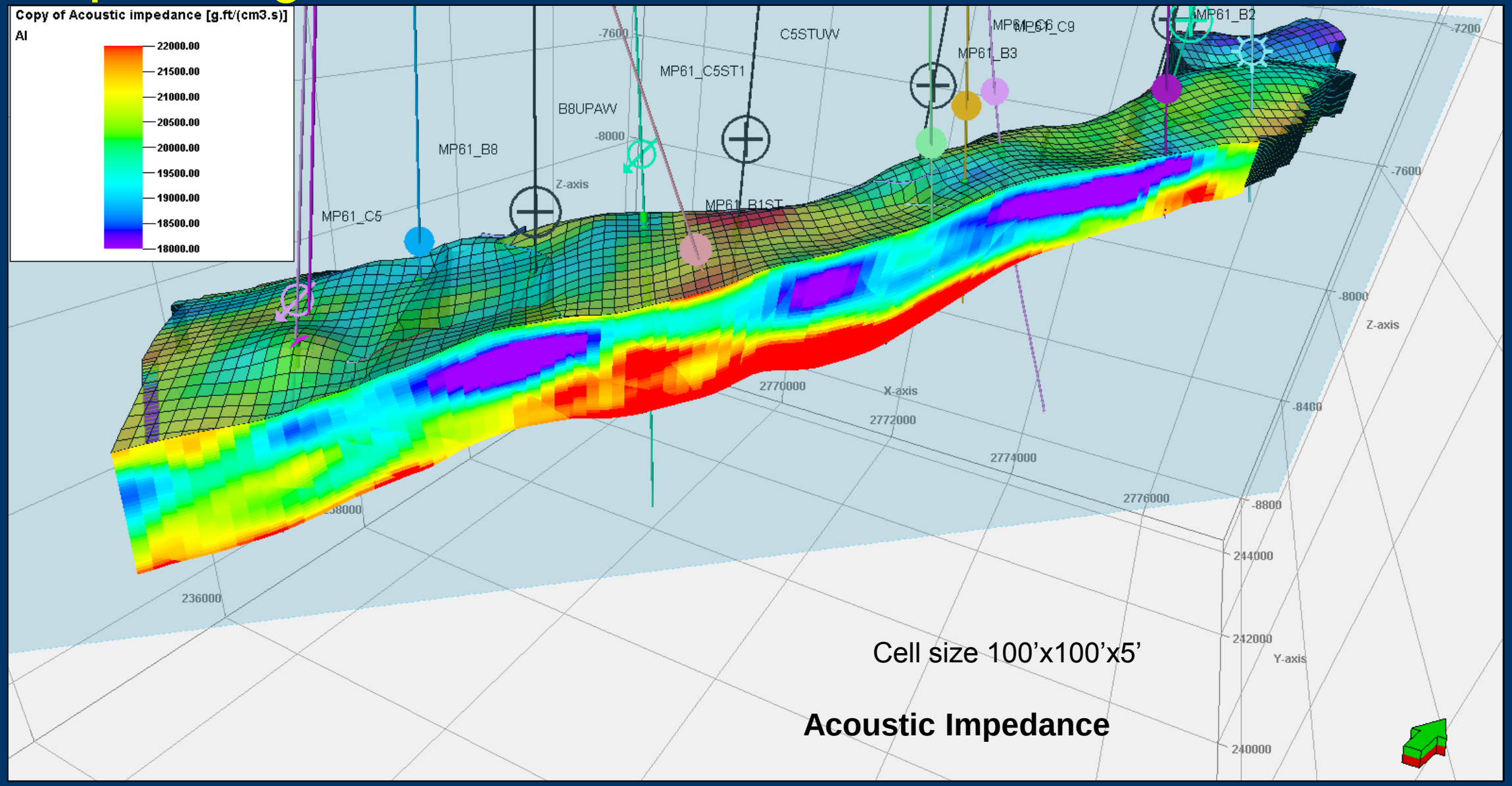




Populating the reservoir model—AI



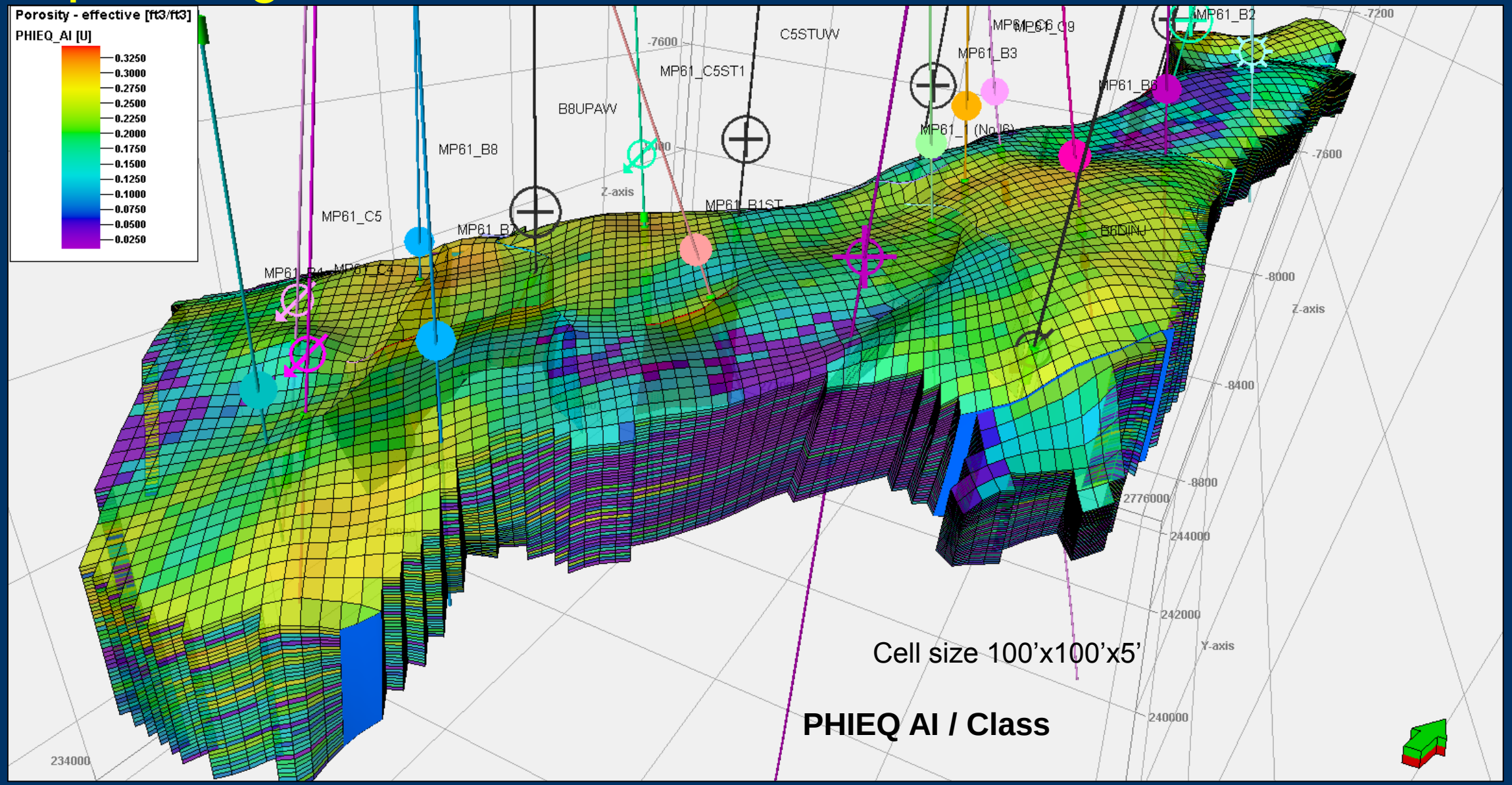
Populating the reservoir model—AI



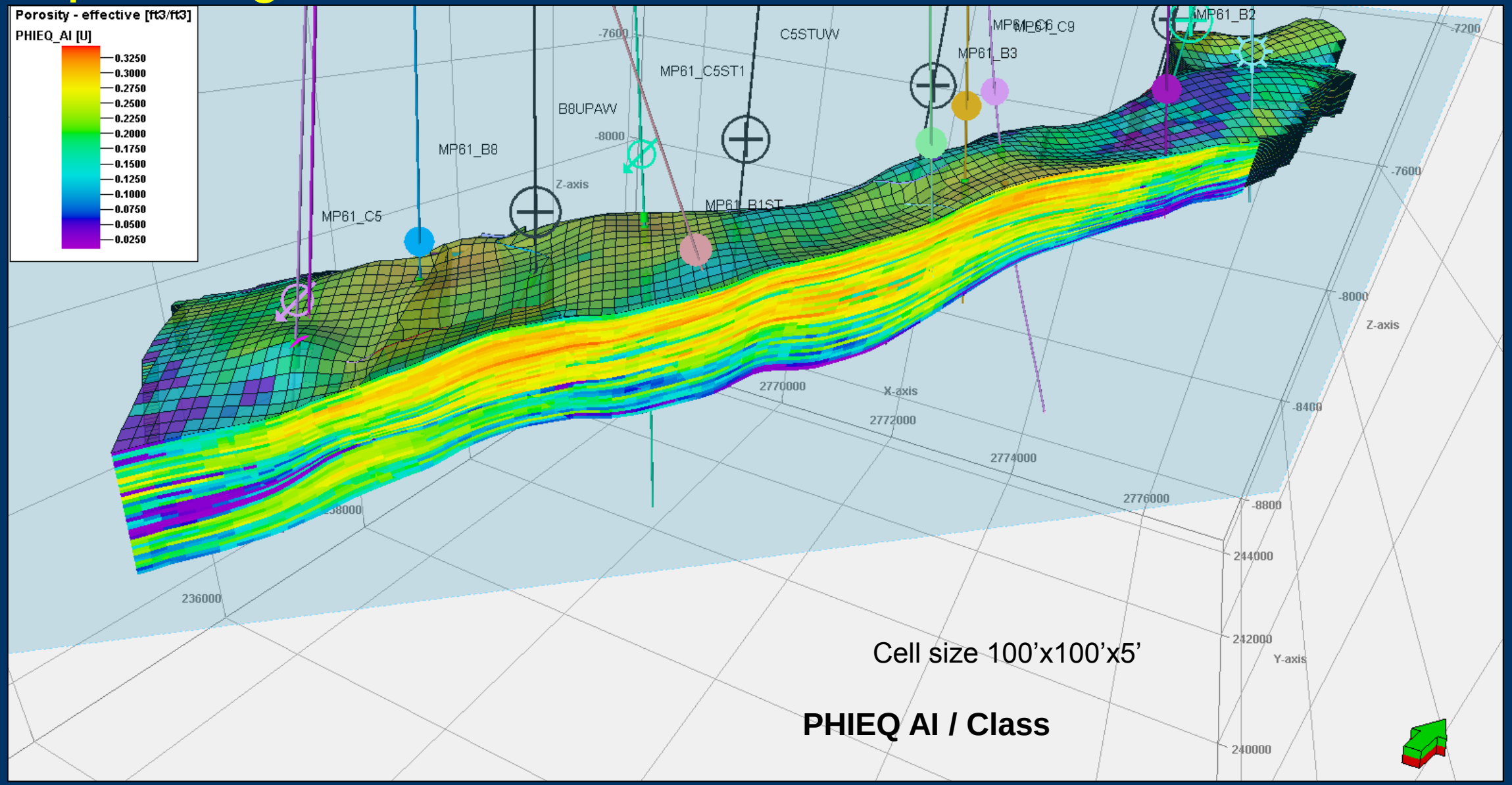
Cell size 100’x100’x5’

Acoustic Impedance

Populating the reservoir model—PHIEQ

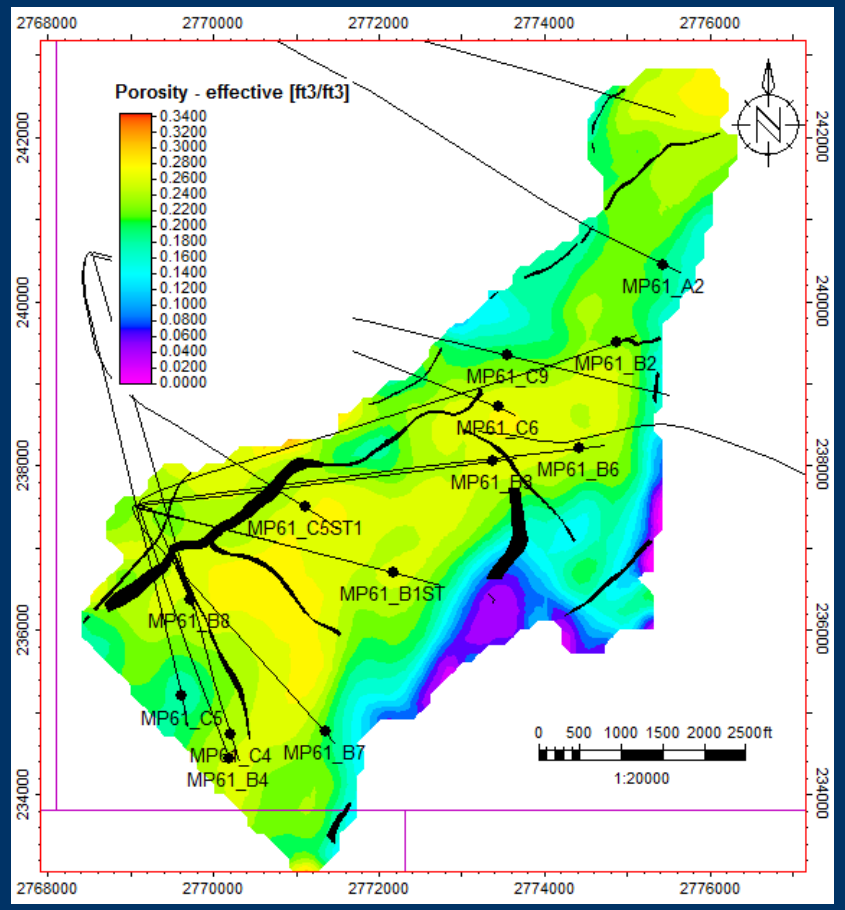


Populating the reservoir model—PHIEQ



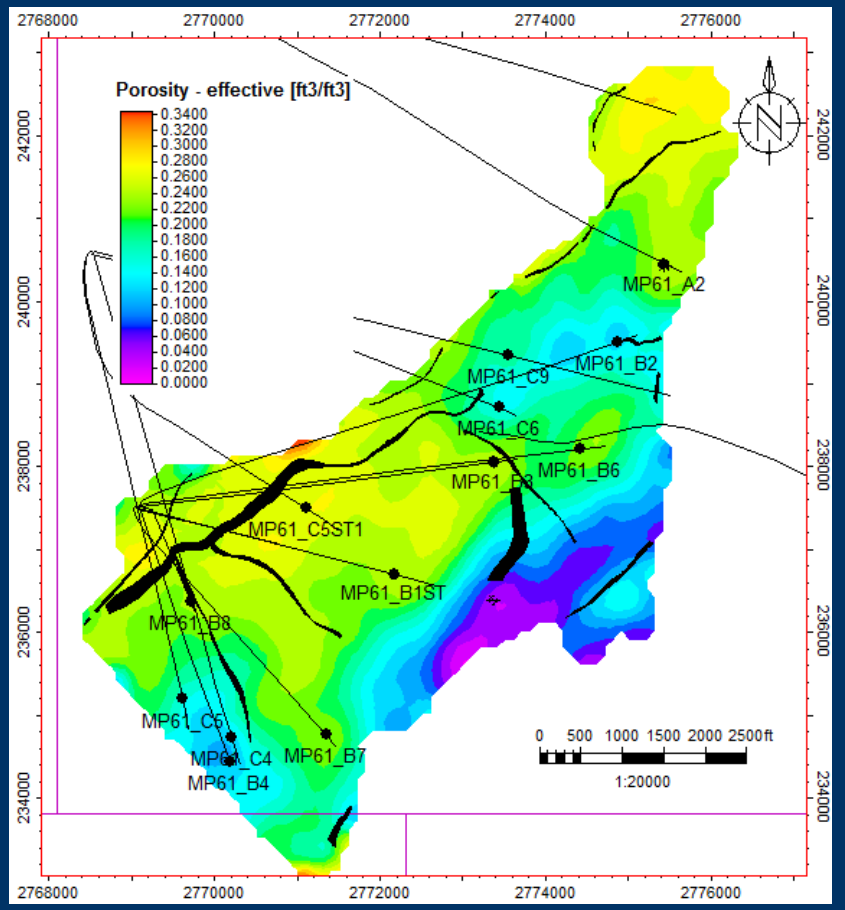
Average PHIE by Lobe (AI derived)

Lobe A



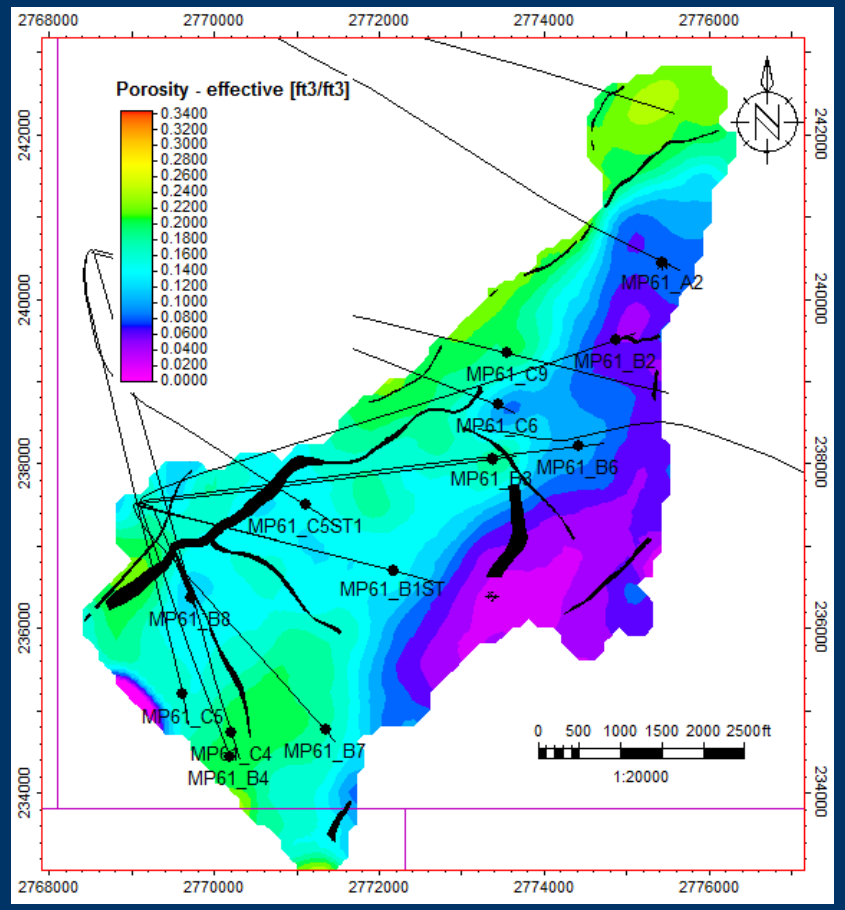
$PHIE_{Ave}$= 23%

Lobe B



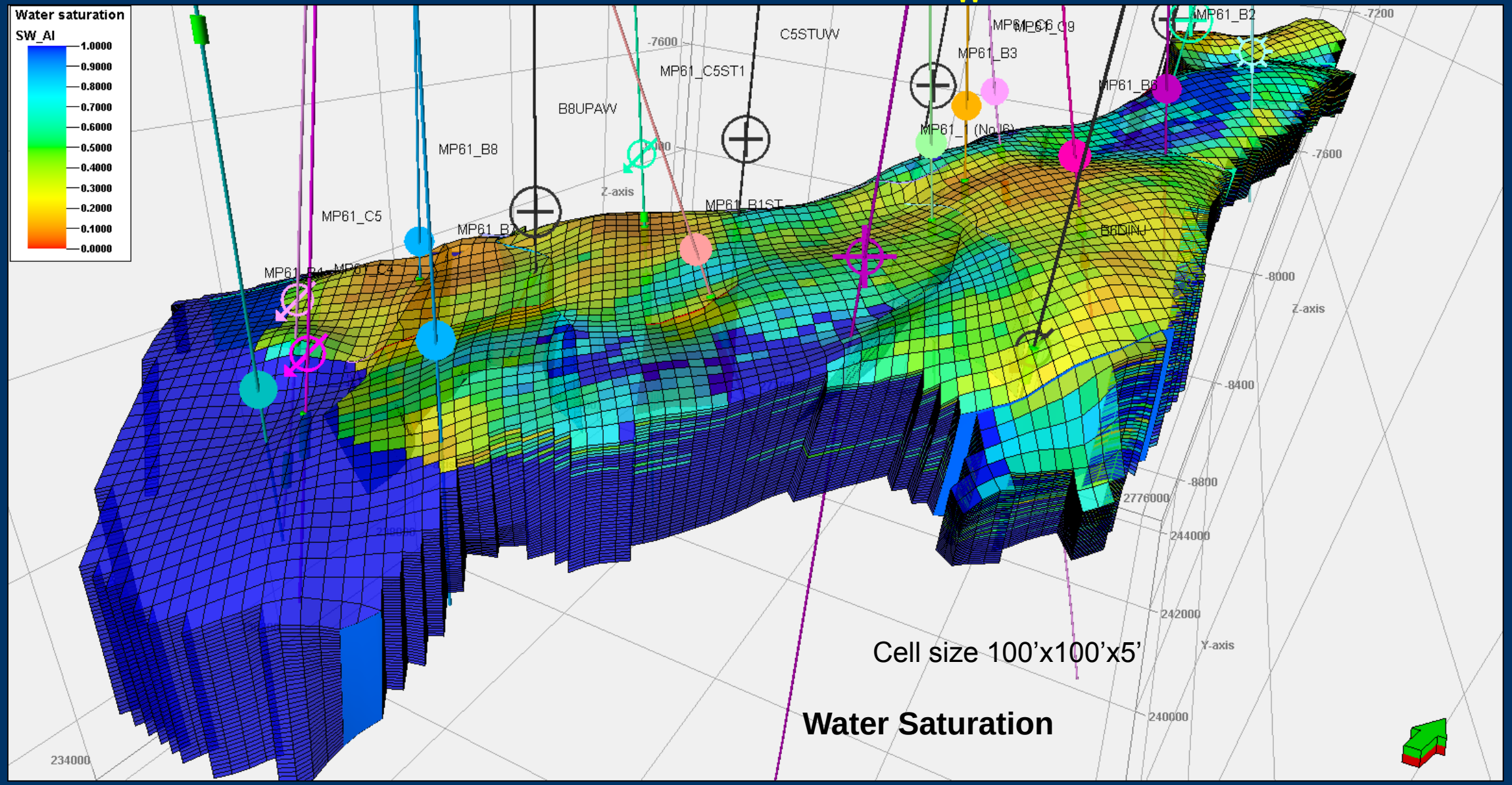
$PHIE_{Ave}$= 20%

Lobe C

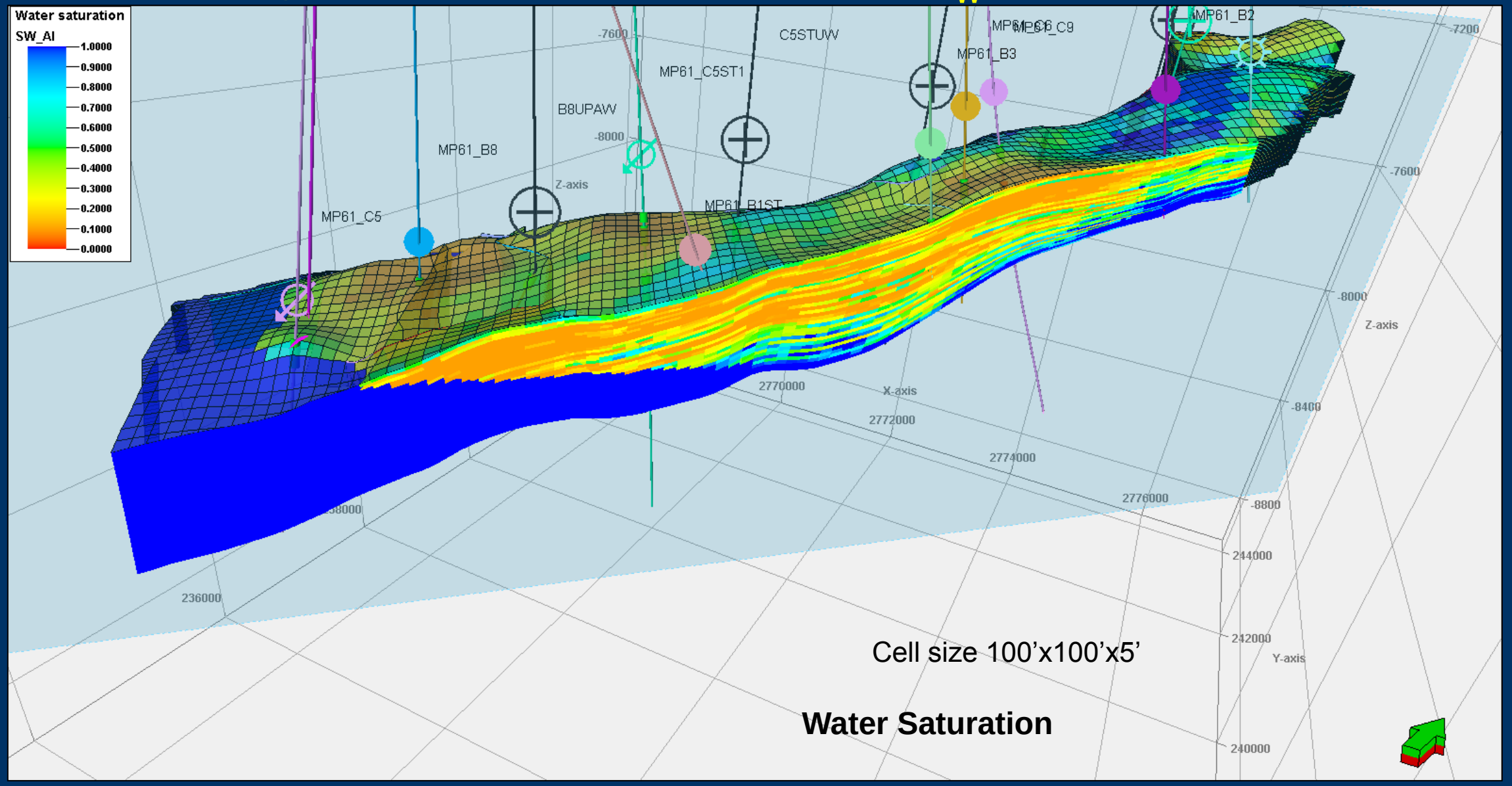


$PHIE_{Ave}$= 14%

Populating the reservoir model—S_w



Populating the reservoir model—S_w



Analysis of Seismic Discontinuities

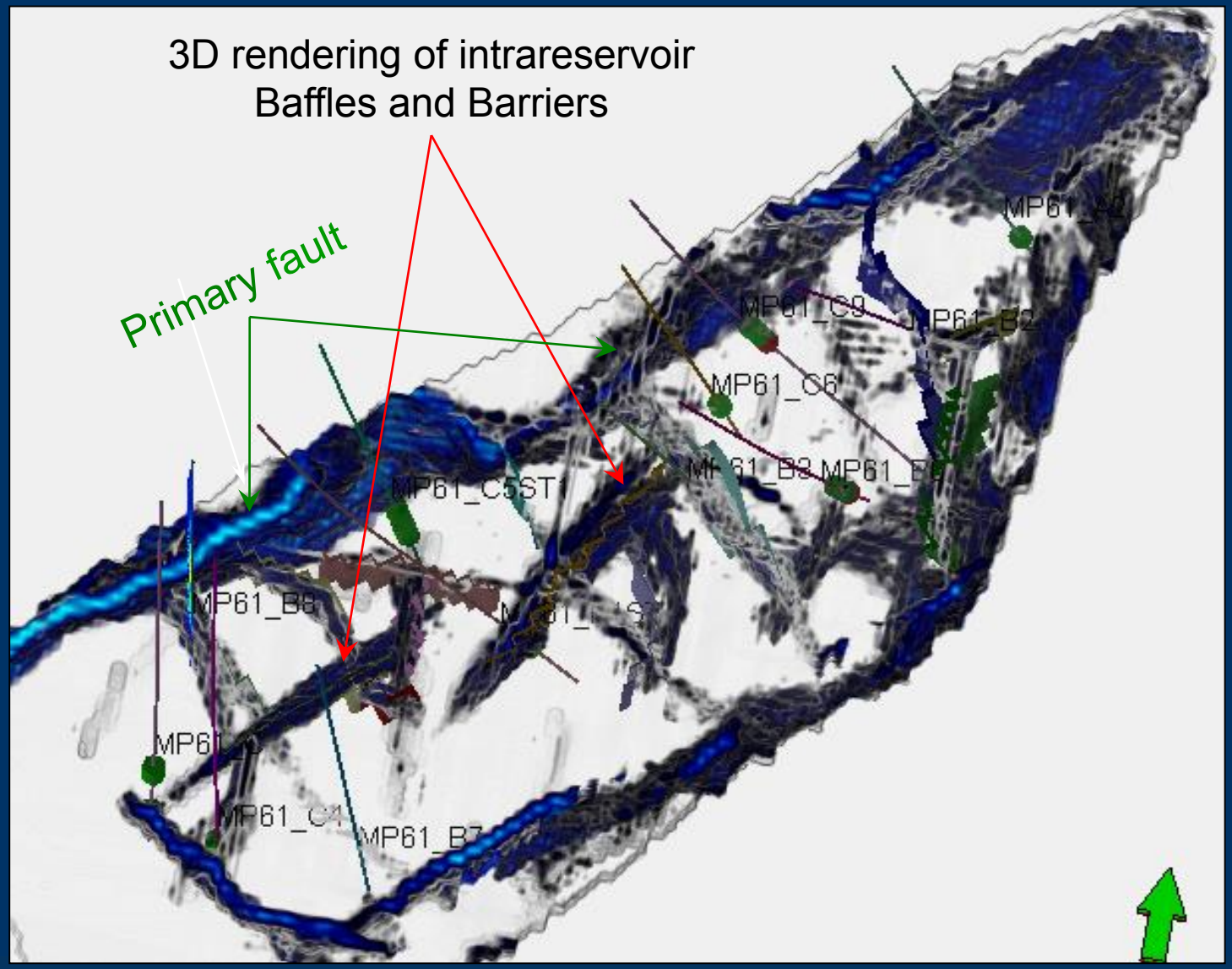
Seismic discontinuity analysis provides a framework for classifying subtle faults and reservoir compartments.

Discontinuities may be baffles, barriers or conduits.

This analysis consisted of two parameterizations of Ant Tracking:

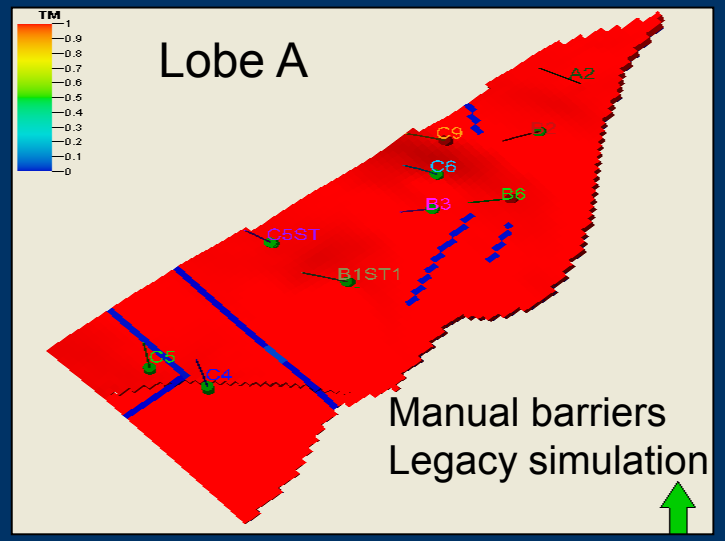
1) Primary faulting

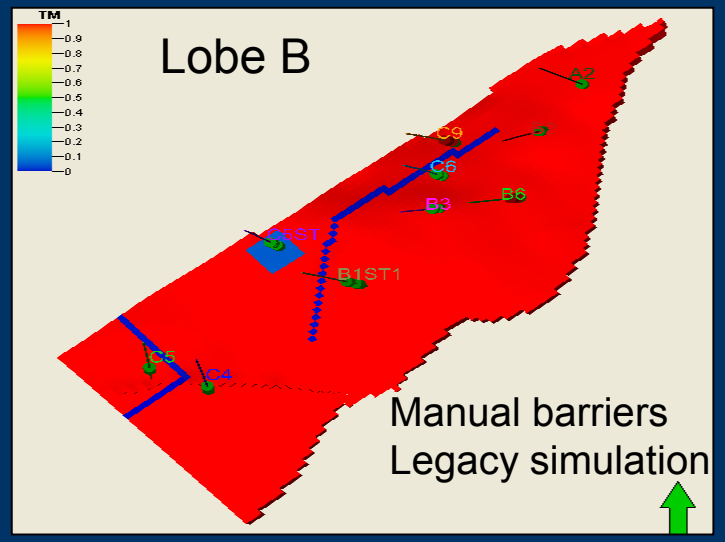
2) Subtle faults, baffles, barriers and reservoir compartments

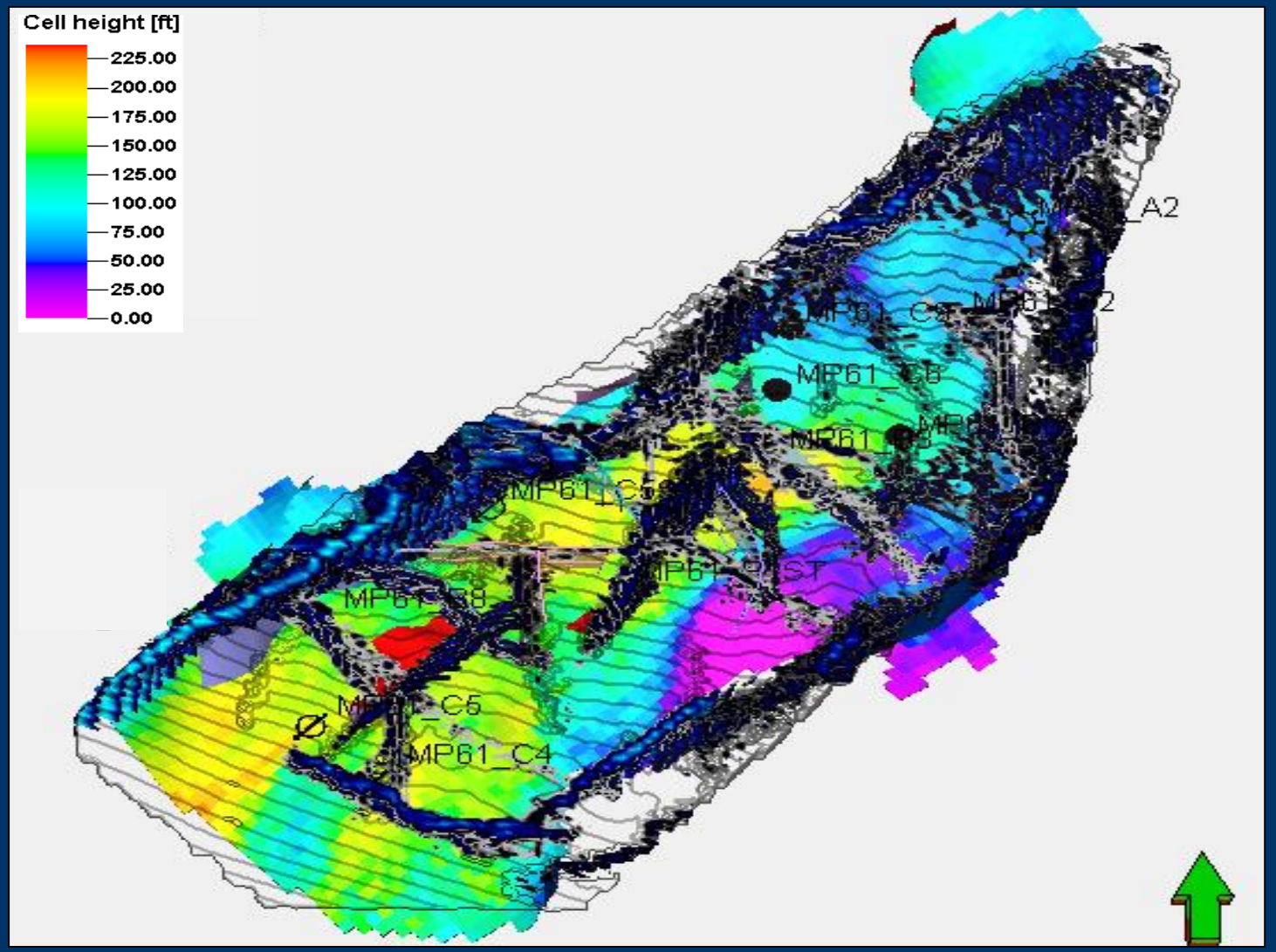


Candidate fluid flow baffles and barriers obtained within the J6 reservoir.

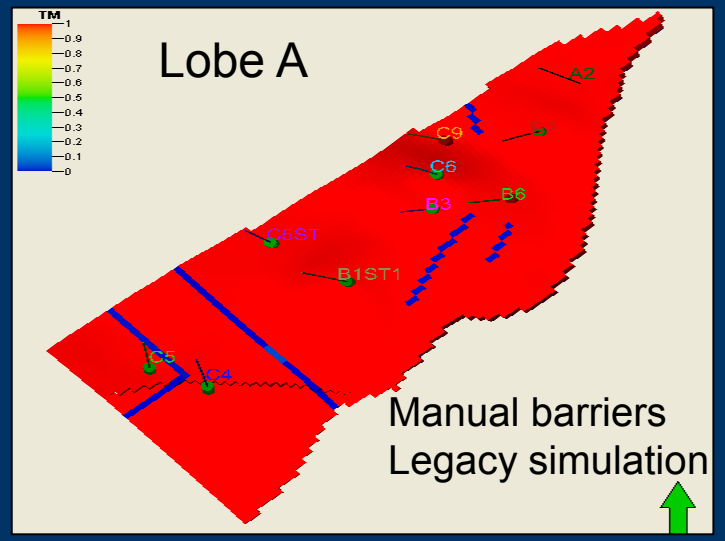
Robust Model Integrates Ant Tracking Baffles and Barriers

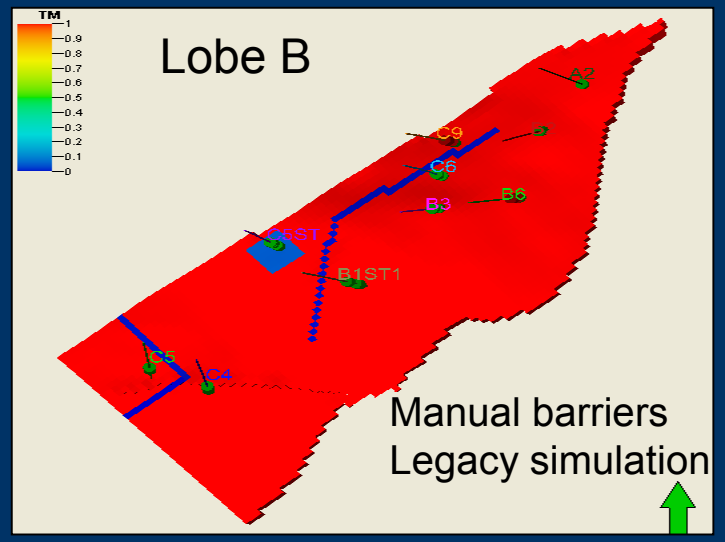


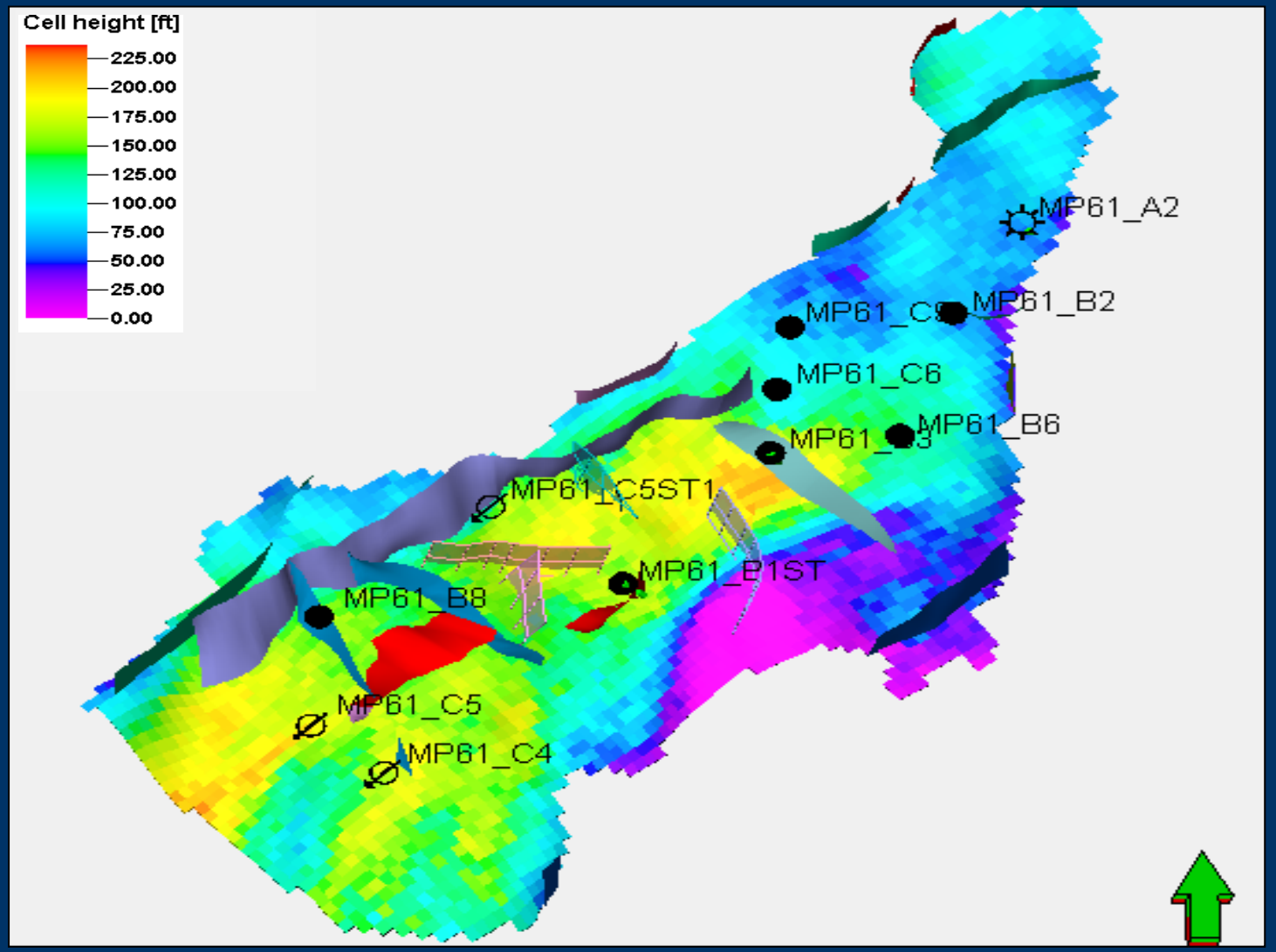




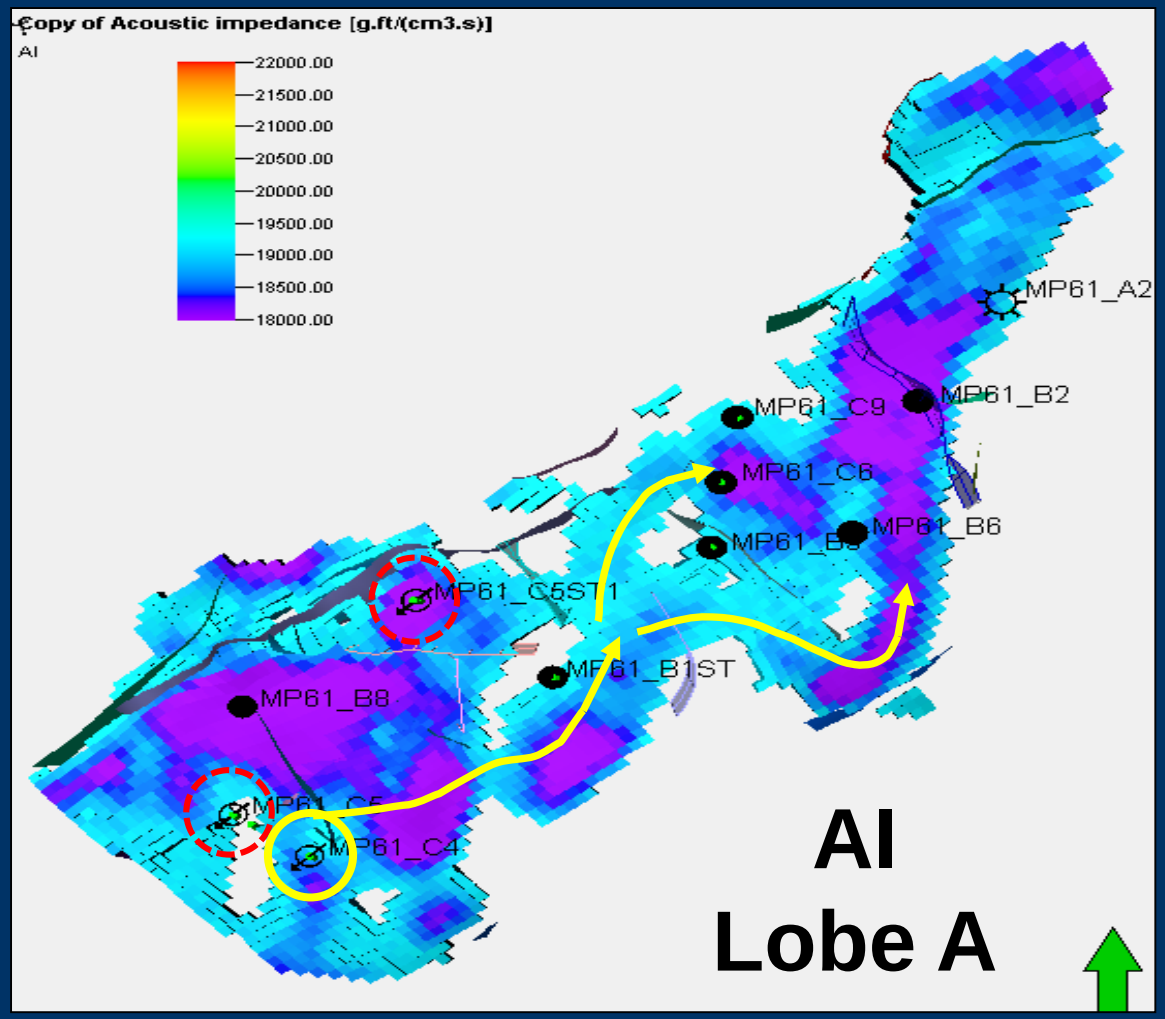
Robust Model Integrates Ant Tracking Baffles and Barriers

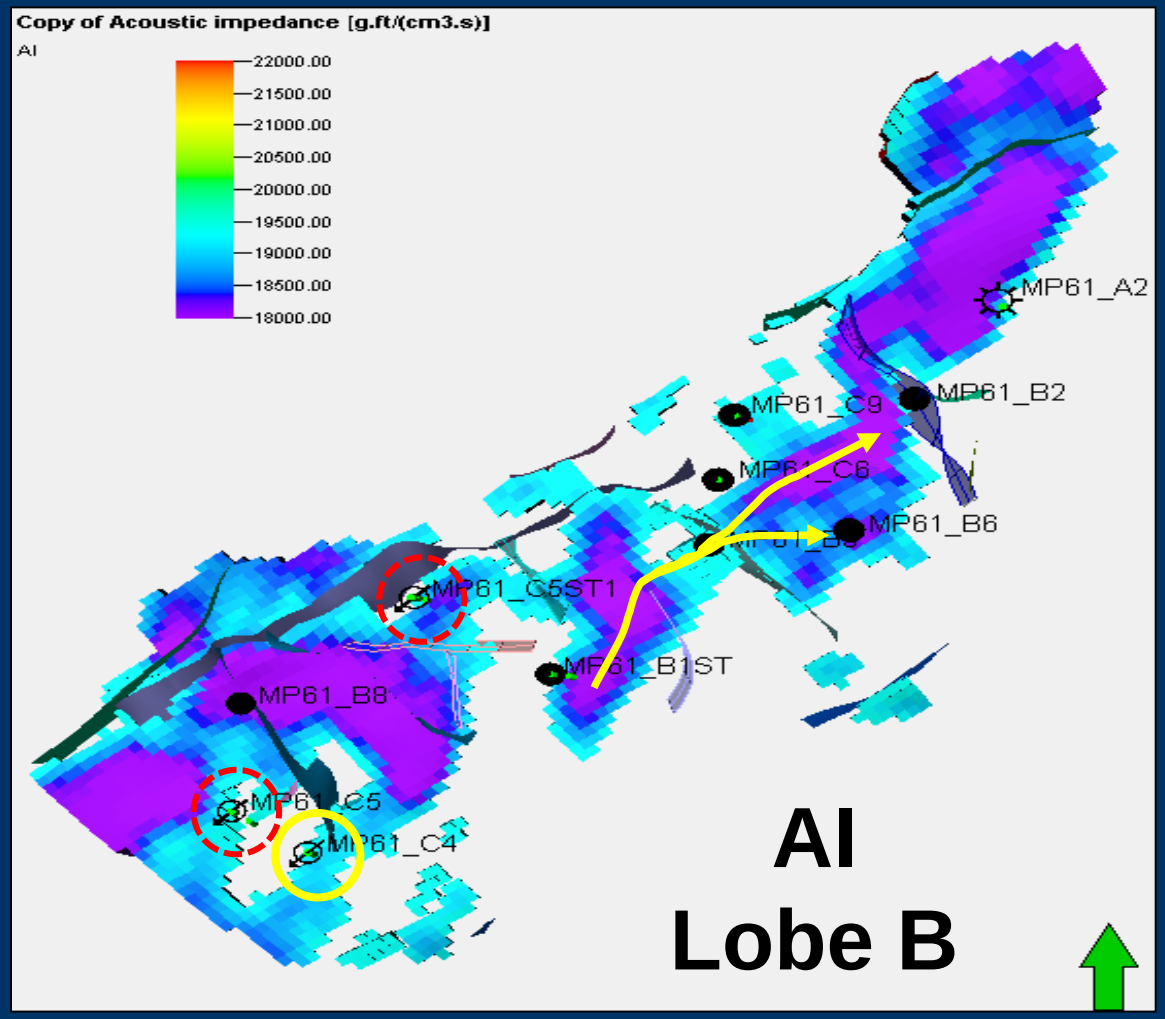




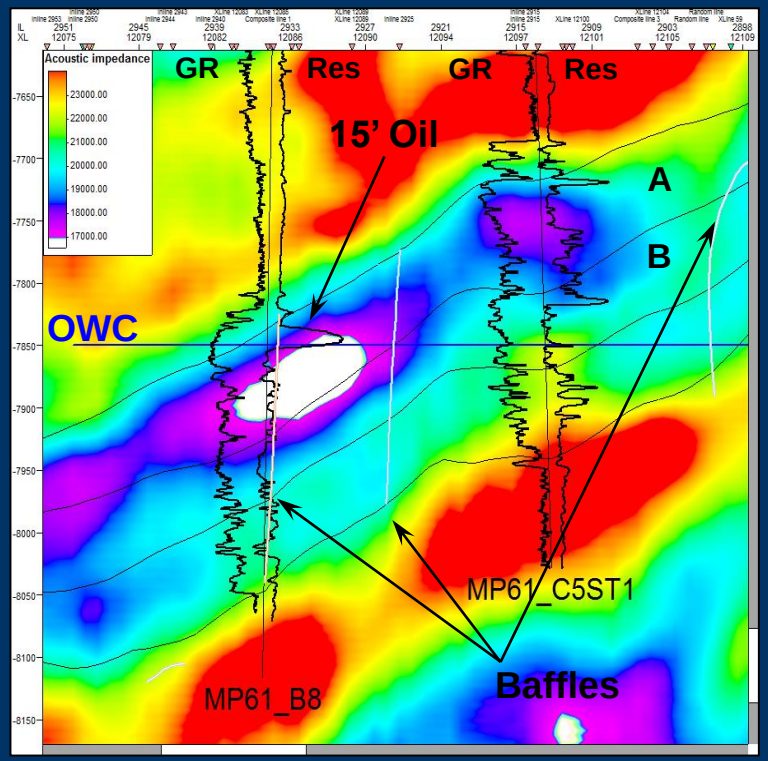


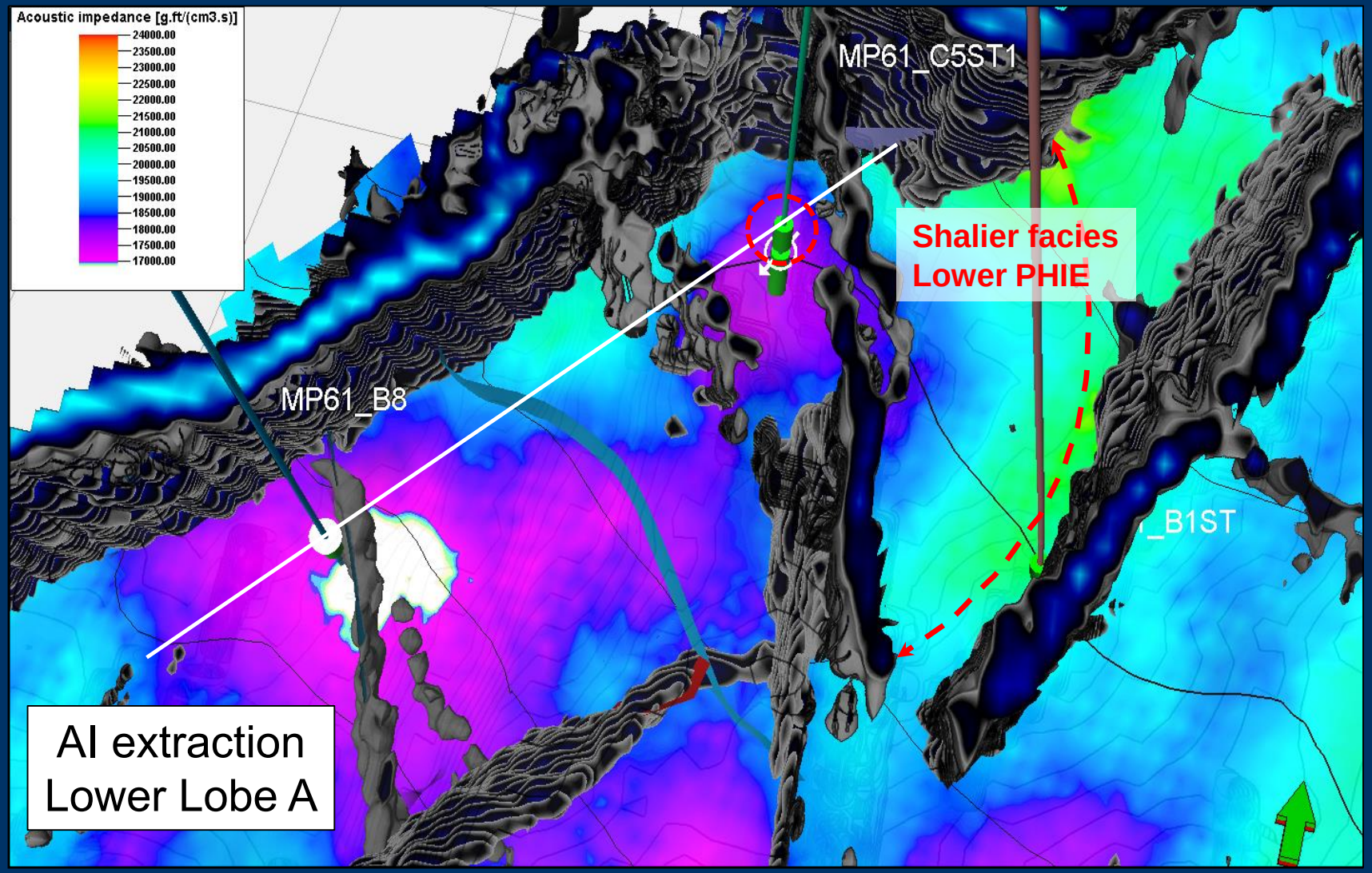
Preferential Water Pathways in Lobes A & B
Acoustic Impedance Geobody and Baffles



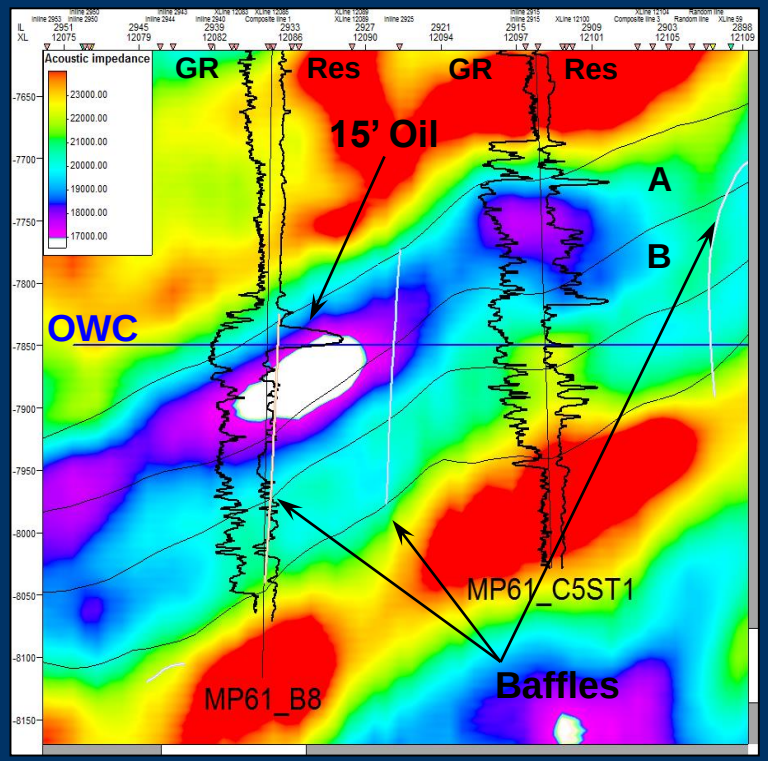


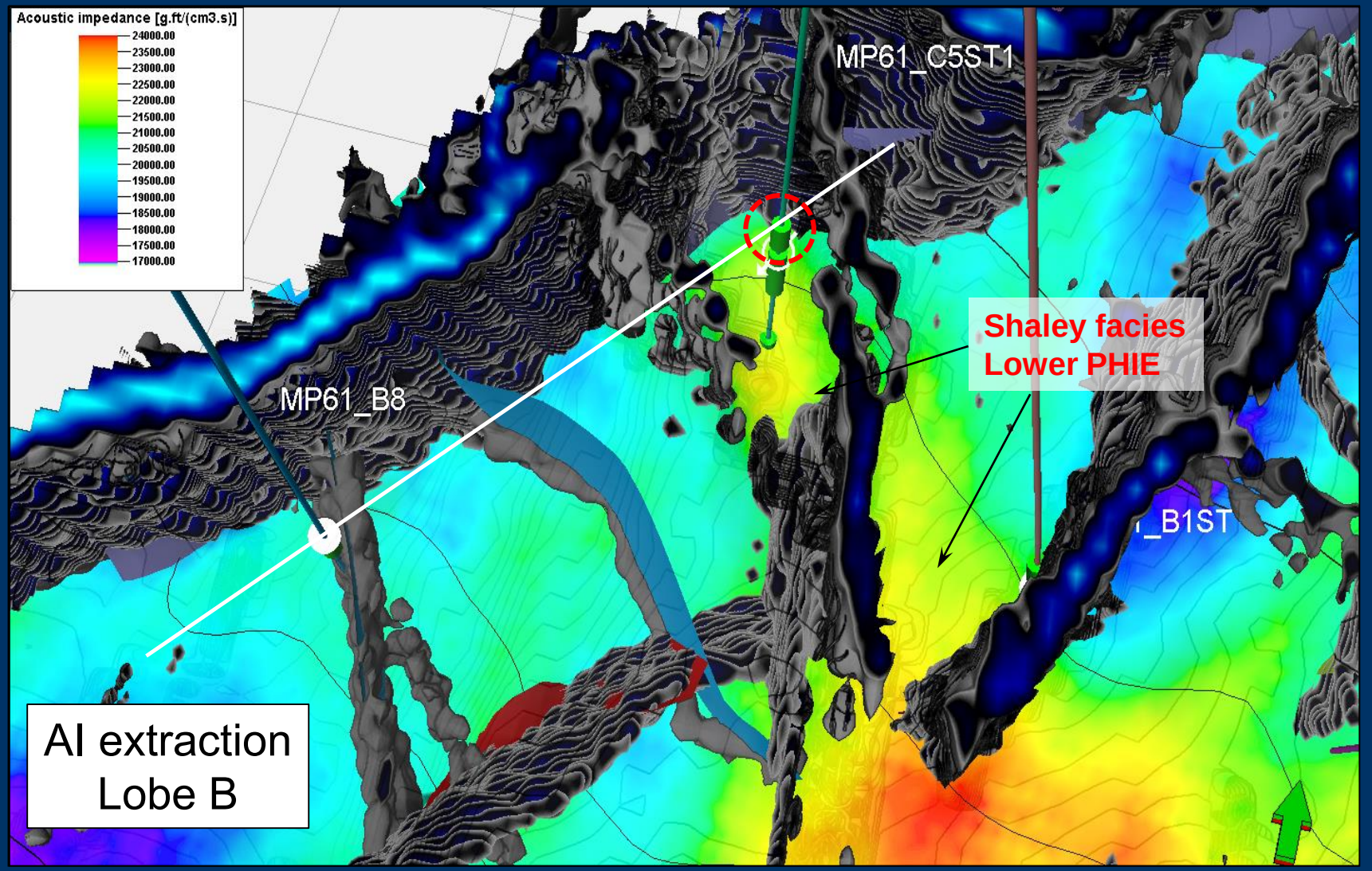
Example: C5ST1 Injector and B8 Baffles



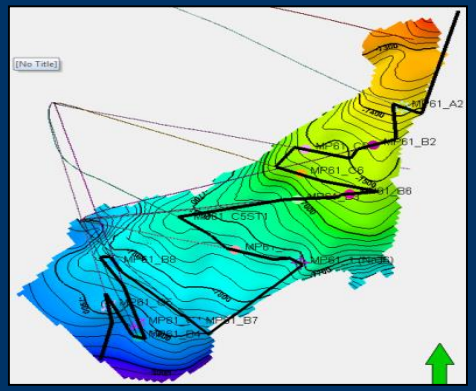


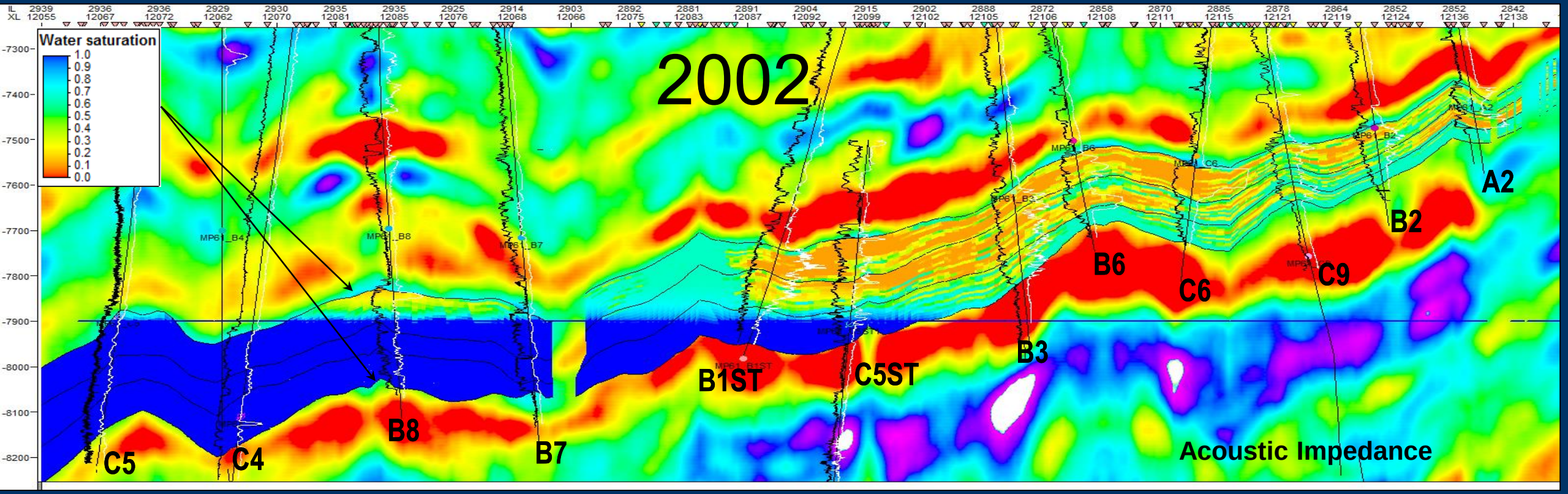
Example: C5ST1 Injector and B8 Baffles



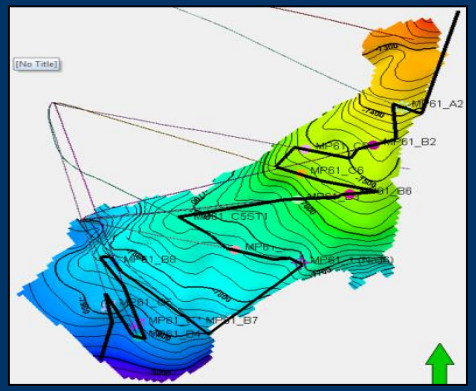


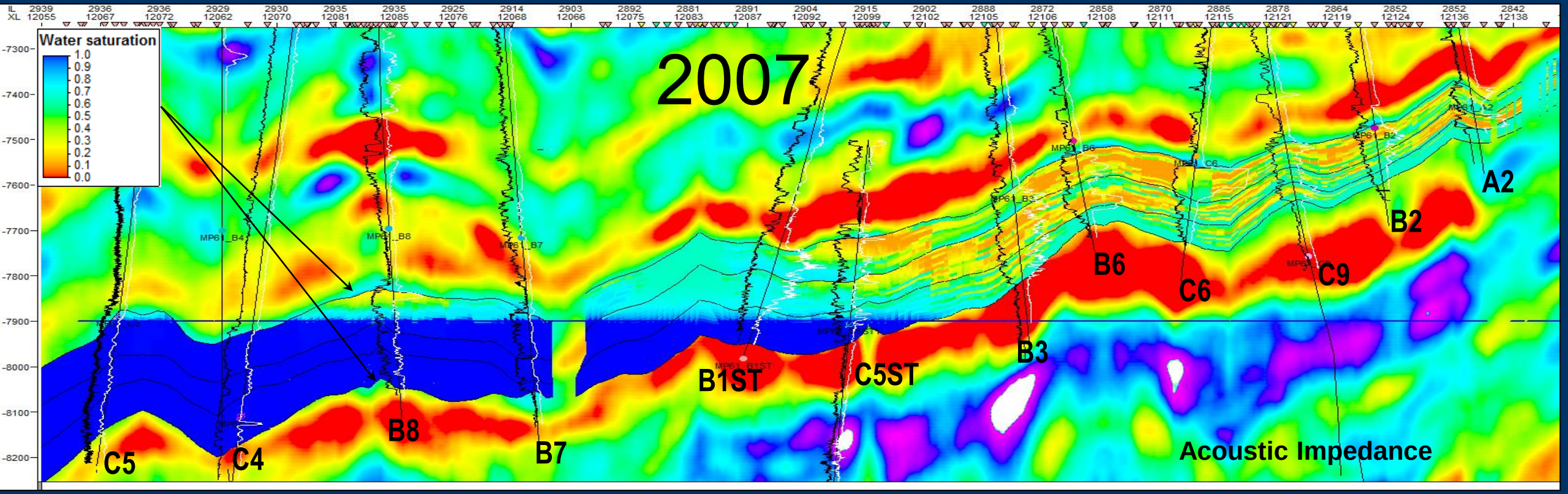
Simulation—Water Saturation



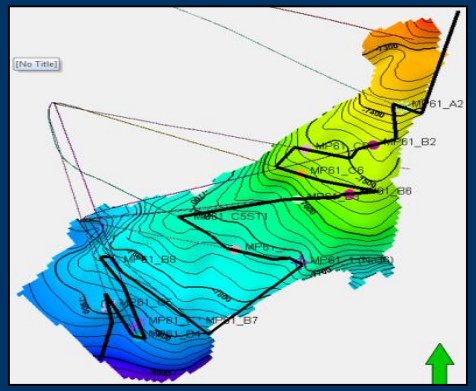


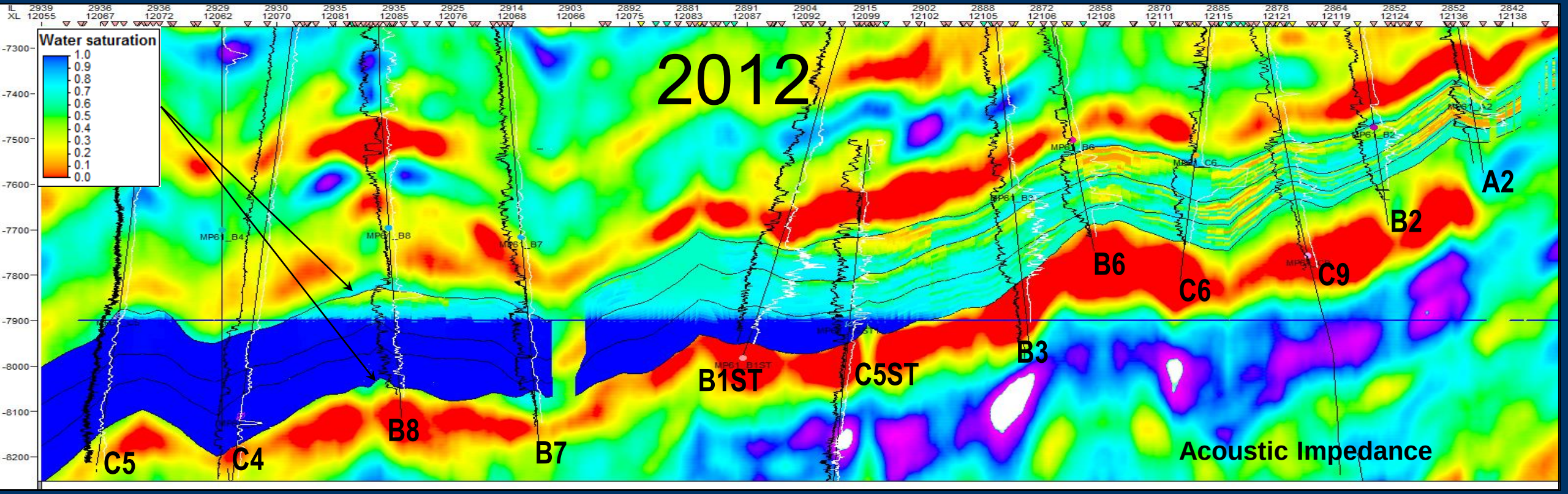
Simulation—Water Saturation



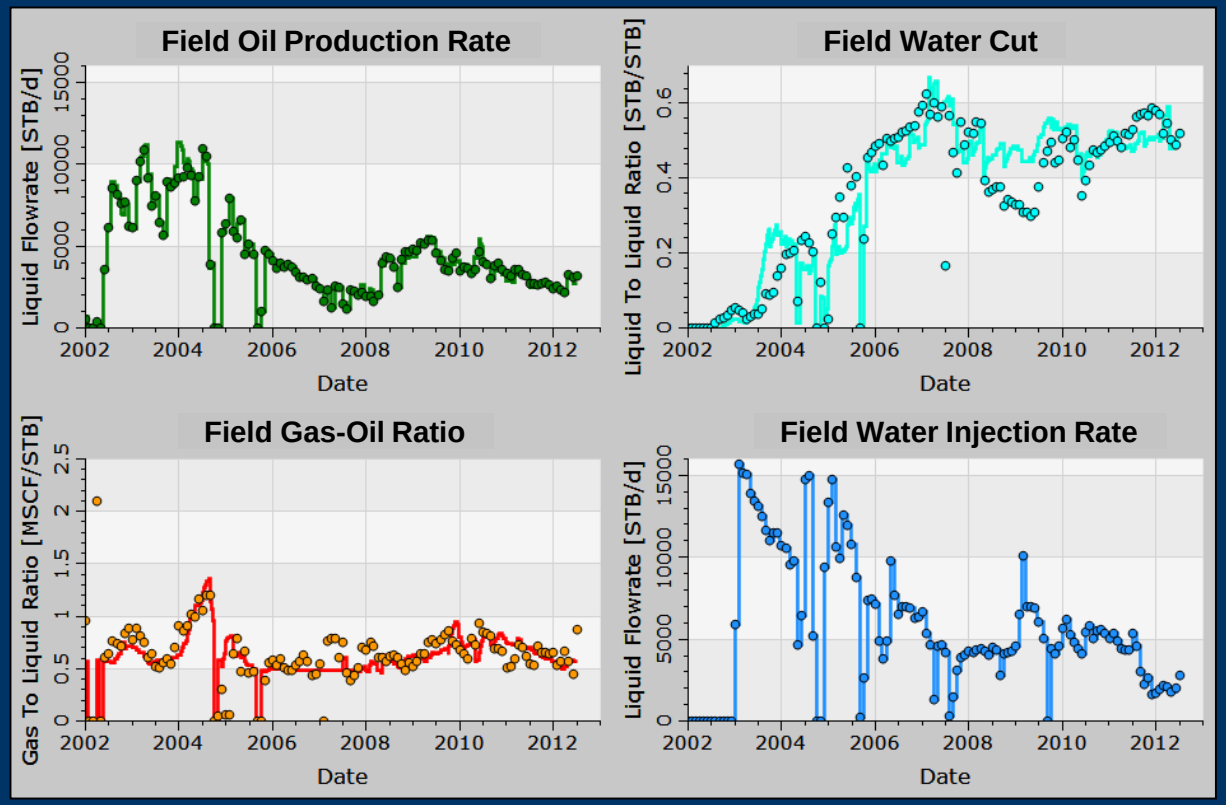


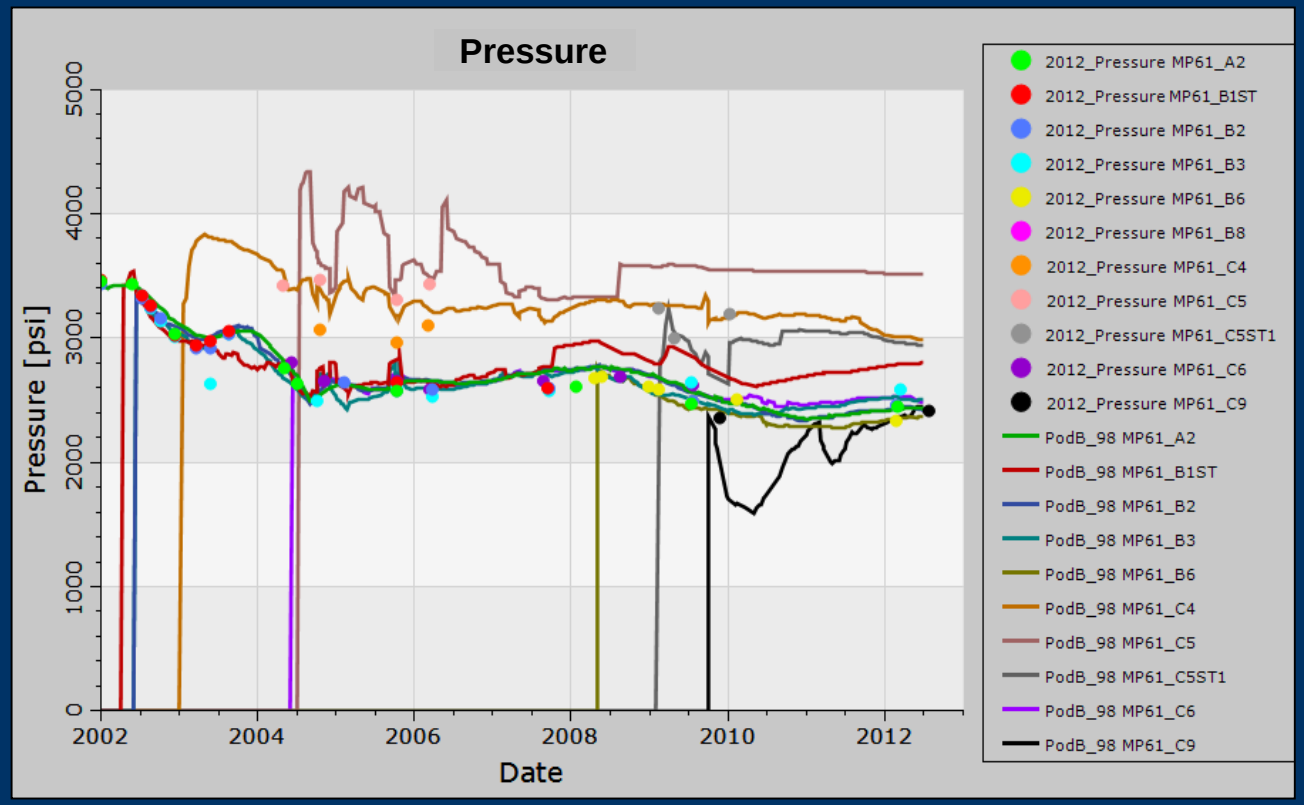
Simulation—Water Saturation



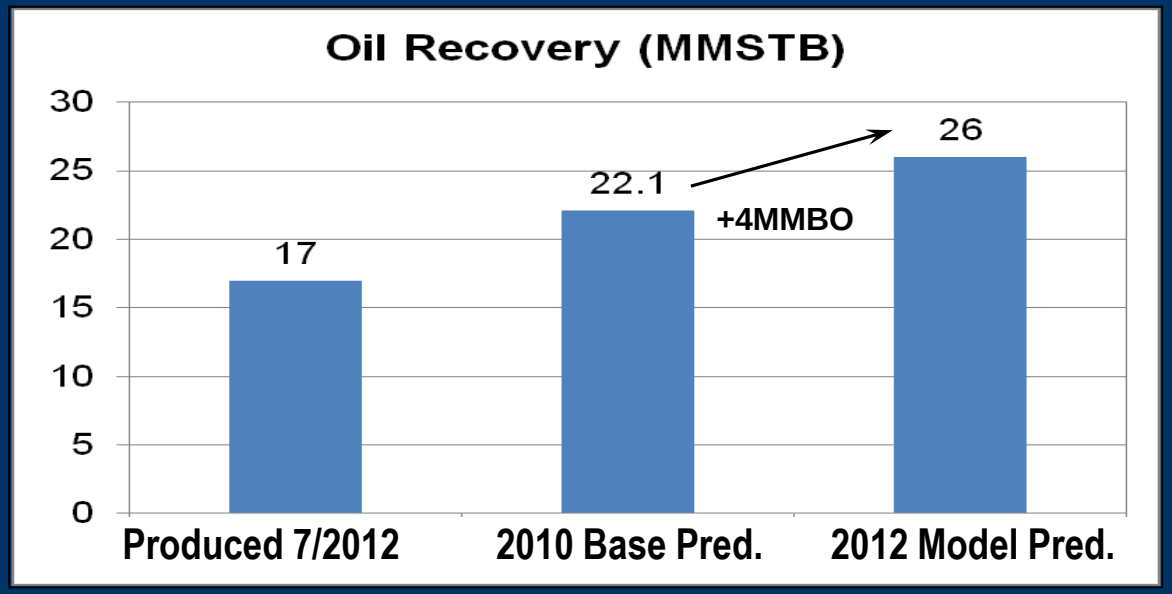


The Field History Match: Oil Rate, Water Cut, Gas-Oil Ratio, Water Injection Rate, and Pressure

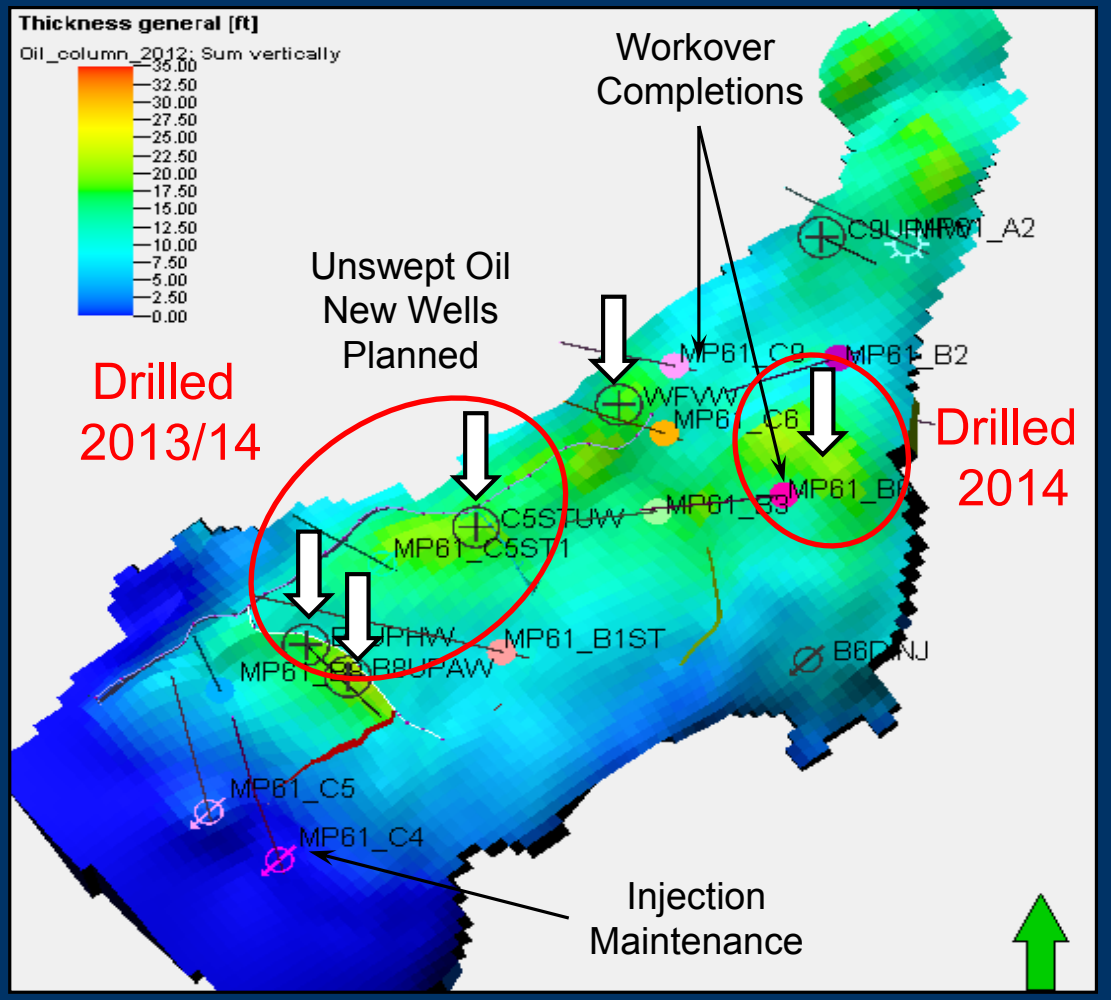




MP61 Pod B Results



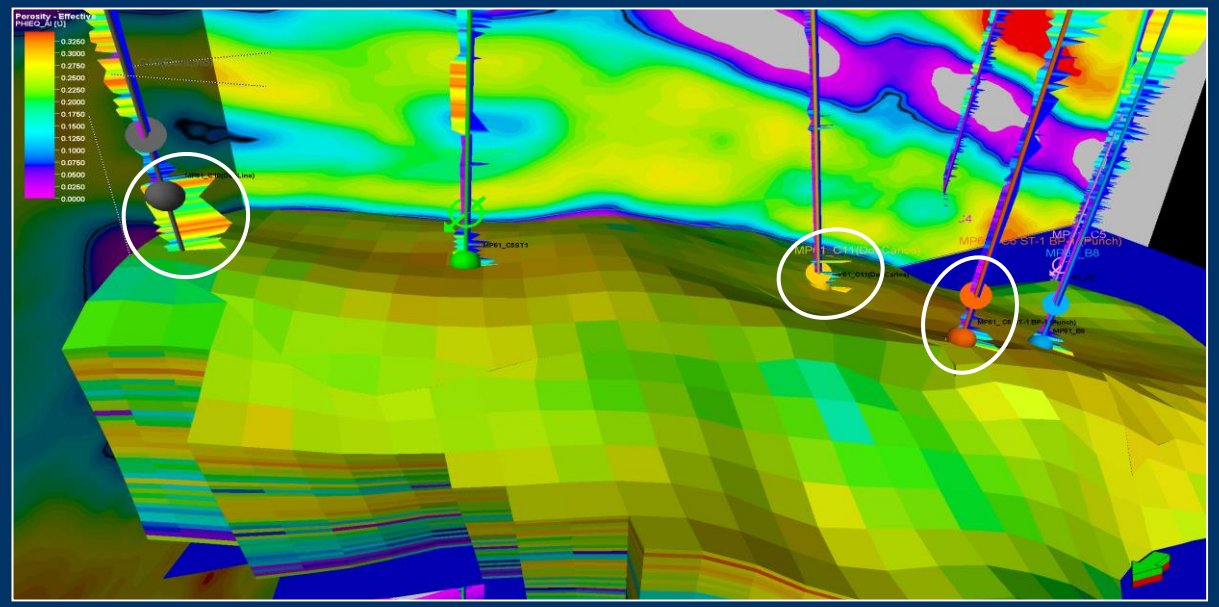
Oil Column 2012



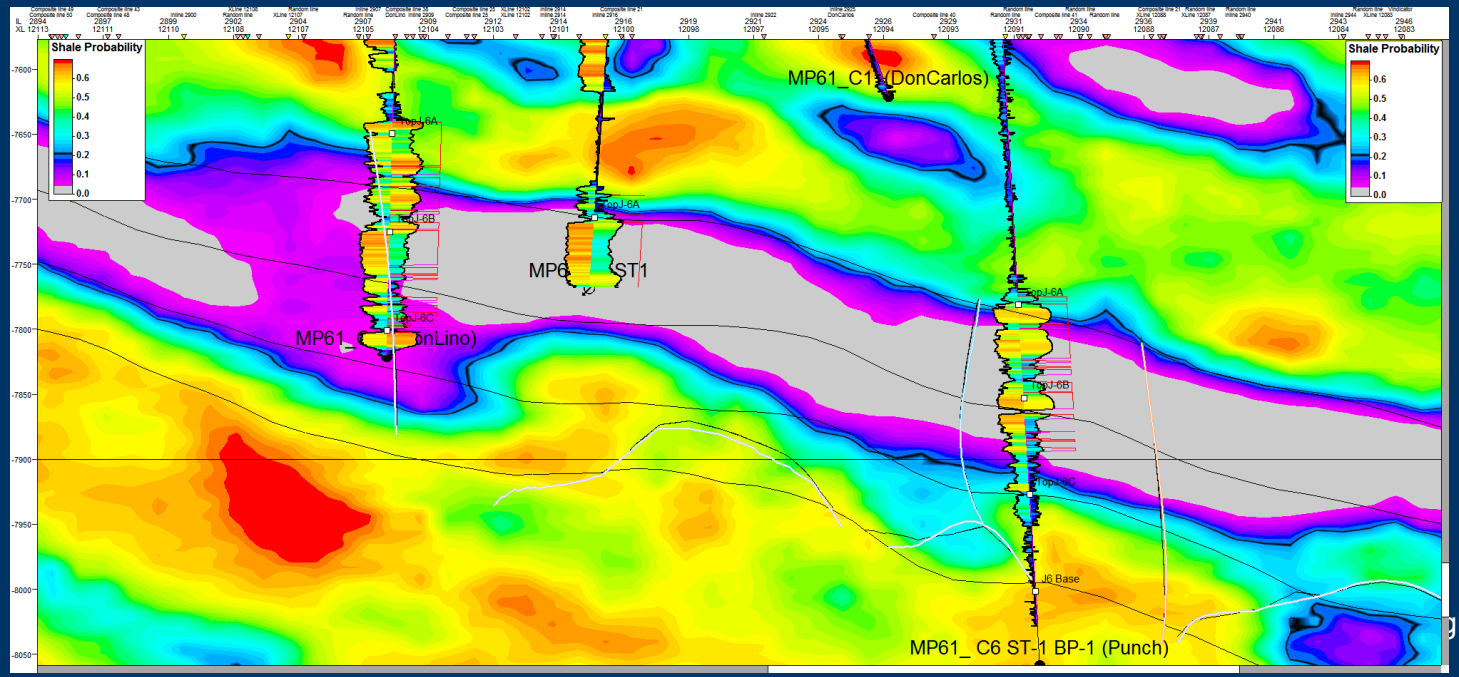
Pod B Results:

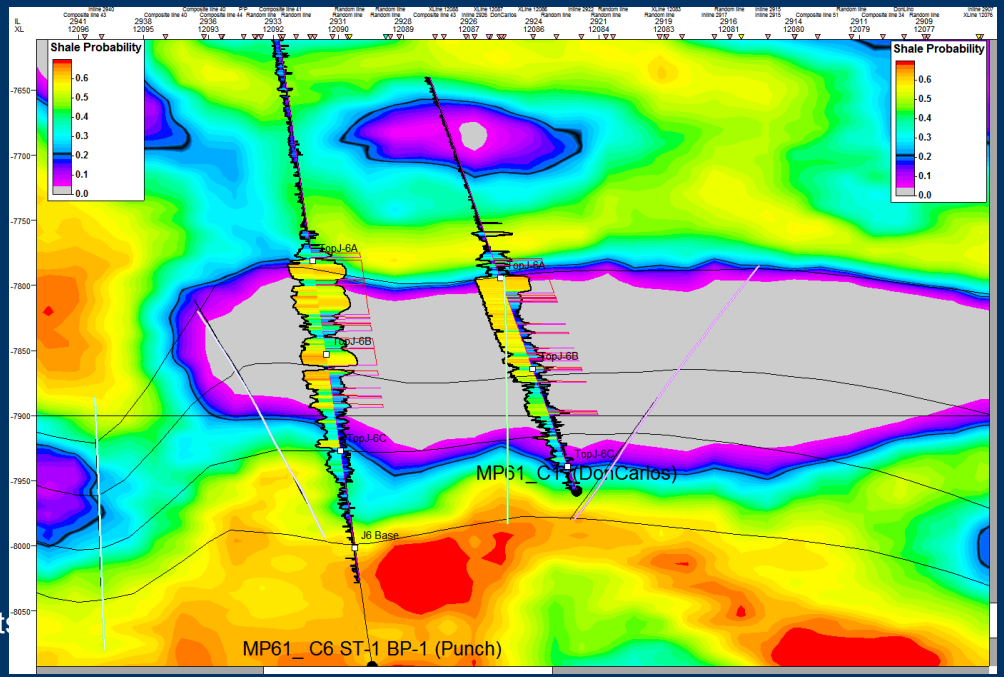
- **Increased recoverable reserves by 4 MMBO+**
- **Identified means for recovery: New drilling locations and workover opportunities**
- **EXXI implemented workovers and drilled 4 new successful wells.**

2012 PHIE Model Observed at New Wells

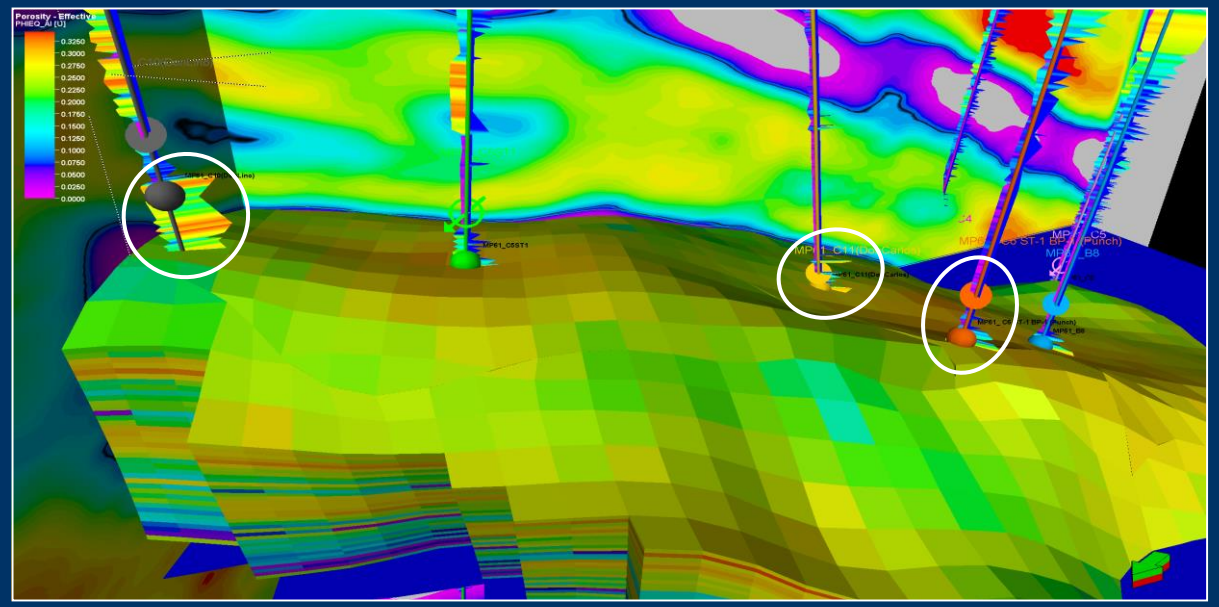


Gaussian Random Function Simulation using collocated co-kriging of AI as the trend model (2012)

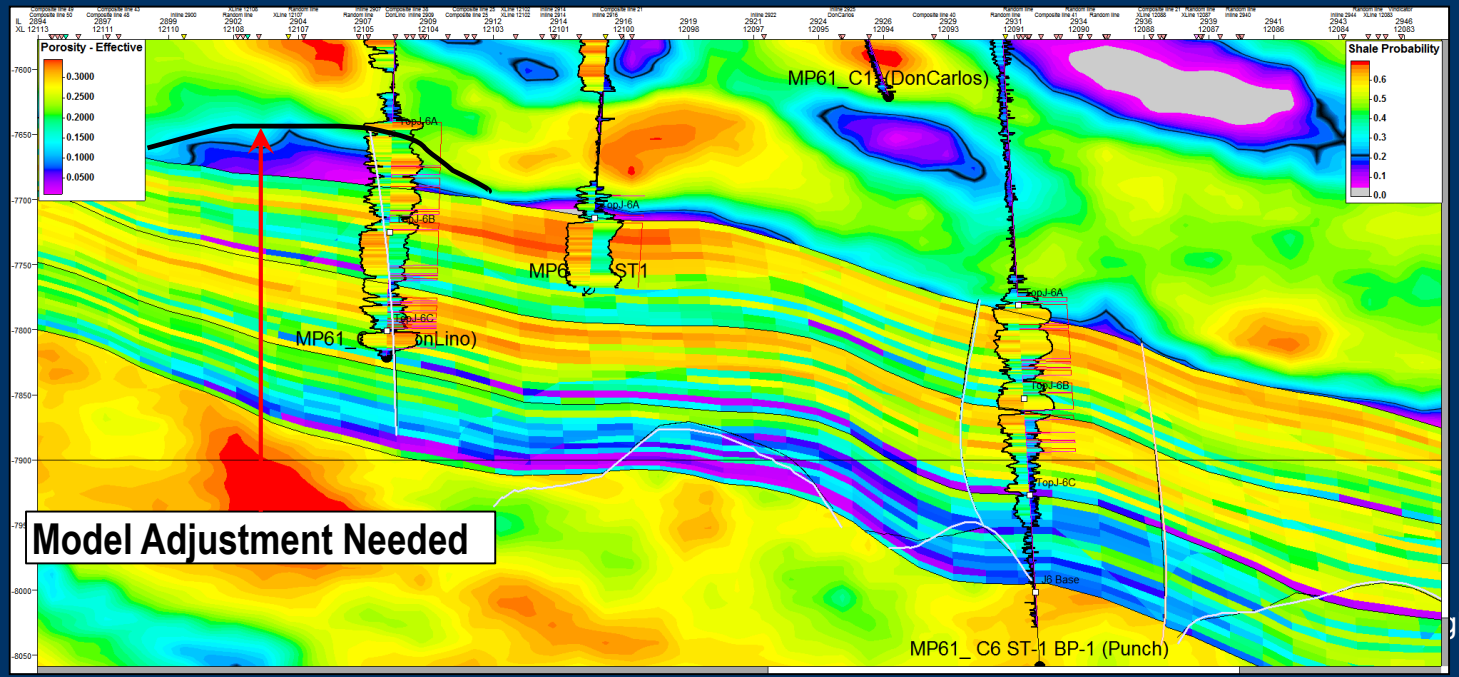


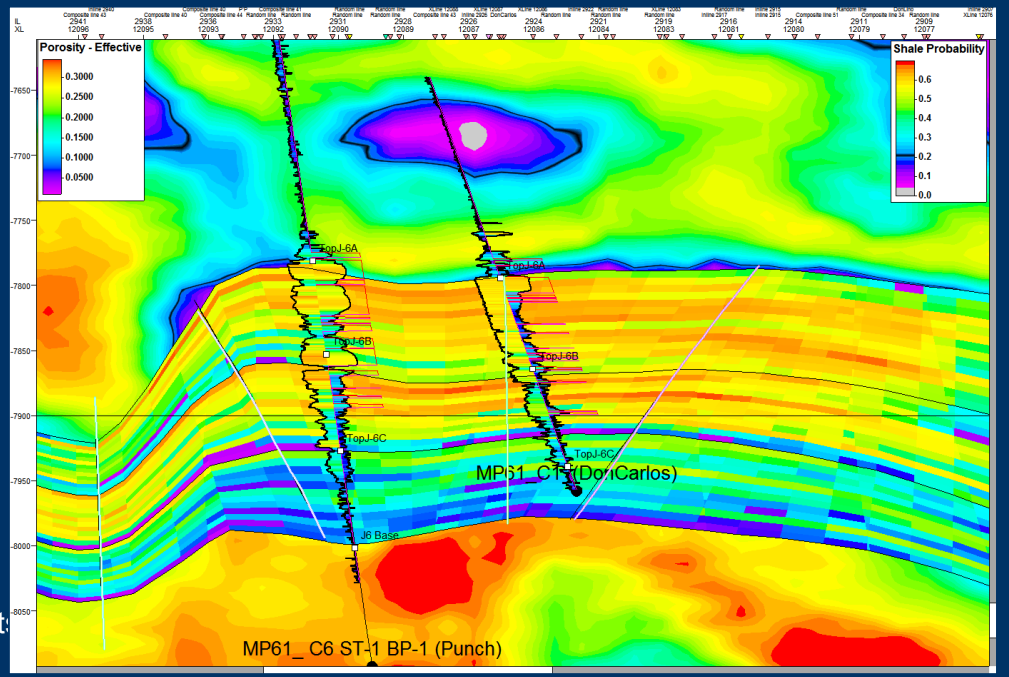


2012 PHIE Model Observed at New Wells

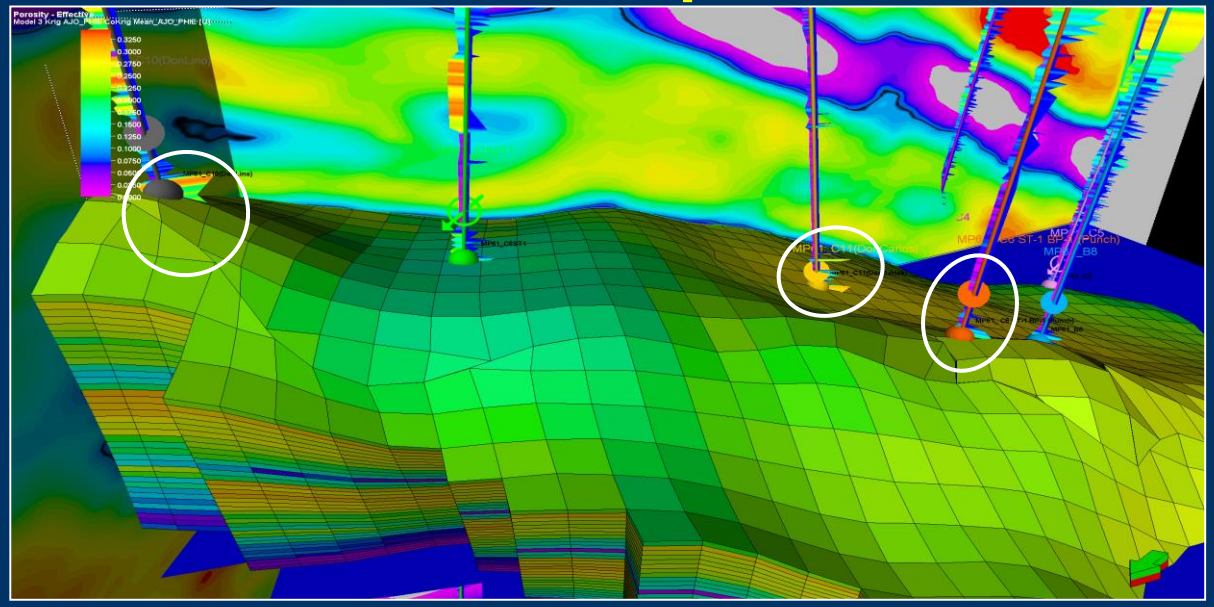


Gaussian Random Function Simulation using collocated co-kriging of AI as the trend model (2012)

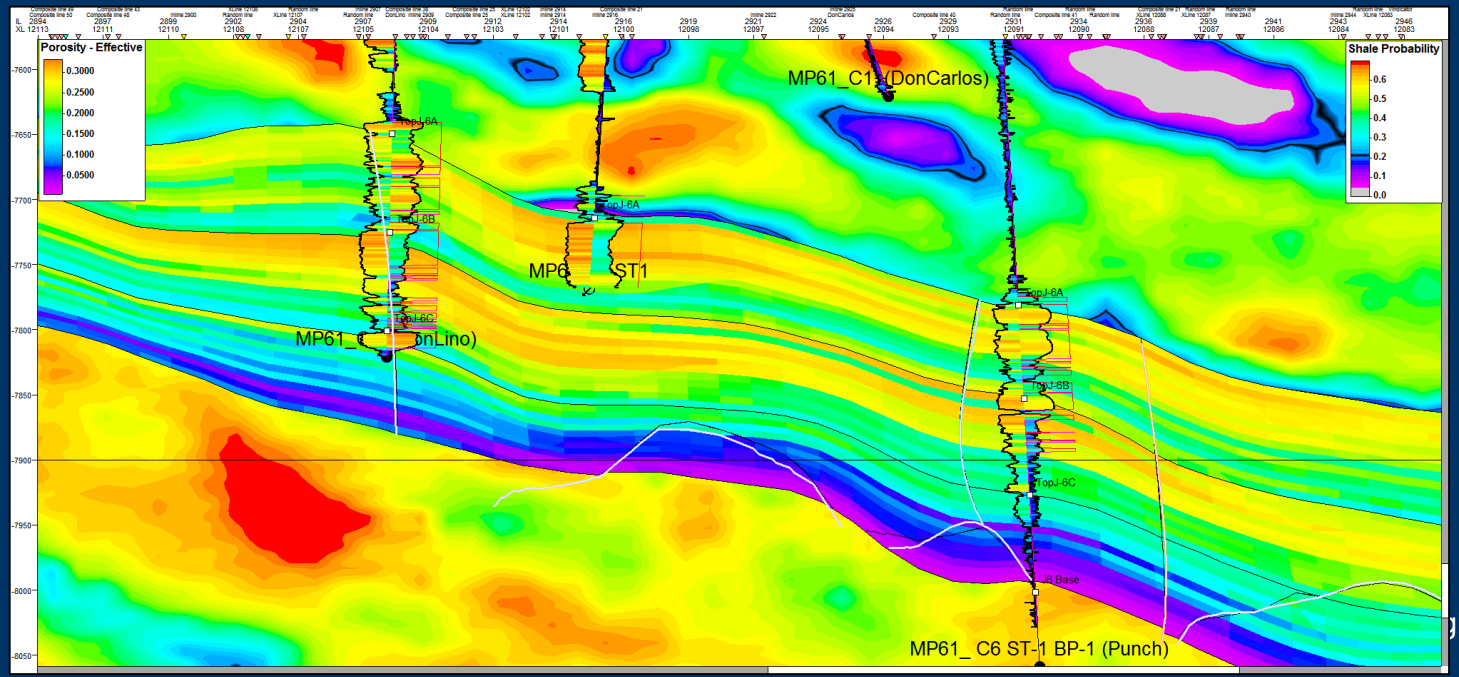


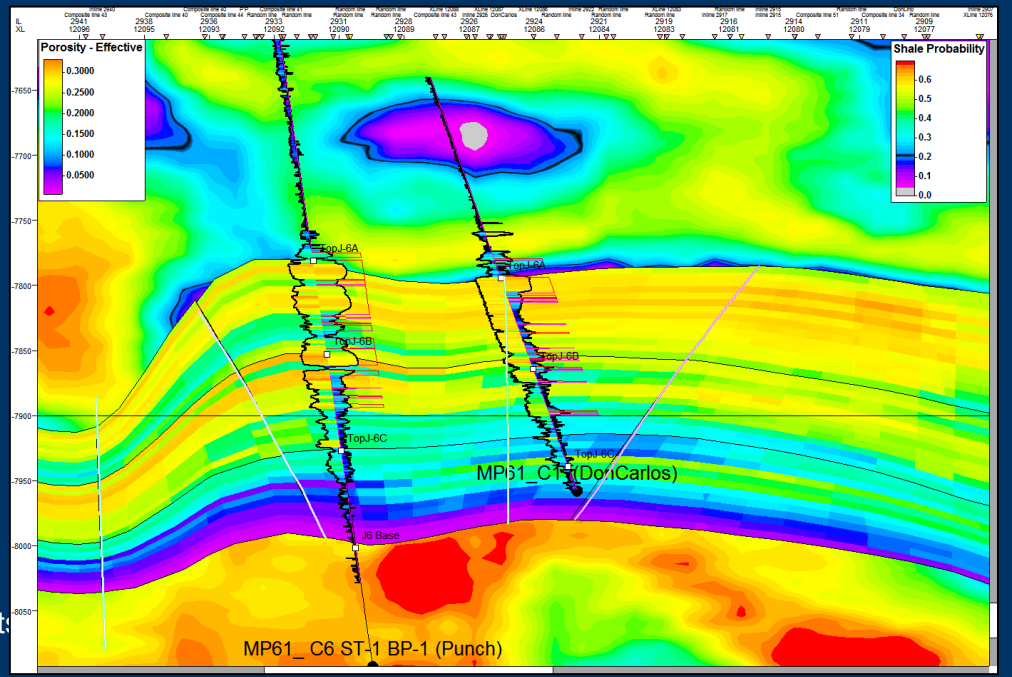


2014 PHIE Model Update with new wells

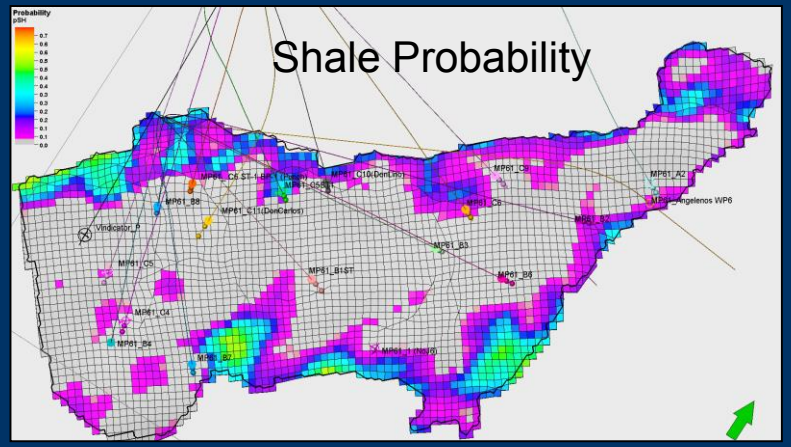


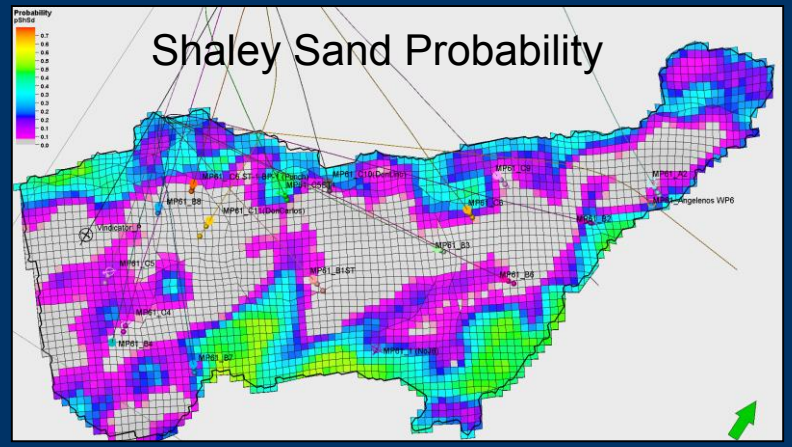
Kriging with collocated co-kriging of a Multivariate Seismic Trend Model (2014)

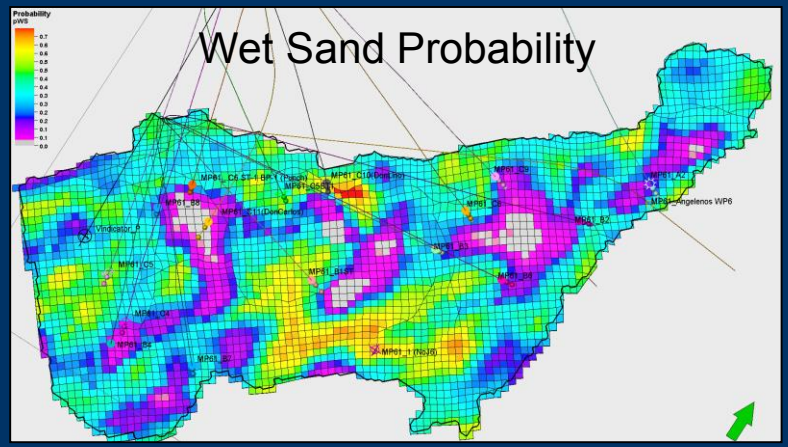


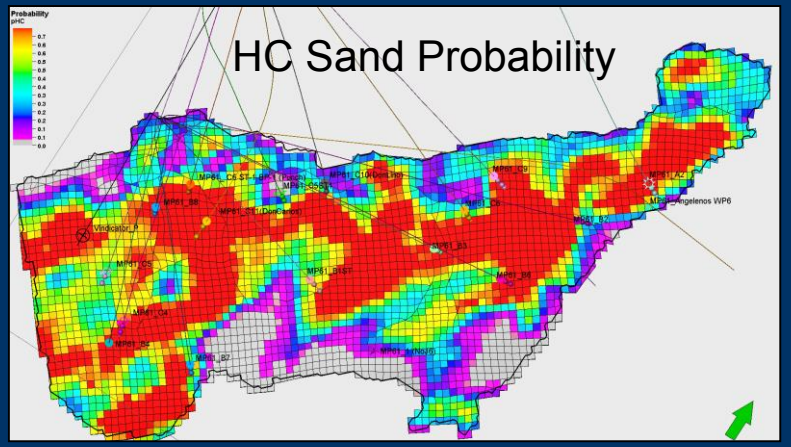


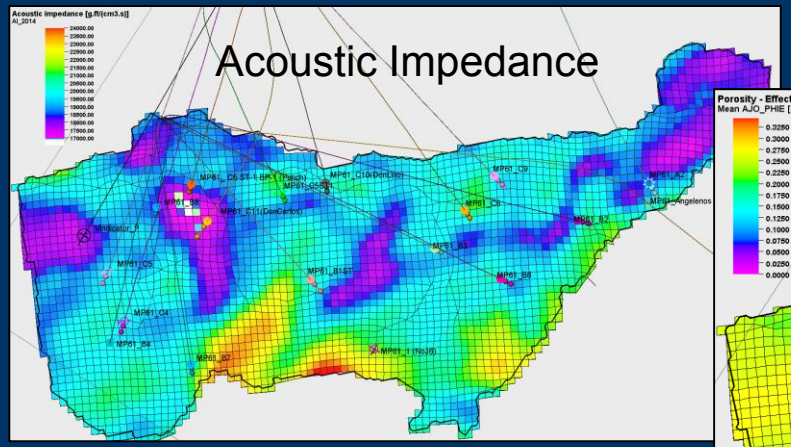
Multivariate Trend Model from Seismic

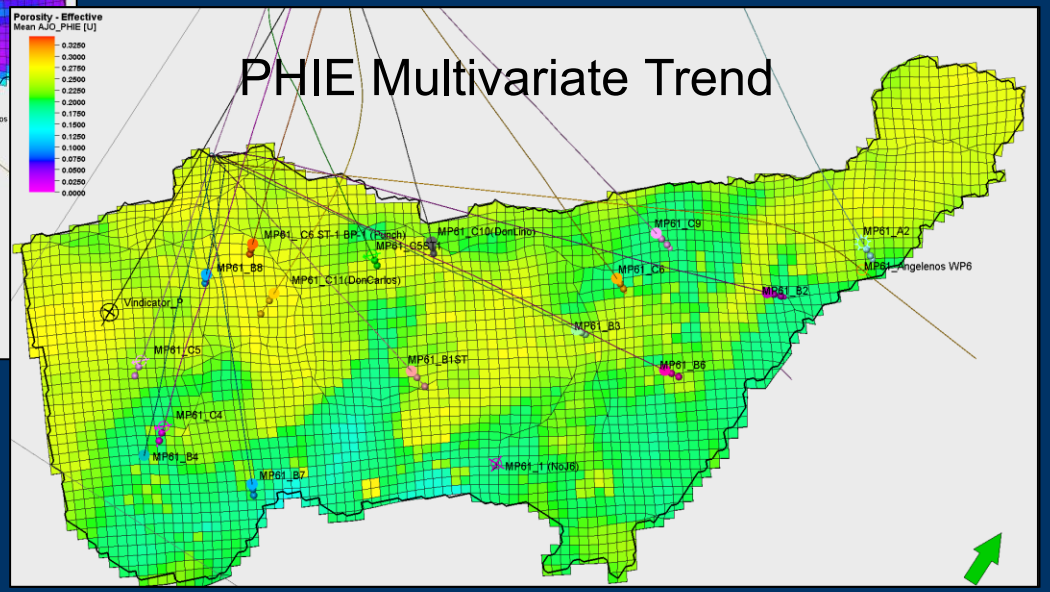












K-Layer 18

Conclusions

Effective integration of seismic information is an important step in optimizing field recovery.

The results of this study:

- Led to significantly improved understanding of the reservoir and production dynamics.
- Provided an important basis for field management and development decisions.
    - Increased recoverable reserves by 4 MMBO+
    - Identified means for recovery: New drilling and workover opportunities
    - Drilled successful wells at optimum locations

Acknowledgements

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83rd Annual Meeting Houston

Society of Exploration Geophysicists
The international society of applied geophysics

Gulf Coast Association of Geological Societies
and the Gulf Coast Section of SEPM
64th Annual Convention - Lafayette

Geophysical Society of Houston Journal
June 2014

2014 SEG/SPE/AAPG/SPWLA/EAGE
Summer Research Workshop – San Diego

Multi-disciplinary Static and Dynamic Reservoir Modeling: Best Practices, Opportunities and Challenges

AAPG Seventh Annual Deepwater and Shelf Reservoirs
Technology Workshop January 27th, 2016

Corresponding Author: Randal Utech, Schlumberger, Houston TX, tel. 713-208-2218