Fast-Track and Robust Reservoir Modeling Using Probabilistic Neural Network*

Islam A. Mohamed[1] and Basem K. Abd El-Fattah[1]

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Abstract

In highly heterogeneous basins with complex subsurface geology, as the Nile Delta basin, the accurate prediction of reservoir characteristics is a must. The reservoir characterization is a continuous process that begins with the field discovery and ends with the last phases of production and abandonment. Reservoir static modeling is the final step in the reservoir characterization process and consists of building an upscaled geologic model to be an input to the fluid simulations. The geostatistical reservoir modeling (stochastic modeling) methods are widely used instead of the traditional deterministic modeling methods to consider the spatial statistics and uncertainties. However, the modeling workflows are slow, requiring months from initial model concept to flow simulation or other outputs; Moreover, the early stages errors become cumulative and are difficult to retrospectively change. The neural network inversion gained popularity over the last decades for its ability to establish nonlinear relationships between the petrophysical logs and seismic data. It has been used to predict various reservoir properties with a reasonable amount of accuracy. Its main limitation resides at seismic resolution, and to overcome this problem a resolution-enhancing workflow has been adopted. This case study is from a Pliocene turbidite field in the offshore Nile Delta to illustrate the proposed modeling workflow. As a beginning, the resolution enhancement of seismic data is accomplished using derivative attributes and structural smoothing. Then, after proper well-log data conditioning, the training and cross-validation of Probabilistic Neural Network (PNN) are performed to produce shale volume (Vsh), porosity (φ), and water saturation (Sw) 3D volumes. The permeability (k) is calculated from poro-perm relationship inside the reservoir. The results are then sampled in 3D grids and tested using dynamic simulation method to assimilate production history. After the initial history match process, PNN parameters are adjusted to improve the match. The final model represents the best match to original field measurements and production data, which is then used in drilling decisions and production planning. The proposed neural network workflow reduces the reservoir modeling construction time by 80-90%, mitigates the cumulative error problems, and decreases the statistical uncertainty as it depends purely on seismic data to distribute the reservoir properties.

References Cited

Cross, N.E., A. Cunningham, R.J. Cook, A. Taha, E. Esmaiel, and N. El Swidan, 2009, 3-D Seismic Geomorphology of a Deepwater Slope Channel System: The Sequoia Field, Offshore West Nile Delta, Egypt: Search and Discovery Article 20078, Web Accessed April 29, 2018, http://www.searchanddiscovery.com/documents/2009/20078cross/ndx_cross.pdf

Mohamed, I., O. Shenkar, and H. Mahmoud, 2017, Understanding reservoir heterogeneity through water saturation prediction via neural network - A case study from offshore Nile Delta: The Leading Edge, v. 36, p. 298-303, Web Accessed April 29, 2018, https://library.seg.org/doi/abs/10.1190/tle36040298.1

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Samuel, A., B. Kneller, S. Raslan, A. Sharp, and C. Parsons, 2003, Prolithic deep-marine slope channels of the Nile Delta, Egypt: AAPG Bulletin, v. 87, p. 541–560.

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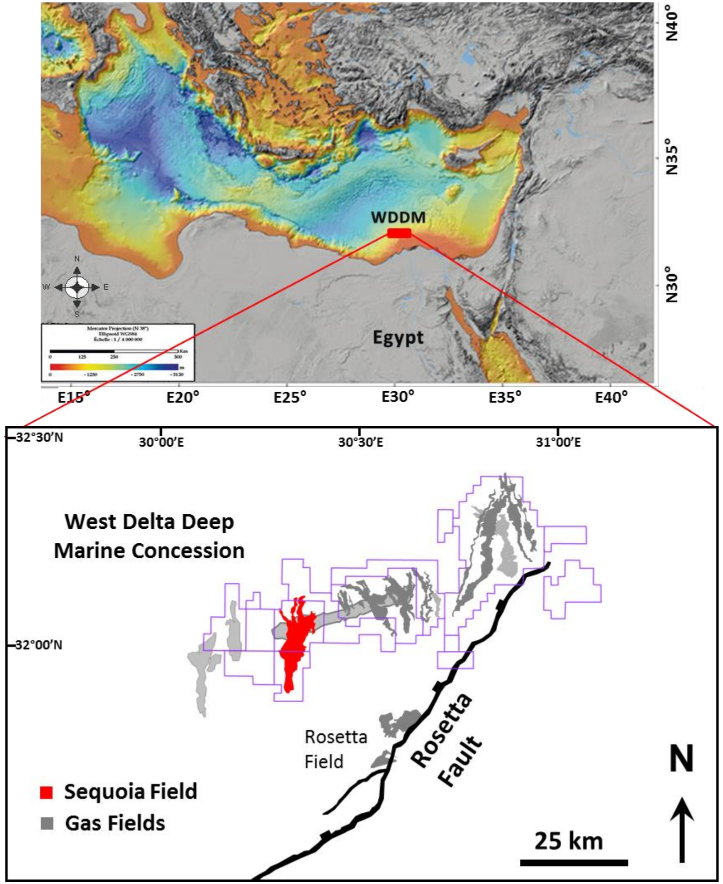
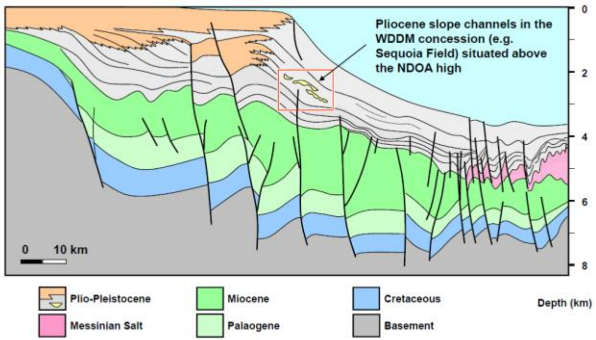
Area of Study

- Location
  - Egypt, Offshore Nile Delta, West Delta Deep Marine (WDDM) concession
- Sequoia field
  - One of the biggest Pliocene gas fields

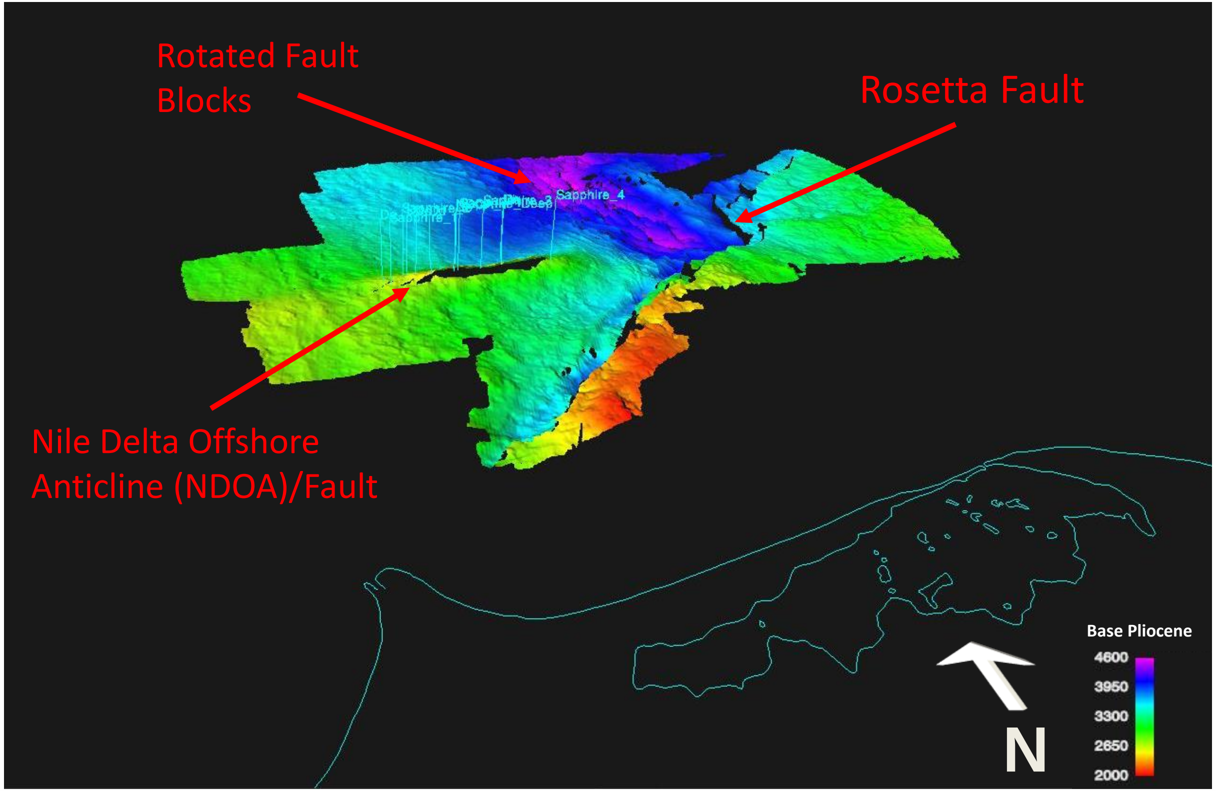


(modified from Mohamed et al., 2014 and Samuel et al., 2003)

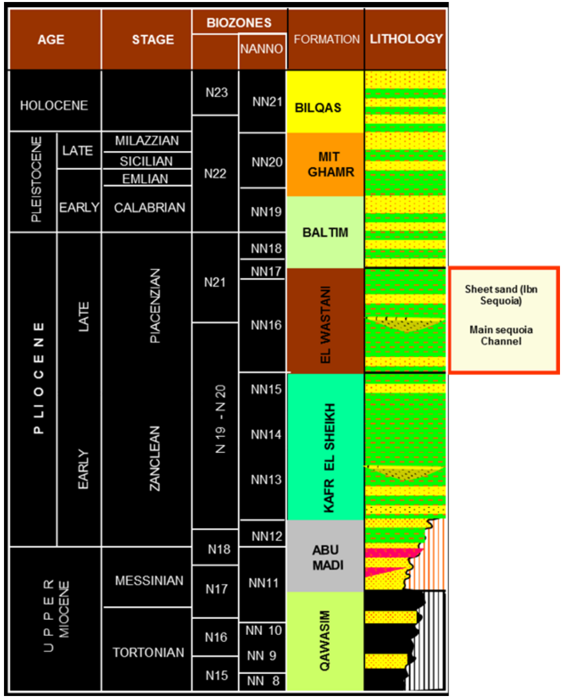
WDDM Major tectonic features



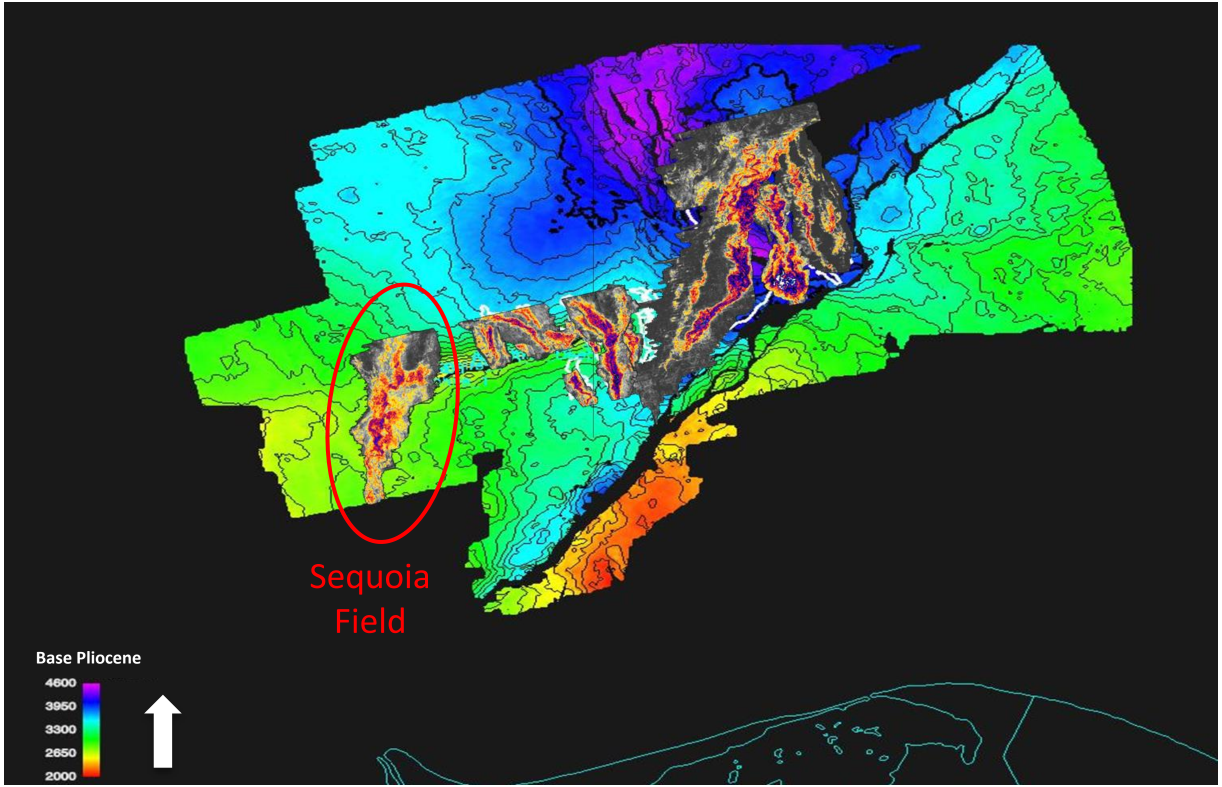
Cross-section modified after Aal et al., 2006



Pliocene reservoirs draped across tectonic elements



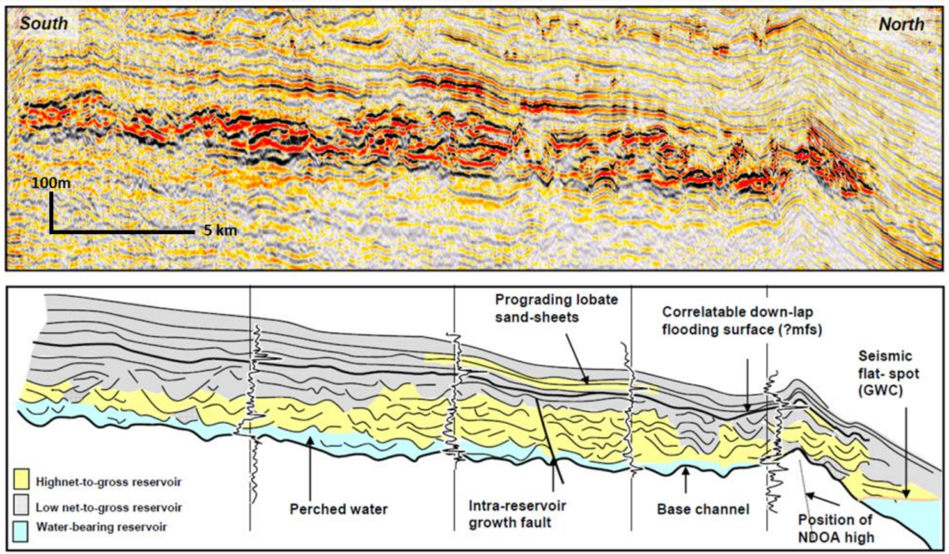
Nile Delta stratigraphic column



Large-Scale Reservoir Architecture

An arbitrary line through Sequoia channel complex

A B



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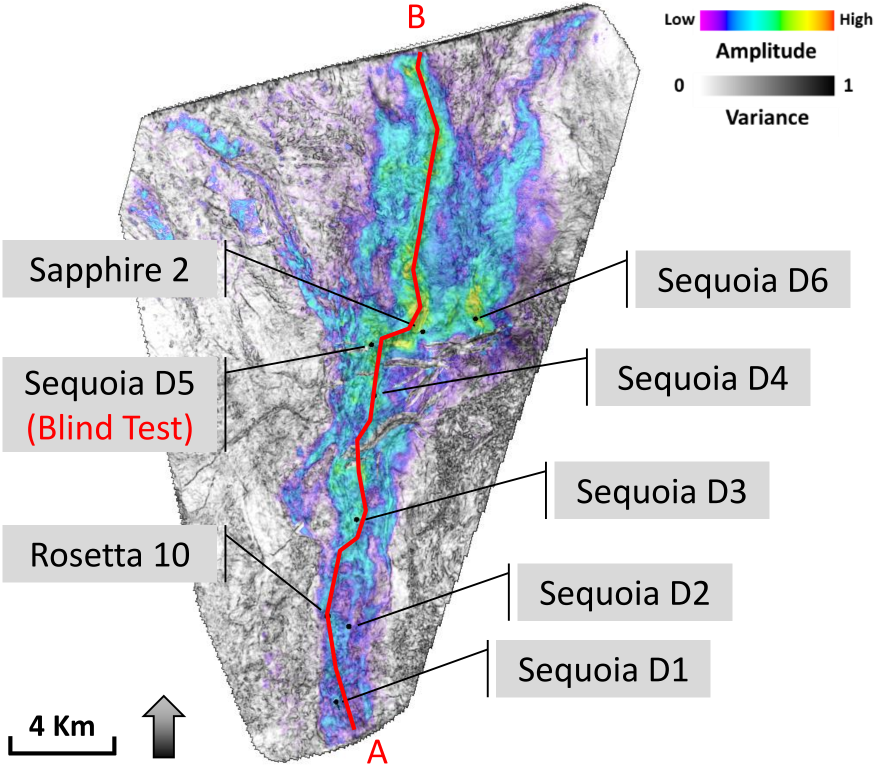


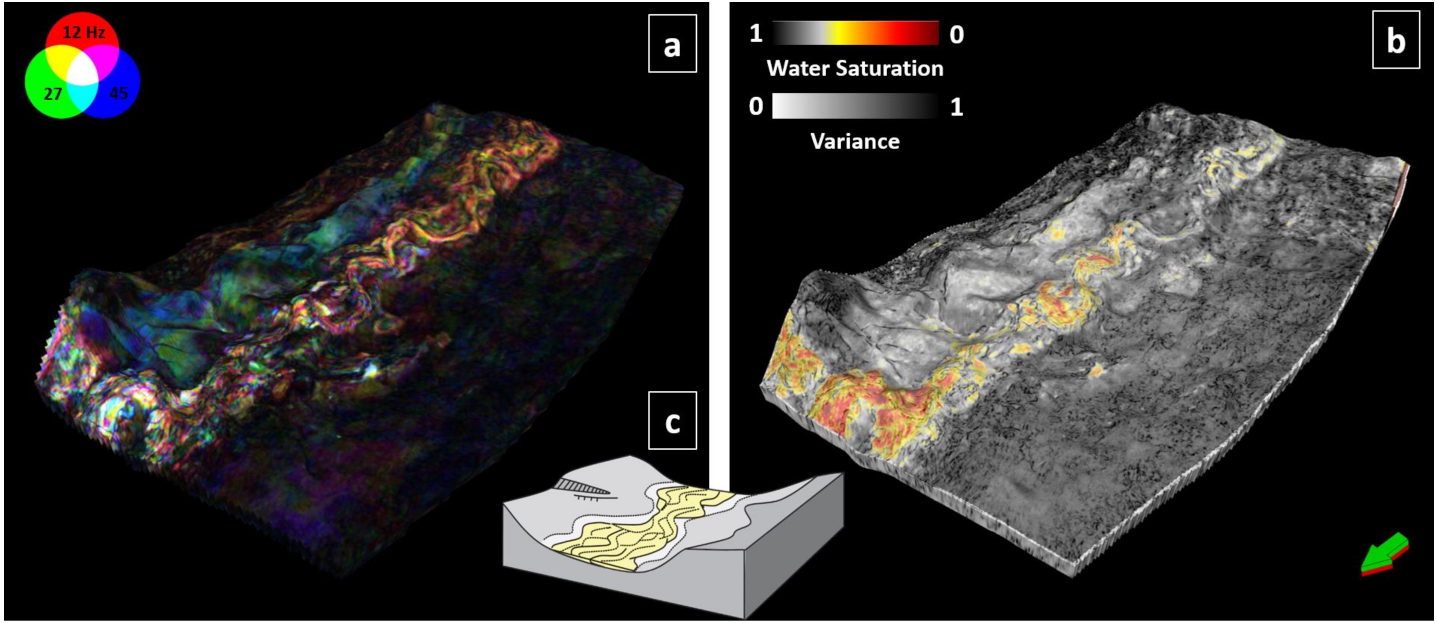
Sequoia Channel Evolution Summary

Ibn Sequoia
Sequioa channel abandonment and minor sheet sands

Stage III
Narrower and straighter channels and splays

Stage II
High sinuosity channel and associated splays

Stage I
Braided, poorly confined channel deposition



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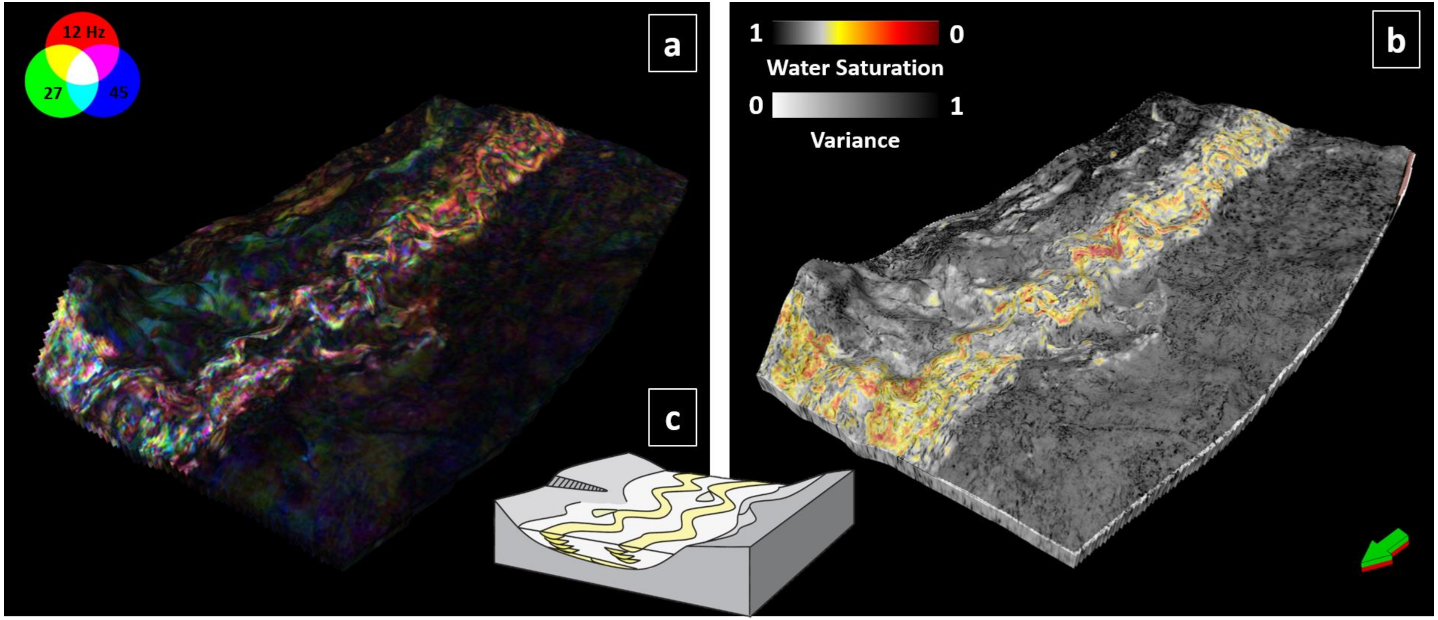

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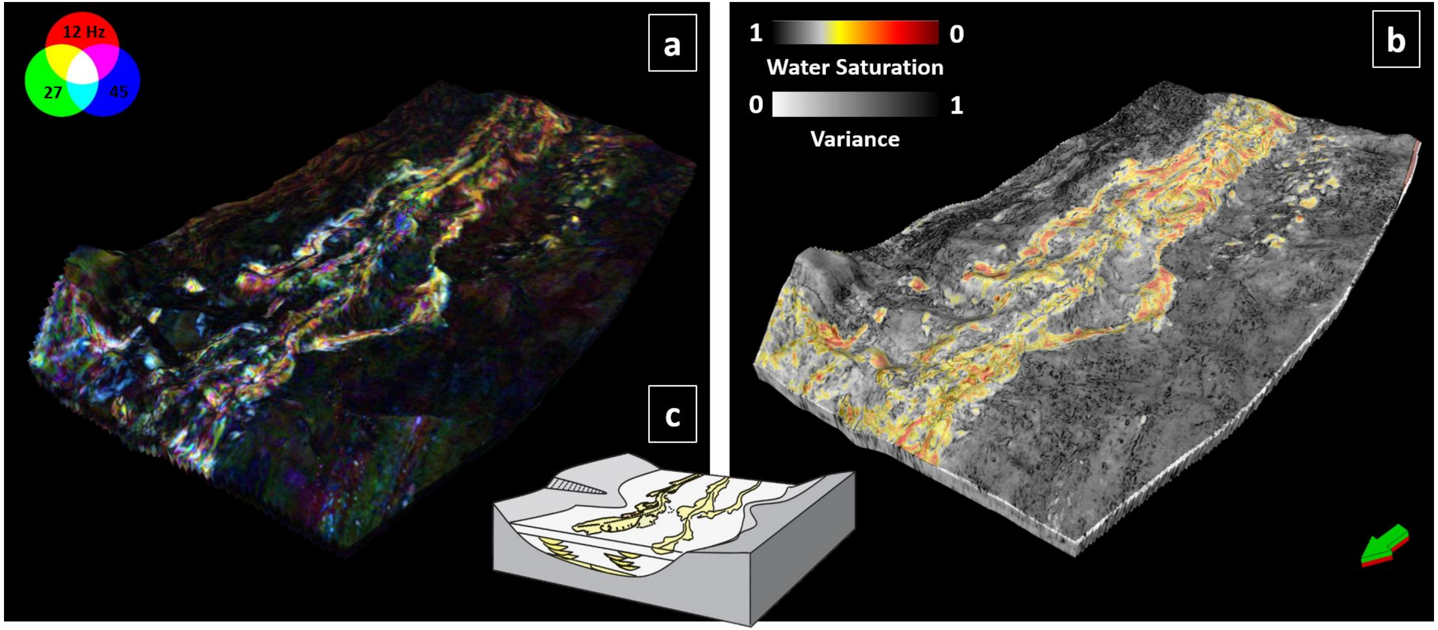


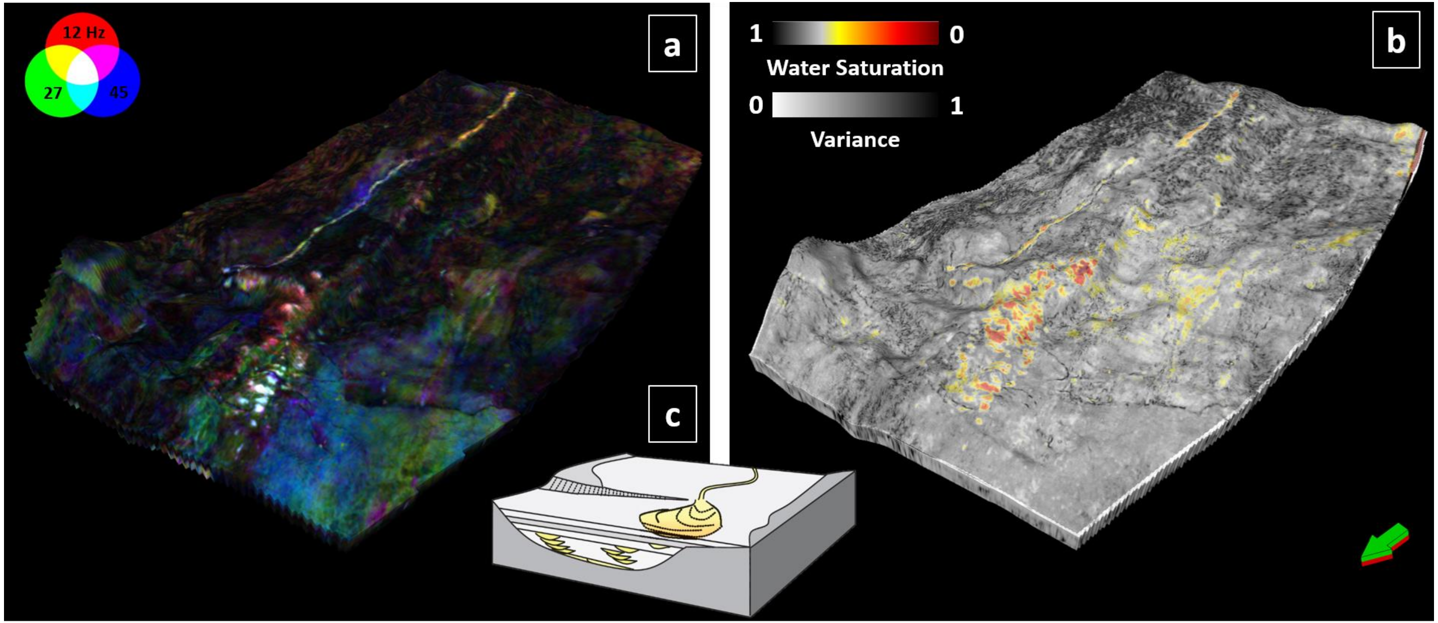
(modified from Mohamed et al., 2017)

Ibn Sequoia
Sequioa channel abandonment and minor sheet sands

Stage III
Numerous small channals and splays

Stage II
High sinuosity channel and associated splays

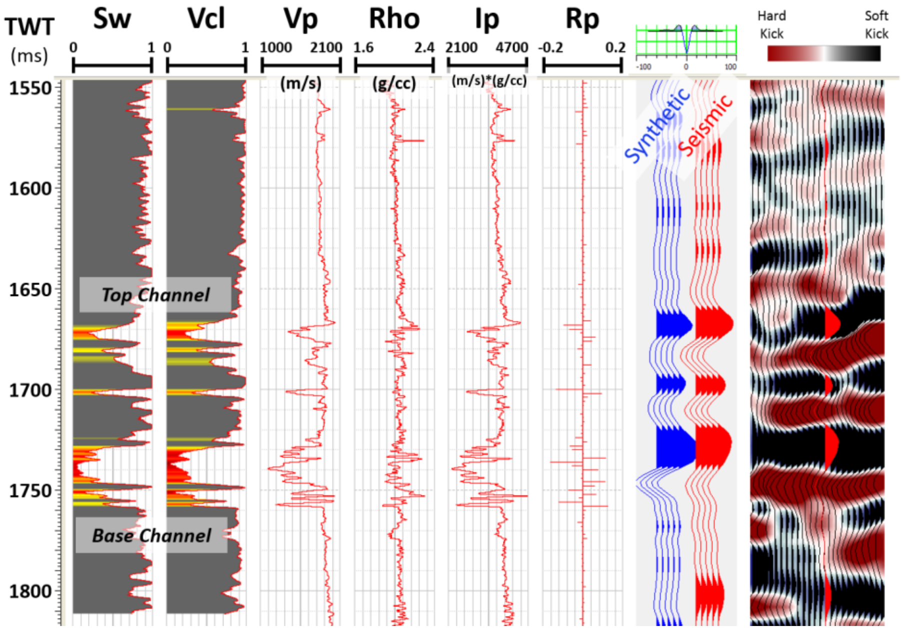
Stage I
Braided, poorly confined channel deposition



(modified from Mohamed et al., 2017)

Sequoia Field – Reservoir Characteristics

- Multiple stacked channels that are up to 200 m in gross thickness, 77 m of pay
- An average effective porosity of 24%
- An average water saturation of 34%



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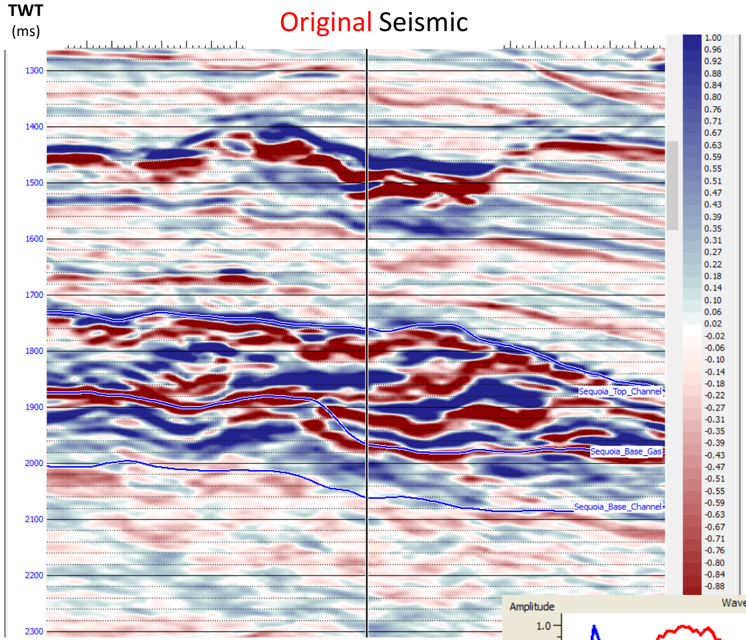
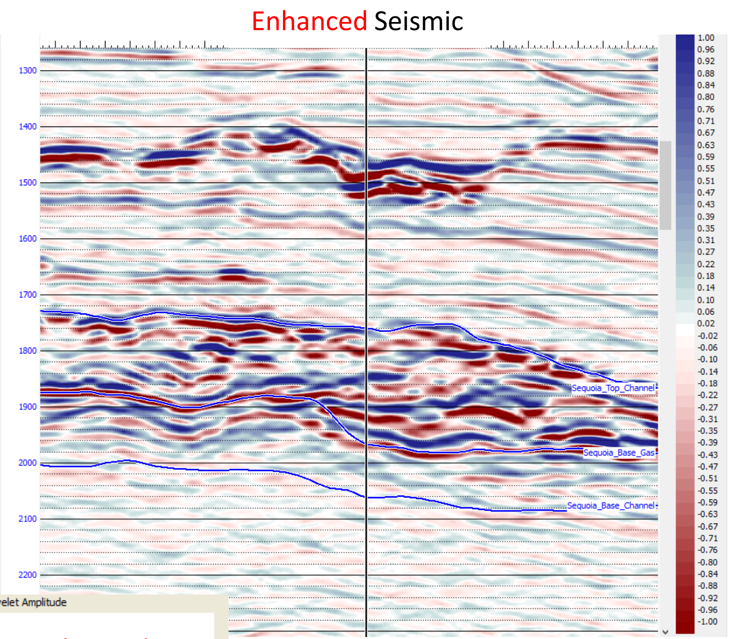
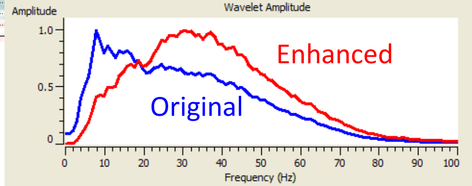
Seismic Resolution Enhancement – Band-Pass Filtering

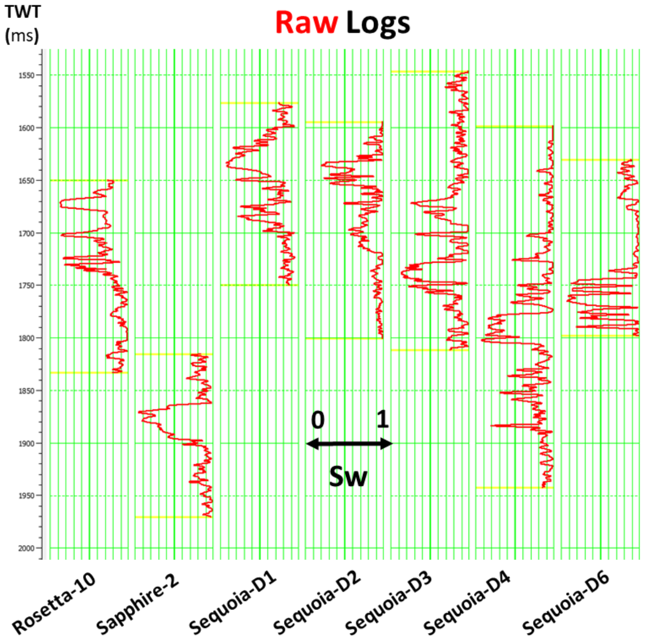




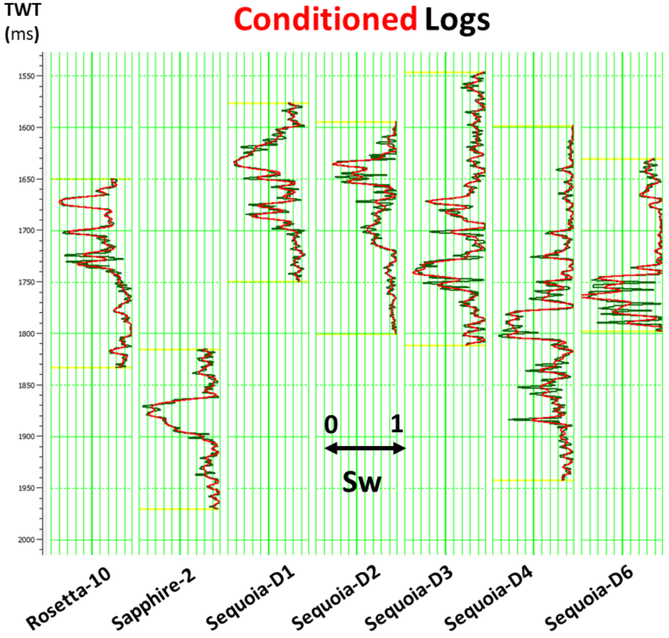
Band-pass filter frequency range (Hz):
0 / 30 / 120 / 130



Well Log Conditioning



Conditioning:
- Resampling @ 4 ms
- Smoothing



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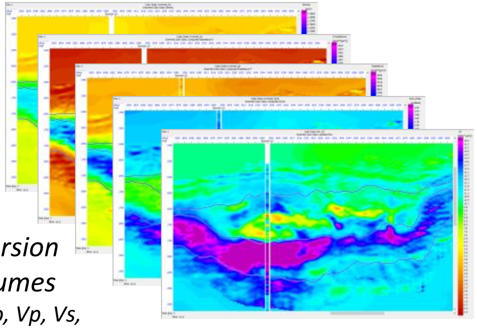
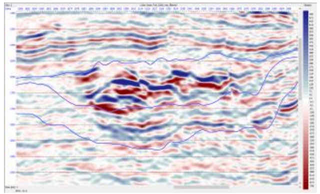
  - Probabilistic Neural Network
  - Static Modeling
  - Dynamic Testing
- Conclusion

Probabilistic Neural Network

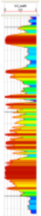


Inversion Volumes (Ip, Is, ρ, Vp, Vs, Vp/Vs, λρ & μρ)

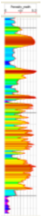


Full-Stack Seismic Volume

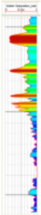
Shale-Volume Logs (Vsh)

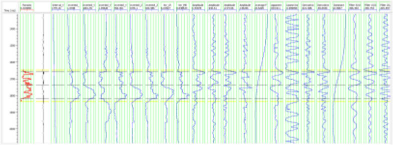


Porosity Logs (φ)



Water Saturation Logs (Sw)

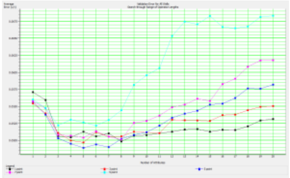




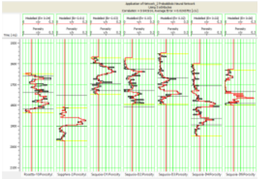
Internal & external attributes

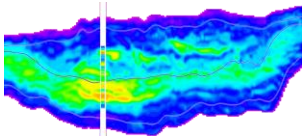
Neural Network

Minimize the error

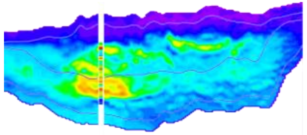


Training & validation

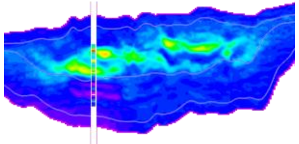




Shale-Volume (Vsh)



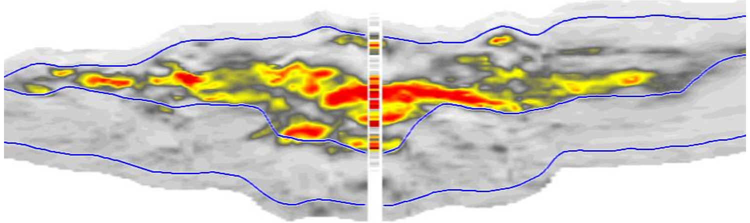
Porosity (φ)



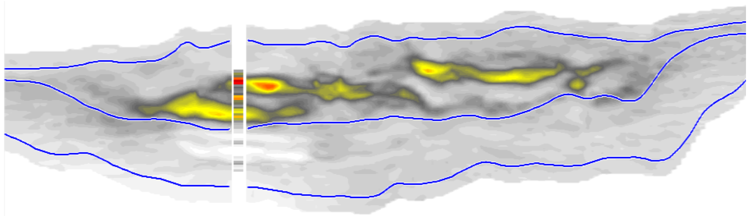
Water Saturation (Sw)

PNN Results – Water Saturation

Water Saturation section (*Sw*) through Sequoia D5 well (Blind Test)



Water Saturation section (*Sw*) through Rosetta 10 well

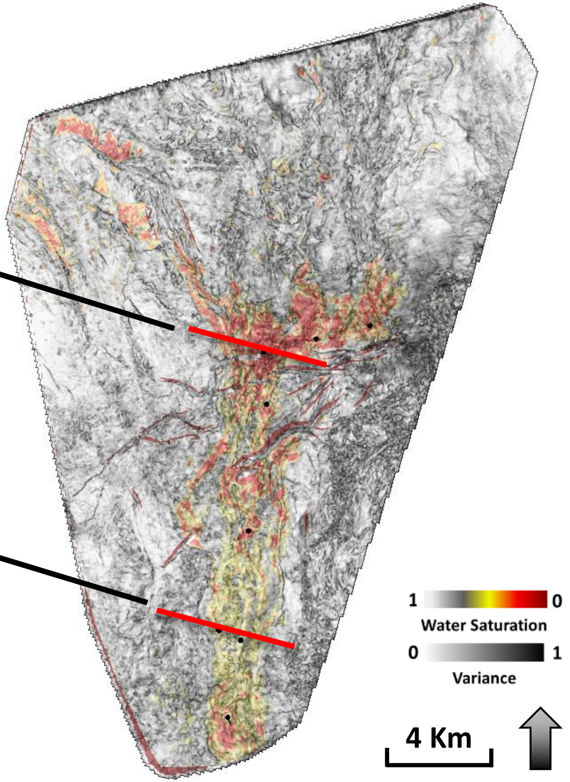


100 m

400 m

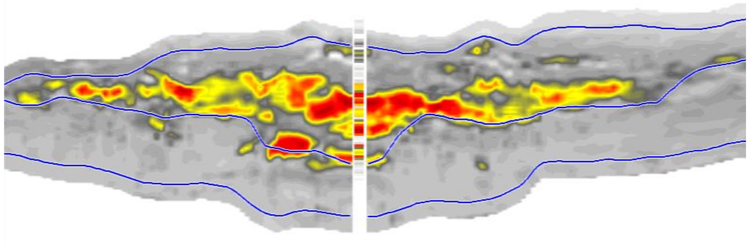
1 0

Water Saturation

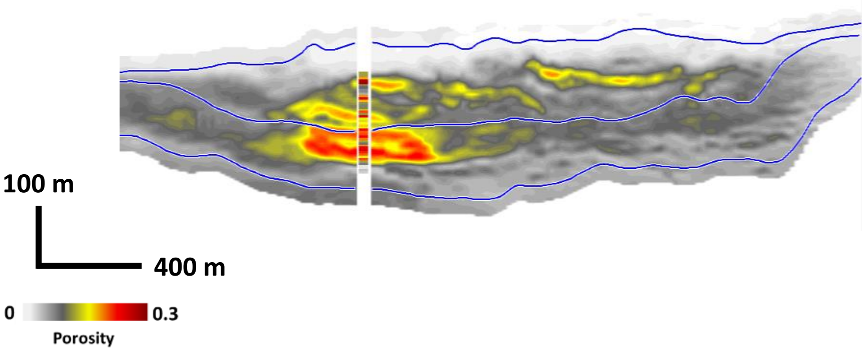


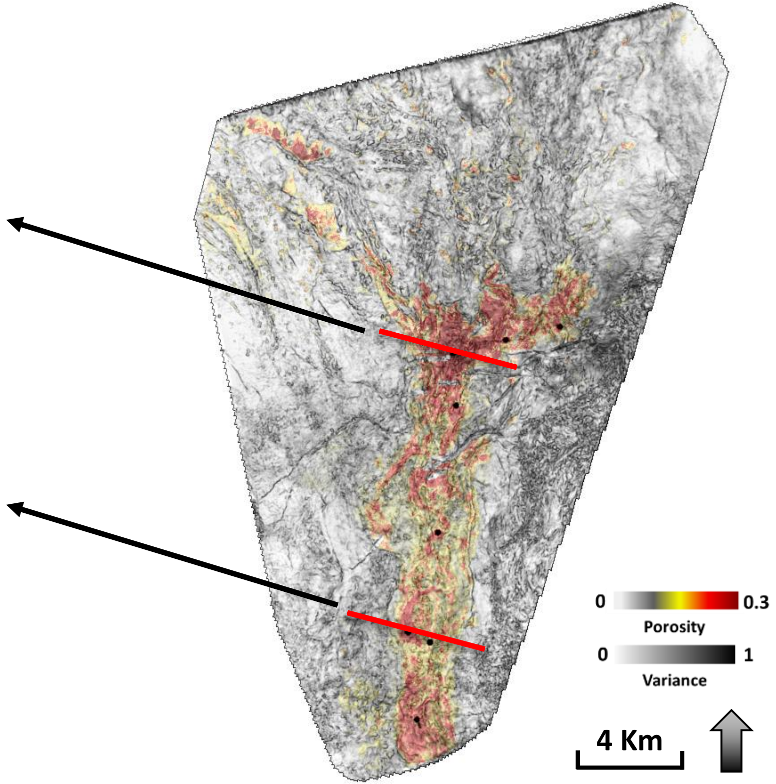
PNN Results – Porosity

Porosity section (φ) through Sequoia D5 well (Blind Test)



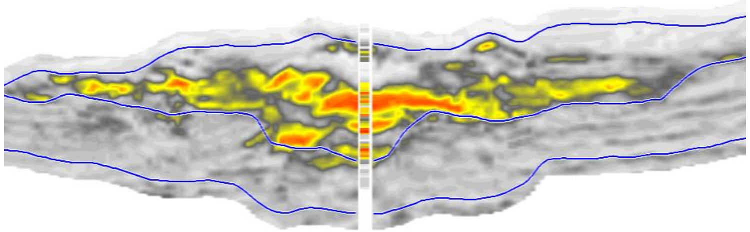
Porosity section (φ) through Rosetta 10 well



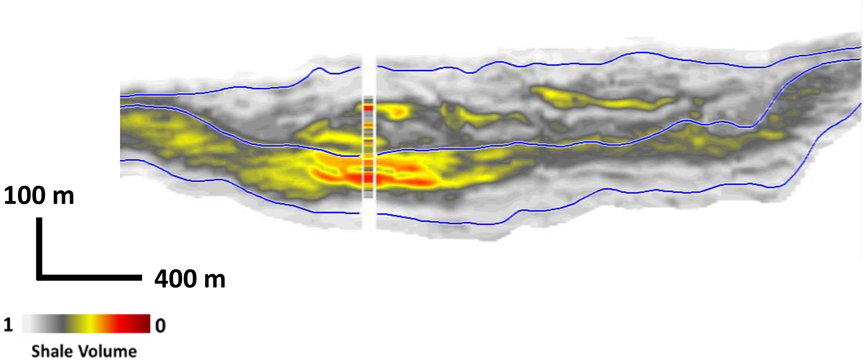


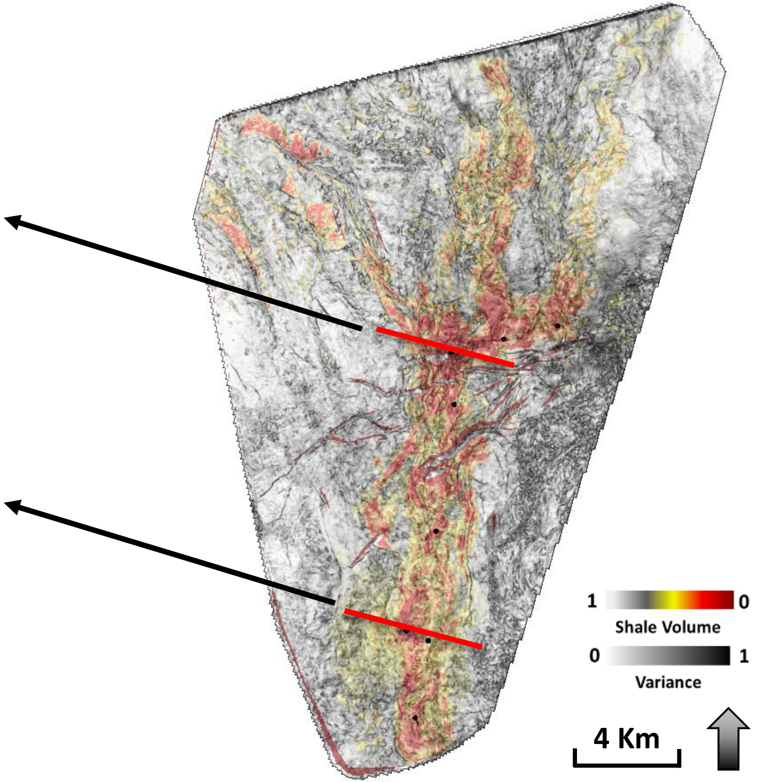
PNN Results – Shale Volume

Shale volume section (*Vsh*) through Sequoia D5 well (Blind Test)



Shale volume section (*Vsh*) through Rosetta 10 well

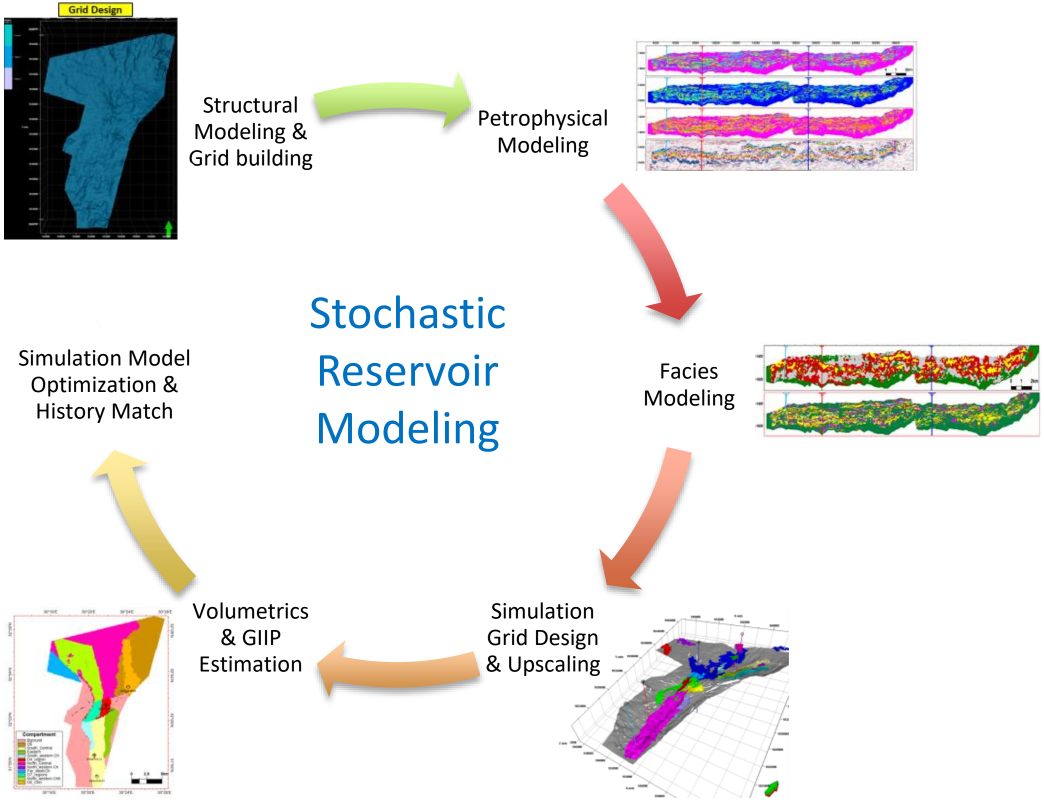




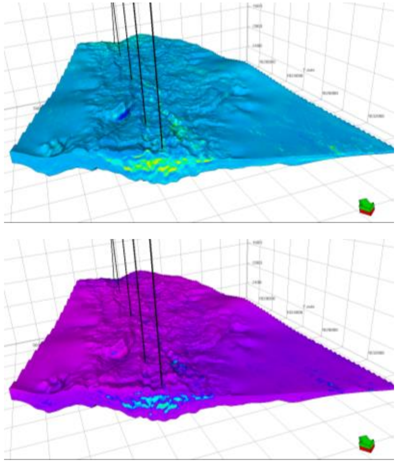
Contents

Stochastic Reservoir Modeling Workflow

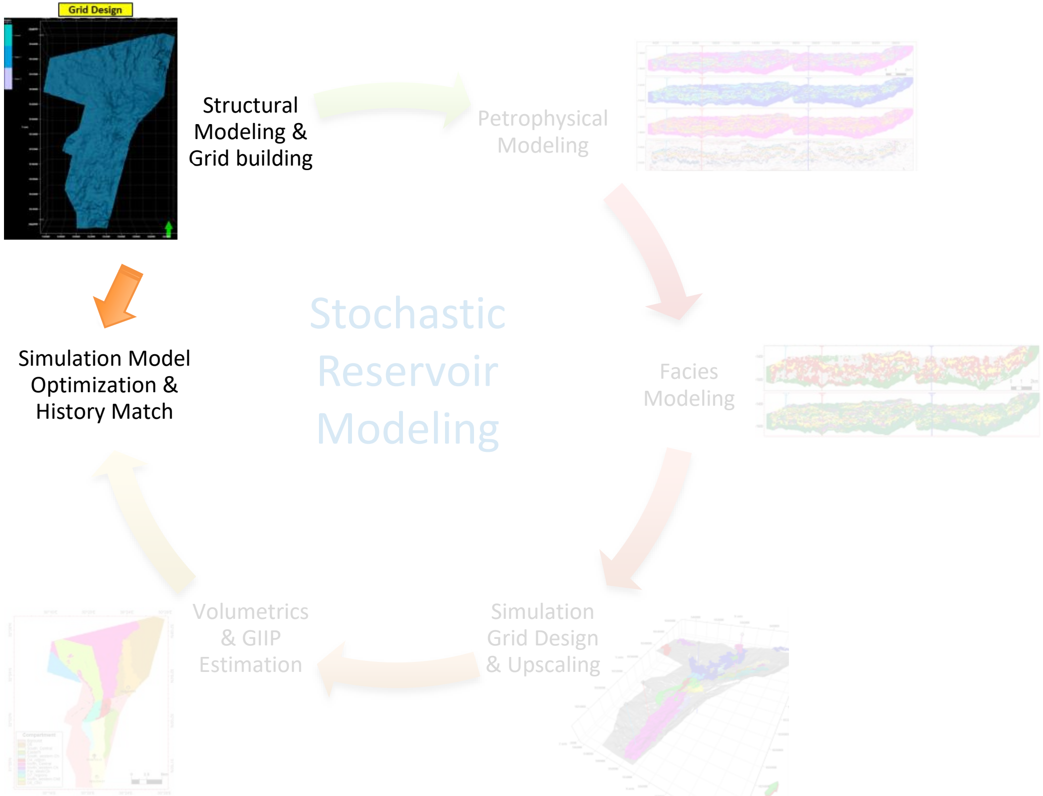
- Stochastic reservoir modeling
  - Consider the spatial statistics and uncertainties.
  - Require months from initial model concept to flow simulation.
  - Early stages errors become cumulative and are difficult to retrospectively change.



The Proposed Workflow

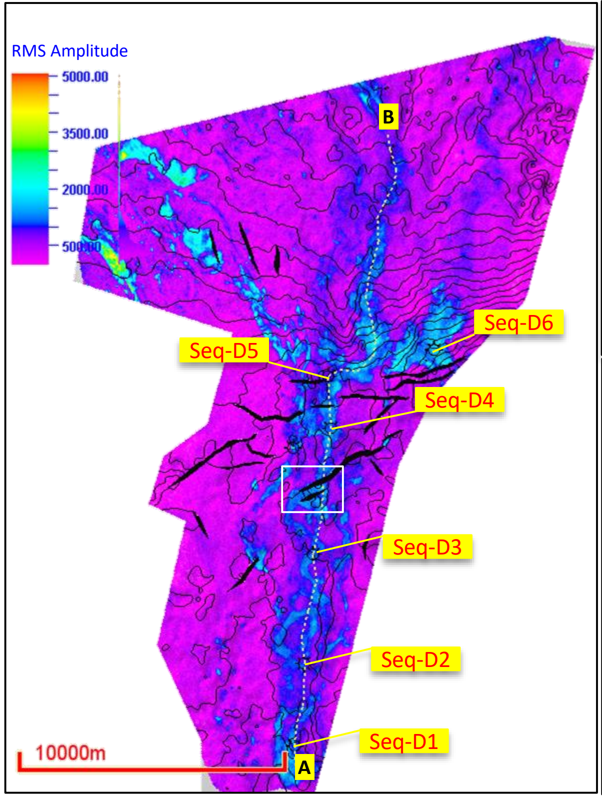


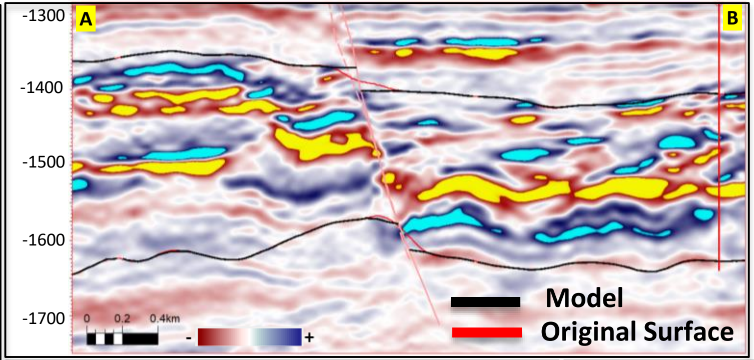
Water Saturation and Porosity from PNN



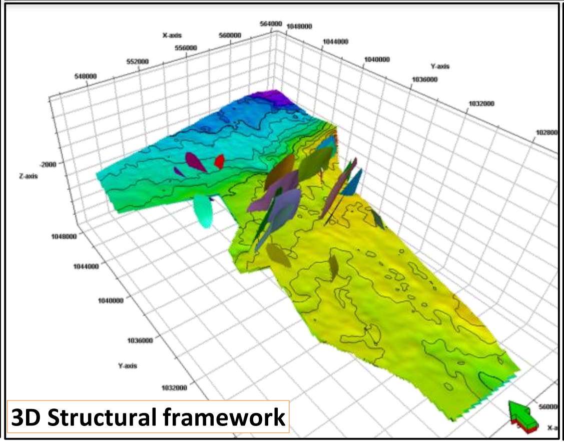
- Decreases the statistical uncertainty.
- Reduces the reservoir modeling construction time by 80%.
- Mitigates the cumulative error problems.

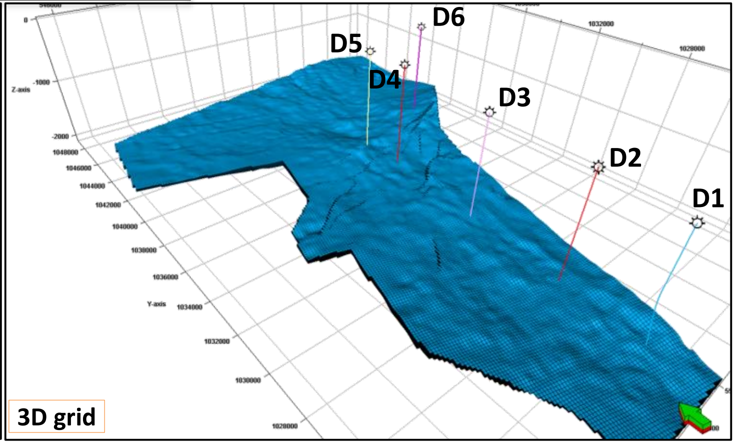
Static Modeling



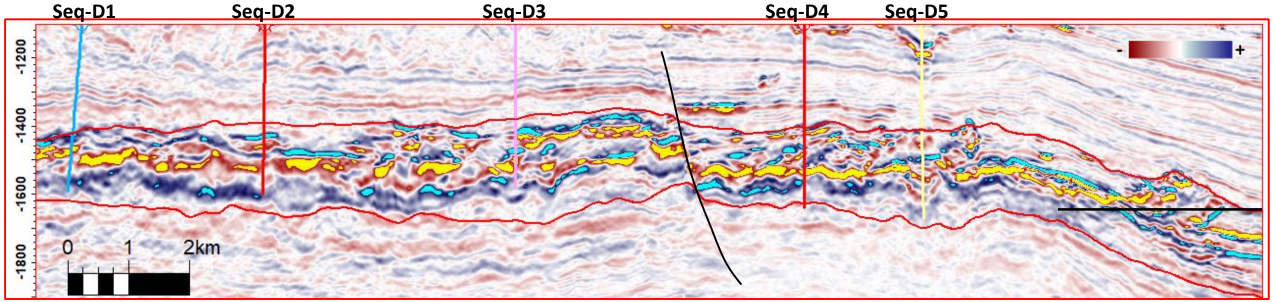


- Structure model:
  - Structural framework method
- Cell size:
  - 100m*100m using proportional layering (1.5m Average cell thickness)

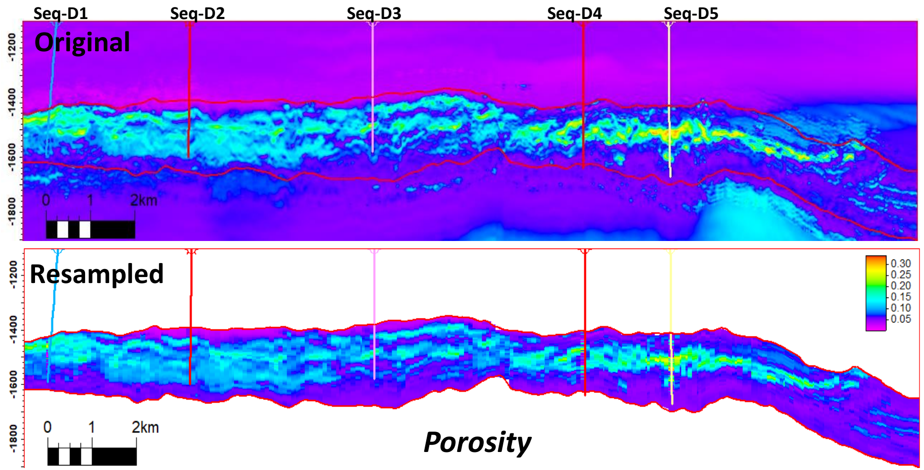




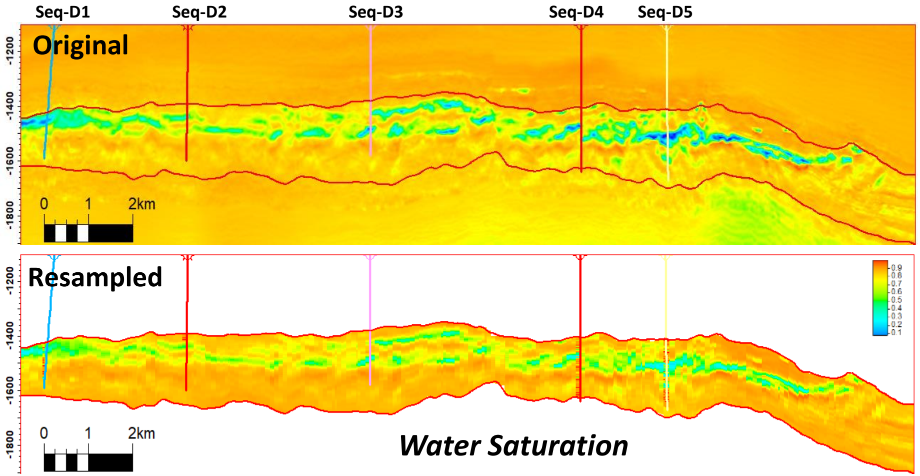
Porosity and Water Saturation Resampling



Property	resampling
Porosity	Arithmetic
Saturation	Arithmetic

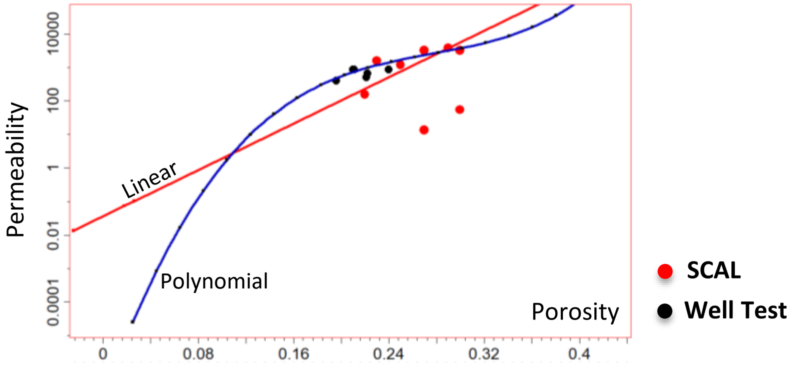


Porosity

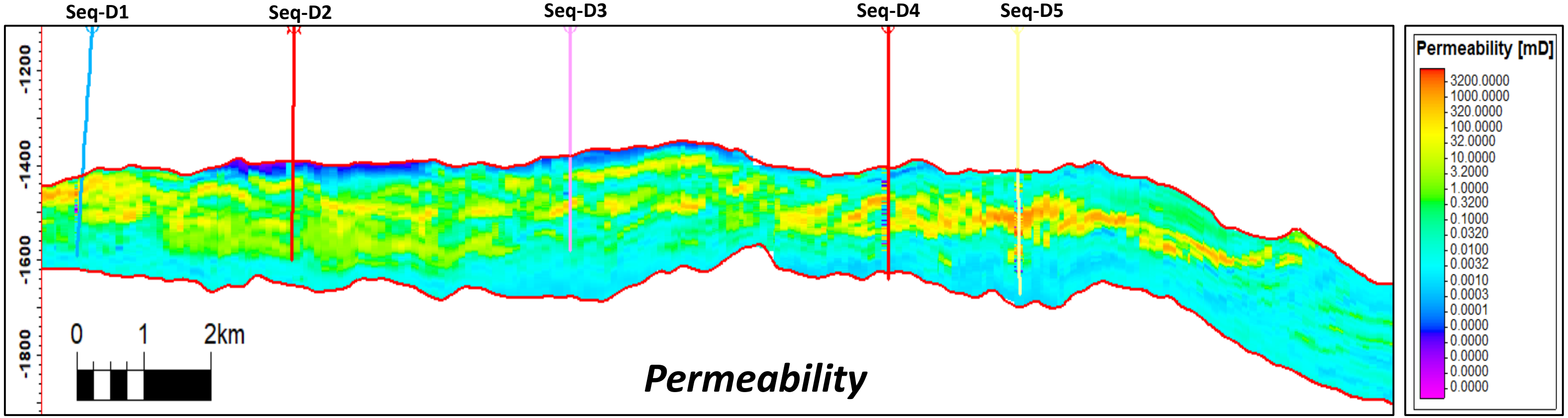


Water Saturation

Porosity-Permeability Relationship



Permeability is calculated from the porosity using a polynomial equation



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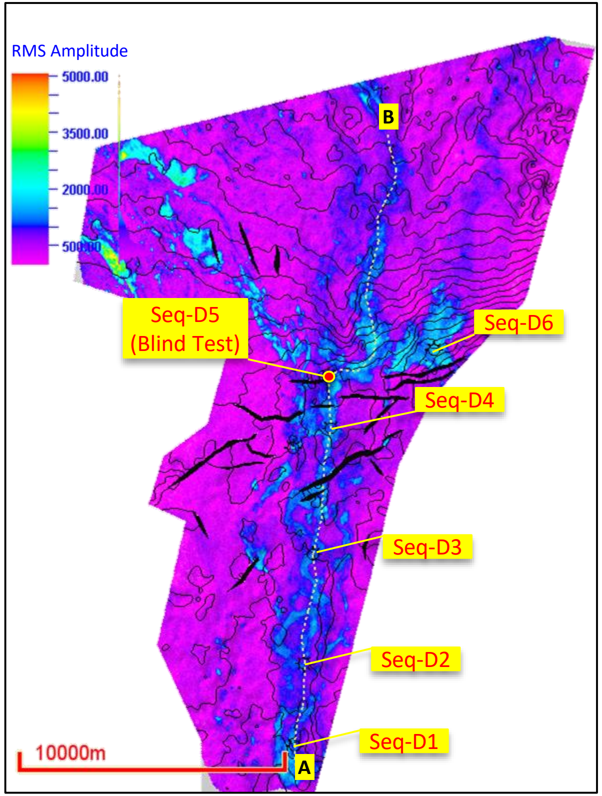
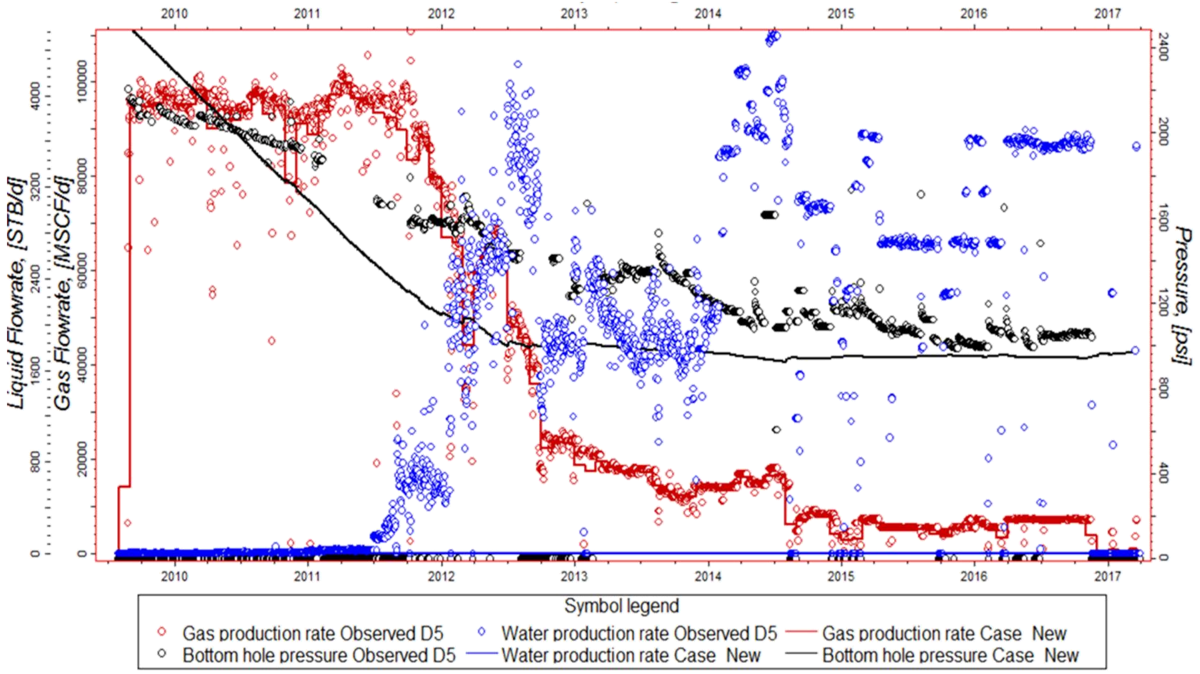
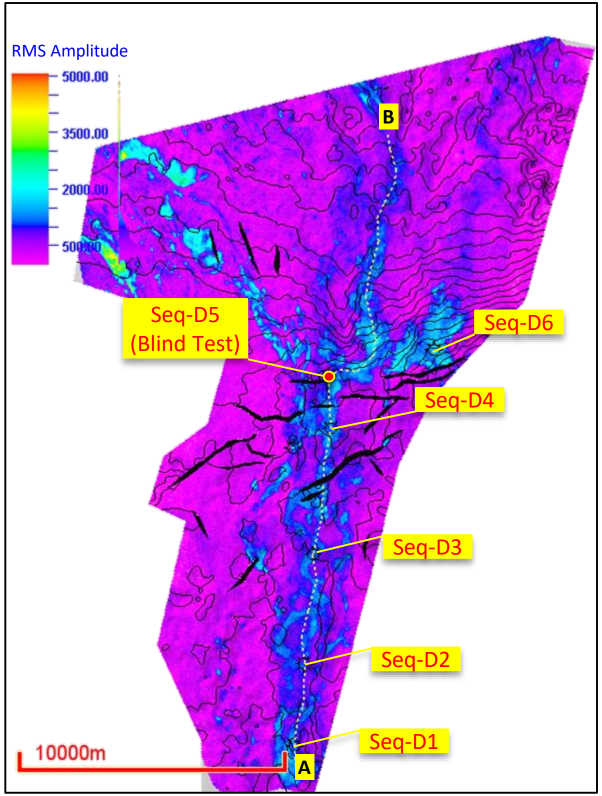
Dynamic Testing



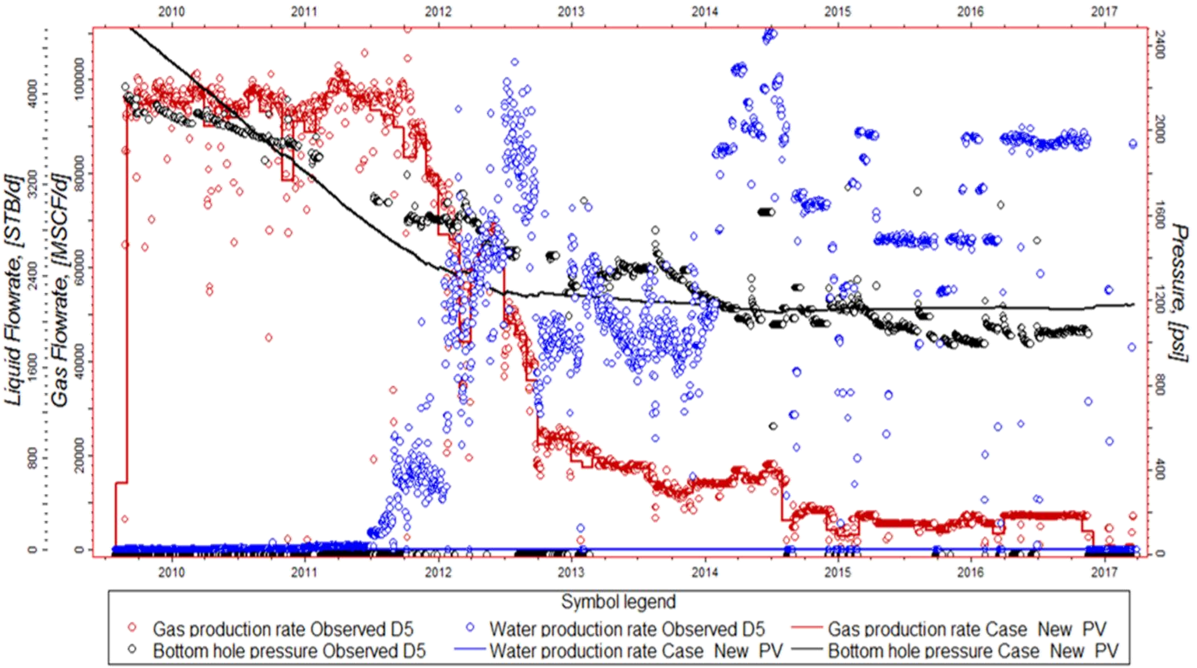
Dynamic simulation results at the blind well (Sequoia D5)



Dynamic Testing



Dynamic simulation results at the blind well (Sequoia D5), additional multiplier is applied for the pore volume (adding 20%)



Contents

Conclusion

- Probabilistic neural network predicts shale volume, porosity, and water saturation 3-D volumes
  - Fast training process
  - Results show high accuracy
- Integrating the PNN in the static modelling
  - Decreases the statistical uncertainty and mitigates the cumulative error problems
  - Reduces the reservoir modeling time by about 80%
- Some details may be lost during the resampling process
  - Finer grid is required or multi-segment model
  - Apply multipliers

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RASHPETCO

EGPC

THANKS

References

Cross, I., Cunningham, A., Cook, R., Taha, A., Esmaiel, E., and Swidan, N., 2009, 3-D Seismic Geomorphology of a Deepwater Slope Channel System: The Sequoia Field, Offshore West Nile Delta, Egypt: AAPG Convention, Denver, Colorado.

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