High-Resolution Three-Dimensional Water Saturation Prediction - A Case Study from Offshore Nile Delta*

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Abstract

Scarab field is part of the offshore Nile Delta that lies in West Delta Deep Marine (WDDM) concession, 50-100 km offshore in the deep water of the present-day Nile Delta. A series of successive exploration and appraisal encountered gas-bearing sands in slope canyon settings on the concession. The Scarab field is submarine delta slope canyon system, with complex turbiditic channel-levee reservoirs. The available data for this study are sorted into well logs and seismic data. The available well logs are P-wave velocity (Vp), S-wave velocity (Vs), and density (ρ) logs for seven wells. Other attributes as λρ were calculated from the original logs. The available seismic volumes are partial angle stacks of near (0°- 15°), mid (15°- 30°) and far (30°- 45°) in addition to full angle stack seismic volume. Prior the inversion, a negative of the second derivative and fourth order derivative attributes were made and compared in an attempt to increase the seismic resolution either for full-stack or for partial-angle stacks. Using the enhanced partial angle stacks of near, mid, and far with proper deterministic wavelets, a geostatistical inversion was conducted in an attempt to improve the inversion resolution and assess model uncertainty. The inversion provides multiple model realizations, each of which honors the seismic data, the well data, and the geostatistics. The mean of the realizations gives a highly resolved estimate of the acoustic impedance and shear impedance. Then, Vp/Vs volume was computed as well as the Lamé parameter volumes of lambda-rho (λρ) and mu-rho (μρ). Implementing probabilistic neural network, the inversion results were used to predict a water saturation 3D volume with the highest possible resolution. The resulted saturation volume was tested using blind well analysis and gave impressive results. The resulted volumes were used to better define the reservoir and optimize the new well location. By honoring existing well-log data, geostatistical inversion provides a way to increase the vertical resolution of acoustic and shear impedances above that available from seismic data. In addition, neural network provides a formulation that can efficiently establish a non-linear link between inversion results and water saturation. The proposed workflow delivered high-resolution water saturation volume that could be used to refine the construction of a reservoir model amenable to fluid-flow simulation and production history match.

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Mohamed, I., H. El-Mowafy, and M. Fathy, 2015, Prediction of elastic properties using seismic prestack inversion and neural network analysis: Interpretation, v. 3/2, T57-T68.

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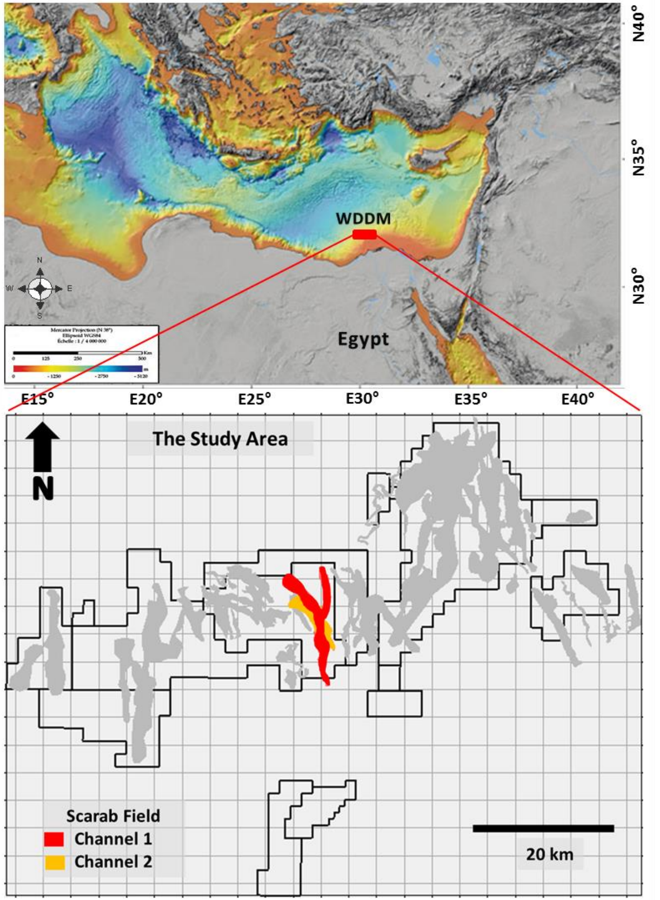
Islam A. Mohamed, Ahmed Hosny, and Abdulrahman A. Mohamed

Contents

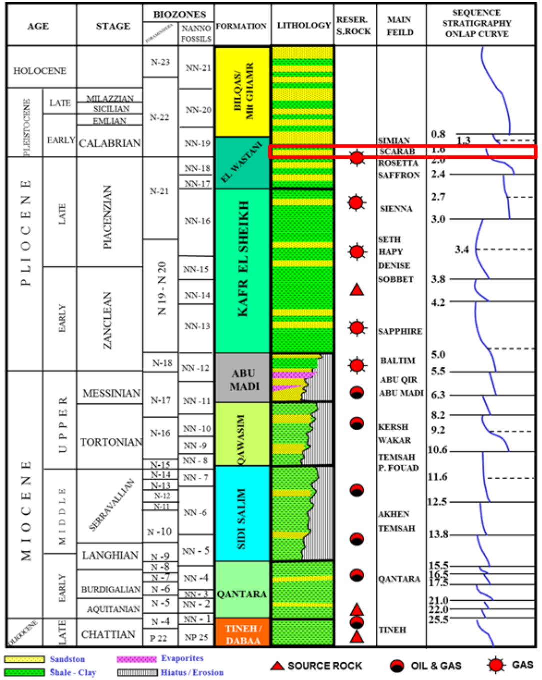
Area of Study

- Egypt
- Offshore Nile Delta
- West Delta Deep Marine (WDDM) concession covers 1366 km^2
- Scarab field is a Pliocene gas field located 90 km north of Alexandria in water depths of 250 – 850m

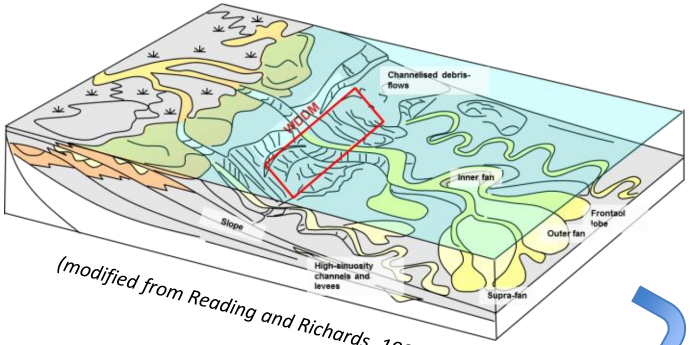


(from Mohamed et al., 2014)

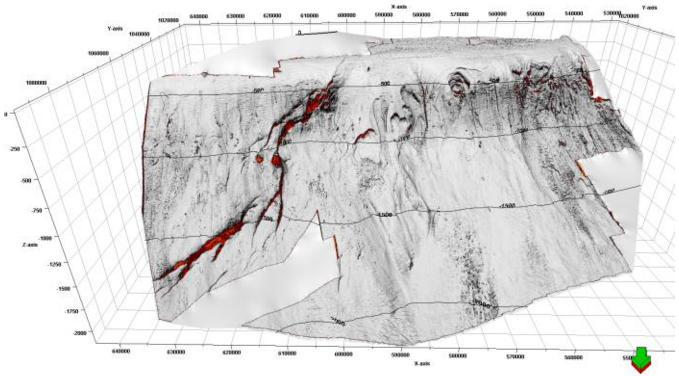
Nile Delta – Tectono-Stratigraphic Setting



Nile Delta stratigraphic column and hydrocarbon system



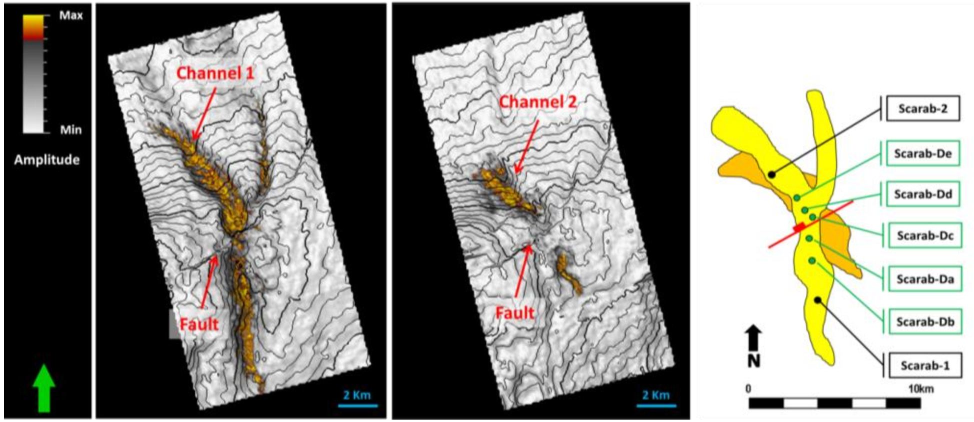
(modified from Reading and Richards, 1994)



Current sea bed map over WDDM concession

Scarab Field – Geological Overview

- Complex submarine channel system
- Two vertically stacked channels: Channel 1 and Channel 2
- Channel 1 is the major reservoir with 16 km long
- Seven wells:
  - Two exploratory wells
  - Five development wells



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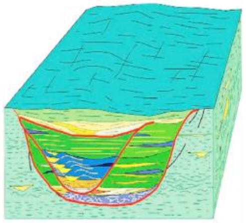
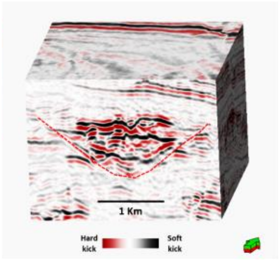


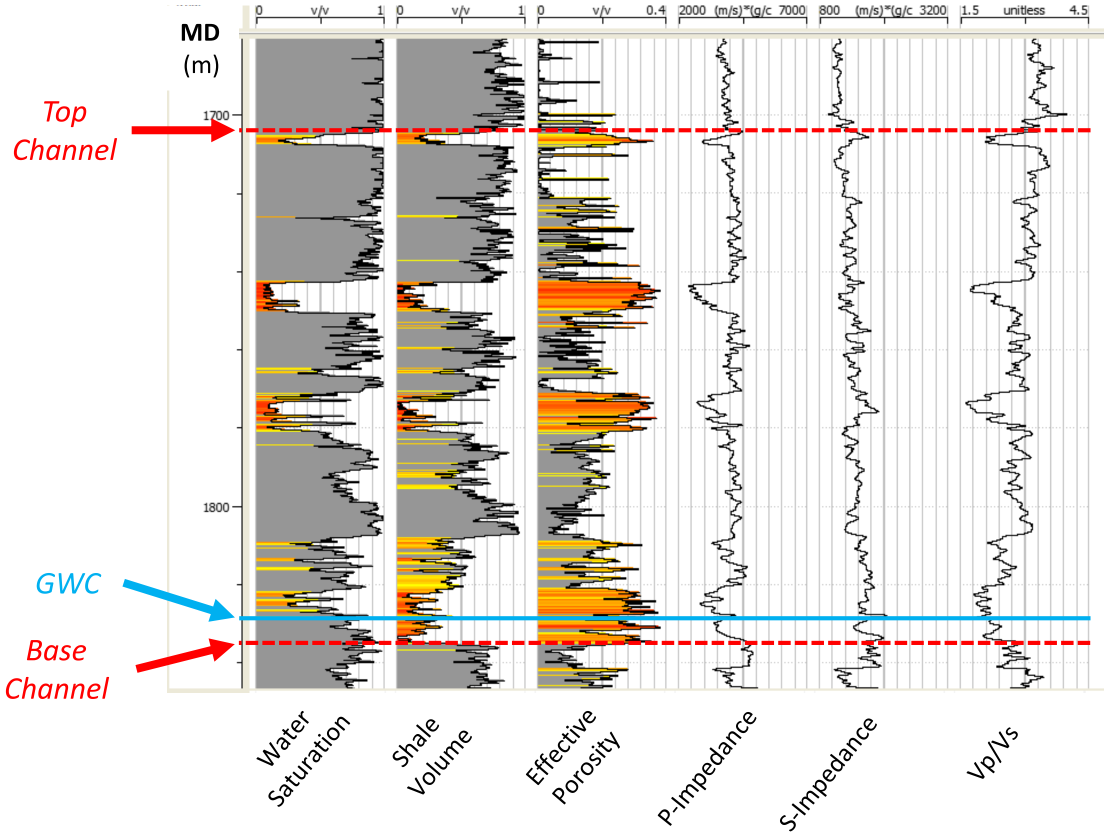
(from Samuel et al., 2003)



Scarab Canyon

Reservoir Characteristics

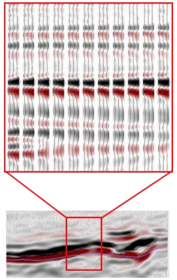
- Multiple stacked channels that are up to 170 m gross thickness and 50 m net-pay
- An average effective porosity of 25%
- An average water saturation of 28%



Contents

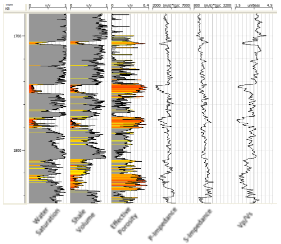
Methodology

Prestack Seismic Data
(Partial Angle Stacks)



Full-Stack Seismic Data

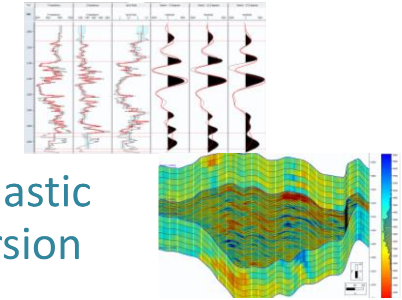
+



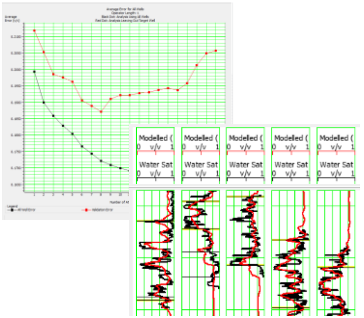
Well Logs

Input Data

Stochastic Inversion



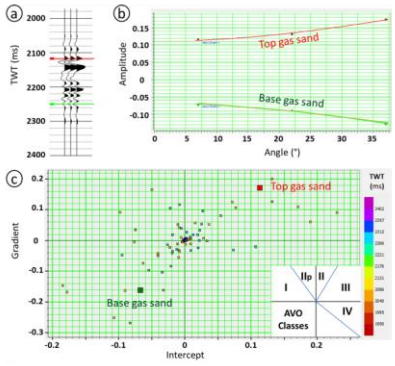
Neural Network



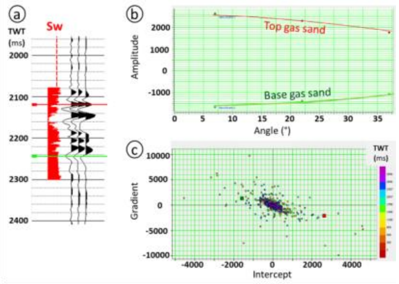
High-Resolution
Water Saturation
3D volume

Contents

Data Conditioning

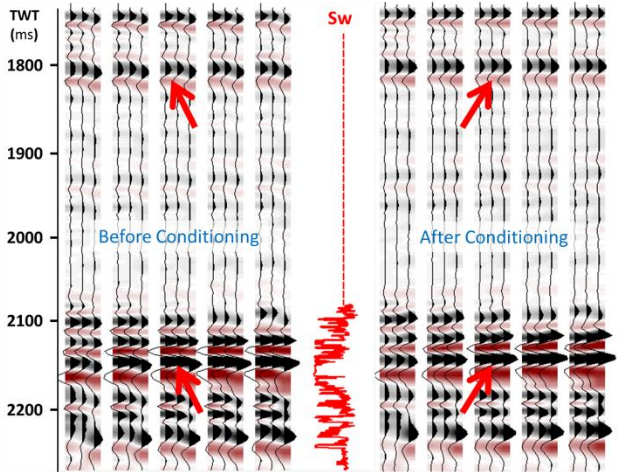


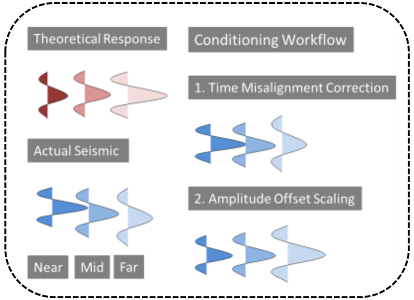
Theoretical AVO Response



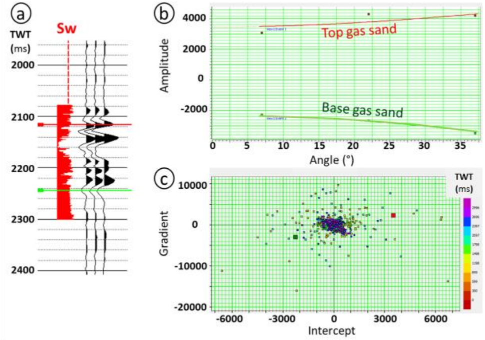
Actual AVO Response
(Before Conditioning)

Partial Angle Stacks



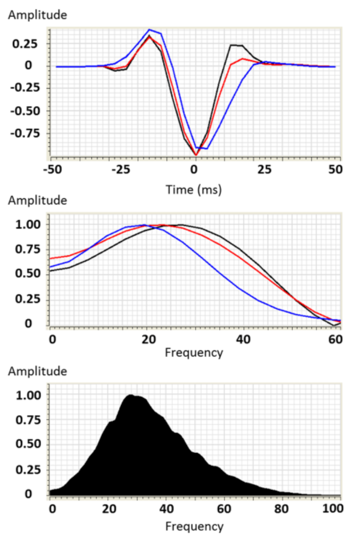


Conditioning Workflow

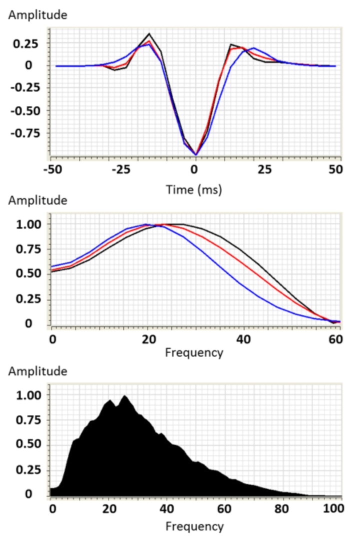


Actual AVO Response
(After Conditioning)

Data Conditioning – Wavelets

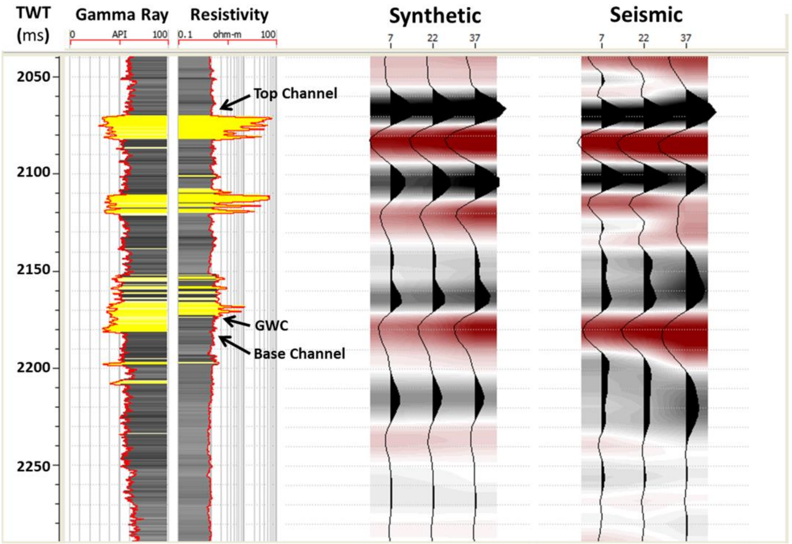


Deterministic Wavelets
(Before Conditioning)



Deterministic Wavelets
(After Conditioning)

- Near (0-15°)
- Mid (15°-30°)
- Far (30°-45°)

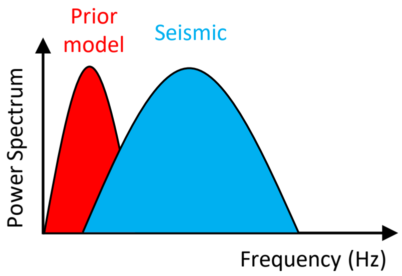


* The polarity convention denotes a decrease in acoustic impedance by a peak

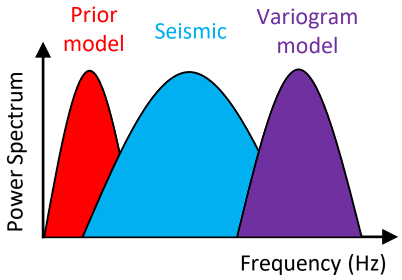
Contents

Geostatistical Prestack Inversion

- The Geostatistical inversion approach is based on Bayesian theory.
- It attempts to address the “non-uniqueness problem” by producing a large range of inversion results for a given input.
- All results are valid solutions to the inverse problem, and honor the expected continuity conditioned by the input variograms.
- Among this range of results, the most likely result and the uncertainty range can be estimated.

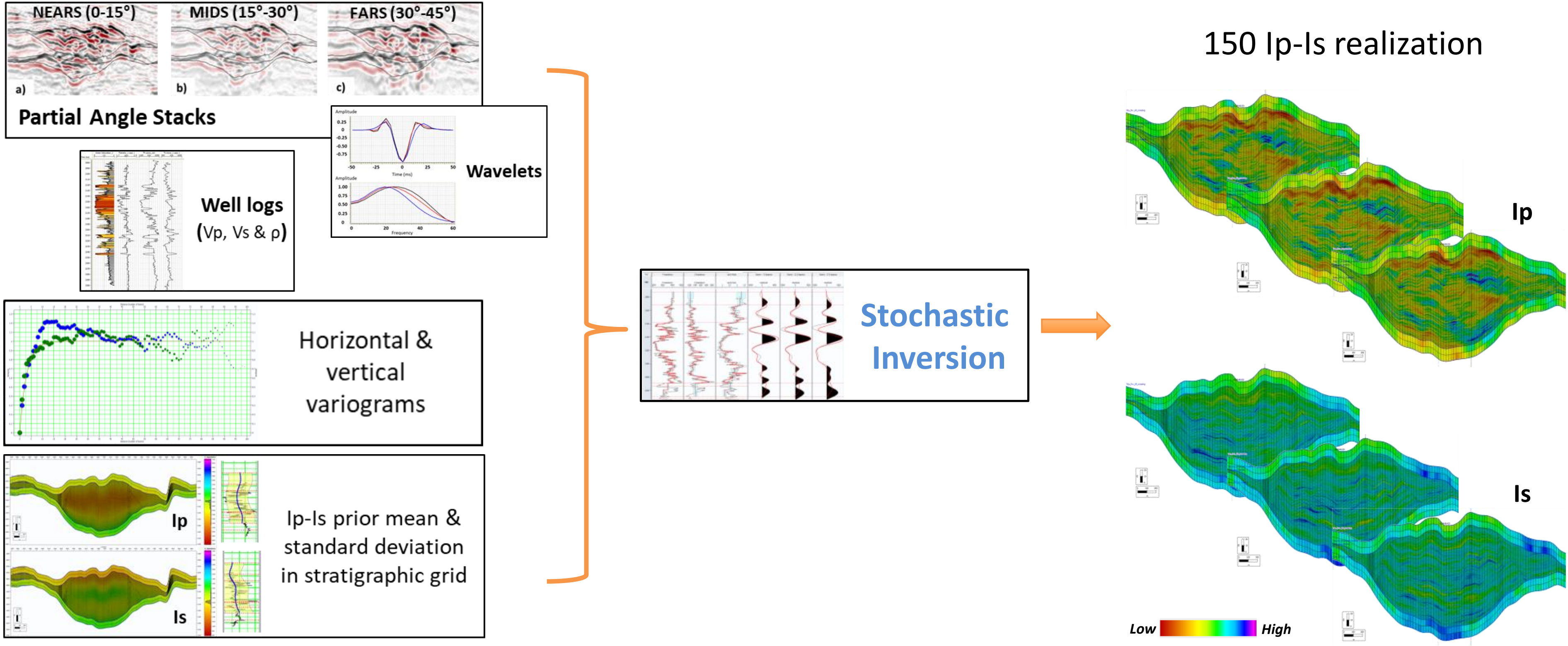


Deterministic Inversion



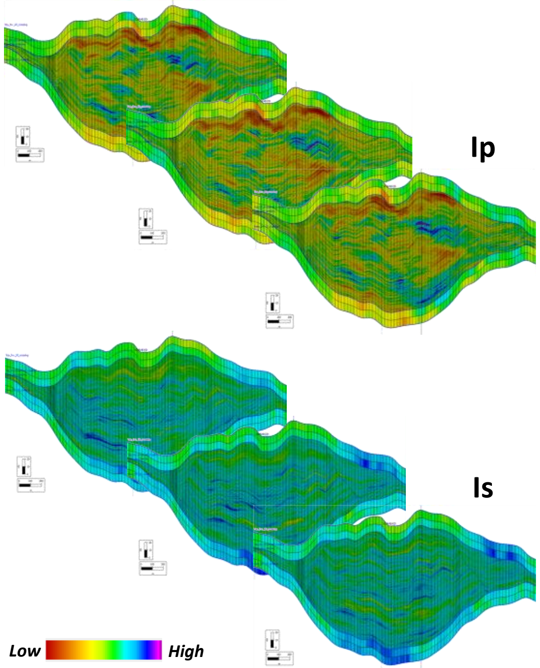
Stochastic Inversion

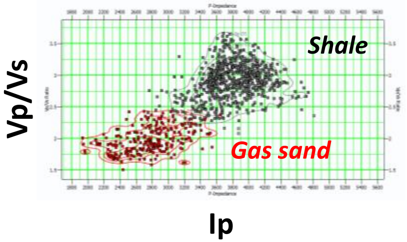
Geostatistical Prestack Inversion Workflow

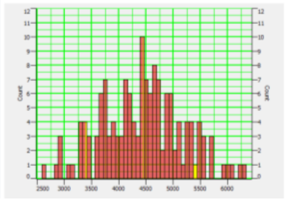


Facies Probability Prediction

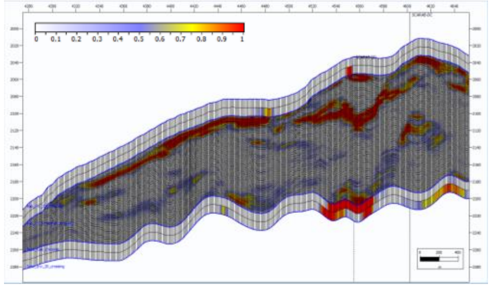
150 Ip-Is realization







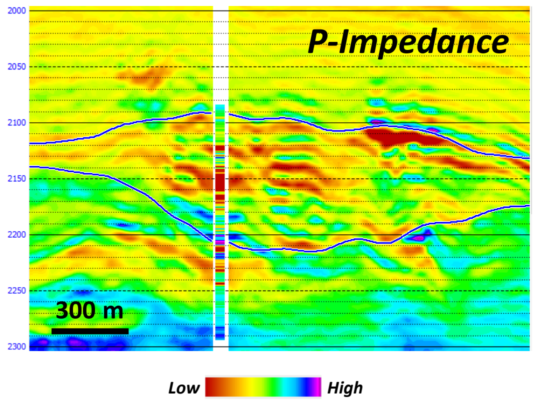
Histogram of gas sand volume



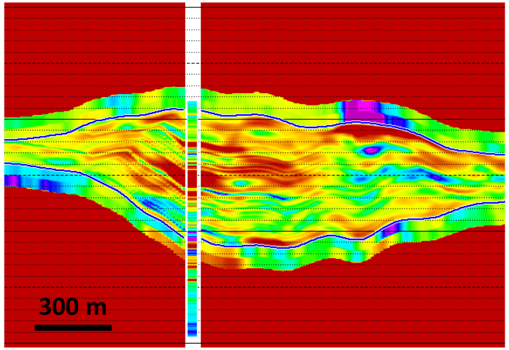
Gas sand probability volume

Deterministic vs. Stochastic Inversion

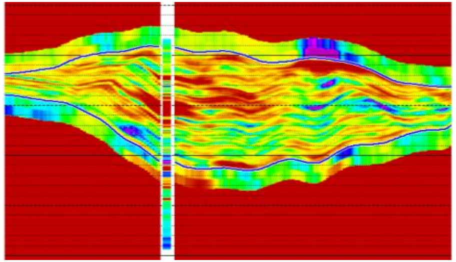
Deterministic Inversion



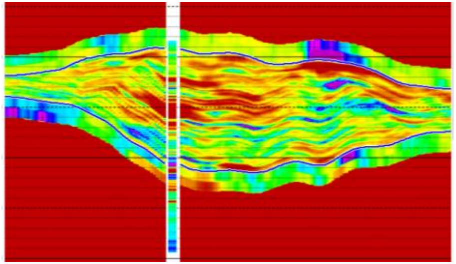
Stochastic Inversion



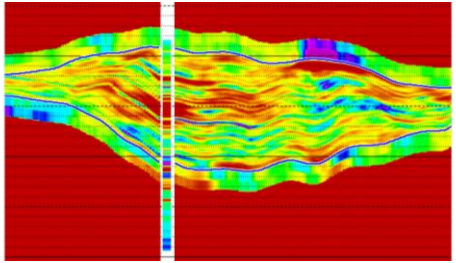
Mean



P10



P50

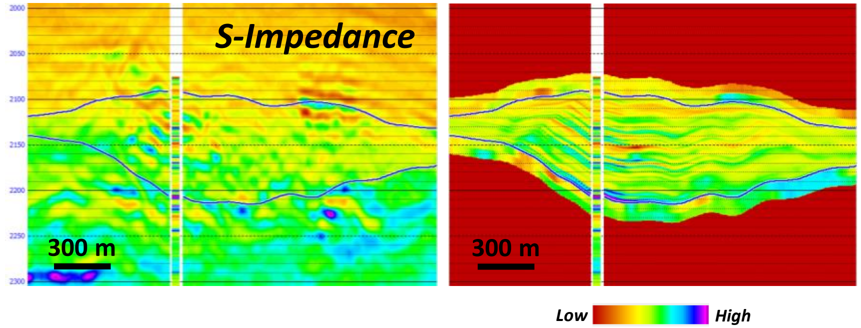


P90

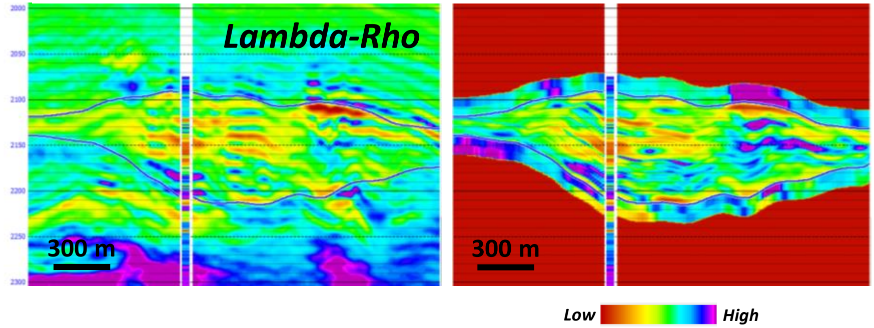
Inversion results at Scarab-De well location

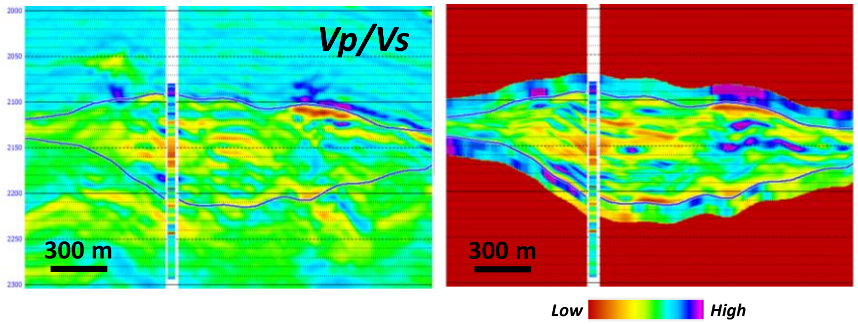
Deterministic vs. Stochastic Inversion

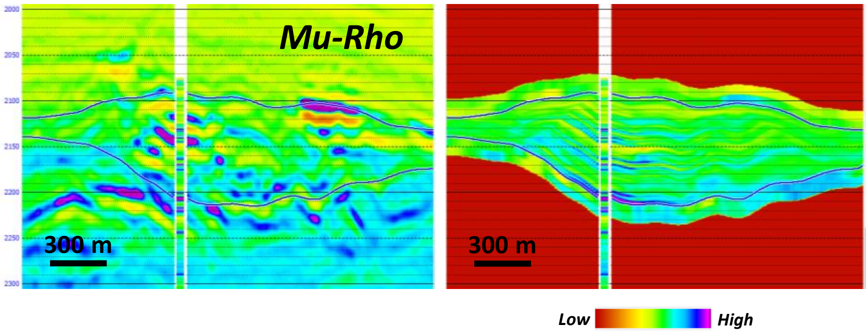
TWT (ms) *Deterministic* Inversion *Stochastic* Inversion



TWT (ms) *Deterministic* Inversion *Stochastic* Inversion

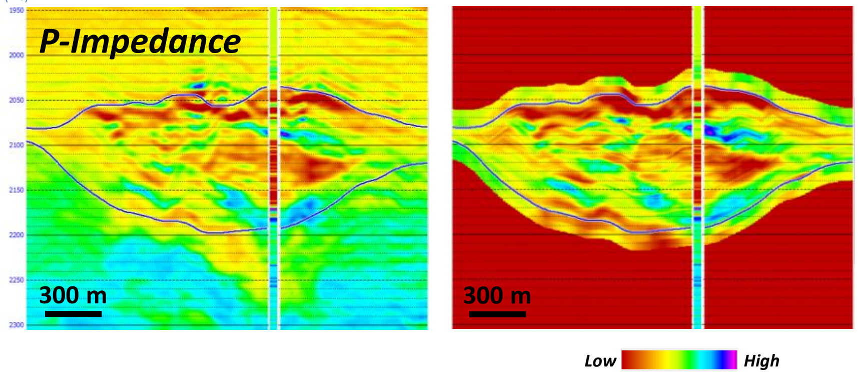


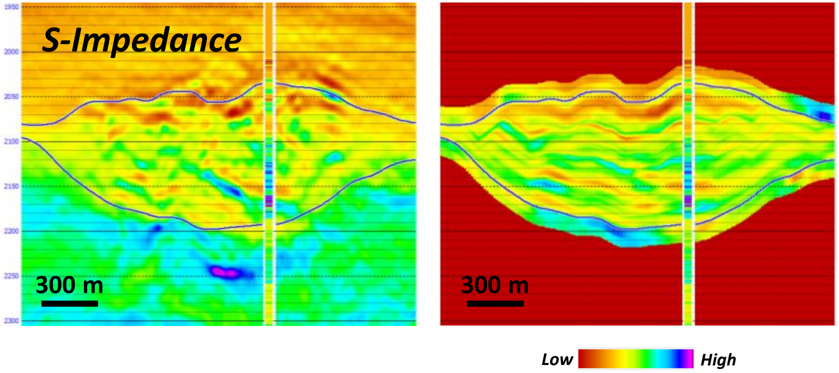


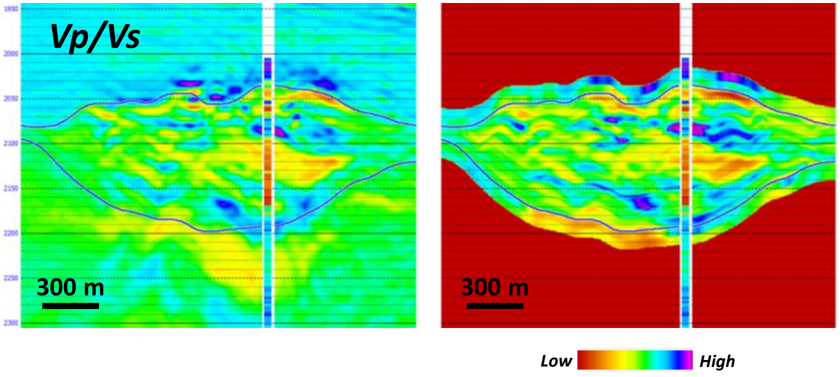


Deterministic vs. Stochastic Inversion – Blind Test

Deterministic Inversion   *Stochastic* Inversion





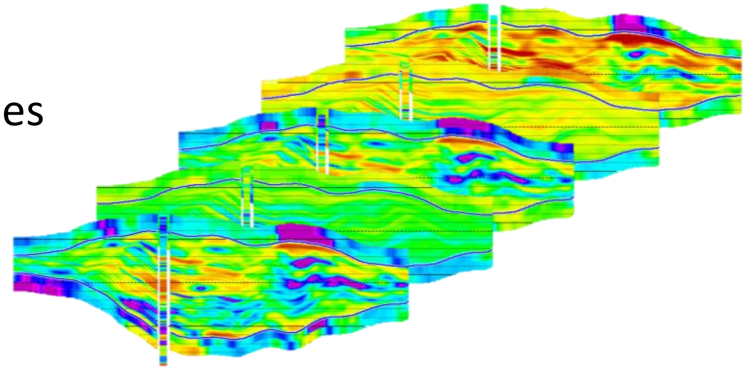


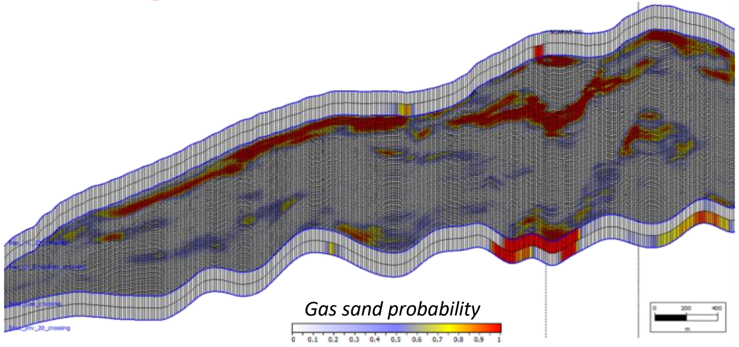
Inversion results at Scarab-Dc
well location (Blind Test)

Geostatistical Inversion Outputs

- P-Impedance
  - Mean
  - P10
  - P50
  - P90
- S-Impedance
  - Mean
  - P10
  - P50
  - P90
- Vp/Vs
  - Mean
  - P10
  - P50
  - P90
- Lambda-Rho
  - Mean
  - P10
  - P50
  - P90
- Mu-Rho
  - Mean
  - P10
  - P50
  - P90
- Gas Sand Probability

Inversion Results:
21 different volumes

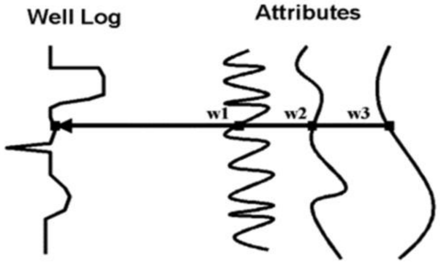




Contents

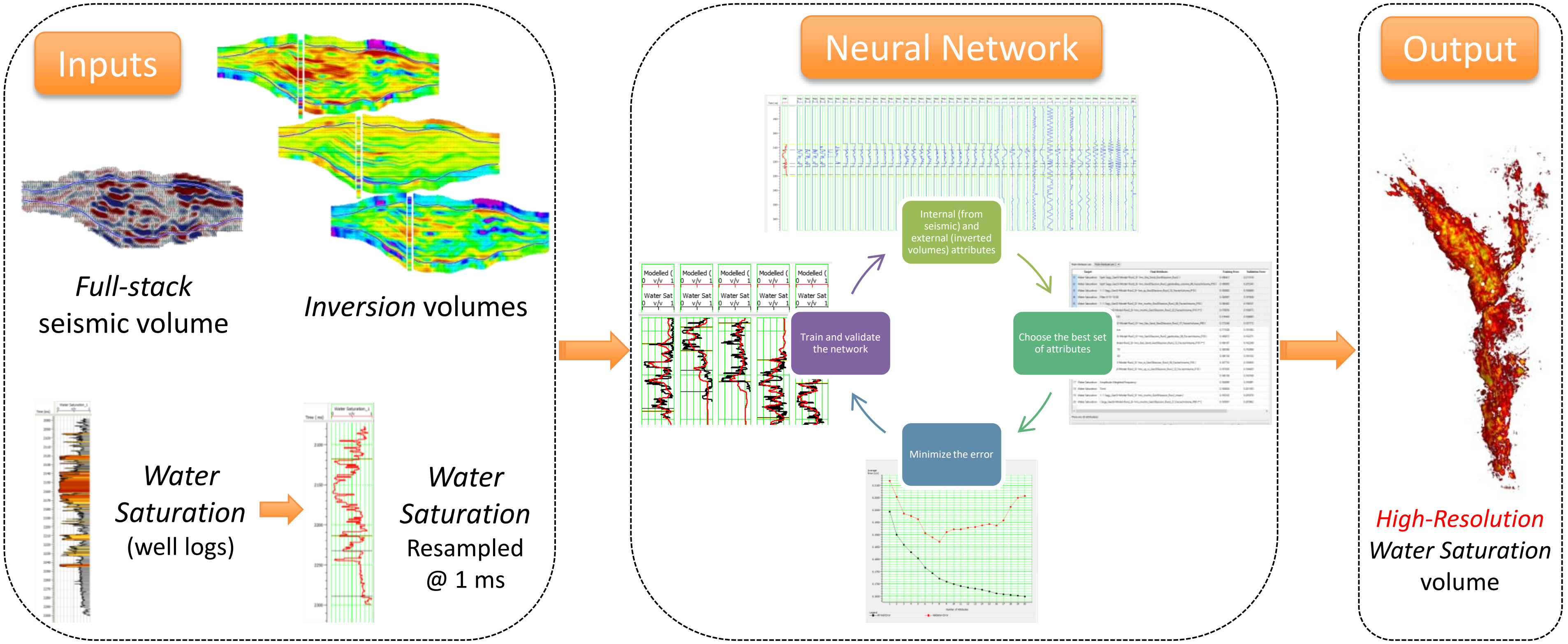
Probabilistic Neural Network

- How it works
  - The PNN finds the weights that depend on the distance from the desired point to the training points. The distance is measured in multi-dimensional attribute space.
  - The distance is scaled by smoothers (the sigma values), which are determined automatically by cross-validation.
  - The weighting functions are multiplied by the known log values to determine the unknown log values.



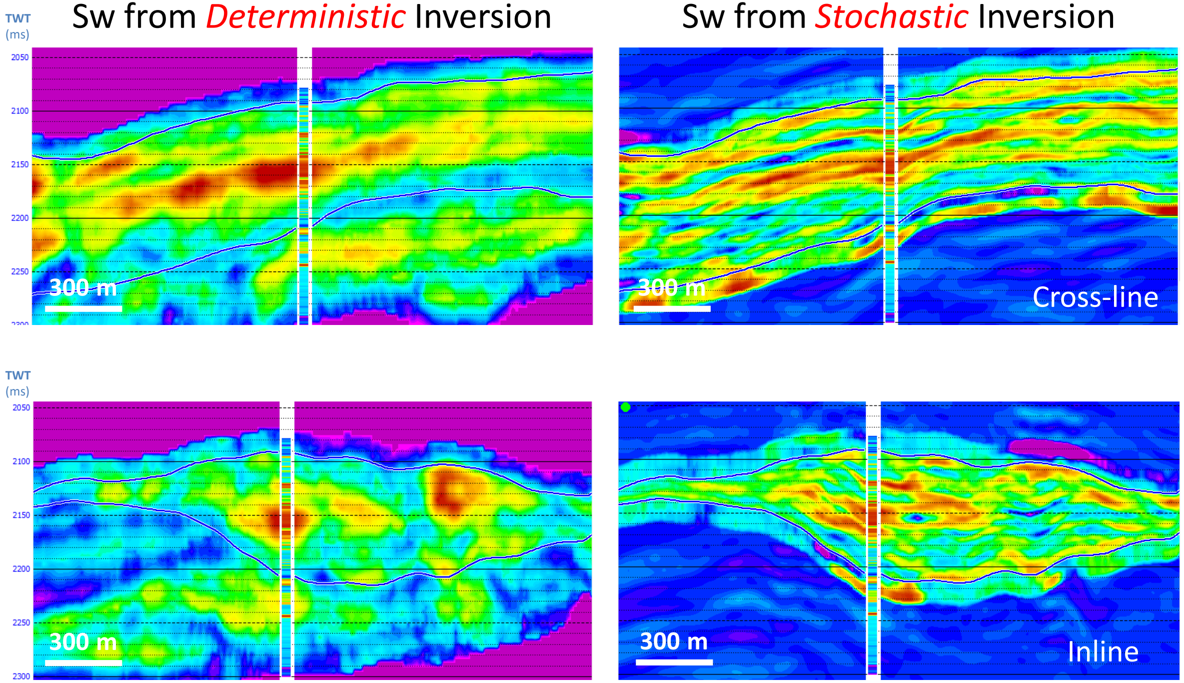
- Theoretically, it can predict any log property.

Probabilistic Neural Network Workflow



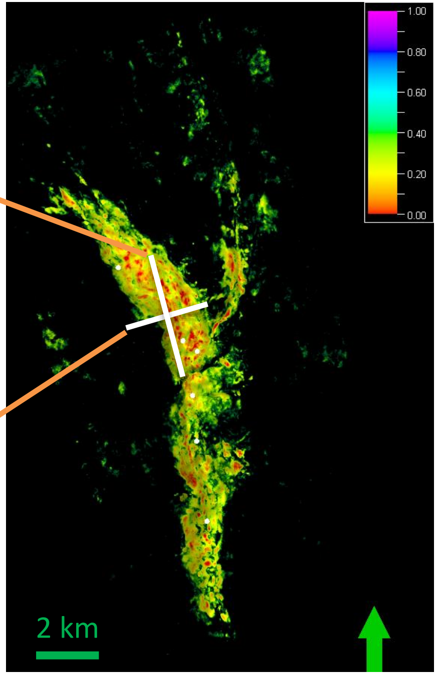
Water Saturation Prediction

Sw from *Deterministic* Inversion | Sw from *Stochastic* Inversion



Sw sections through Scarab-De well location

0 1

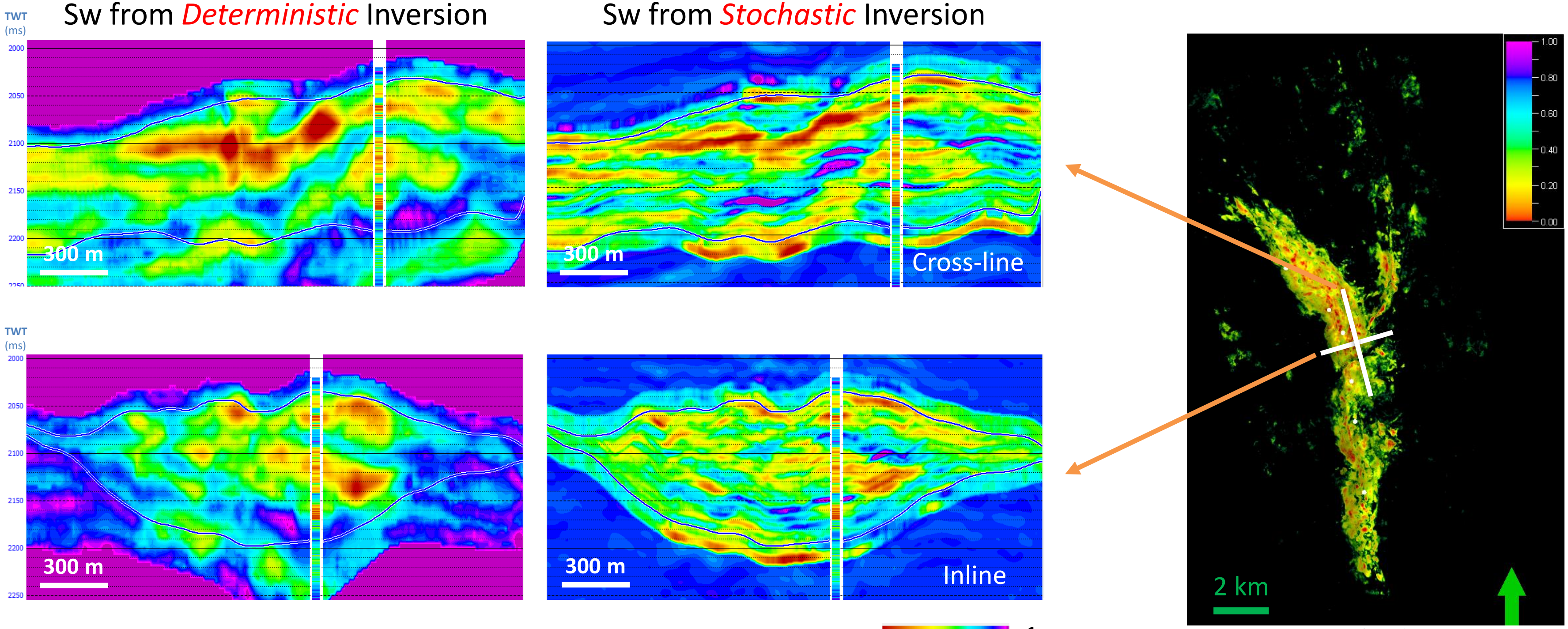


Sw min. amplitude map over Scarab channel 1 reservoir

Water Saturation Prediction – Blind Test

Sw from *Deterministic* Inversion

Sw from *Stochastic* Inversion



Sw sections through Scarab-Dc well location (Blind Test)

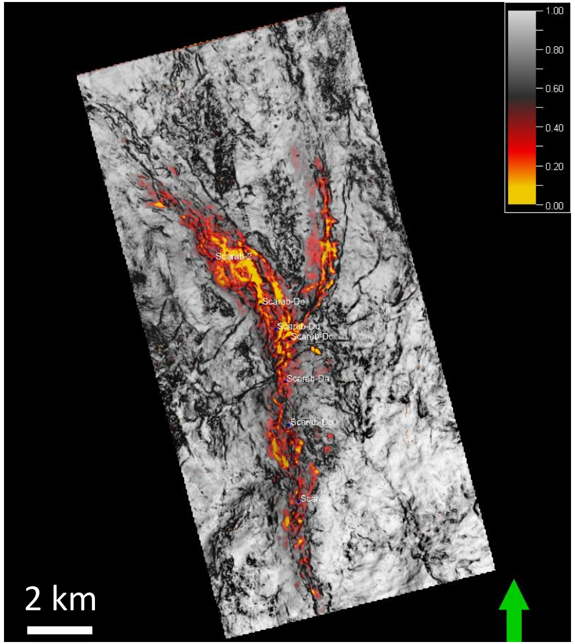
0 1

Sw min. amplitude map over Scarab channel 1 reservoir

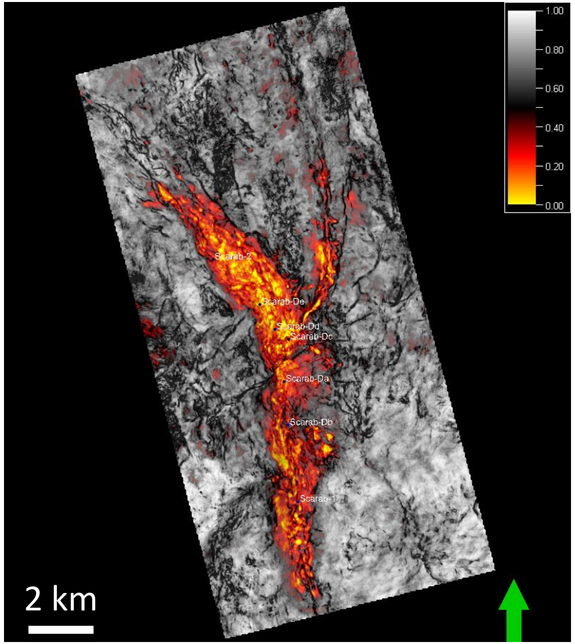
Water Saturation Prediction – Deterministic vs. Statistical Inversion

- High-resolution saturation volume (from stochastic inversion) shows:
  - More gas sands inside channel 1 reservoir
  - Better lateral continuity
  - Better Consistency with the drilled wells results

Sw from *Deterministic* Inversion



Sw from *Stochastic* Inversion



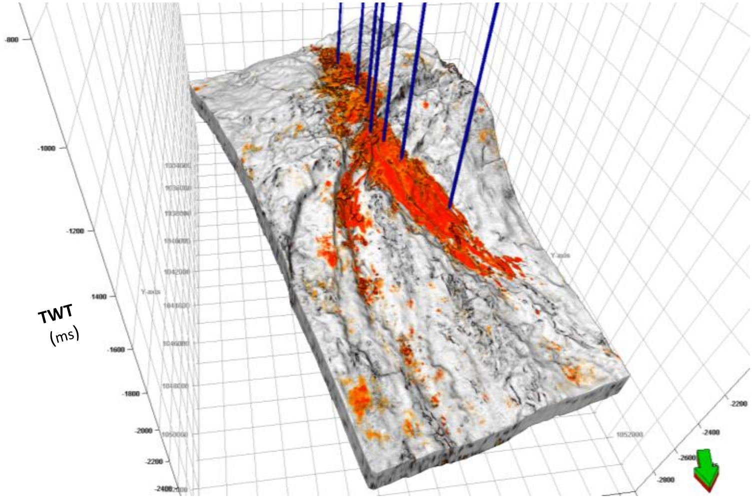
Sw minimum amplitude map overlaying variance map over Scarab channel 1 reservoir

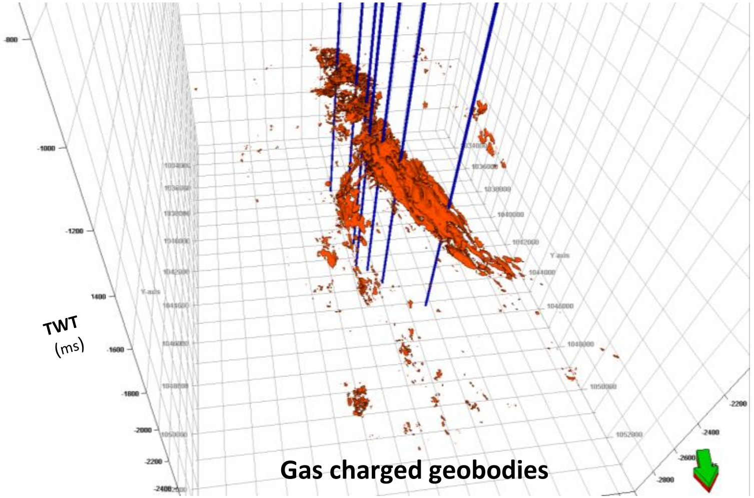
Contents

- Introduction
- Methodology
  - Data Conditioning
  - Geostatistical Prestack Inversion
  - Probabilistic Neural Network
- Results
- Conclusions

Results – Geobodies Extraction

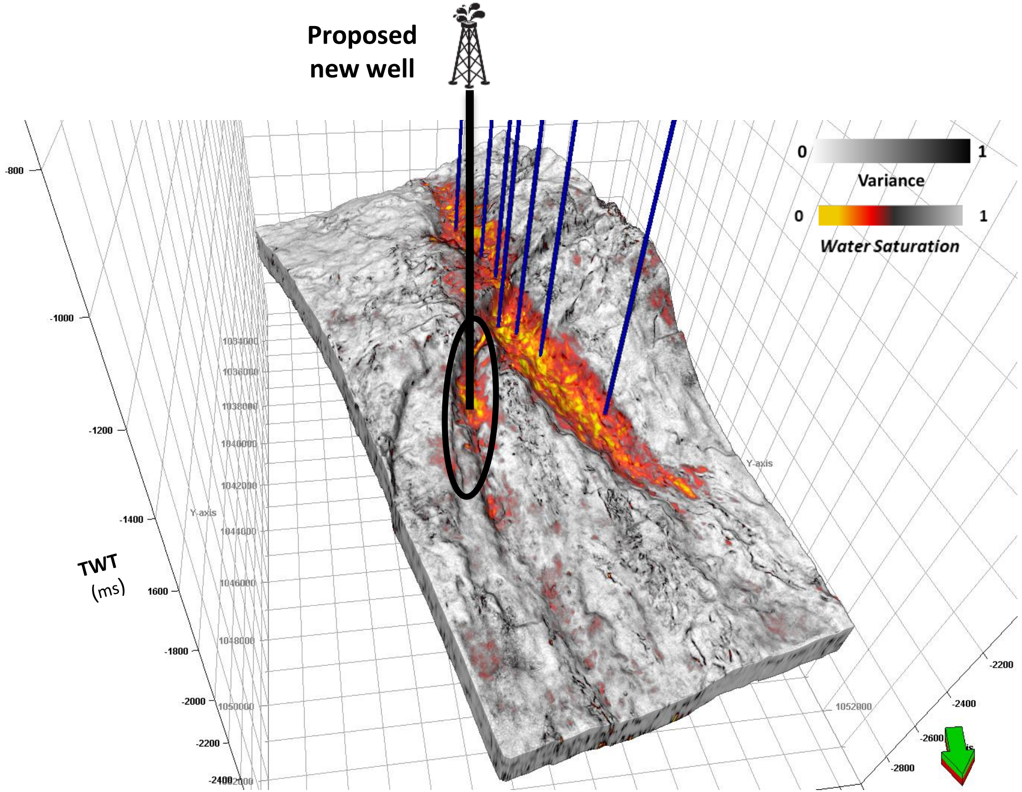
- Using of high-resolution water saturation provides an excellent 3-D insight into the sand-body makeup and reservoir architecture.
- Using gas-sand geo-bodies can improve the reservoir static model building and Gas Initial In-Place (GIIP) calculation.





Results – Infill Wells

- Increase the Chance of Success (CoS) of the eastern flank
- Proposing a *new well* and optimizing its target location to drain the eastern flank



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- Introduction
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Conclusions

- Unlike the deterministic inversion, geostatistical prestack inversion approach addresses the “non-uniqueness problem” and produces high frequency volumes.
- The probabilistic neural network predicts accurately water saturation 3D volume with the highest possible resolution (1 ms).
- The high-resolution saturation volume helps in:
  - Better delineating hydrocarbon-saturated reservoir in 3-D space.
  - Better Gas Initial In-Place (GIIP) calculation and reservoir static model building.
  - Contribute to optimal well placement and improve the field development plan.
- The main challenges that face the proposed workflow:
  - Large memory requirements
  - Long running time
  - Needs at least three wells for the PNN

Acknowledgement

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THANKS

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