PS Enhancing Pre-Stack Seismic Inversion Using Neural Networks for Clastic Reservoir Characterization – Simian Field, Offshore Nile Delta, Egypt*

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Abstract

In hydrocarbon exploration, seismic guided estimation of reservoir properties away from well calibration is a common problem that geophysicists, geologists and reservoir engineers face. This problem arises due to the low resolution of seismic data (typically 10's meters and non-unique) relative to petrophysical data (typically 10's centimeter resolution and well calibrated to real rocks and fluids) as well as a lack of suitable models linking the two dataset. The characterization of reservoirs is a challenge to geoscientists who need to understand vertical and horizontal property distribution over the whole hydrocarbon field and supporting aquifer. The objective of this paper is to develop a framework under which we can improve the clastic reservoir characterization by using the pre-stack inversion and the neural-network analysis. The aim is to go beyond the limitations of full-stack seismic data and reduce the uncertainty as much as possible. The pre-stack inversion is a very powerful method to delineate the reservoirs and has been successfully used in the reservoir characterization but also has its limitations regarding the requirement of a reliable set of wavelets, suitably wire-line logged wells and sufficiently dense initial model. Therefore, the need arises for using another complementary method that can overcome the pre-stack inversion limitations. Artificial Neural Networks have the ability to recognize complex, non-linear relationships between seismic attributes and petrophysical data. The proposed workflow applied to the Simian gas field, one of the offshore Nile Delta's Pliocene gas fields. The available dataset includes; seismic partial angle stacks, well log data, and interpreted horizons. The workflow includes two main stages; pre-stack inversion stage and the neural network analysis. In the first stage, we applied the pre-stack inversion to produce elastic volumes (P- and S-impedances, and density) along with the derived facies volume. Then, we used the full-stack seismic as an internal attributes generator, and the inverted volumes as external attributes to train the artificial neural network to predict the water saturation and porosity. Hence, the integration of the two methods provides an intelligent solution for the clastic reservoirs' characterization. As the pre-stack inversion provides reliable impedance volumes and the neural-network analysis goes beyond the inversion limitations and characterizes the clastic reservoirs effectively.

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Aal, A.A., M. Barkooky, M. Gerrits, H. Meyer, M. Schwander, and H. Zaki, 2006, Tectonic evolution of the eastern Mediterranean Basin and its significance for the hydrocarbon prospectivity of the Nile Delta deep-water area: GeoArabia, v. 6/3, p. 363-384.

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INTRODUCTION

AIMS

The objective of this paper is to develop a framework under which we can improve the clastic reservoir characterization by using the pre-stack inversion and the neural-network analysis. The aim is to go beyond the limitations of full-stack seismic data and reduce the uncertainty as much as possible.

LOCATION

The Simian field is found offshore Egypt as part of the proven Pliocene gas fields in the Western Delta Deep Marine concession (WDDM) of the Nile Delta, Egypt (Fig. 1).

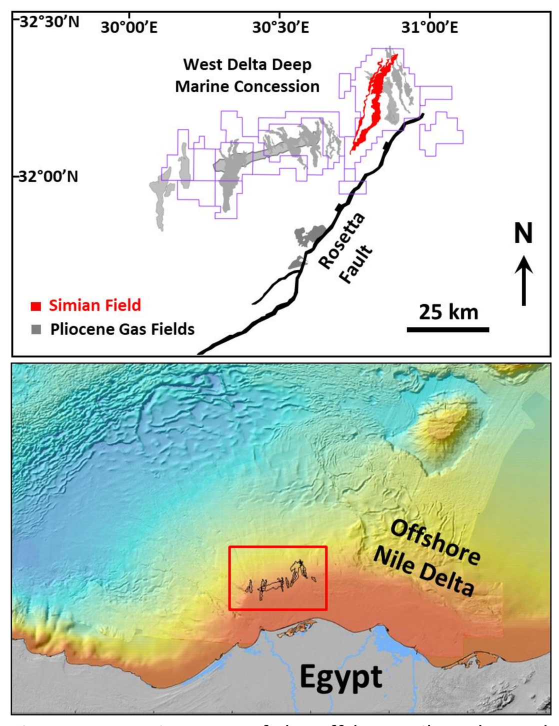

Figure 1. Location map of the offshore Nile Delta and study area (red box). Upper Pliocene gas fields are in gray, and Simian Field is in red. Modified from Samuel et al. (2003).

RESERVOIR GEOLOGY

The Simian field is believed to be a slope channel complex deposited on the Nile delta slope in the early Pliocene within El-Wastani package (Figure 2). The reservoirs consist of complex submarine channel systems exhibiting strong lateral variations, thin bedding, variable sand distribution and a variety of channel architecture (Figure 3). sands are likely to be unconsolidated, have excellent reservoir quality and porosity in the range of 24-36% (Aal et al., 2000).

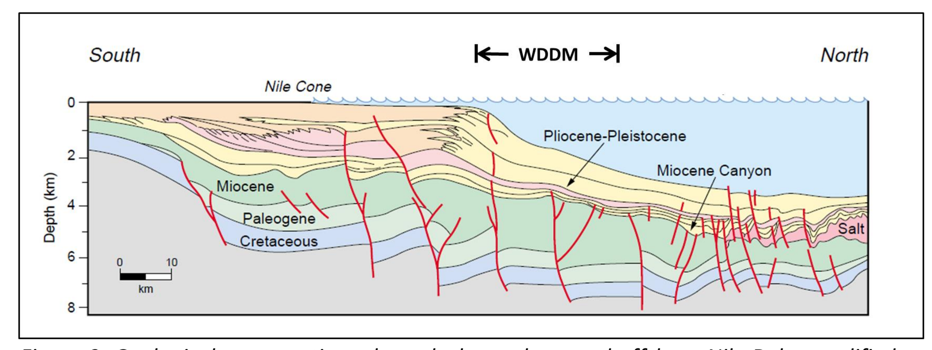

Figure 2. Geological cross-sections through the onshore and offshore Nile Delta modified after Abdel Aal et al., 2006.

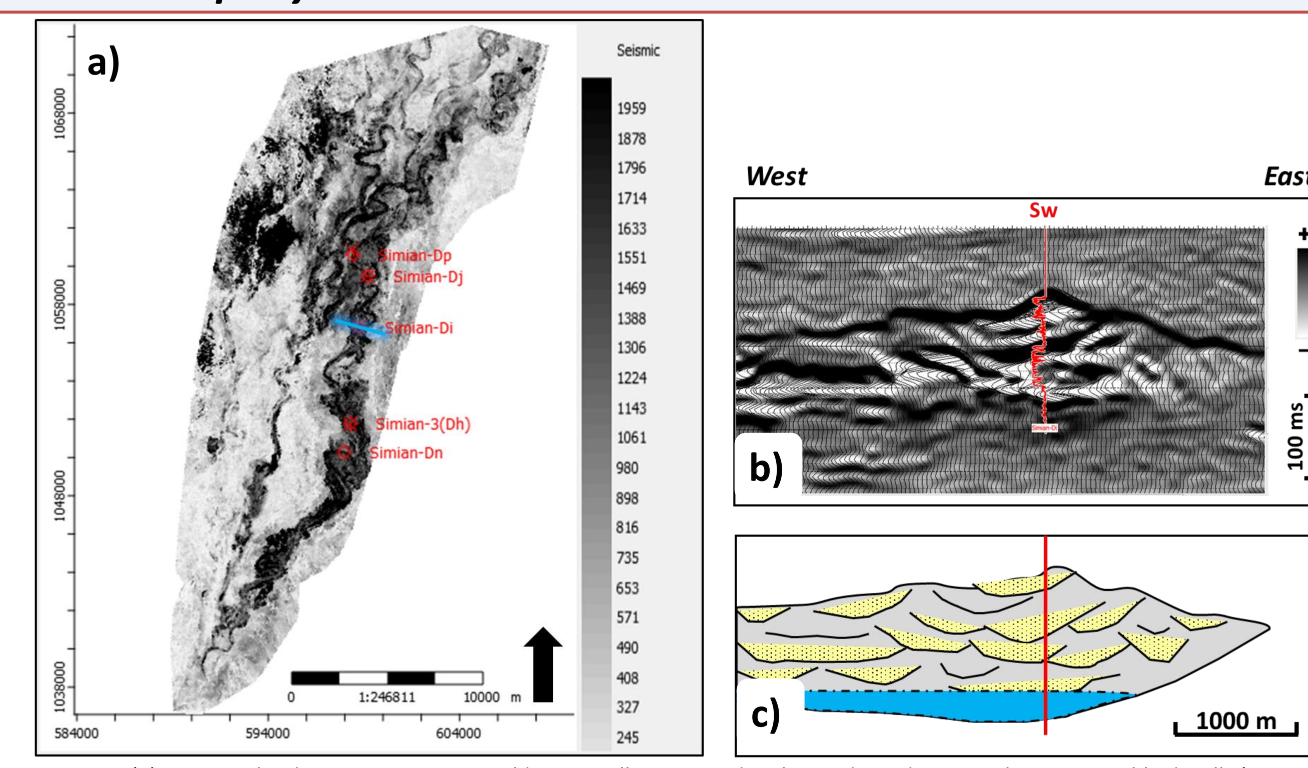

Figure 3. (a) RMS amplitude map over Simian Field. Four wells were used in this study, and one was kept as a QC blind wells (Simian-Dj). (b) an actual seismic expression and (c) schematic block diagram of the depositional model for representative canyon complexes.

WORKFLOW

The workflow includes two main stages; pre-stack inversion stage and the neural network analysis:

- In the first stage, we applied the pre-stack inversion to produce elastic volumes (P- and S-impedances, and density) along with the derived facies volume.
- Then, we used the full-stack seismic as an internal attributes generator, and the inverted volumes as external attributes to train the artificial neural network to predict the water saturation and porosity.
- Hence, the integration of the two methods provides an intelligent solution for the clastic reservoirs' characterization. As the pre-stack inversion provides reliable impedance volumes and the neural-network analysis goes beyond the inversion limitations and characterizes the clastic reservoirs effectively.

PRE-STACK INVERSION

- The inversion method reverts acquired 3D seismic data back to useful geological attributes. The three essential tools to do this are a representative wavelet, an initial model spanning the entire seismic volume and a reliable suite of well logs distributed amongst the field.
- The well ties were performed with two different wavelet sets: statistical and deterministic. The deterministic wavelets were better tied to seismic than the statistical ones. The four wavelets represent near-, mid-, far and ultra far-angle stacks for the sub-stacks volumes. All wavelets were extracted using a constant wavelet length of 100 ms, and their phases were close to 180°. The four deterministic wavelets were then used in the Prestack inversion as shown in figure 4.
- The initial low-frequency model was constructed using well log data; Zp, Zs, and ρ, three horizons; top, base gas and base Channel. We used the inverse distance weighting algorithm for the interpolation, which is a simple interpolation method.
- Once the model is built, we simultaneously inverted the Pre-stack data using the linearized approximation of the Aki-Richards equation. The program started with the initial models, Zp, Zs, and ρ, and it created model-based synthetic traces. To improve the fit between the actual seismic traces and the synthetic traces, it iteratively modified the initial models. Hence, the Pre-stack inversion outputs were P-impedance, S-impedance, and density volumes. We then calculated other attributes: Vp/Vs, Lambda-Rho (λρ), and Mu-Rho (μρ) (Figure 5).
- The lambda-mu-rho crossplots from the well logs showed that the gas sandstone reservoirs are characterized by low λρ values while the brine sandstone characterized by high λρ values. The lithofacies polygons were used to invert the λρ and μρ volumes to lithofacies volume. the extracted geobodies represent gas sandstone and brine sandstone (Figure 6).

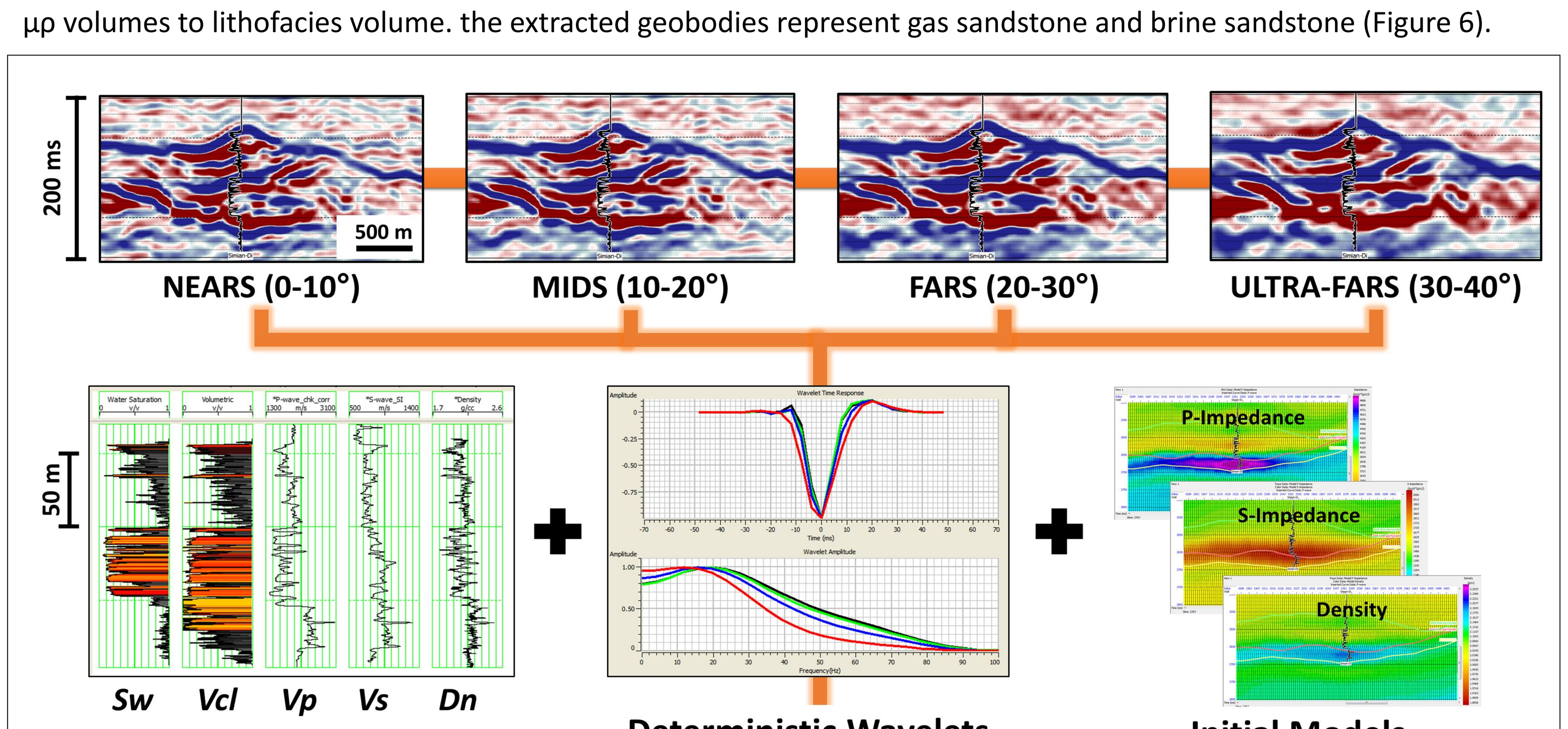

Figure 4. The Prestack inversion workflow: near-, mid-, far-, and ultra far-angle stack seismic volumes, well log data, extracted deterministic wavelet set for the angle stacks with time response on top and respective amplitude spectrum on the bottom, and the initial low-frequency models; p-impedance, s-impedance and density.

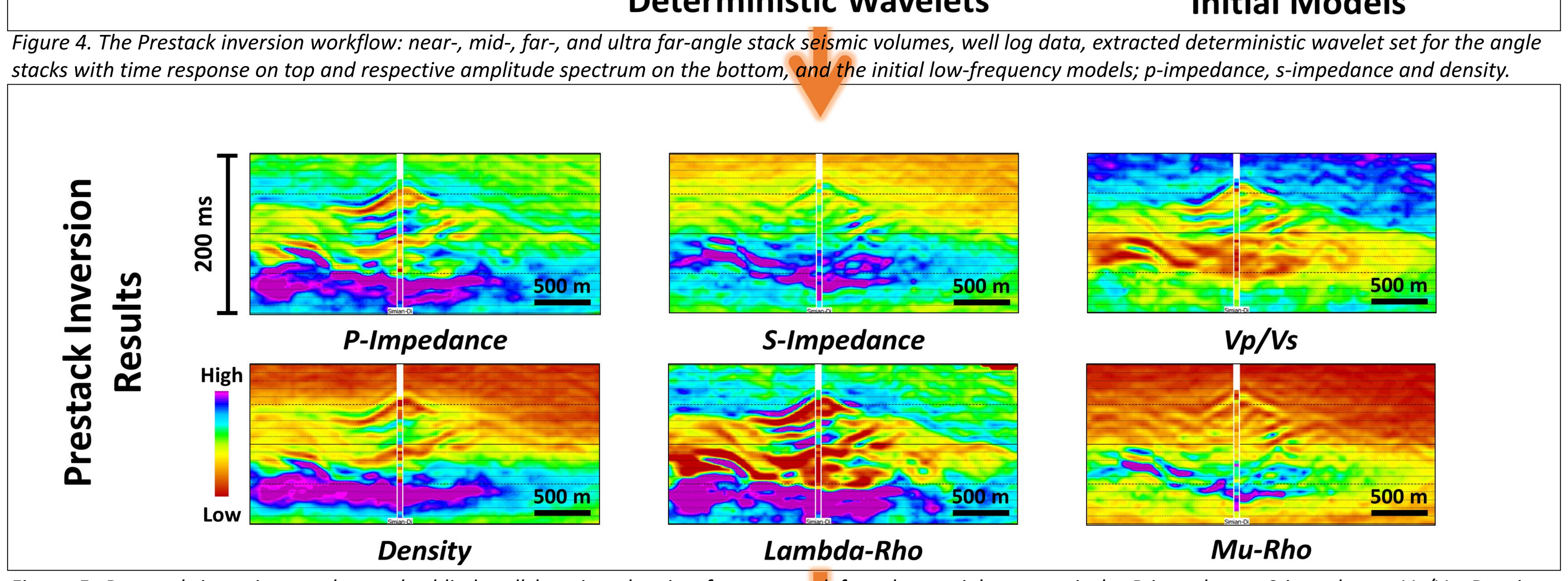

Figure 5. Pre-stack inversion results at the blind well location showing from upper left to lower right respectively: P-impedance, S-impedance, Vp/Vs, Density, Lambda-Rho and Mu-Rho.

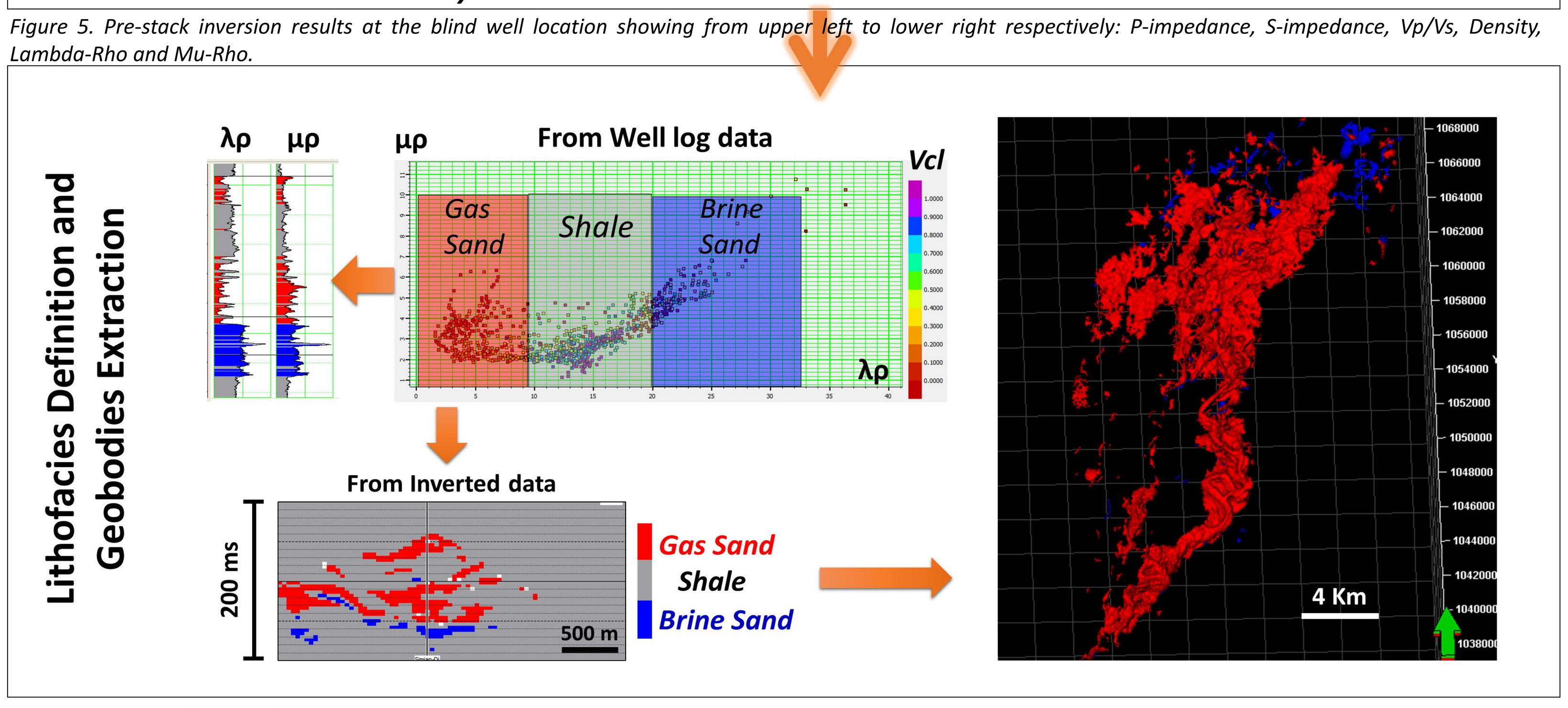

Figure 6. The Lithofacies definition using Lambda-Mu-Rho crossplot, with a clay volume log (Vcl) as a colour bar. Gas sand, shale, and brine sand are highlighted within the rectangles. Applying the crossplot to the inverted volumes, the Lithofacies are plotted in a cross-section and extracted in a 3D map.

NEURAL NETWORK

- The neural network estimation of the reservoir properties proved the accuracy and consistency with the well logs, which might compensate for the inversion parameters' uncertainty.
- The workflow is quite simple and includes three steps (Figure 7):
  1- The first step is to load and QC input seismic data/Sw/porosity logs, calculate seismic-internal attributes, load external inversion volumes and perform Sw/porosity logs conditioning.
  2- The second step is to train the network using the conditioned well-log data and seismic internal/external attributes and to validate the network by hiding some wells and predict them using the trained network.
  3- The third step is to apply the trained network to the seismic data.
- Data conditioning was applied to the logs to make the well data consistent with the seismic data for the neural network analysis. This was done by resampling the Sw/porosity logs to match the seismic scale (4 ms), smoothing the logs, and filtering the log data to the seismic frequency range (high pass 120 Hz and high cut 130 Hz) so that aliasing is avoided when down-sampling log data to seismic resolution.
- After the conditioning, we applied the PNN method following the workflow provided by Hampson et al. (2001) and edited by Mohamed et al. (2014) to produce the Sw and porosity volumes.
- A good match was obtained between the well data and the neural network results. The Correlation coefficients between the predicted and measured porosities and water saturation show a correlation of more than 0.9 for all wells and more than 0.8 for the blind well (Figure 8).
- The blind wells' results confirmed the success of this technique in the 3D Sw and porosity prediction.

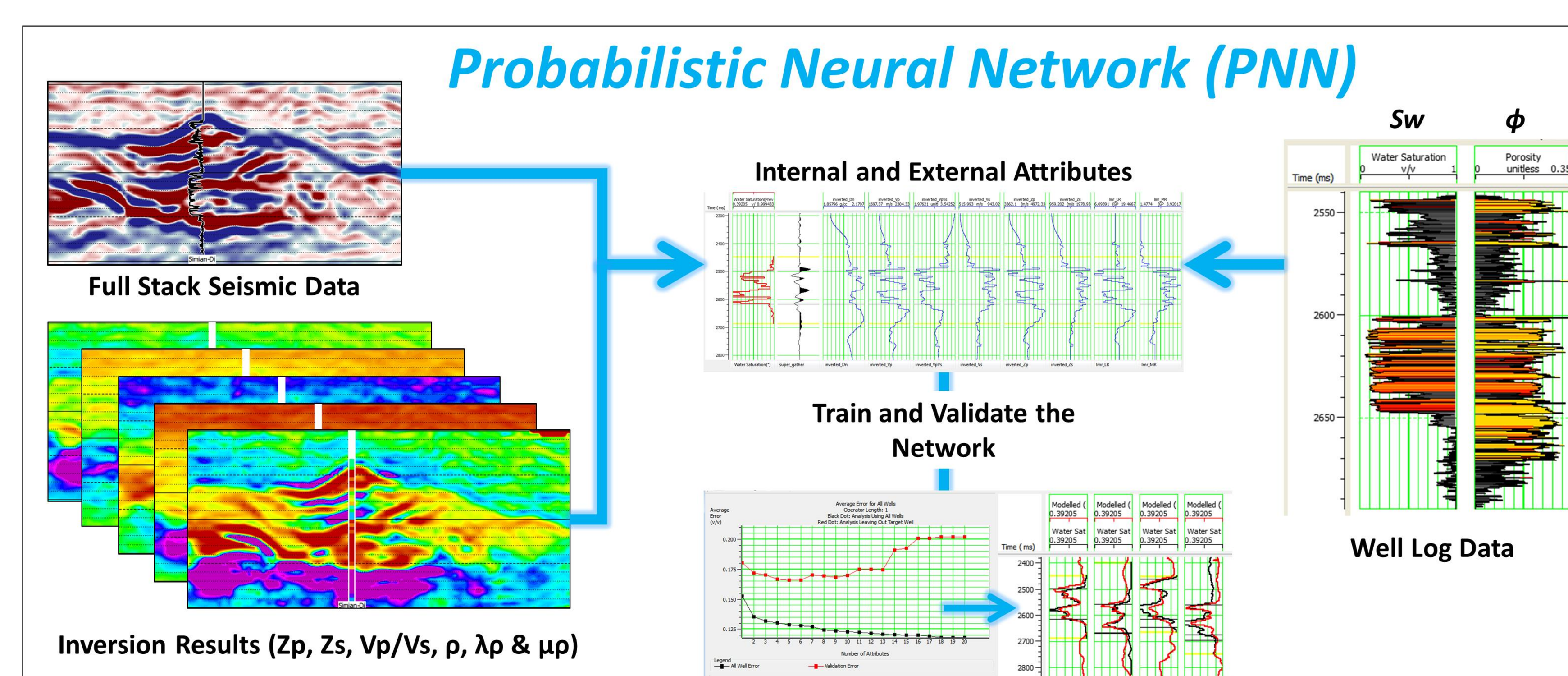

Figure 7. Probabilistic Neural Network Workflow: seismic full-stack seismic data, inversion results, and well log data as inputs. Training and validation of the network. And prediction of water saturation (Sw) and porosity (ϕ) volumes.

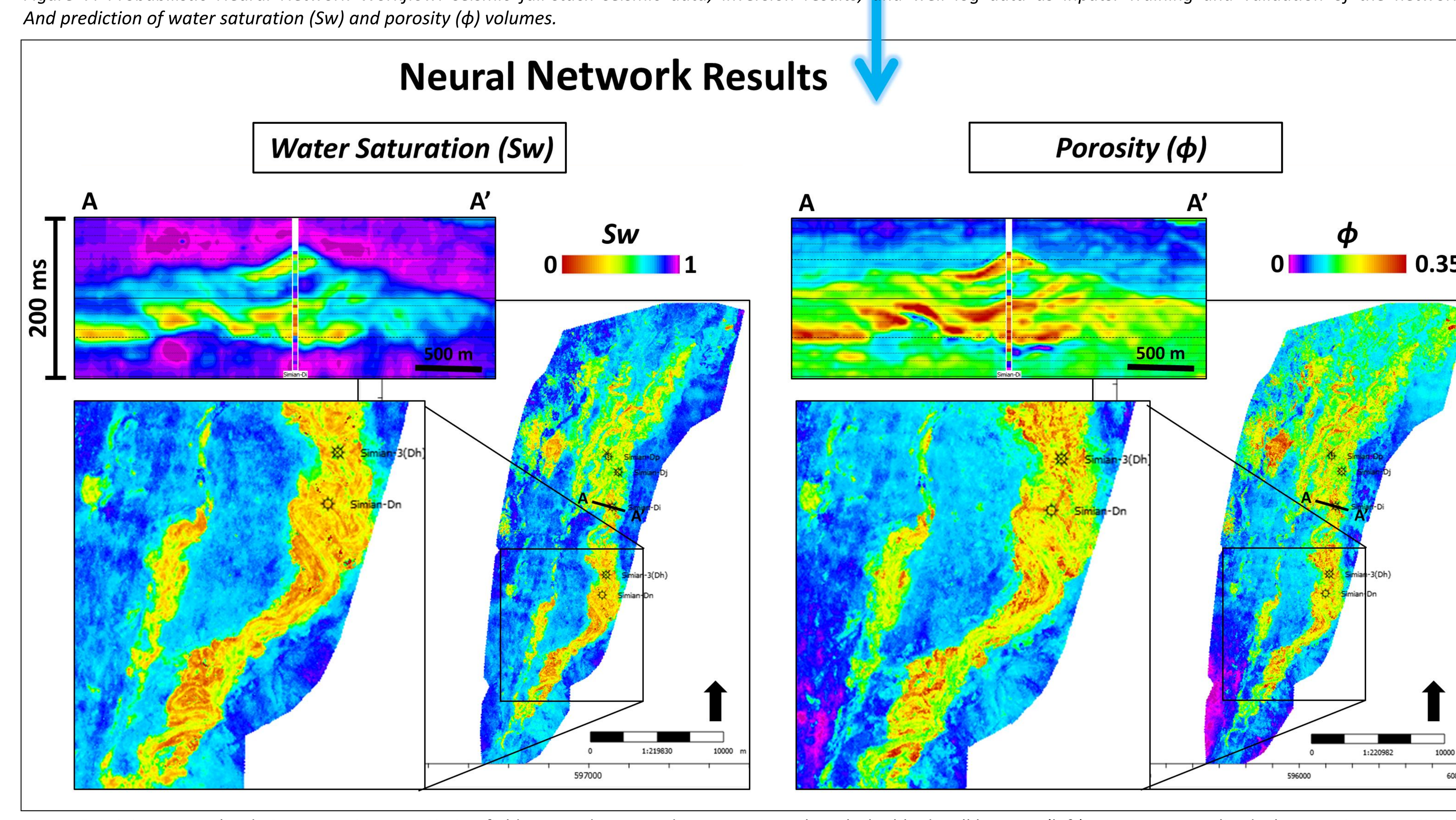

Figure 8. Minimum amplitude Sw extraction over Simian field, zoomed map, and cross sections though the blind well location (left). Maximum amplitude ϕ extraction over Simian field, zoomed map, and cross sections though the blind well location (left).

CONCLUSION

- The pre-stack inversion is a very powerful method to delineate the reservoirs and has been successfully used in the reservoir characterization, but also has its limitations regarding the requirement of a reliable set of wavelets, suitably wire-line logged wells and sufficiently dense initial model. Therefore, the need arises for using another complementary method that can overcome the pre-stack inversion limitations.
- Artificial Neural Networks have the ability to recognize complex, non-linear relationships between seismic attributes and petrophysical data.
- The integration of the two methods provides an intelligent solution for the clastic reservoirs' characterization.
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