Simultaneous Inversion of Clastic Zubair Reservoir: Case Study from Sabiriyah Field, North Kuwait*

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Abstract

The zone under study is the Zubair Formation of Cretaceous age in the Sabiriyah Field. This formation is broadly divided into upper, middle, and lower units, where the lower unit has commercial hydrocarbon accumulation. The objective of this study is to characterize the hydrocarbon bearing sands at the base of the Zubair using simultaneous inversion. Reservoir characterization using post stack deterministic inversion method to estimate acoustic impedance (P-impedance) was unable to differentiate the reservoir and non-reservoir lithologies in this formation due to the low contrast in P-impedance between sand and shale. A feasibility study was conducted and the results show that prediction of hydrocarbon bearing sands in the Zubair Formation is feasible using P-impedance and Vp/Vs. Consequently, the simultaneous inversion method was carried out to derive these rock properties from the 3D seismic data integrated with well log data. The results from simultaneous inversion show that the sand bodies at the base of the Zubair can be discriminated using the combination of P-impedance and Vp/Vs elastic properties that allowed refining the planning and placement of wells with higher confidence.

Introduction

The Sabiriyah Field is located in the northern part of Kuwait and east of the Raudhatain Field (Figure 1). The Zubair Formation is a major oil reservoir in the Raudhatain Field, but was explored and exploited to limited extent in the Sabiriyah Field. The Zubair Formation belongs to the Thamama group of Barremian age, which is composed of dominantly sandstone succession with some shale intercalations and minor limestone (Figure 2) making up a gross thickness of about 1,500 feet. It represents littoral and partly deltaic sediments derived from the erosion of the Arabian Shield (Alsharhan and Nairn, 1997).

The 3D seismic survey of the north Kuwait area was acquired in 1996 and covered approximately 950 km^2 including the Raudhatain Field. The present area of study is limited to 484 km^2. The seismic data was re-processed in year 2012 to improve the data quality, suppress coherent and random noise including interbed multiples as well as preserve the amplitude. Four angle stacks (0-10°, 10-20°, 20-30° and 30-40°) were processed for the simultaneous inversion study. Structural interpretation was carried out on the full stack. Four interpreted key horizons were included in the study from top to bottom are the Shuaiba, Zubair, Ratawi Shale, and Ratawi Limestone, respectively. In earlier study, reservoir characterization using post stack deterministic inversion method to estimate acoustic impedance (P-impedance) was attempted, but was unable to discriminate the reservoir and non-reservoir lithologies in this formation due to the low contrast in P-impedance between sand and shale. In

this paper the study conducted using simultaneous inversion method by which we were able to discriminate the lithology and then map the sand bodies.

Methodology and Results

The objective of this study is to delineate and map sand bodies within the Zubair Formation. Before carrying out the simultaneous inversion, petrophysical conditioning of the well log data was performed to remove artifacts in the data created by the borehole or other problems during the logging run. Eleven wells were used that have P-Sonic, S-Sonic, and Density logs. Formation evaluation was performed to derive volumetric analysis of minerals and fluids for input to the rock physics modeling phase (Xu and White, 1995). The petrophysical conditioning and rock physics modeling were carried out in an iterative workflow that includes the wavelet estimation and well tie to ensure consistency of the derived petro-elastic model with both the well log data and the seismic data. Figure 3 shows well log view of elastic and interpreted logs.

Subsequently, a feasibility study was carried out to assess the quality and reliability of the well logs and seismic data to determine if we can achieve the project objectives. The feasibility study was comprised of forward modeling and well logs crossplot analysis.

In forward modeling, four synthetic seismic angle stack models were generated with angle ranges 0-10, 10-20, 20-30, 30-40 degrees. Figure 4 shows example of noise free synthetic seismic angle stack models. Based on the analysis of these synthetic models, it was observed that angle stacks up to 30-40 degrees are suitable for the simultaneous inversion. The forward modeling has revealed encouraging results after simultaneous inversion of these synthetic models, where the response of low Vp/Vs in the Zubair Formation corresponds to Zubair pay sands in Well-013 as well as the sands are better resolved using the Vp/Vs result (Figure 5). The well Well-013 has reasonably thick pay reservoir at the base of the Zubair and top of the Ratawi Shale, which is seismically resolvable within the seismic bandwidth.

The well log crossplot analysis was performed to evaluate the relationship between the reservoir properties and seismic properties as shown on Figure 6, where P-impedance alone is not enough to discriminate the sand from the shale in the Sabiriyah Field, whereas using the combination of P-impedance and Vp/Vs can discriminate the hydrocarbon bearing sands with low P-impedance and low Vp/Vs response.

Based on the forward model and well log crossplot analysis, it is feasible to predict the hydrocarbon bearing sands using P-impedance and Vp/Vs elastic properties, therefore the simultaneous inversion method was chosen for reservoir characterization of the Zubair reservoir of the Sabiriyah Field.

Simultaneous inversion method integrates multiple partial angle stack seismic data, geological interpretation, and well log data to generate acoustic and shear impedance data volumes. These resulting volumes have higher resolution than the input seismic data due to removal of wavelet effects (Rudiana et al., 2008). The process works by removing the wavelet from the seismic data, converting seismic interface properties into layer properties, and integrating a low frequency models (Anderson and Bogaards, 2000). The results of simultaneous inversion are elastic rock properties such as P-impedance, S-impedance, and Vp/Vs constrained to well data (Latimer et al., 2000). The simultaneous inversion algorithm utilized in this study determines the optimum combination of P-impedance, Vp/Vs, and density derived from the seismic angle stack data. The use of the angle stacks simultaneously results in reduced sensitivity to noise in the input seismic data (Jarvis et al., 2004).

The simultaneous inversion was conducted to produce 3D volumes of P-impedance, Vp/Vs, and density properties using the four seismic angle stacks processed in year 2012, interpreted horizons, wavelet estimated for each angle stack, and the low frequency 3D models built using the conditioned and modeled elastic well logs. Figure 7 shows three section views: the full stack seismic data, the simultaneous inversion results of P-impedance, and the Vp/Vs across the three wells Well-011, Well-013, and Well-014, where low P-impedance and low Vp/Vs show in hot color. Based on the well log crossplot from Figure 6 it was clearly seen that the reservoir filled with hydrocarbon is characterized by low P-impedance and low Vp/Vs. Also in Figure 7 we can see the Zubair pay at the base of the reservoir at Well-013 showing low Vp/Vs.

The geobody analysis of P-impedance and Vp/Vs volumes were carried out in 3D visualization. Figure 8 shows example of 3D geobodies capturing within the Zubair Formation, where the geobodies are captured from P-impedance and Vp/Vs volumes with criteria of low P-impedance and Vp/Vs inside the black polygon shown on the crossplot to capture hydrocarbon bearing sands. The geobodies displayed in colors are those that meet criteria of minimum 200 face connected voxel cells.

Conclusions

The application of simultaneous inversion in the Sabiriyah Field has demonstrated the ability to discriminate reservoir sand from non-reservoir shale and to map the distribution of hydrocarbon bearing sand channels. The results show that using a combination of P-impedance and Vp/Vs from simultaneous inversion has enabled the prediction of hydrocarbon bearing zone in the Sabiriyah Field, Zubair Formation for the future well planning.

Acknowledgments

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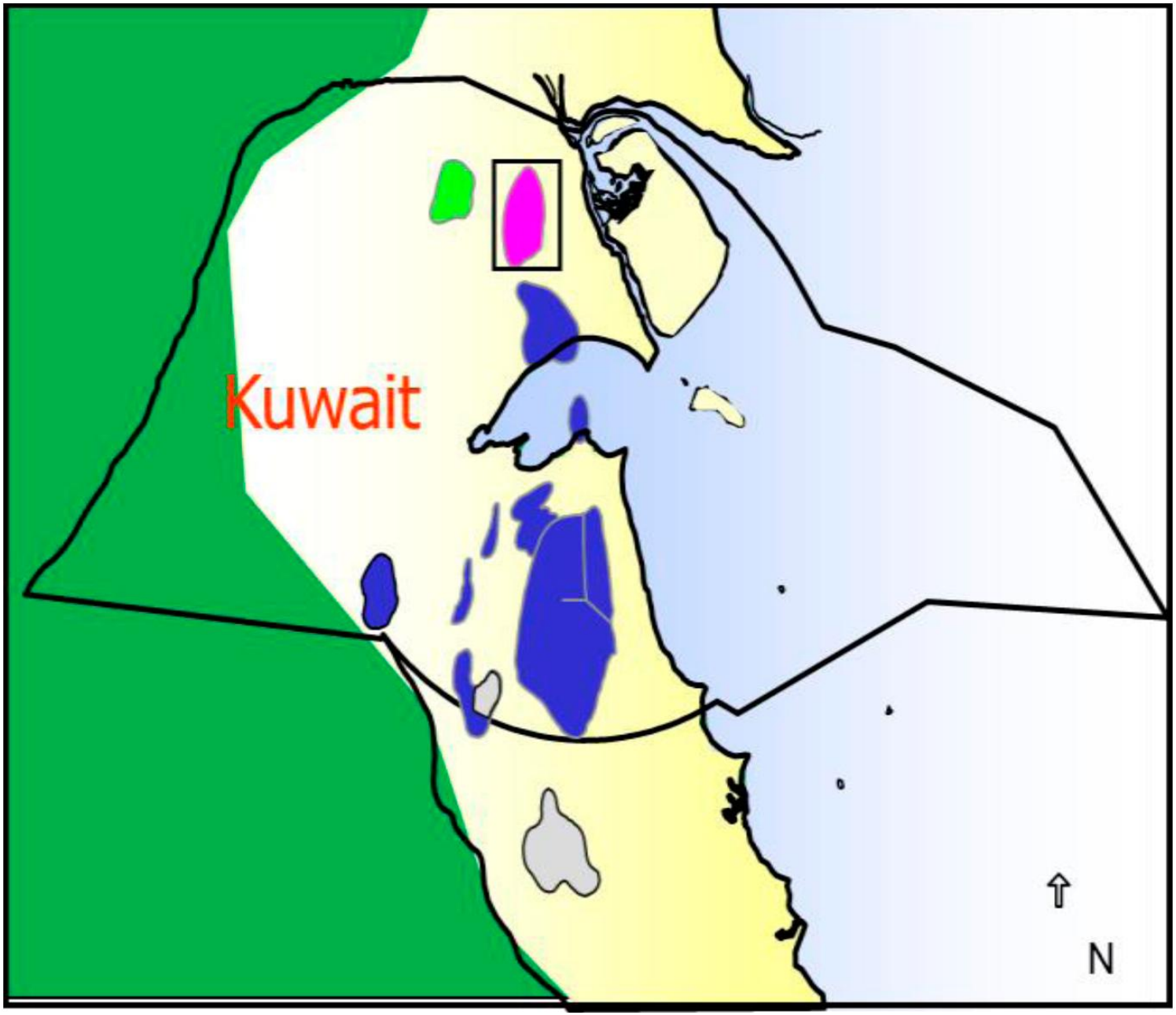

Figure 1. Location map of Sabiriyah Field shown in black rectangle.

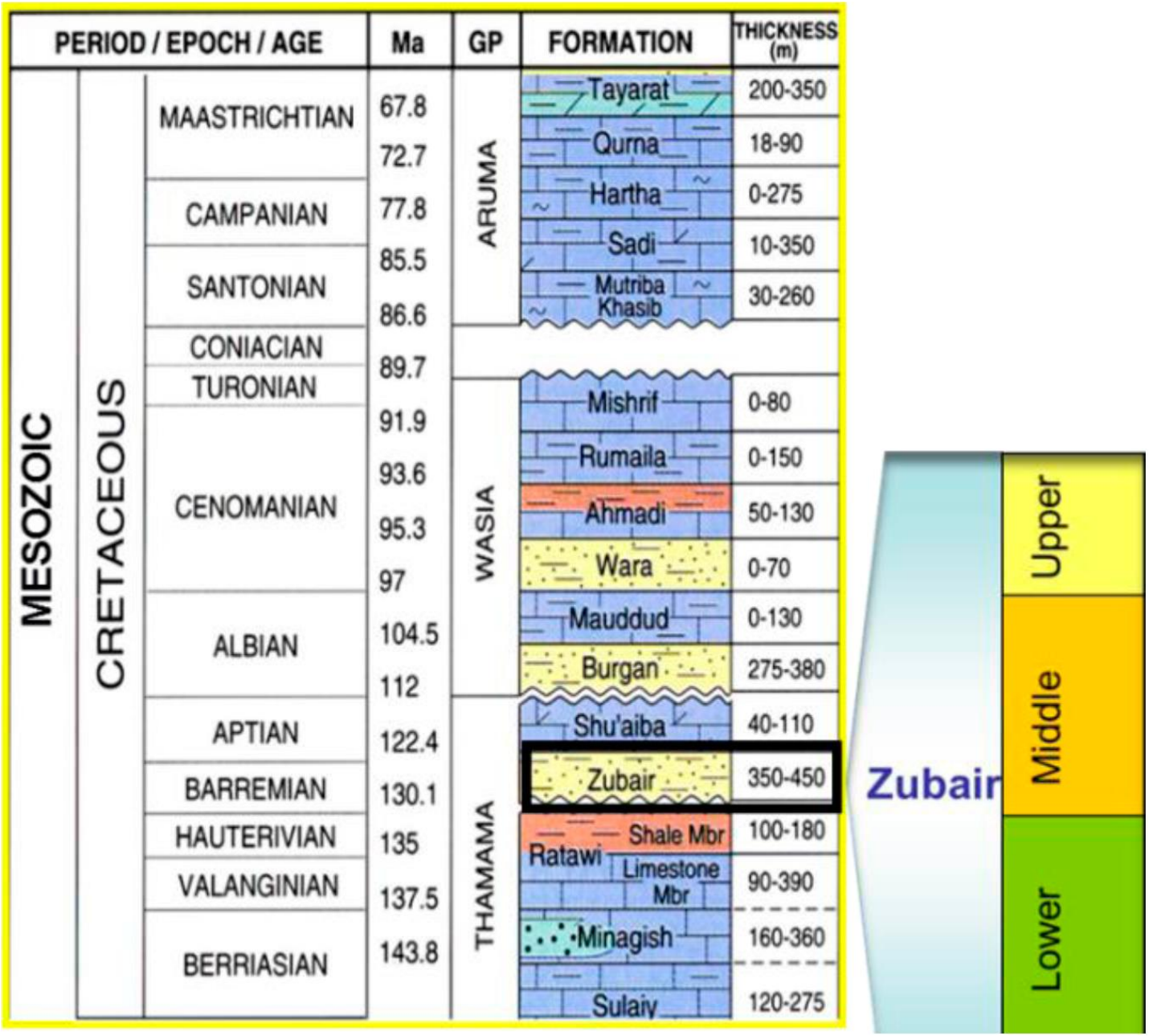

Figure 2. Generalized Kuwait stratigraphic column highlighting Zubair Formation.

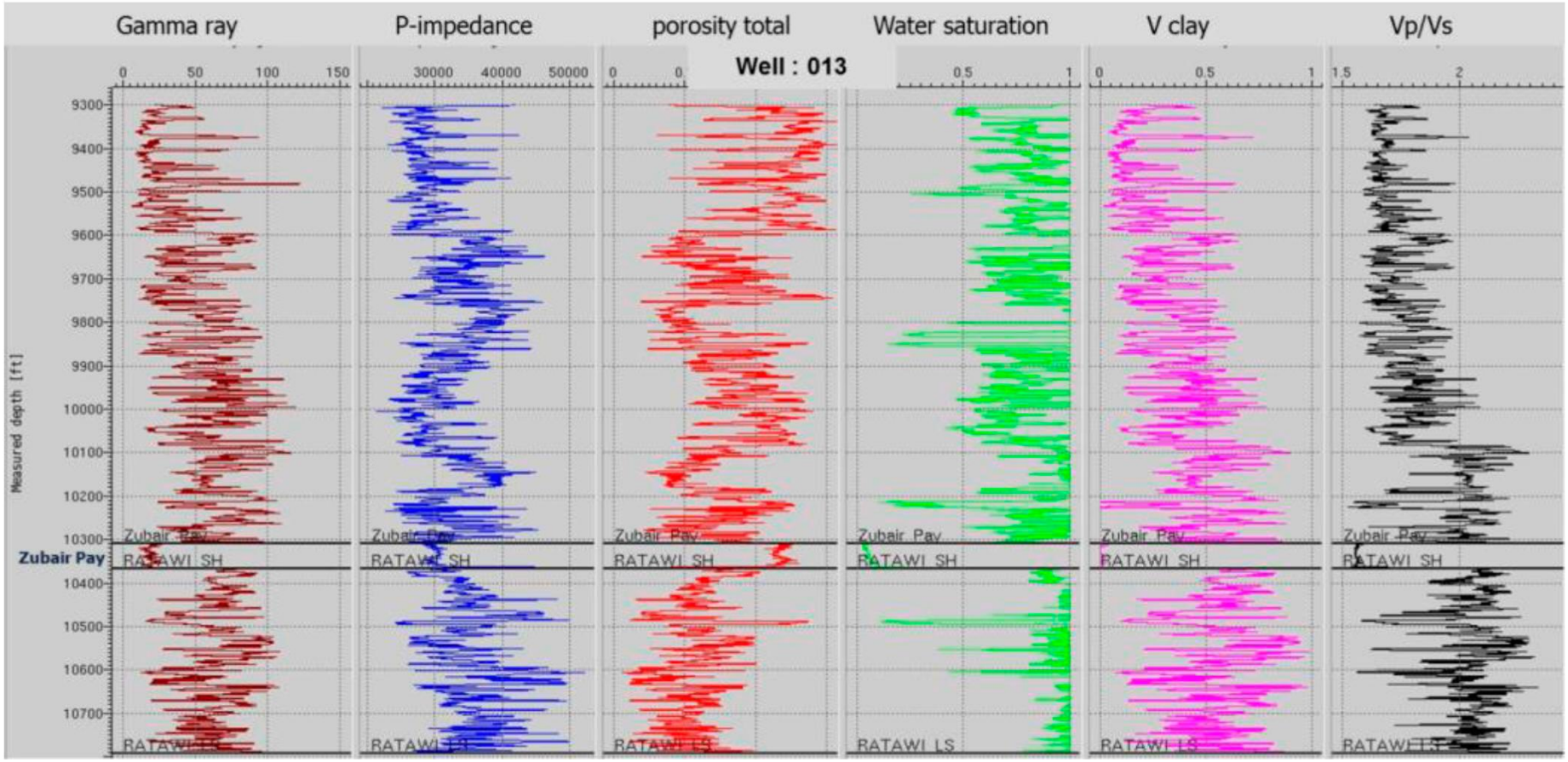

Figure 3. Well log view of Well-013.

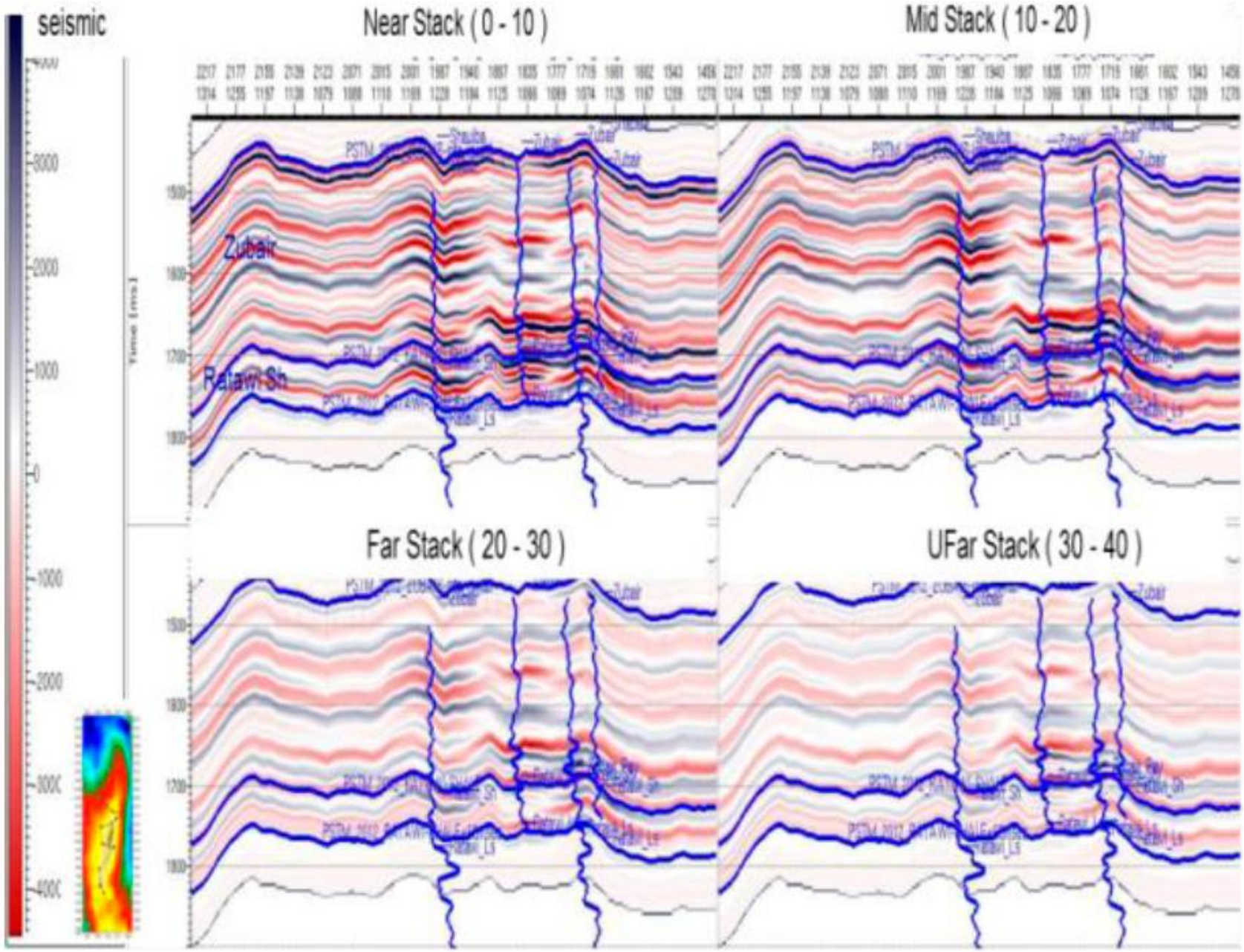

Figure 4. Generation of seismic synthetic models of angle stacks.

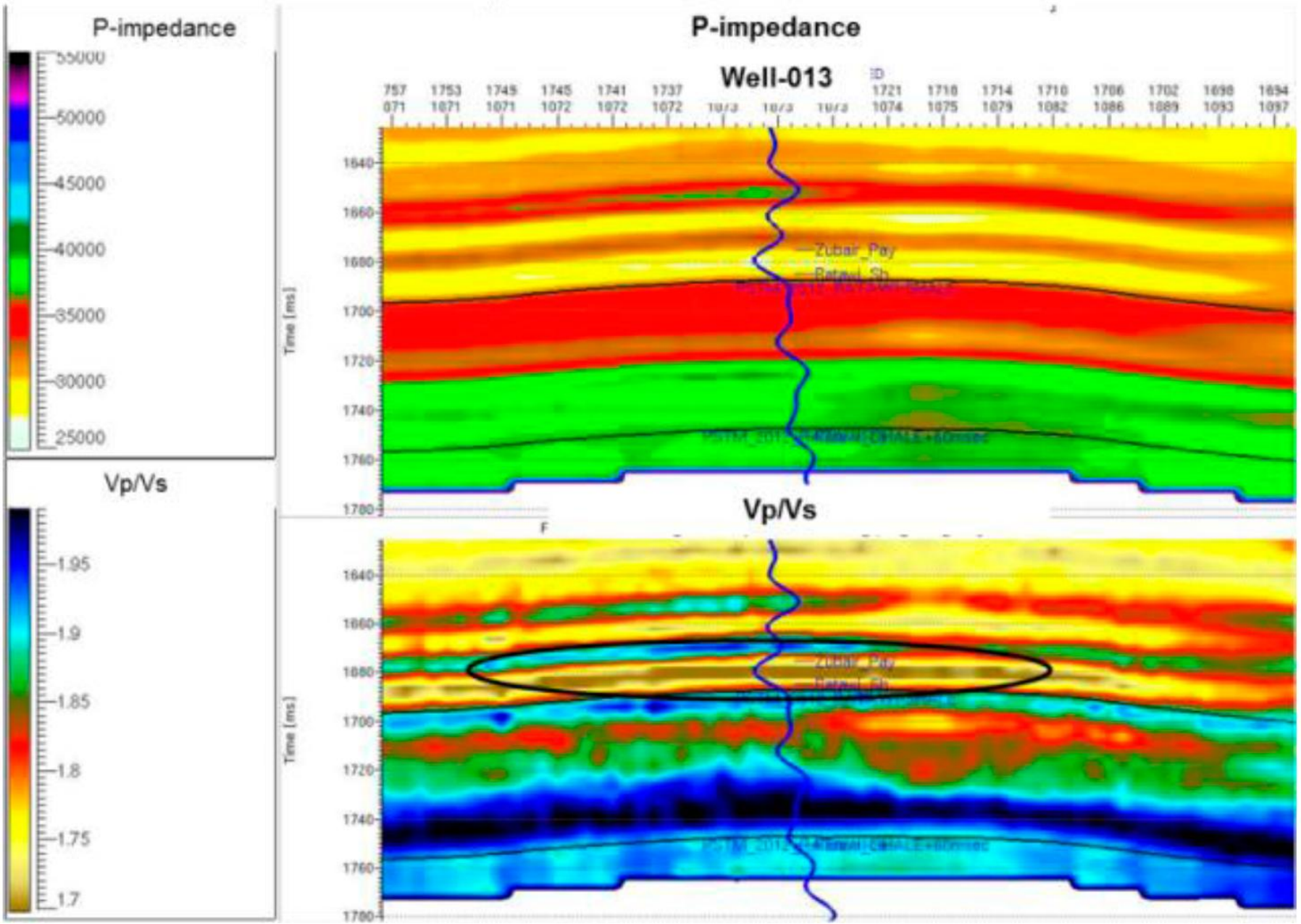

Figure 5. P-impedance and Vp/Vs results after inversion of synthetic models. Response of Vp/Vs at Zubair pay is shown in black circle.

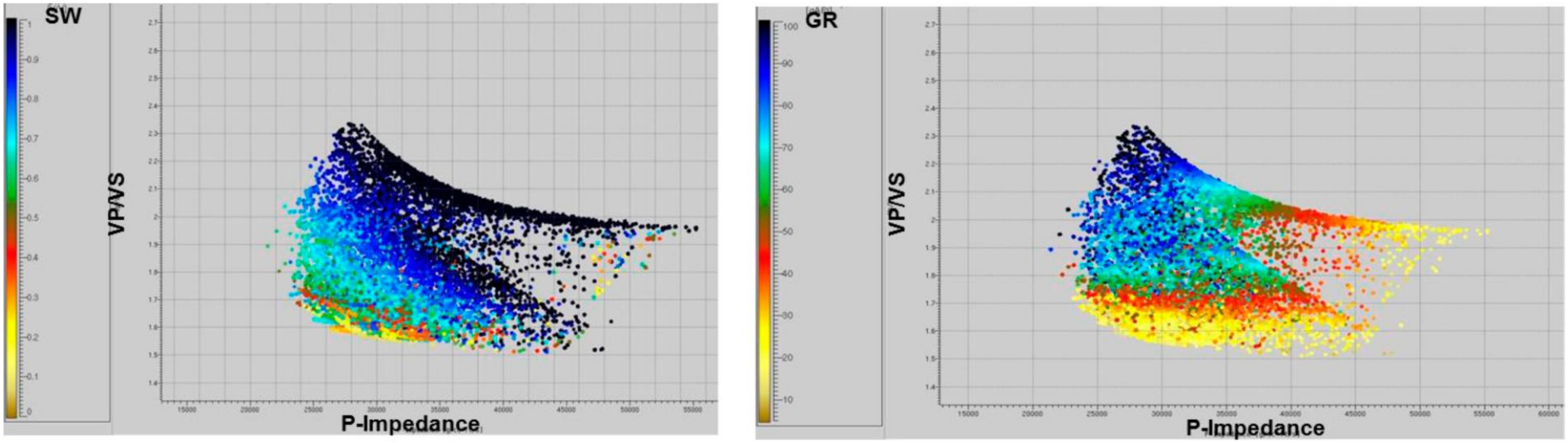

Figure 6. Crossplot of P-impedance versus Vp/Vs color coded with water saturation (left) and gamma ray (right) for the interval of Zubair and Ratawi Shale formations.

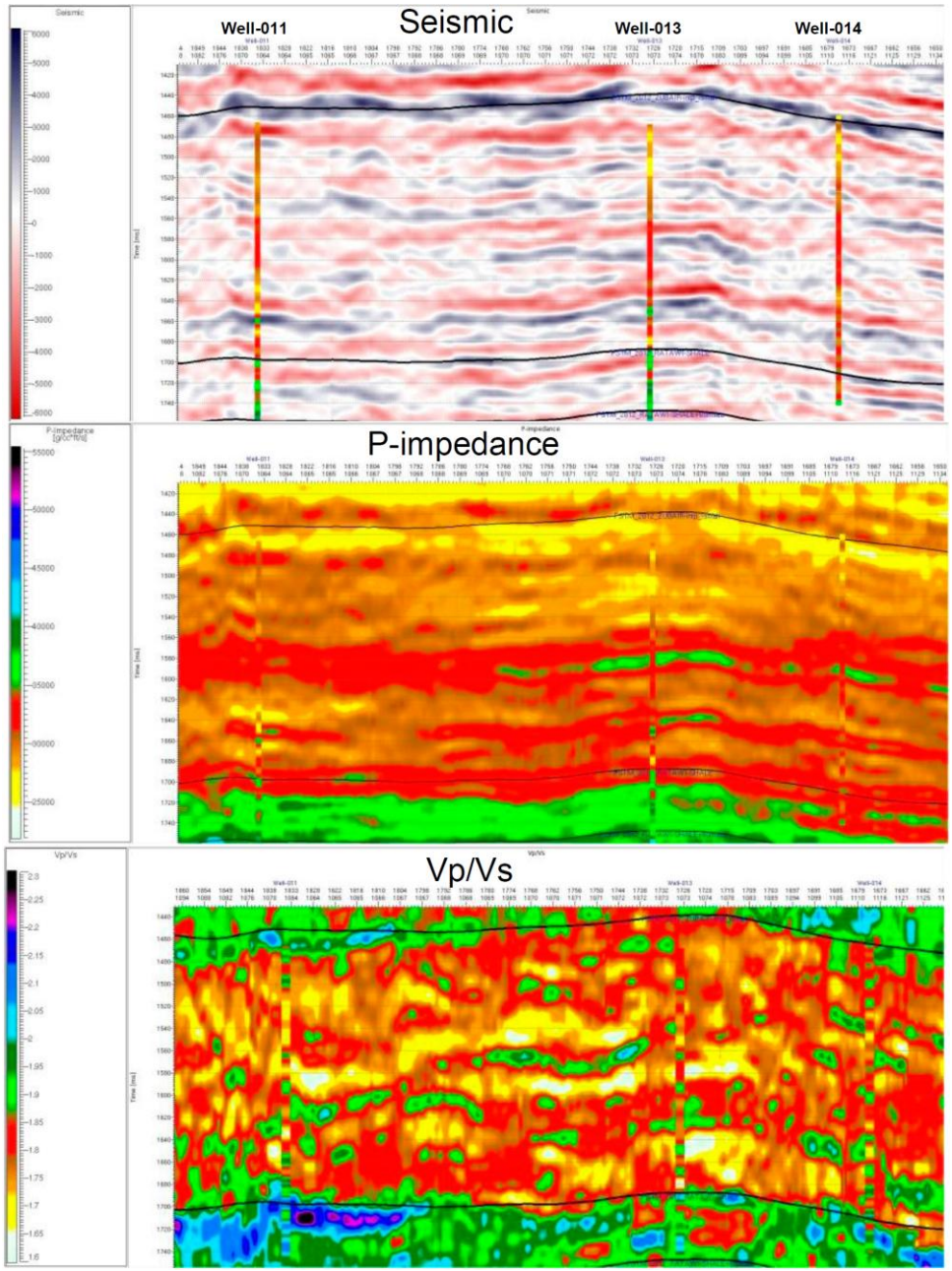

Figure 7. Full stack seismic (top) with P-impedance (middle) and Vp/Vs (bottom) inversion results through three wells.

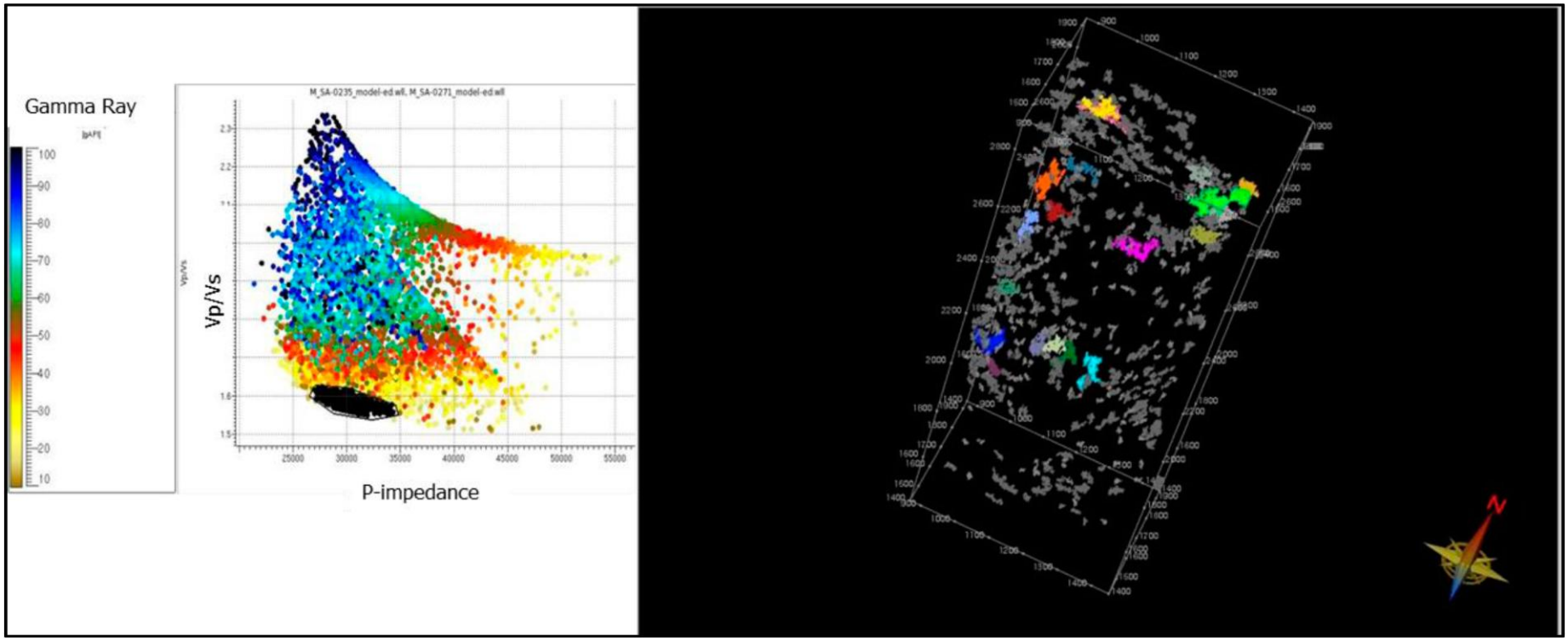

Figure 8. Geobody capturing of inversion results with low P-impedance and Vp/Vs captured within the black polygon on crossplot.